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ELEMENTS OF CHEMISTRY.

ELEMENTS OF CHEMISTRY:

THEORETICAL AND PRACTICAL.

BY

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PART I.

CHEMICAL PHYSICS.

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ADVERTISEMENT.

THE work, of which the First Part is now presented to the Reader, was originally designed to supply the Students who were attending the Course of Lectures on Chemistry at King's College with a text-book to guide them in their studies.

The present Part, on *Chemical Physics*, is devoted to a subject upon which no elementary work has appeared in this country since the publication of the excellent Treatise of the late Professor Daniell, and in attempting to supply what the author, in his own experience, has felt to be a want, he ventures to hope that the result of his labours may be found useful to persons beyond the circle of his own immediate Class. Much new matter, which has never yet been reduced to a systematic form, is now presented to the Student, particularly in the chapters on *Adhesion*, on *Heat*, and on *Voltaic Electricity*.

It is proposed to complete the work in Three Parts. The Second Part, which will be devoted to *Inorganic Chemistry*, is expected to be ready by the end of the present year; and the Third Part, which will embrace *Organic Chemistry*, in the spring of next year.

As the author was originally a pupil of Professor Daniell, and was subsequently, for several years, associated with him as Lecturer on Chemistry, it has happened that in some of the subjects treated of in this volume, the thoughts and mode of arrangement resemble those adopted by that distinguished philosopher in his *Introduction to the Study of Chemical Philosophy.*

The second edition of that work was published so far back as 1843; and even if the work itself had not been long out of print, the progress of science would have detracted greatly from its utility as a text-book. The adaptation of that work to the systematic teaching of the present day would have involved changes of an extensive character: moreover, every teacher who takes an interest in the progress of his class has his own views and methods. The Author, therefore, judged it better, after much consideration, to bring out a new work, leaving untouched that of his late Master, as the true exponent of his views upon some of those branches of science which his researches had contributed to advance and adorn.

The Author cannot omit to avail himself of the present opportunity of expressing his obligations to his friend, Mr. C. Tomlinson, for many valuable suggestions, and for the warm interest which he has taken in the progress of the work, but more especially for the devotion of no inconsiderable portion of time and labour to the revision of the proof sheets.

King's College, London, March, 1855.

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ERRATA.

Page 31, 13 lines from the top, for *aerometer*, read *areometer*.
,, 79, 15 ,, ,, ,, (52) ,, (53).
,, 89, 10 ,, bottom, after *attraction*, insert *exists*.
,, 98, 3 ,, top, for 40, read 39.
,, 100, 6 ,, bottom, transfer *three* from the end to the beginning of the line.
,, 102, the position of first crystal in figs. 43 and 44 is incorrect with reference to the horizontal axis.
,, 105, 13 lines from the bottom, for *fig.* 48, read *fig.* 49.
,, 106, 11 ,, top, ,, *fig.* 51, ,, *fig.* 50.
,, 124, 5 ,, bottom, ,, *equally*, ,, *equal*.
,, 128, 10 ,, ,, read, *from* M *and* R, *let fall the perpendiculars* M N *and* R Q.
,, 160, 7 ,, ,, for *assume*, read *exert upon light*.
,, 207, 24 ,, ,, ,, *Bichloride of sulphur*, read *Dichloride of sulphur*.
,, 279, 18 ,, top, after *now regarded*, insert *as*.
,, 354, 14 & 21 lines from ,, for $\frac{10E-e}{\frac{10R+r}{2}}$ read $\frac{10E-e}{\frac{10R}{2}+r}$
,, 359, 11 ,, ,, ,, *electrical phenomena generally*, read *the wire through which the Leyden jar is being discharged*.
,, 381, 13 ,, ,, dele *with*.
,, 383, 5 ,, bottom, for *adjoining*, read *joining*.

ELEMENTS OF CHEMISTRY.

PART I.

CHEMICAL PHYSICS.

CHAPTER I.

PRELIMINARY VIEW OF CHEMICAL AFFINITY—LAWS OF COMBINATION.

(1) *Chemical Distinction of Bodies into Elements and Compounds.*—Modern science has shown that, numberless as are the substances presented to us in the daily experience of life, there are very few which cannot be separated into other substances of a less complicated nature, which enter generally into the formation of the various bodies with which we are familiar. For example, the wood of our tables, the paper on which we write, the pen which records our thoughts, are each separable into three or four distinct substances; namely—oxygen, hydrogen, carbon, and nitrogen; from which, however, further efforts fail to extract other simpler forms of matter. It is the province of chemistry to ascertain the nature of these different component substances, to trace their mutual actions on each other, to effect new combinations of these components with each other, and to define the conditions under which the combinations existing around us are producible. Bodies which have hitherto resisted all attempts to resolve them into simpler forms of matter are in chemical language termed *elements*, or *simple substances*. In popular language, the word element is often referred to *fire*, *air*, *earth*, and *water*. A very slight acquaintance with chemistry is sufficient to prove that air, earth, and water are compound bodies, and that fire is mainly the result of high temperature on certain bodies.

Simple or elementary substances, then, are limited in number. In the present state of the science only sixty-one are known. (12) Many of these are familiar to us in the form of metals, such as gold, silver, copper, iron, lead, tin, and mercury. There are other simple substances which are equally familiar, but which have no resemblance to the metals; such as charcoal, sulphur, and phosphorus. Some simple substances exist in the form of air or gas. Such, for example, are the two essential components of the atmosphere, oxygen and nitrogen.

Simple substances have been divided into two great classes—*non-metallic* and *metallic*. The substances comprised in the latter class are the more numerous, but those in the former are the more abundantly distributed.

The elements enumerated as non-metallic are thirteen in number—viz.,

Oxygen
Hydrogen
Nitrogen
Carbon
Chlorine
Bromine
Iodine
Fluorine
Sulphur
Selenium
Phosphorus
Boron
Silicon

Of these substances, oxygen, hydrogen, nitrogen, chlorine, and probably fluorine are gaseous; bromine is liquid, and carbon, iodine, sulphur, selenium, phosphorus, boron, and silicon, are solid at ordinary temperatures.

All natural objects consist either of simple bodies, or they are composed of two or more of these simple bodies united according to certain rules or laws which form the groundwork of the science of chemistry. Substances thus produced by the union of two or more elements are termed *compound* bodies. These compounds have in general no more resemblance in properties to the elements which have united to form them than a word has to the letters of which it is made up.

(2) *Differences between Physical and Chemical Properties.*—The properties which characterize objects in general, may be classed under two heads, viz., *physical* and *chemical.*

The physical properties of an object are those which refer to its condition, whether solid, liquid, or gaseous. Crystalline form, specific gravity, hardness, colour, transparency or opacity, and the relations of the object to heat and electricity, are physical properties. Physical properties are independent of the action which the body exerts upon other bodies; whilst the chemical properties of the body relate essentially to its action upon other bodies, and to the permanent changes which it either experiences in itself, or which it effects upon them. For example, in indicating the physical properties of such a substance as sulphur, we should refer to its brittleness, its faint peculiar smell, yellow colour, crystalline structure, its semi-transparency, the facility with which if rubbed it exhibits electrical attraction, and so on; but if we would take note of the chemical properties, it would be necessary to refer to those operations by which the body usually becomes changed, and loses its distinctive physical characters—such as the ease with which it takes fire, the rapidity with which it unites with silver or copper, especially if heated, its insolubility in water and spirit, and its solubility in turpentine or in alkaline liquids.

It is not however always possible to draw the line between physics and chemistry; this is of the less importance, since the chemical nature of any substance could be but imperfectly studied, without a tolerably complete knowledge of its leading physical characters, which are those by which it is most readily defined.

(3) *Physical States of Matter.*—Natural objects are presented to us in three states, or physical conditions—viz., the *solid*, the *liquid*, and the *gaseous*, *aeriform*, or *vaporous*. Every substance exists in one or other of these conditions. The same body may, however, often assume any one of these conditions at different times, and may pass from one to the other for an indefinite number of times, according as it is exposed to a greater or less degree of heat. Ice, water, and steam are all the same material in three different states. Whichever be the form that matter assumes, it always retains that attraction for the earth which gives it weight, whether visible, as in the state of ice or water, or invisible, as in that of steam. A quantity of ice or water that weighs a pound, will still, as steam, be equally a pound in weight. So it is with all gases; the air, although invisible, is not the less capable of being weighed and measured.

(4) *Porosity—Divisibility of Matter.*—Natural objects, of whatever form, are composed of particles which are not in actual contact, but are separated by spaces or intervals termed *pores*. A lump of sugar or of salt is at once seen to consist of a collection of smaller solid particles, with intervening spaces; but the porosity of such bodies as water, of spirit of wine, or of iron, is not so obvious, although the existence of the property is not less certain. The porosity of spirit and of water may be shown as follows:—Take a long narrow tube with a couple of bulbs blown in it, and furnished with an accurately fitting stopper, as represented in fig. 1; fill the tube and lower bulb with water, then carefully and completely fill up the upper bulb and neck with spirit of wine, and insert the stopper. The structure of the apparatus, and the different densities of the

FIG. 1.

two liquids, prevent them from mixing; but on turning the tube upside down and back again, three or four times, so as to mix the spirit and water thoroughly, and then holding the instrument with the bulbs downwards an empty space will be seen in the tube after they have been thus mixed, showing that they now occupy less space than before; that their particles are in fact closer together. Proofs of porosity are afforded even by the metals; for example, many of them become more compact by hammering, as is the case with platinum: all of them, not excepting platinum and gold, two of the densest forms of matter, however cold they may be, shrink into a smaller space when rendered still colder. The ultimate particles therefore cannot be in contact.

What the real size of these ultimate particles may be we have no means of determining, although, as will be seen hereafter, there are strong grounds for believing that the divisibility of matter, extreme as it is, has its assigned and definite limits. Experience, however, shows that whatever be the form of matter selected for our experiments, that divisibility may be carried to an extent which transcends our powers of conception. The divisibility of gold is often given in illustration of this point. In the ordinary process of making gold leaf, a single grain of gold is hammered out until it cover a square space seven inches in the side. Each square inch of this may be cut into 100 strips, and each strip into 100 pieces, each of which is distinctly visible to the unaided eye. A single grain of gold may thus, by mechanical means, be subdivided into $49 \times 100 \times 100 = 490{,}000$ visible pieces. But this is not all; if attached to a piece of glass, this gold leaf may be subdivided still further; 10,000 lines may be ruled in the space of one single inch, so a square inch of gold leaf, $\frac{1}{49}$ of a grain, may be cut into 10,000 times 10,000, or 100,000,000 pieces, or an entire grain into 4,900,000,000 fragments—each of which is visible by means of the microscope. Yet we are quite sure that we have not even approached the possible limits of subdivision, because, in coating silver wire, the covering of gold is far thinner than the gold leaf originally attached to it, as in drawing down the gilt wire the gold continues to become thinner and thinner each time, in proportion as the silver wire itself is reduced in thickness. When a substance is dissolved in any liquid, the subdivision is carried still further, since the particles are rendered so minute as to escape our eyesight even when aided by the most powerful magnifiers.

(5) *Varieties of Attraction.*—Mere mechanical subdivision, or even the more perfect separation of the particles which compose a

compound body, by the process of solution, does not, however, suffice to put us in possession of the simple substances from which the compound is formed. A piece of loaf-sugar may be reduced, by trituration, to an impalpable powder, but every particle of that powder will still be sugar: it may be dissolved in water, but each drop of the liquid will still contain sugar, unaltered except in appearance. Sugar, however, is composed of three elements—carbon, hydrogen, and oxygen; but no mere trituration or solution in water would enable us to extract any of these substances from loaf-sugar.

The existence of a body as a solid in one continuous mass is owing to the exertion of *cohesion*—a force of considerable intensity, but which varies in different bodies, and by this variation produces varieties in the toughness, hardness, and brittleness of bodies. But the power which unites the various chemical elements to form a new compound, with properties entirely different from those of any of its constituents, is of a different nature from cohesion, and of a more subtle kind. *Chemical affinity*, as this force is termed, is exerted between the smallest or ultimate particles of one element, and the corresponding particles of the other elements with which it is associated in the particular compound under examination. These ultimate particles are often spoken of as *atoms*, a term which implies that the particles admit of no further sub-division.

The separation of a body into its constituents is the business of *chemical analysis*, and it has for its object the determination, first, of the nature of the components—this is *qualitative* analysis; secondly, the determination of their quantity—this being *quantitative* analysis. The successful performance of these operations of analysis requires a somewhat extensive acquaintance with the principles and the facts of the science, combined with considerable skill in manipulation.

(6) *General Characters of Acids, Alkalies, and Salts.*—It will facilitate the comprehension of the remarks on chemical affinity which are about to follow, to allude briefly to the general characters of three very important classes of substances, viz., *acids*, *alkalies*, and *salts*.

Acids are for the most part substances which dissolve in water, have a sour taste, and exert such an action on vegetable blue colours as to change them to red. For example, tincture of litmus, which is of a blue colour, is exceedingly sensitive to the action of a small quantity of acid: paper, stained with this tincture, is in frequent use by the chemist for detecting the presence of acids.

An *alkali* is a substance possessing many qualities exactly the reverse of those which belong to an acid. It dissolves in water, and produces a liquid which is soapy to the touch, and has a peculiar nauseous taste; it restores the blue colour to vegetable infusions which have been reddened by an acid; it turns many of these blues to green, as in the cases of the red cabbage and syrup of violets, and it gives a brown colour to vegetable yellows, such as turmeric and rhubarb. Litmus paper, feebly reddened by an acid, is a useful means of showing the presence of an alkali, and is more sensitive than paper stained with turmeric or with rhubarb, which is also in common use for the same purpose. These different *test papers,* as they are called, show whether an acid or an alkali be predominant in a solution.

Vinegar or acetic acid, oil of vitriol or sulphuric acid, spirits of salt or hydrochloric acid, aquafortis or nitric acid, are familiar instances of the class of acids.

Potash, soda, and hartshorn or ammonia, are instances of well-known alkalies. Both acids and alkalies are remarkable for their great chemical activity. The metals, compact as they are, dissolve in the acids. Nitric acid attacks copper quickly and violently, with brisk effervescence, and the copious escape of red fumes, whilst a blue liquid is formed from the action. Sulphuric acid shows similar energy, if mixed with water and placed in contact with iron or zinc. Moreover, these acids, when not much diluted with water, produce instant destruction of the skin, and of nearly all animal and vegetable matters. The solvent action of potash, or of soda, is not less marked. Either of these alkalies destroys the skin if allowed to remain upon it; and also gradually dissolves portions of earthenware, or glaze from the vessels which contain it, and it quickly removes paint from the surface of any object on which the solution falls. But the most remarkable property of acids and alkalies, is the power which they have of uniting with each other, and destroying or *neutralizing* the chemical activity which distinguishes them when separate.

Some of these properties of acids and alkalies may be submitted to experiment by means of a coloured vegetable solution, such, for example, as the purplish liquid prepared by slicing a red cabbage and boiling it with water. If a quantity of this infusion be divided into two portions, and to the one be added a quantity of dilute sulphuric acid, a red liquid is obtained; and if to the other a solution of potash be added, a liquid of a green colour is formed; then, on gradually adding the alkaline solution to the other, stirring the mixture constantly, the green colour of the portions first added instantly disappears, and the whole liquid remains red; as more and more of the alkali is added, the red by degrees passes into purple, and on continuing to add the alkaline solution, a point is attained when the liquid has a clear blue tint; at this moment there is neither potash nor sulphuric acid in excess in the liquid, the two have chemically united with each other. The characteristic properties of both have disappeared, and on evaporating the solution at a gentle heat, a solid crystalline substance is obtained, resulting from the combination of the sulphuric acid with the potash. This substance is the salt called *sulphate of potash*. Any compound produced by the union of an acid with an alkali is termed a *salt*.

It must not be supposed that all acids closely resemble those which have been just mentioned, and which are freely soluble in water; some acids on the contrary, are but slightly soluble, such for instance is arsenious acid, the white arsenic of the shops: other acids do not dissolve at all: silica, or common flint, is a true acid, although it may remain undissolved in water for ages. The leading character of an acid, in a chemical sense, is its power of uniting with alkalies to form salts: and this character is possessed by silica, in common with various other bodies not familiarly regarded as acids. Of course if an acid be insoluble it has no sourness, and is without action on vegetable blues.

There are no alkalies which are insoluble, but there are substances which greatly resemble them which are but sparingly soluble, such as lime and baryta; these are termed *alkaline earths*. There are a large number of substances, compounds of oxygen with the metals, termed oxides, which are insoluble in water, but which dissolve with ease in acids, and form crystalline compounds or salts, such for instance as oxide of silver, oxide of iron, and oxide of lead. With nitric acid the oxide of silver forms nitrate of silver; with sulphuric acid, oxide of iron unites to form green vitriol or sulphate of iron; with acetic acid, oxide of lead combines and forms sugar of lead or acetate of lead. A substance which thus unites with acids and neutralizes them, is called a *base*, whether it dissolves in water or not; hence the alkalies constitute one sub-division of the more numerous class of bodies known as bases.

(7) *Characters of Chemical Affinity.*—Chemical affinity is distinguished by well marked characters from other kinds of force which act within minute distances.

I. Chemical affinity is exerted within its own limits with intense energy, but beyond those limits it is entirely powerless. An iron wire, for example, which will support a weight of 1000lb. without breaking, will yet in a few minutes yield to the almost noiseless action of a mixture of oil of vitriol and water; the stubborn metal will dissolve, and a clear solution of the metallic mass will be formed—particle by particle will be detached from the iron, and no vestige of its structure or tenacity will remain. It is rarely possible, by trituration or other mechanical means, to bring about a sufficient approximation amongst the subdivided particles to produce chemical action. Tartaric acid and carbonate of soda may be incorporated by grinding for hours in a mortar, but they will not act chemically upon each other. It is not until a more intimate contact is effected by the addition of water, which dissolves the particles of both, and allows them mutually to approach closer, that the brisk effervescence, due to the expulsion of the carbonic acid gas, occurs, which indicates the union of the soda with which it was previously in combination, with the tartaric acid.

A very striking illustration of the difference between the effects of mechanical intermixture and those of chemical combination is afforded in the case of ordinary gunpowder. In the manufacture of this substance, the materials of which it is made, viz., charcoal, sulphur, and nitre, are separately reduced to a state of fine powder; they are then intimately mixed, moistened with water, and thoroughly incorporated by grinding for some hours under edge stones; the resulting mass is subjected to intense pressure, and the cakes so obtained, after being broken up and reduced to grains, furnish the gunpowder of commerce. In this state it is a simple mixture of nitre, charcoal, and sulphur. Water will wash out the nitre. Bisulphide of carbon will take up the sulphur, and the charcoal will be left undissolved. By evaporating the water we obtain nitre, and on allowing the bisulphide of carbon to volatilize, the sulphur remains. If, however, we cause the materials to enter into chemical combination, all is changed; a spark fires the powder; a large volume of gaseous matter is produced; the charcoal disappears, and no trace of the original ingredients which formed the powder is left.

II. From its very nature, chemical affinity must be exerted between dissimilar substances. No manifestation of this force can take place between two pieces of iron, two pieces of copper, or two pieces of sulphur; but between sulphur and copper, or sulphur and iron, chemical action of the most energetic kind may occur.

III. Generally speaking, the greater the difference in the properties of the two bodies, the more intense is their tendency to combination. The metals, as a class, differ as widely from the acids as possible, but the acids rapidly dissolve the metals. Copper, for instance, is briskly attacked by nitric acid, iron by dilute sulphuric acid, and so on. Between bodies of a similar character, the tendency to union is but feeble. For example, two metallic bodies, copper and zinc, will, under the influence of a high temperature, unite and form brass, an alloy, the properties of which are intermediate between those of its constituents; but brass, on being heated strongly, may be again separated into copper, which remains; and into zinc, which nearly all passes off in vapour.

IV. Another of the most remarkable features of chemical affinity is the entire change of properties which it occasions in both the substances dealt with, a change which no *à priori* reasoning could possibly predict. If the blue liquid obtained by dissolving copper in nitric acid be evaporated, a blue crystalline salt will be procured which has no resemblance either to the acid or to the metal. There is an equally striking difference between the tough metallic insoluble iron, and the corrosive oil of vitriol, and the beautiful crystalline, green, soluble, inky tasted salt which is produced by their combination.

V. The next important peculiarity of this power which may be noticed, is that it is exerted between different kinds of matter with different but definite degrees of force. Nitric acid will oxidize, dissolve, and combine with most of the metals, such, for instanc, as silver, mercury, copper, and lead; but it unites with them with very different degrees of intensity. With silver the combination is less powerful than with mercury, less so with mercury than with copper; and with copper less again than with lead.

This fact may easily be determined by dissolving half an ounce of nitrate of silver in half a pint of water, and pouring into it a small quantity of clean mercury; in a few days a beautiful crystallization of metallic silver will be obtained, whilst a corresponding quantity of mercury will have dissolved, and will have combined with the nitric acid previously in union with the silver. In a similar manner mercury will be displaced from a solution of nitrate of mercury by a strip of metallic copper; and copper, in its turn, will be displaced by a piece of lead introduced into a solution of nitrate of copper. From a solution of nitrate of lead zinc will, in like manner, displace the lead, which will be deposited in beautiful crystals.

Indeed, the different elements may be arranged in tables indicating the order of their affinity for any one element which is placed at the head of the list. For example, in the first column of the following table, several of the more important metals are arranged in the order in which they exhibit a tendency to combine with oxygen, the metal which stands at the head of the list having the strongest affinity, that which stands second the next, and so on to the one mentioned last, in which the affinity is the weakest:—

Oxygen.	*Sulphuric Acid.*
Potassium.	Baryta.
Zinc.	Lime.
Iron.	Potash.
Tin.	Soda.
Lead.	Ammonia.
Copper.	Oxide of Zinc.
Mercury.	
Silver.	
Gold.	
Platinum.	

Similar tables may be formed, exhibiting the tendency of compound bodies, such as bases, to combine with other compounds, such as acids. In the second column of the foregoing table the various bases are arranged in the order of their affinity for sulphuric acid.

VI. These experiments on the displacement of one metal by another, further show that, although in combination, the properties of the components are masked, and to all ordinary observation the constituents have entirely disappeared, yet they really exist in the compound, and can be again reproduced in their original form by taking away the substance with which they had combined.

It is, indeed, a principle of universal application that, whenever chemical combination occurs, no destruction of the bodies so entering into combination ever ensues. However much the materials may change their form, the weight of the new products, if collected and examined, will be found to be exactly equal to that of the substances before combination. The following experiment shows that, even although the substance may vanish from our sight, it continues to exist as a gas, which has the same weight as the solid which furnished it. Into a glass flask *A* (fig. 2), of about 250 cubic inches capacity, and which is provided with a brass cap and stop-cock, introduce 10 or 12 grains of gun-cotton; attach the flask to the air-pump, exhaust it very completely, and afterwards weigh it. Then set fire to the cotton by means of a voltaic current sent through the wires, *a b*, which are insulated from each other and from the cap of the instrument, by passing through a varnished cork. The cotton will entirely disappear with a brilliant flash, and the flask, if weighed again, will be found to be as heavy as it was before the cotton was fired.

FIG. 2.

VII. There are two modes in which chemical compounds are formed; the simplest is that where the two substances unite directly together, as when hydrogen burns in air, and, by direct union with oxygen, produces water; or when an acid and an alkali, as hydrochloric acid and ammonia, combine and produce a salt. This mode of combination usually prevails between bodies which have a powerful tendency to unite.

The other mode in which compounds are formed is still more common; it occurs where, in a body already formed, one of the ingredients of that body is displaced by another substance, and a new compound results.

The instances already specified, in which one metal precipitates another from its solution, are cases of this nature, when new bodies are produced by the displacement of one of the substances in a compound previously formed.

This method of forming compounds by displacement, or *substitution*, is one of great importance; and the study of its various modes of action is rapidly contributing to the discovery of many subtle processes concerned in the chemistry of organized beings.

VIII. Chemical combination, in a large proportion of cases, does not commence spontaneously. A heap of charcoal remains unaltered in the air for years; but, if a few pieces be made red hot, and then be thrown upon the heap, chemical action is commenced by the heat, and it continues until the whole mass is burned; that is, the chemical action between the oxygen of the air and the charcoal continues as long as any charcoal remains unacted on. In other instances, however, the chemical effects begin without the application of any extraneous force. A bit of phosphorus begins to burn slowly the instant it comes into the atmosphere, and in warm weather it speedily bursts into a blaze.

IX. Whenever substances unite directly with each other, heat is emitted, and the more rapidly the union is effected, the larger is the quantity of heat emitted in a given time, until, in some cases, it rises so high that ignition and combustion ensue; light as well as heat being abundantly extricated when the temperature attains a sufficient degree, as all solid substances, when heated beyond a certain point, become luminous.

When compounds are formed by substitution, the liberation of heat is always much less, and is sometimes not perceptible without special contrivances.

X. Very frequently the physical state of one or of both the bodies which enter into combination is altered by the operation of chemical affinity. Two solids may become converted into a liquid; two liquids may solidify, or even two gases may be reduced to the solid form. Differences of state are therefore not in all cases due to differences of temperature. Differences in the chemical arrangement of the particles are equally important in bringing about physical differences of condition.

The foregoing leading characters by which chemical affinity is distinguished from other forces, may be thus summed up in a few words.

Chemical affinity is a power of extreme energy, which acts only on the minutest particles of matter, and at distances too small to be perceptible by our unaided senses. Under its influence the comparatively few elementary bodies arrange themselves into the numberless compounds which constitute the different forms of matter around us. Affinity, from its very nature, operates only between the particles of dissimilar kinds of matter, and by its exertion, produces new properties in the resulting compound. It exists between different kinds of matter with different but definite degrees of intensity. As a result of its operations, no destruction of matter occurs in the materials submitted to its influence; there is consequently no loss of weight, but mere change of form. The act of combination may either occur instantly on mixture, or may be indefinitely postponed till some other force, heat, for example, conspires to commence the action. Compounds may be formed either by the direct union of their ingredients, or by the displacement of one substance by a different one in a compound previously formed; and lastly, heat and light, in amount proportioned to the rapidity of the action, are generally emitted in cases of the direct union of the constituents.

(8) *Laws of Combination.*—The relative proportion in which the different elements unite is regulated by fixed laws. These important laws, which are three in number, regulate the mode of combi-

nation of every known chemical compound. These are usually termed *the laws of chemical combination.*

(9) The first of these laws is the law of *Definite Proportions,* which although of great simplicity, is one of fundamental importance to the science of chemistry. This law may be stated in very few words; it is as follows — *In every chemical compound the nature and the proportions of its constituent elements are fixed, definite, and invariable.* For instance, 100 parts of water contain 88·9 of oxygen and 11·1 of hydrogen. Whether water be derived from the snows of high mountains, or from rain-clouds, or from dews, or from direct chemical action, as in the burning of a lamp or candle, its composition is uniform and certain. So also a piece of flint, or of rock crystal, in whatever part of the world it be found, will, on analysis, yield in every 100 parts, 48·2 of silicon and 51·8 of oxygen. In fact, the existence of the law of definite proportions gives value to analysis, by giving certainty and uniformity to its results. Mere mechanical intermixture is at once distinguished from true chemical combination by the absence of all regularity in the proportions of the bodies that have been mingled; and in the same manner chemical affinity stands strongly contrasted with that kind of adhesion which produces the solution of solids in a liquid.

(10) The second law of combination is usually termed the law of *Multiple Proportions.* It frequently happens that a pair of elementary bodies unite together in more than one proportion. The compounds so obtained are very different from each other; but there is still a uniformity in the plan upon which these compounds are formed, and the proportions of the two elements in each are very simply related. The law of multiple proportion may be thus stated:—*If two elements, A and B, unite together in more proportions than one, on comparing together quantities of the different compounds, each of which contains the same amount of A, the quantities of B will bear a very simple relation to each other;* such as

$$A+B, \quad A+2B, \quad A+3B, \quad A+4B, \text{ \&c.;}$$
$$\text{or, } 2A+3B, \quad 2A+5B, \quad 2A+7B, \text{ \&c.;}$$
$$\text{or, } A+B, \quad A+3B, \quad A+5B, \text{ \&c.}$$

Water, for instance, is a compound of oxygen and hydrogen; in 100 parts, by weight, there are, as already mentioned, 88·9 of oxygen and 11·1 of hydrogen. But there is another compound of oxygen and hydrogen known to chemists, termed the peroxide of hydrogen. By analysis it has been found that 100 parts of this body contain 94·1 of oxygen and 5·9 of hydrogen. Now, on comparing together the quantities of oxygen which in these two compounds are united with an equal quantity, say 1 part of hydrogen, it is evident that in water, for 1 of hydrogen there are 8 of oxygen

$$\text{Since } 11{\cdot}1 : 88{\cdot}9 :: 1 : 8$$

And by a similar process it is seen that in the peroxide of hydrogen, for 1 part of hydrogen 16 of oxygen are present—

$$5{\cdot}9 : 94{\cdot}1 :: 1 : 16$$

The quantity of oxygen combined with the hydrogen in the peroxide being just double what it was when combined with the same quantity of hydrogen in water.

A similar simple proportion between the quantities of the combining elements is found to hold good in every series of compounds formed by the union of two elements with each other. A certain quantity of one of the elements combines with a certain quantity of the other; in the next compound with twice as much as in the first; in the next with three times; in the next with four times that quantity, and so on. Sometimes the proportion is rather less simple, two proportions of one element combining with 3, 5, 7, or 9 of the other.

This important law, which was first clearly established by Dalton, was explained by him by means of his *Atomic Theory*. Upon this hypothesis the ultimate particles of each element are considered to be uniform in size and in weight for that element, and moreover to be incapable of further subdivision. When bodies unite chemically, as the particles of the same element have all the same size and relative weight, the proportions in which they combine must be *definite;* and further, if they unite in several different proportions, those proportions must be simply related to each other. Thus, water may be conceived to be a compound in which each separate particle of hydrogen is united with a single particle of oxygen; and peroxide of hydrogen would be represented as consisting of a combination of two particles of oxygen with each particle of hydrogen.

(11) This explanation will simplify the consideration of the third law, which is usually known as the *Law of Equivalent Proportions*. It may be stated as follows:—*An elementary substance, in combining with other elements, does so in a fixed proportion, which may be represented numerically.*

If a certain proportion of an element, A, unites with certain other fixed quantities of different elements, B, C, D, &c., to form compounds AB, AC, AD, &c., the quantities of B, C, and D which so unite with A will also be the quantities in which B and C, C and D, combine to form compounds BC, BD, CD, &c.

This principle of equivalent proportion may be illustrated by reference to the experiments upon the displacement of the metals from solutions of their nitrates by the introduction of some other metal, the affinity of which for the acid is stronger than that of the metal with which it is already combined. When mercury is introduced into a solution of nitrate of silver, the two metals change places, owing to the stronger chemical attraction of the nitric acid for the mercury than for the silver; part of the mercury is dissolved, nitrate of mercury is formed, and a corresponding quantity of silver is deposited. On making the experiment with suitable care, it is found that for each 100 grains of mercury dissolved, 108 of silver are separated in crystals. Again, when a bright slip of copper is introduced into a solution of nitrate of mercury, the surface of the copper becomes quickly coated with mercury, and for every 100 grains of mercury deposited, 32 of copper have dissolved. In a similar way, when a strip of lead is placed in solution of nitrate of copper, a deposit of metallic copper is separated, and for each 32 grains of copper thrown down, 104 of lead will have dissolved; whilst, lastly, a strip of zinc in a solution of nitrate of lead will lose 32 grains in weight for each 104 grains of lead which crystallizes upon its surface.

From this series of experiments we learn that different, but definite amounts of the various metals are capable of displacing each other; for it appears that 108 parts of silver, 100 of mercury, 32 of copper, 104 of lead, and 32 of zinc, are each capable of exactly supplying the place of the other, in combination with one uniform amount (54 parts) of nitric acid; and, in chemical language, these different quantities of the metals are said to be *equivalent* to each other. A chemical equivalent represents the numerical amount of each element which is capable of supplying the place of the corresponding quantity of any other element. Now it is remarkable that these numbers represent not only the quantity of each element which is capable of being substituted for other elements, as in the particular compounds with nitric acid just referred to, but they represent also the proportions in which these elements unite among themselves when they so combine with each other.

(12) *Tables of Equivalent Numbers.*—Chemists are in the habit of referring the results obtained by analysis to the proportion contained in 100 parts of the body submitted to experiment. Thus the analysis of water furnishes in 100 parts, 88·89 of oxygen and

11·11 of hydrogen. 100 parts of lime contain 28·58 of oxygen and 71·42 of the metal calcium; whilst 100 parts of potash consist of 17·02 of oxygen and 82·98 of potassium. These illustrations are sufficient to show that the quantity of oxygen is not the same in the different compounds; but the method of stating the result is not the one best adapted to exhibit the numerical relations in their simplest form. These relations are rendered much more evident in the following way. Having ascertained the proportion in 100 parts of the various compounds which each elementary body forms when it combines with oxygen, determine by calculation the proportion in which each element unites with the same ***fixed quantity*** (say 8 parts) *of oxygen*. A series of proportional numbers will thus be furnished which will represent the ratios in which each of the elements combines with oxygen. In this manner it will be seen that in water, for each 8 parts of oxygen 1 part of hydrogen is present,

For 88·89 : 11·11 :: 8 : 1

In lime, for each 8 parts of oxygen, 20 of calcium are present—

For 28·58 : 71·42 :: 8 : 20

And in potash, for every 8 oxygen there are 39 of potassium—

For 17·02 : 82·98 :: 8 : 39

1 of hydrogen, 20 of calcium, and 39 of potassium, are the equivalent quantities of each of these bodies, which combine with 8 parts of oxygen.

On the continent, many chemists, following the example of Berzelius, assume 100 parts of oxygen as the standard quantity, to which, in all such calculations, reference is made. The objection to this plan is, that the numbers thus obtained, and to which reference is constantly required, are inconveniently large, and consequently more difficult to retain in the memory, besides frequently involving fractional quantities: the number for hydrogen on this scale is represented as 12·5.

In this country the combining number of hydrogen is made the unit of comparison, a system which has many advantages. Hydrogen combines with oxygen in a smaller proportion than any other known substance, and the numbers representing the equivalents of all other bodies may, with few exceptions, without material error, be taken as multiples by whole numbers of the equivalent of hydrogen. The equivalent of hydrogen on this scale is 1, and as one part of hydrogen is united in water with exactly eight parts of oxygen, the equivalent number for oxygen is 8.

In the following Table the elementary substances are arranged alphabetically, with the symbol (15) used by chemists, affixed to each; the numbers, as actually determined by careful experiment, both on the hydrogen and oxygen scale, are given for convenience of reference. The numbers on the hydrogen scale will be adopted in this work, and, generally speaking, fractional quantities will be disregarded. A large proportion of the numbers are either exactly multiples by a whole number of the equivalent of hydrogen, or they differ from such multiples so slightly as to fall within the limits of differences due to experimental errors.

The numbers on the oxygen scale may readily be converted into those on the hydrogen scale, by multiplying the oxygen numbers by 8 and dividing by 100.

The names of the metals which from their rarity may be regarded as unimportant are given in Italics.

Table of Elementary Substances with their Equivalents and Symbols.

Element.	Symbol.	Equivalent Number.		Compounds with Oxygen, &c.
		H=1	O=100	
Aluminum	Al	12·672	170·9	$Al_2 O_3$, alumina
Antimony (Stibium)	Sb	129·03	1612·9	$Sb O_5$, antimonic acid
Arsenicum	As	75·	937·5	$As O_3$, white arsenic
Barium	Ba	68·64	858·03	Ba O, baryta
Bismuth	Bi	212·86	2660·75	$Bi Cl_3$, chloride of bismuth
Boron	B	10·9	136·2	$B O_3$, boracic acid
Bromine	Br	79·97	999·62	$Br O_5$, bromic acid
Cadmium	Cd	55·74	696·76	Cd O, oxide of cadmium
Calcium	Ca	20·12	251·31	Ca O, lime
Carbon	C	6·	75·	$C O_2$, carbonic acid.
Cerium	Ce	46·	575·	$Ce_2 O_3$, sesquioxide of cerium
Chlorine	Cl	35·49	443·67	$Cl O_5$, chloric acid
Chromium	Cr	26·27	328·38	$Cr O_3$, chromic acid
Cobalt	Co	29·49	368·65	Co Cl, chloride of cobalt
Copper (Cuprum)	Cu	31·65	395·6	Cu O, black oxide of copper
Didymium	D	48·	600·0	Di O, oxide of didymium
Erbium	E			
Fluorine	F	19·	237·5	Ca Fl, fluor spar
Glucinum	G	6·97	87·12	$Gl_2 O_3$, glucina
Gold (Aurum)	Au	98·33	1229·16	$Au_2 Cl_3$ soluble chloride of gold
Hydrogen	H	1·	12·5	HO, water
Ilmenium	Il			
Iodine	I	126·88	1585·99	$I O_5$, iodic acid
Iridium	Ir	98·56	1232·08	Ir O, protoxide of iridium
Iron (Ferrum)	Fe	28·04	350·5	$Fe_2 O_3$, red oxide of iron
Lantanium	La			La O, oxide of lantanium
Lead (Plumbum)	Pb	103·57	1294·64	Pb O, litharge
Lithium	L	6·53	81·66	L O, lithia
Magnesium	Mg	12·65	158·14	Mg O, magnesia

Table of Elementary Substances with their Equivalents and Symbols—(Continued).

Element.	Symbol.	Equivalent Number.		Compounds with Oxygen, &c.
		H=1	O=100	
Manganese	Mn	27·57	344·68	$Mn\,O_2$, black oxide of manganese
Mercury (Hydrargyrum)	Hg	100·10	1251·29	$Hg_2\,Cl$, calomel $Hg\,Cl$, corrosive sublimate
Molybdenum	M	47·69	596·1	$M\,O_3$, molybdic acid
Nickel	Ni	29·54	369·33	$Ni\,O$, protoxide of nickel
Niobium	Nb			
Nitrogen	N	14·	175·06	$N\,O_5$, nitric acid
Osmium	Os	99·41	1242·62	$Os\,O_4$, volatile oxide of osmium
Oxygen	O	8·	100·	$H\,O$, water
Palladium	Pd	53·24	665·47	$Pd\,O$, oxide of palladium
Phosphorus	P	32·02	400·3	$P\,O_5$, phosphoric acid
Platinum	Pt	98·56	1232·08	$Pt\,Cl_2$, bichloride of platinum
Potassium (Kalium)	K	38·96	487·	$K\,O$, potash
Rhodium	Ro	52·16	651·96	$Na\,Cl + Ro_2\,Cl_3$, double chloride with sodium
Ruthenium	Ru	52·11	651·39	$Ru_2\,Cl_3$, sesquichloride of ruthenium
Selenium	Se	39·62	495·28	$Se\,O_3$, selenic acid
Silicon	Si	21·36	267·00	$Si\,O_3$, silica
Silver (Argentum)	Ag	108·0	1350·	$Ag\,Cl$, chloride of silver
Sodium (Natrium)	Na	22·97	287·17	$Na\,O$, soda
Strontium	Sr	43·84	548·02	$Sr\,O$, strontia
Sulphur	S	16·0	200·0	$S\,O_3$, sulphuric acid
Tantalum, or *Columbium*	Ta			$Ta\,O_3$, tantalic acid
Tellurium	Te	64·08	801·76	$Te\,O_3$, telluric acid
Terbium	Tb			
Thorinum	Th	59·50	743.86	$Th\,O$, thorina
Tin (Stannum)	Sn	58·82	735·29	$Sn\,O_2$, tinstone
Titanium	Ti	24·12	301·55	$Ti\,O_2$, titanic acid
Tungsten (Wolfram)	W	94·64	1183·3	$W\,O_3$, tungstic acid
Uranium	U	60·0	750·0	$U_2\,O_3$ uranic acid
Vanadium	V	68·46	855·84	$V\,O_3$, vanadic acid
Yttrium	Y			$Y\,O$, yttria
Zinc	Zn	33·52	406·59	$Zn\,S$, blende
Zirconium	Zr	33·58	419·73	$Zr_2\,O_3$, zirconia*

(13) The chief value of a table such as the foregoing, arises from the circumstance that, as already mentioned, it not only

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* The student should commit to memory the chemical equivalents of those bodies on the hydrogen scale, which are not printed in italics. A short summary of the principal data upon which this table has been constructed will be given after the special description of the metals has been completed. Those elements to which no equivalent numbers are attached, have been too incompletely studied to enable the chemist to assign their combining proportions.

represents the quantities of the different elements which unite with 8 parts of oxygen, but it also indicates the simplest proportions in which they can unite *with each other*. For example, not only do 1 part by weight of hydrogen, 16 parts of sulphur, and 39 of potassium severally unite with 8 parts of oxygen, but 16 parts of sulphur form a compound with 1 part of hydrogen, and another compound with 39 parts of potassium. Hence 16 parts of sulphur are in combination equivalent to 8 parts of oxygen, and 39 of potassium to 1 part of hydrogen. These numbers are therefore termed the *chemical equivalents* of the respective substances which they represent.

Compound bodies unite with other compounds, just as simple bodies unite with other simple ones. Carbonic acid, for instance, unites with lime; and as might be anticipated, the combining numbers of such compounds are represented by the sums of the equivalent numbers of all the elements which enter into their composition. For example, the equivalent numbera of the following compounds are thus obtained :—

Water (1 Eq.O = 8 + 1 Eq.H = 1) HO = 9
Carbonic Oxide (1 Eq.O = 8 + 1 Eq.C = 6) CO = 14
Carbonic Acid (2 Eqs.O = 16 + 1 Eq.C = 6) CO_2 = 22

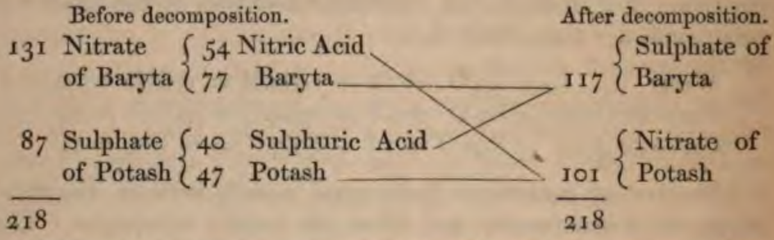
The law of equivalents holds good equally between the combinations of compounds and those of simple substances. The reactions between compounds often exhibit very striking exemplifications both of the generality of this law and of the manner in which it may be turned to useful account. The following example of the reaction between sulphate of potash and nitrate of baryta will afford an illustration of this kind.

The alkali potash is a substance consisting of 39 parts of potassium united with 8 of oxygen; its equivalent number is therefore 47. Now this body unites with sulphuric acid to produce sulphate of potash, and forms a salt which is perfectly neutral in its reaction to test papers. As the equivalent of sulphuric acid is 40, we should expect that sulphate of potash would be composed of 47 of potash and 40 of sulphuric acid, and would have an equivalent of 87. Analysis justifies the correctness of this anticipation.

In like manner, baryta is the oxide of the metal barium, and it consists of 69 parts of barium and 8 of oxygen. Baryta therefore has an equivalent of 77. Baryta, like potash, may be made to combine with an acid. Its compound with aqua fortis or nitric acid, for example, consists of 77 parts of baryta united with 54 of nitric acid; the equivalent of the nitrate of baryta is therefore 131. Nitrate of baryta is also a perfectly neutral salt.

If now we mix together a solution of 87 parts of sulphate of potash with 131 of nitrate of baryta, a very instructive change occurs;—the nitric and sulphuric acids change places: the nitric acid unites with the potash, to produce nitrate of potash, and the sulphuric acid unites with the baryta, to produce sulphate of baryta; the sulphate of baryta being insoluble, precipitates as a white powder; but the remarkable point is, that there is neither more nor less nitric acid than is required for exact union with the potash; neither more nor less sulphuric acid than is needed for the baryta: 54 of nitric acid are therefore truly equivalent to 40 of sulphuric acid; or may be substituted for the latter in composition, and 47 of potash are as truly equivalent to 77 of baryta.

This interchange or *double decomposition*, as it is usually termed, is illustrated in the diagram that follows:—



The solutions after mixture are still without action either upon litmus or turmeric paper.

If instead of using exactly the equivalent quantities of the two salts, an excess of either had been employed, suppose that 100 instead of 87 parts of sulphate of potash had been used, this excess of 13 parts would not have influenced the result, but would have remained unchanged in the solution. One great advantage therefore that is derived from the employment of a scale of equivalents, is economy in the use of the materials employed in the formation of compounds, since by its means it is possible to calculate the exact proportions of the chemical agents which would be required, in order to obtain the full effect of their mutual reaction.

The law of equivalent proportions also forms the basis upon which most of the calculations in chemical analysis are founded. Suppose it were desired to ascertain the proportion of baryta present in the solution of nitrate of baryta. By collecting on a filter the precipitate which is produced by adding sulphate of potash to a given bulk of the liquid, then drying and weighing the powder with suitable precautions, the quantity of baryta could at once be calculated; for it is a necessary consequence of the law of equivalent combination that every 117 grains of sulphate of baryta contain 77 of baryta. From this result the proportion of nitrate of baryta in solution could also easily be deduced, inasmuch as 77 grains of baryta, for conversion into the nitrate, would require 54 grains of nitric acid, and would therefore represent 131 grains of nitrate of of baryta; or 117 grains of sulphate of baryta would indicate 131 of nitrate of baryta in the liquid under examination.

The doctrine of chemical equivalents receives an easy explanation upon Dalton's atomic theory, for in his view these equivalent numbers express simply the relative weight of the ultimate particles or atoms of each element. Hence these numbers are often spoken of under the term of the *atomic weights* of those bodies. A better expression, however, is that of *chemical equivalents,* a term of which frequent use will be made in this work.

One or two additional illustrations of these principles will serve further to elucidate them. If the weight of the atom or smallest particle of hydrogen be taken as unity or 1, the weight of the particle of oxygen would be 8, that of zinc and of copper 32, of lead 104, of silver 108, and of mercury 100. When one particle or atom of oxygen unites with one atom of hydrogen, the combination necessarily occurs in the proportion of 8 parts by weight of oxygen with 1 of hydrogen. When one particle of oxygen unites with one particle of lead to form oxide of lead, these elements necessarily combine by weight in the proportion of 8 parts of oxygen to 104 of lead, and so on. A similar process occurs in the combination of compounds with other compounds.

(14) *Law of Volumes.*—When bodies are capable of assuming the form of gas or vapour, a very simple relation has been observed between the volumes or bulks of any two gases which combine together. It has been found, for example, that the gases unite together either in the proportion of equal bulks, or else that two measures, or volumes of the gas which may be distinguished as A, combine with one measure of a second gas, which may be called B, or that three measures of A unite with one of B, or sometimes that three measures of A unite with two of B. Some simple proportion of this kind is always observed between the volumes of two gases which enter into combination. The cause of this uniformity depends upon the circumstance that the chemical equivalent of each elementary substance forms a volume of gas or vapour, which, under similar conditions of temperature and pressure, occupies

either the same bulk, or else double the bulk of that of some element taken as the standard of comparison.

For example, taking a number of grains of each element which corresponds with its equivalent number :—

	Cubic inches.
8 grains of oxygen, at 60° F. and 30 inches Bar.	= 23·33
1 grain of hydrogen	= 46·66
35·5 grains of chlorine	= 46.66
14 grains of nitrogen	= 46·66

and so on.

An equivalent of hydrogen, of chlorine, or of nitrogen, therefore, occupies double the volume of an equivalent of oxygen. Oxygen is, consequently, 16 times as heavy as hydrogen.

Combination by volume, therefore, is to be carefully distinguished from combination by weight. In each case the proportions are, however, equally definite.

After the union of the gases with each other, the bulk of the compound, though it is often less than the joint bulk of the two separate gases, yet bears a simple relation to it. It may happen that the two gases combine without undergoing any change of volume; or three measures of the gases may condense into the space of two; or three measures may occupy the bulk of one measure; or, again, two volumes may be condensed into the space of one volume.

The mode of combination of hydrogen with oxygen may be taken as an illustration of some of these points. Hydrogen gas unites with oxygen gas in the formation of water, in the proportion of two volumes of hydrogen to one volume of oxygen. This, therefore, corresponds by weight to one part of hydrogen and eight parts of oxygen. The steam produced by their union, however, instead of occupying the space of three volumes, is condensed into that of two; but the weight of the steam formed is equal to that of the united weights of the oxygen and of the hydrogen which have entered into its composition.

Compound gases and vapours, in combining, follow the same regularity and simplicity in the proportions by volume in which they unite, as is observed to prevail among elementary bodies, and the compounds resulting from such union, when gaseous, or convertible into vapour, exhibit the same equally simple ratio in bulk to that of their components.

(15) *Symbolic Notation.*—Before proceeding further, it will be advantageous to describe the principles of notation, as applied in

the construction of chemical formulæ. This notation constitutes a kind of short-hand, which materially facilitates the representation of chemical changes, since it greatly abridges the labour of description, and, with a little practice, enables the student to trace at a glance reactions even of a complicated character. Its employment has, in fact, become indispensable both to the teacher and to the pupil.

Every elementary substance is represented by a symbol, consisting of the first letter of its Latin name: in cases where more than one element has the same initial, a second distinguishing letter is added. These symbols, when used singly, always represent one equivalent of the body which they indicate. The symbol O, therefore, stands for one equivalent of oxygen; H, for one equivalent of hydrogen; C, for one equivalent of carbon, and so on.

A compound body, composed of single equivalents, is represented by writing the two symbols side by side, thus HO indicates one equivalent of water.

If more than one equivalent of a body has to be expressed, it is signified either by prefixing the number, as 2 H, two equivalents of hydrogen; or, as is more usual, by writing a small figure to the right of the letter below the line, as H_2: HO_2, would indicate peroxide of hydrogen; CO_2, carbonic acid.

Secondary compounds, such as salts, are expressed in an analogous way, the base being always placed first, $CaO + CO_2$ representing one equivalent of carbonate of lime. Frequently a comma is placed between the two compounds instead of the algebraic sign +. Carbonate of lime may be written CaO, CO_2. This mode is usually adopted to express a more intimate union than when the sign + is used. Where it is necessary to indicate more than one equivalent of a compound, the whole formula of that compound is included in a bracket, and preceded by the indicating number. Thus three equivalents of carbonate of lime would be written $3\,(CaO, CO_2)$. The figure prefixed multiplies nothing beyond the symbols included within the bracket. Thus, in the formula for crystallized alum—

$$Al_2O_3,\ 3\ (SO_3) + KO,\ SO_3 + 24\ HO.$$

The 3 which precedes SO_3 only indicates that three equivalents of sulphuric acid are present. Frequently the employment of brackets is neglected, and then the figures multiply all the symbols included between them and the next comma, or sign of addition.

A very little practice will make these various modifications familiar to all. To expedite the acquisition of this knowledge, the student will find it advantageous to exercise himself in the expression of chemical changes by symbols, whenever the opportunity occurs, until he is thoroughly acquainted with their signification and use. The reaction between nitrate of baryta and sulphate of potash (13), might be expressed by symbols in a single line, which, if the equivalent numbers of the elements concerned were fixed in the memory, would convey all the information of a minute description, thus—

$$\overbrace{\mathrm{KO,\ SO_3}}^{\text{Sulphate of potash.}} + \overbrace{\mathrm{BaO,\ NO_5}}^{\text{Nitrate of baryta.}} \text{ yield } \overbrace{\mathrm{BaO,\ SO_3}}^{\text{Sulphate of baryta.}} + \overbrace{\mathrm{KO,\ NO_5}}^{\text{Nitrate of potash.}}$$

CHAPTER II.

WEIGHTS AND MEASURES—SPECIFIC GRAVITY.

(16) *Weights and Measures.*—The foundation of all accuracy in experimental science consists in the possibility of determining with exactness the quantity and the bulk of those substances which are submitted to examination. In the force of gravity we possess an unvarying standard of comparison. A pound weight, for example, at the same spot of the earth's surface, is invariably attracted towards the earth with the same force, so that its weight is uniformly the same at that spot.

The force of gravity diminishes slowly from the pole to the equator. A mass of matter which would compress a spring with a force equal to that of 194 lb. at the equator, would act upon it with a force of 195 lb. at the poles. This difference would not, of course, be perceived in the ordinary mode of weighing by the balance, as both the weights and the body weighed would be similarly and equally affected.

The common process of weighing consists in estimating the force with which any given mass is attracted towards the earth, by comparison with other known quantities of matter, arbitrarily selected for the purpose; consequently, the *weight* of a body is the expression in terms of the standard so selected, of the amount of force which is exactly required to prevent the body under examination from falling to the ground.

The standard of weight used in this country is the avoirdupois pound, which is subdivided into 7000 grains.

The system of weights is connected with the measures of capacity in use in this country, through the medium of the Imperial gallon; which is defined by an Act of Parliament of the year 1824 to be a measure containing 10 lb. avoirdupois of distilled water, weighed in air at a temperature of 62° F., the barometer standing at 30 inches. The gallon of distilled water, therefore, contains 70,000 grains.

These measures of capacity are related to those of length by the determination that a gallon contains 277·276 cubic inches. A cubic inch of distilled water weighs, in air at 62°, with the barometer at 30 inches, 252·456 grains, *in vacuo* (23) it weighs 252·722 grains. The standard of length is the yard measure, and is subdivided into 36 inches.*

(17) *French System of Weights and Measures.*—The French system of weights and measures is connected together in a manner far more philosophical than the foregoing; and, as it is the one generally adopted by scientific men abroad, and is gradually being introduced into the writings of men of science in this country, it is essential that the principles upon which it is based should be understood.

The standard of reference is a measurement of one of the great circles encompassing the earth itself. The ten-millionth part of a quadrant of the meridian constitutes the unit of the system. This quadrantal arc was fixed at 6213 miles and 1450 yards English measure; consequently the ten-millionth part of this, the *metre*, is equivalent to 39·37079 English inches, nearly 3½ inches more than our standard yard, or a fraction of an inch longer than the seconds pendulum. This metre is subdivided into tenths, called *decimetres;* hundredths, or *centimetres;* and thousandths, or *millimetres.* A *kilometre,* or thousand metres, nearly ⅝ of an English mile, is employed in many parts of France as the ordinary road measure. Fig. 3 represents a decimetre subdivided into centimetres, one of which is subdivided into millimetres, compared with English inches. The measures of capacity are connected with those of length by making

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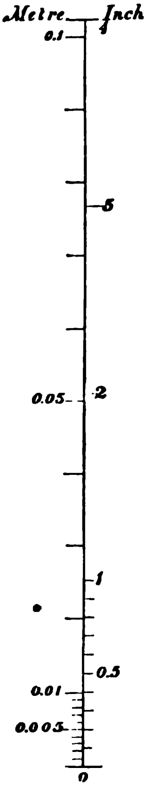
* In order further to connect the measures of length with those of weight, Captain Kater determined the length of a seconds pendulum, the oscillations of which are produced by the action of the force of gravity. The length of a pendulum, which beats seconds at the level of the sea *in vacuo,* and in the latitude of Greenwich, he found to be 39·13929 inches.

Fig. 3.



the unit of capacity in this series a cube of a decimetre, or 3·937 English inches in the side; this is termed a *litre* which is equal to 1·765 Imperial pints, or rather more than 1¾ English pints. The litre is again subdivided into tenths, or *decilitres*, and hundredths, or *centilitres*; and finally, the system of weights is connected with both the preceding, by taking as its unit the weight of a cubic centimetre of distilled water, at the temperature of 39°·2 F., it weighs 15·433 English grains. The *gramme*, as this quantity is called, is further subdivided into tenths, or *decigrammes*; hundredths, or *centigrammes*; and thousandths, or *milligrammes*; and its higher multiple, 1000 grammes, forms the *kilogramme*. The kilogramme is the commercial unit of weight, and is something less than 2¼ lb. avoirdupois, being 15433 English grains. The litre, as it consists of 1000 cubic centimetres of water, at 39°·2, contains exactly a kilogramme of water, and is equivalent, at 39°·2, to 61·024 cubic inches English.

(18) *The Balance.*—The familiar operation of weighing, is for most part effected by means of the balance.

This instrument consists essentially of an inflexible bar, delicately suspended at a point exactly midway between its extremities, from which depend the scale-pans; in one of these the weights, in the other the objects to be weighed are placed. When the balance is *in equilibrio*, the arms of the beam assume a direction perfectly horizontal. The main points requiring attention are—1st, Equality in the lengths of the arms of the beam; 2nd, suspension of the lever just above its centre of gravity; and 3rd, care that the friction at the points of suspension both of the beam and of the scale-pans be reduced to a minimum. The points of support in delicate balances are usually made of fine edges of hardened steel, which bear against flat polished plates of agate. Provided the suspensions be sufficiently delicate, it is easy to obtain exact weighings by means of a balance the arms of which are not equal. For this purpose, the material to be weighed is accurately balanced with shot, sand, or any other convenient substance; it is then removed from the pan, and weights substituted, until the sand or shot remaining in the other pan is again accurately counterpoised: the number of weights needed will shew the weight of the substance under experiment. In all delicate experiments the balance must be screened from currents of air, and the bodies weighed must have sensibly the same temperature as that of the surrounding atmosphere, otherwise currents of air, ascending or descending within the case, will be produced, and they will impair the accuracy of the observation. A delicate balance will indicate a difference of weight equal to about $\frac{1}{100,000}$ of what it will carry in each pan.

Specific Gravity.

(19) If equal bulks of matter of different kinds be compared together, they will be found to differ very greatly in weight.

			lb.	Grains.
100 cubic inches	of hydrogen	will weigh		2·14
,, ,,	of air	,,		31·00
,, ,,	of water	,,	3·604	25246·00
,, ,,	of iron	,,	28·11	
,, ,,	of platinum	,,	75·68	

Platinum, the heaviest body with which we are acquainted, is upwards of 200,000 times as dense, bulk for bulk, as hydrogen, which is the lightest material known.

The comparison of the weights of equal bulks of different bodies, when referred to a uniform standard, constitutes their specific gravity, or relative weight, *i.e.*, the weight which is specific or peculiar to each kind of matter. The specific gravity of a body forms one of its most important and distinguishing physical characters. The mineral iron pyrites, for instance, is in colour almost exactly like gold; but it is at once distinguished from the precious metal by the difference in specific gravity, an equal bulk of gold being nearly four times as heavy. The numbers used to represent the specific gravity of solids or liquids are obtained by comparing a known weight of the body under experiment with the weight of an equal bulk of distilled water, which has been selected as the standard of reference. In this country the experiment is made at a temperature of 60° F. For gases and vapours, atmospheric air at 60° F., and the barometer standing at 30 inches, is employed as the standard.* For the purpose of calculating the specific gravity of

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* Unfortunately the standard temperature and pressure adopted in France differs from that employed in England. In France, 32° F. is the temperature; and 760 millimetres, or 29·922 inches is the height of the barometer which is assumed as the standard. The unit of density, however, is not

any substance, solid or liquid, it is therefore simply necessary to ascertain, first, the weight of the body in question, then that of an equal bulk of water. When this is done, we obtain by simple proportion the specific gravity of the body under examination, that of water being assumed as 1. If, as is the case with a large number of solids, they are heavier than water, the specific gravity merely tells how many times heavier they are than their own bulk of that fluid:—

$$\left.\begin{array}{c}\text{Weight of}\\ \text{equal bulk}\\ \text{of water}\end{array}\right\} : \left\{\begin{array}{c}\text{Specific gravity}\\ \text{of water,}\\ 1{\cdot}000\end{array}\right\} :: \left\{\begin{array}{c}\text{Weight of}\\ \text{body in}\\ \text{in air}\end{array}\right\} : \left\{\begin{array}{c}\text{Specific}\\ \text{gravity}\\ \text{required.}\end{array}\right.$$

(20) The determination of the weights of equal bulks of liquids and of water is easily made in the following manner:—Take a light bottle furnished with a stopper, and weigh it when empty; fill it with water, and weigh it again; the difference, of course, will be the weight of the water which it contains. Empty the bottle, then fill it with the liquid for trial and weigh. On deducting the weight of the bottle, we obtain the weight of a bulk of liquid exactly equal to that of the water. In practice it is usual to employ a bottle that holds exactly 1000 grains of distilled water at 60°, as when the bottle is filled with the liquid under trial, the weight in grains of the liquid represents the specific gravity at once, without calculation. For convenience, a counterpoise of brass is adjusted to the weight of the empty bottle. Suppose the counterpoised bottle, which, when filled with water, weighs 1000 grains, in addition to the counterpoise, to be filled with pure alcohol; it will now weigh only 792 grains, and the specific gravity of the alcohol will be 0·792; for 1000 : 1·000 :: 792 : 0·792. The same bottle filled with oil of vitriol would weigh 1845 grains. Its specific gravity would therefore be represented at 1·845.

FIG. 4.

For accurate purposes, a flask of the annexed form (fig. 4) is preferable to all others; a mark at *a*, in the contracted portion of the neck,

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the volume of an equal bulk of water, at 32°, but at 39°.2, the point of maximum density of this fluid. (137.)

These relations are much more complex than those adopted in England; though in the case of liquids and gases there is an advantage in the facility of securing a uniform temperature of 32° at all times, by the use of melting ice.

indicates the level occupied by 1000 grains of water at 60°. The flask filled with the liquid under trial, a little above this mark, is then placed for an hour in water, which must be maintained at 60°. At the end of that time the superfluous liquid in the flask is drawn off by means of a pipette till it stands exactly at the level of the mark; the stopper is inserted, and the weight, after careful drying of the outside, is taken. Bottles which contain only 100 or 200 grains up to the graduation on the neck, may often be employed with advantage instead of the larger one.

In principle, the determination of the specific gravity of gases is the same: a flask or globe is weighed when empty, again when filled with air, and a third time, when the gas under trial has been substituted for atmospheric air. Gases, however, are liable to considerable changes of bulk from slight variations of external circumstances; hence, in taking their specific gravity, certain precautions are necessary, which will be fully described further on (140).

(21) With solids, a different, but not less simple method is adopted, though resting on a principle by no means so obvious. This principle was one of the great discoveries of Archimedes: it may be thus explained:—When a body is plunged beneath the surface of liquid it obviously displaces a bulk of such liquid equal to itself, and consequently it is pressed upon or supported in the liquid, with a force exactly equal to that with which the particles of the liquid were supported, when they previously occupied its place; the solid will therefore appear to have lost weight exactly equivalent to that of the bulk of liquid which it occupies. The operation required for ascertaining the specific gravity consists, therefore, in weighing the solid in air, then having suspended it by a horsehair from the scale-pan, placing it in distilled water at 60°, and again weighing; the difference of the two weights will be that of its own bulk of water. (fig. 5)

FIG. 5.

A piece of lead for instance, weighs in air . . 820 grains.
" " " in water . . 749 grains.

Loss: being the weight of an equal bulk of water. 71 grains.

The specific gravity of the lead is obtained from these data by the application of proportion, in the following manner:—

71 : 1·000 :: 820 : x (= 11·54 sp. gr. of lead.)

The rule for obtaining the specific gravity of a solid may therefore be expressed in the following terms: divide the weight of the body in air by the loss which it experiences when weighed in water; the quotient is the required specific gravity. The experimental proof of the correctness of the principle, viz., that the solid loses weight equal to that of the water which it displaces, is easily given. Take a metal cylinder which accurately fits, and completely fills the cavity of a cylindrical cup; counterpoise the two when suspended in air from one extremity of the balance beam. Then withdraw the metal plug, and suspend it by a hair to a hook at the bottom of the cup, which must still remain attached to the balance, and place the plug so suspended in distilled water; the counterpoise will now be much too heavy: fill the cylindrical cup with water—(add, that is, the weight of a bulk of water equal to the bulk of the plug,) and the balance will be restored.

Occasionally it happens that a knowledge of the specific gravity of a body in the form of a powder is required; in such a case the method of taking the specific gravity requires to be slightly modified. Suppose it be desired to find the specific gravity of a species of sand, we may proceed as follows:—take a bottle which contains, when full, a known weight of distilled water, 1000 grains, for example; weigh into it, when empty, a quantity, *e. g.*, 150 grains, of sand. Supposing that the sand had not displaced any water, the bottle when filled up with that fluid, would now weigh 1150 grains; but on actually weighing the bottle after it has been filled up, it is found that the water and sand together weigh only 1096 grains; the sand therefore has displaced 54 grains of water. We have thus the data for calculating the specific gravity of the sand, viz.

54 : 1·000 :: 150 : x (= 2·764), the specific gravity of the sand.

If the substance be soluble in water, it must be weighed in air as usual; then in spirit of wine, in oil of turpentine, or in some liquid which does not dissolve it, and the specific gravity of which is known. If the body be so light as to float in water, it must be attached to a solid, the weight of which in water has been ascertained, and which is sufficiently heavy to keep the lighter body, when fastened to it, beneath the surface; the weight in water of the two united bodies is then determined, and the result thus obtained is deducted from the weight of the heavier solid in water: if to this remainder the weight of the light body in air be added, we are furnished with the weight of a bulk of water equal to that of the lighter solid, and have the data for calculating the specific gravity by proportion, in the usual manner.

(22) *Hydrometer.*—Another method of taking the specific gravity of liquids, consists in the use of the instrument called the *hydrometer* or *aerometer.*[*]

FIG. 6.

The hydrometer (fig. 6) consists of a graduated scale, which is made to float vertically in the liquid, by means of a hollow ball of glass or brass, counterpoised by a duly adjusted weight attached to the lower end of the instrument. A portion of the stem of the instrument must always float above the surface of the liquid, the specific gravity of which is to be determined. It is obvious, that when placed in any fluid contained in a vessel of sufficient depth, it will sink until it has displaced a bulk of liquid equal to its own weight; in dense liquids it will sink to a smaller depth; in a lighter liquid it will sink to a greater extent, an additional portion of the stem being in the latter case immersed, until it has displaced a sufficient additional quantity of the liquid to compensate for the diminished density of the fluid under trial. The instrument may either be supplied with a scale, graduated upon the stem by trial in liquids of known specific gravity, so as to give the result by mere inspection, or an arbitrary scale of equal parts may be used, and the values indicated may be ascertained by reference to tables constructed for the purpose. In practice, it is found convenient to employ two instruments, one graduated for fluids lighter than water, another for those which are heavier; the need of an inconvenient length of stem is thus obviated.

The hydrometer is, with suitable precautions, capable of

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[*] Table of Beaumé's and Twaddell's hydrometers will be found in the Appendix.

affording very accurate results. It is employed by the Excise, for determining the strength of spirituous liquors. The ordinary glass instruments, however, only furnish approximations to the truth, which, for the common purposes of the arts, are quickly obtained, and are sufficiently exact.

(23) *Correction of Weights taken in Air.*—The apparent weight of every substance in the atmosphere (that is, the force with which it appears to be drawn to the earth), is always a little less than its actual weight, because the air tends to support the body with the same force with which it would support a portion of air of the same bulk as the body itself. The weight of this displaced portion of air may easily be ascertained, if the specific gravity of the body be known; as from the observed weight of the body, we can calculate directly the weight of an equal bulk of water, and $\frac{1}{817}$ of this weight will give the weight of a corresponding bulk of air at mean temperature and pressure. This weight must be added to that actually found; at the same time a similar and opposite correction will be required for the metal weights used in the experiment, because they will also appear lighter than they really are; and an amount of weight greater than the true one will be required to effect the counterpoise. If, therefore, the weights have the same specific gravity as the body counterpoised, the two corrections will neutralize each other; but if, as in weighing gases, there is a great difference between them, the correction will be one of importance. The true weight sought will be thus obtained:—Add to the weight of the body in air the weight of the bulk of air it has displaced, and deduct from this, the weight of the bulk of air displaced by the metal weights employed.

The correctness of the foregoing observations admits of an easy experimental illustration. If a light body, such as a piece of cork, be suspended in air from one end of a scale beam, and be counterpoised at the other by a metal weight, then on placing the apparatus under the receiver of the air-pump, and exhausting the air, the cork will gradually appear to preponderate; but on again admitting the air, the equilibrium will be restored.

CHAPTER III.

ON SOME VARIETIES OF MOLECULAR FORCE.

I. *Elasticity.*—II. *Cohesion.*—III. *Adhesion.*—IV. *Crystallization.*

(24) Besides the attractive power of gravity which operates through distances so vast that the mind is lost in the attempt to estimate and explore them, other forms of attraction exist; but they are exerted only through distances so minute, as to be inappreciable to our unaided senses: and yet, upon the exertion of these forces, the form, and even the chemical properties of bodies depend.

The first of these forces is known as *cohesion*, and it acts between the particles of matter which are similar in kind. The intensity of this force determines whether the body be solid, liquid, or gaseous.

The second of these forces is that of *adhesion*, and it is exerted between dissimilar kinds of matter, and unites them, as in the case of the intervention of cements, into one consistent whole.

The third, and to the chemist the most important of these forces, is that known as *chemical affinity*, which causes the union of dissimilar particles of matter of invisible minuteness, re-arranges them in new forms, and produces a compound body endowed with new properties.

Reacting against all these molecular attractions, is the repulsive power of HEAT, which may be raised high enough to overcome them all, and which in a modified form, when balanced against these attractive forces, produces that equipoise in distance between the constituent particles of material objects in general, which is designated as *elasticity*.

Forces which thus act at these minute distances only, are termed *molecular* forces, in contradistinction to those which like gravity, act upon the mass, and operate through great distances.

§ I. ELASTICITY—MECHANICAL PROPERTIES OF GASES.

(25) By *elasticity* we understand the resistance that a body offers to compression or to extension, and the power which it possesses of regaining its form or bulk when the pressure or tension is withdrawn.

The law which regulates elasticity, in perfectly elastic bodies, may be expressed by the statement that the resistance is directly proportioned to the compressing force. Thus a bow, or a spring, bent to a certain extent with a force of 10 lb., will be bent to double that extent with a force of 20 lb.

All solids have limits to their elasticity, and there are very few which are perfectly elastic, even within those limits; that is to say, there are few bodies which perfectly recover their form after having been stretched or compressed; if compressed beyond a certain point, they either 'set,' and alter their shape, as is the case with lead; or they break, as is the case with glass.

The elasticity of glass and steel is, within the bounds of their cohesion, almost perfect: that of caoutchouc, on the contrary, is imperfect; for, by frequent stretching, it becomes permanently elongated.

Liquids possess a small, but very perfect elasticity, which varies in amount in different liquids; the densest liquids, in general, being those which least admit of compression. The following table exhibits some experimental results obtained on this subject by Messrs. Colladon and Sturm:*

Compressibility of Liquids.

	Temp. ° F.	Compression in Millionths for each additional atm.	Range of pressure in atmospheres.	Variations in compressibility.
Mercury	32°	5·3	1 to 30	regular
Sulphuric Acid	"	32.	1 " 16	"
Water	"	51·3	1 " 24	"
Acetic Ether	"	72	1 " 16	76 to 68
Oil of Turpentine	"	73	1 " 26	regular
Hydrochloric Ether	52°	84	1 " 12	85 9 to 82·2
Alcohol	"	93·5	1 " 24	96·2 to 89
Ether	"	145·	1 " 24	146 to 138

One million parts of mercury, for example, was found by each additional pressure of 15 pounds upon the square inch, to diminish in bulk 5·3 parts. One million parts of water suffered a compression nearly ten times as great, being reduced more than 51 parts; the pressure of the atmosphere being estimated on an average at 15 pounds upon every square inch of the earth's surface.

Regnault has more recently determined the compressibility both of water and of mercury with very great care. He considers the results of Colladon and Sturm to be a little too high; and estimates the compression of mercury for each atmosphere at 3·5 millionths of its bulk; whilst he found that of water to be equal to 47 millionths of its bulk.

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* *Ann. de Chimie et de Physique*, II. xxxvi., 113, 225.

The compressibility of liquids is greater at low than at high temperatures.

(26) *Boyle's or Marriotte's Law of Elasticity in Gases.*—It is, however, in gases that the most extensive and perfect display of elasticity is to be seen; it constitutes indeed their most important physical peculiarity. It may be stated without sensible error, that within the limits of ordinary experiment, 'the volume of an aeriform body is inversely as the pressure to which it is exposed:' consequently by doubling the pressure we halve the volume, by trebling it we reduce it to one third; 'but the elasticity is increased directly as the pressure;' by doubling the pressure we double the elasticity. These facts are strikingly exhibited in the following experiment devised by Boyle, and more accurately performed by Marriotte, and the law has hence been termed Boyle's or Marriotte's law.

FIG. 7.

Take a bent tube (fig. 7) of uniform bore, one limb of which is about 12 inches long, and furnished with a stop-cock; the other limb being 6 feet in length, and open at the top. Pour a little mercury into the bend of the tube, and close the stop-cock. The air in the short limb is now of the same elasticity as that of the atmosphere at the spot; and the air at the surface of the earth, as will presently be more fully explained, is under the pressure due to the weight of its own superincumbent mass; the amount of this pressure is ascertained by observing the height of the mercurial column in the barometer at the time. Next pour mercury into the open limb of the bent tube, the air in the shorter limb will slowly diminish in bulk: when the mercury in the longer limb stands at a height above the level of that in the shorter, exactly equal to the height of the barometer at the time, the compressed air will occupy a length of the shorter tube, exactly equal to one half of that which it did at the beginning of the experiment; the air is subject to a pressure exactly double. On adding more mercury, till the column is twice the height of the barometric column, the pressure will be increased threefold, and the air will now occupy only one third of its original bulk.[*]

(27) Gases and vapours or *elastic fluids*, as they are frequently termed, differ from liquids in the entire absence of cohesion among their particles. A vessel may be filled either partially or completely with a liquid, and this liquid will have a definite level surface or limit. With gases it is otherwise; they always perfectly fill the vessel that contains them, however irregular its form. Instead of cohesion there is a mutual repulsion among their particles. These particles have a continual tendency to recede further from each other, and they therefore exert a pressure in an outward direction upon the sides of the vessel which contains them. This outward pressure is greater or less according as the elasticity of the gas is increased or diminished. Indeed, the bulk of a gas depends entirely upon the pressure which is exerted upon it. These facts admit of experimental proof in the following way.

Procure a stout cylindrical glass tube open at one extremity, and capable of being closed at the other by a stop-cock; fit it with a solid plunger that slides air-tight up and down within it: open the stop-cock, place the plunger half way down, and fill the vessel with some coloured gas, such as the peroxide of nitrogen, NO_4: now close the

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[*] The elaborate experiments of Magnus (*Ann. de Chimie et de Physique*, III. iv. 330.) and of Regnault (*Ib.* iv. 1. and v. 52.) have, however, shewn that this law is not rigidly accurate. For atmospheric air, for hydrogen, oxygen, and nitrogen, and generally for gases which have either never been liquefied, or only liquefied under enormous pressures, the law is very nearly correct. even under a pressure of several atmospheres, but for those which liquefy more readily it is not so, the nearer they are made to approach to the point of liquefaction the greater is the difference between the volume actually observed, and the result calculated. The contraction is always found to be more considerable, by experiment, than it should be by the law usually assumed.

Regnault, in his experiments, obtained the results embodied in the following table; they show considerable deviations from the law in four important gases under high pressures.

Elasticity of Gases at High Pressures.

Pressure in Atmospheres.	Air.	Nitrogen.	Carbonic Acid.	Hydrogen.
1	1·000·000	1·000·000	1·000·000	1·000·000
10	9·916·220	9·943·590	9·226·200	10·056.070
20	19·719·880	19·788·580	16·705·400	20·268·270

The elasticity of hydrogen therefore increases even *more rapidly* than the pressure; with the other gases the elasticity does not quite keep pace with it. It would seem from these experiments as if there were more probability of liquefying oxygen than nitrogen, and both these than hydrogen.

stop-cock and draw the piston upwards, the gas will be seen to dilate, and the red vapour will still entirely fill the tube; but a considerable resistance to the upward motion of the piston is experienced, the dilated gas has its elasticity reduced below that of the external air, and on releasing the piston it is forced back to the middle of the tube; the elasticity of the gas within, and that of the air without, are now equal. Now attempt to thrust the piston to the bottom of the tube; great resistance will be experienced, but the gas will yield to the pressure and will be condensed into a smaller space, while its elasticity will be proportionately increased; but the instant the pressure is discontinued, the piston will rise up again, and occupy its first position midway between the two ends of the cylinder. (fig 8.)

FIG. 8.

(28) *Air Pump.*—Advantage is taken of this elasticity and expansibility of gases in the construction of the air-pump, an instrument designed for the removal of air from closed vessels. The principle of its construction may be explained in the following manner.

Suppose that a metal cylinder, accurately bored, be fitted with a piston similar to that shown in fig. 8, but provided in addition with a small opening, covered by a flap or valve of oiled silk, which opens upwards or outwards; on forcing the piston downwards, the compressed air will escape through the valve, but on attempting to withdraw the piston no air will be able to re-enter the cylinder, and a resistance will be experienced, owing to the pressure on the upper surface of the piston occasioned by the elasticity of the external air. If the cylinder be provided with a second valve at the bottom, opening in the same direction as that in the piston, this valve will, on thrusting down the piston, be closed by the elasticity of the included air, while the upper valve will be opened; on withdrawing the piston, the effect is reversed, and the lower valve rises, the air enters, while the valve in the piston is firmly closed. Such an arrangement constitutes the exhausting syringe or air-pump in its simplest form. (fig. 9.) In the usual and more convenient form of the air-pump, (fig. 10) a brass tube passes from the bottom of the syringe and terminates in the centre of a disk of brass or of glass, ground accurately flat: the edge of

FIG. 9.

Fig. 10.

the vessel from which the air is to be exhausted is also ground truly, and it is inverted upon the plate. On working the syringe, the elasticity of the air within the vessel or receiver raises the lower valve, and the dilated air enters the vacuum produced in the lower part of the cylinder by withdrawing the piston; the air thus admitted again raises the valve of the piston, when the latter is so far depressed as to render the elasticity of the air beneath it superior to that of the atmosphere: the same action goes on with every successive motion of the piston, until the elasticity of the air within becomes so much diminished as to be insufficient to raise the lower valve. For convenience, two of these exhausting syringes are often combined in the air-pump, and are made to work alternately by a rack and pinion.

Fig. 11.

(29.) *Pump with Single Barrel.*—A more complete vacuum may be obtained with a pump of simpler construction, but the labour of using it is considerably greater. The difference between this form of the instrument and the one just described will be readily understood with the assistance of figure 11. This pump consists of a single barrel, within which a solid plunger A, moves air-tight. The plunger is connected with a smooth solid rod R, which also works air-tight through a stuffing box S, at the top of the barrel. In this stuffing-box is a conical metal plug, or valve V, which opens upwards, and which projects a little way below the under surface of the stuffing-box, which is ground flat. The communication P, between the plate of the pump and the barrel is made at a sufficient distance from the bottom to allow the plunger to pass completely beyond it. In order to use the instrument the plunger is carried down to the bottom of the barrel, the receiver is then attached to the plate, and the piston raised. In rising, the air contained in the barrel is expelled through the valve in the stuffing-box, and bubbles up through the oil placed there to keep the joints air-tight. When the piston now descends, a complete vacuum is formed below it, until it passes below the aperture which leads to the receiver; the air then rushes in above the piston; this portion is in turn expelled by raising the piston again; and the exhaustion may in this way be carried on till it becomes almost complete, because the valve is now raised not simply by the elasticity of the air confined below the piston, but it is pushed up by the upper surface of the piston itself, and the last bubble of air is displaced by a drop of oil which flows past the valve and thus effects its expulsion.

(30) The increase in bulk of the enclosed air, and consequent decrease in its elasticity, may be illustrated by placing a tube, blown into a bulb at one end, full of air, and with its open mouth downwards, inserted in a vessel containing water, under the receiver of the pump. With each movement of the piston, the air in the bulb expands, a portion of it in the act of expanding escapes, and bubbles up through the water. An amusing variation of this experiment may be made by placing a number of shrivelled apples in the receiver, and then working the pump. The apples contain air in their pores, which is prevented from escaping by the rind; on working the pump the diminished pressure causes this imprisoned air to expand; in consequence, they swell up, and regain their fresh and plump appearance. The illusion vanishes the moment the atmospheric air is readmitted, because the pressure of the external air reduces that in the apples to its former bulk. The elastic force thus exhibited is very considerable, as may be shown by the following experiment. Take a thin vessel, such as a light flask, and seal it up full of air; now if the air be exhausted from a receiver placed over it, it will burst into fragments. The powerful pressure which air exerts against the internal surface of the vessels in which it is contained, may also be exhibited by allowing a weight of several pounds to rest upon a bladder placed under the receiver of the air-pump. On exhausting the air from the receiver, the air in the bladder expands, and lifts the weight.

(31) *Condensing Syringe.*—If the valves in the syringe be made to open in the opposite direction to those of the air-pump the instrument constitutes the *condensing syringe.* By attaching it to a reservoir capable of resisting the pressure, air may be compressed without difficulty, and stored up as a mechanical power (fig 12.); the elasticity of air so compressed is capable of being brought suddenly into exercise, and thus a force of great intensity may be applied. Instances of this kind are furnished in the compressed air-fountain,

FIG. 12.

and in the common forcing pump, one variety of which constitutes that invaluable machine, the fire-engine. A still more striking illustration is seen in the air-gun, where the power of compressed air is made to execute the office of ordinary gunpowder, a compound which may be regarded as a magazine of condensed air which can be brought into action at will.

(32) *Weight of the Air.*—By means of the air-pump it is easy to show, by direct experiment, that air, in common with every form of matter, has weight, and even to measure its weight. For this purpose a well shaped globular flask, F, fig 13, furnished with a small stopcock, is screwed to the plate of the pump, and the air is exhausted. In this state it is transferred to a delicate balance and accurately counterpoised; it is then attached to a graduated jar, G, filled with air, also provided with a stop-cock, and standing over water; the moment that, by turning the stop-cocks, a communication is made between the jar and the flask, the air rushes into the exhausted vessel. The amount that thus enters is read off by noticing the level of the water before the stop-cocks are opened, and then estimating its rise afterwards by the marks on the side of the jar. On transferring the flask back to the balance, it will be found to have increased in weight several grains.

FIG. 13.

Minute attention to a variety of circumstances is required to ensure a correct result in this experiment. It is by experiments conducted on this principle that the average weight of the air has been well ascertained. (140.)

Dr. Prout found that 100 cubic inches of air at a temperature of 60° F., where the column of mercury in the barometer stands at 30 inches, weigh 31·0117 grains. Regnault found that 1 litre of air at

32° F., weighed (barometer 29·922 inches) 1·283187 grammes. This, if reduced to the English standards, would make the weight of 100 cubic inches of air amount to 30·954 grains.*

We may form some notion of the actual weight of the air by calculating the quantity contained in a given space. Take for example, a room 30 feet long, 28 feet wide, and 19 feet high, offering a cubic content of 15960 cubic feet; since 100 cubic inches of air weigh 31 grains, 13 cubic feet of air weigh nearly 1 lb. The total weight of air in such a room is, therefore, about 1220 lb., a little more than half a ton.

It is obvious that if, in the experiment with the flask, just described, the graduated jar had contained any other gas instead of atmospheric air, it would be possible to ascertain the weight of a given quantity of such gas; and by comparing this weight with that of an equal bulk of air, to ascertain its density approximatively.

(33) *Household Pump.*—The pressure of the air is the power which raises water in the bore of an ordinary pump. The construction of this very useful machine will be at once understood from the description of the air-pump which has been already given; the arrangement of the valves being similar. On depressing the piston-rod (fig. 14), air escapes through the upper valve A, and on raising it again a fresh portion enters from the pipe attached below the second valve B. The weight of the atmosphere upon the surface of water in the well, forces up a portion, the weight of which compensates for the diminished elasticity of the air in

FIG. 14.

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* According to Regnault, the specific gravity of mercury, at 32° F., is 13·596, water at 39·2° F. being taken as 1; consequently the relative weights of equal measures of air, water, and mercury will be—

Air at 32° F.		Water at 39° F.		Mercury at 32° F.
1	:	773·3	:	10513·1

under a barometric pressure of 29·922 English inches, at 32°. Calculating these values all at the English standard temperature of 60° F., and at the barometric pressure of 30 inches, and allowing for the relative expansion of water and mercury by heat, the proportions will be the following—

Air.		Water.		Mercury.
1	:	816·8	:	11058.

the barrel, till on again depressing the piston several times successively, the whole of the air has its place supplied by the water which is thus raised from the well below, the pressure of the atmosphere being removed from the surface of that part of the water contained in the pipe beneath the valves. It is manifest, however, that there must be a limit in the height to which water can be raised in this way. As soon as the column of water in the pump above the level of that in the well is long enough to balance the weight of a similar column of air extending to the upper limits of the atmosphere, the water will rise no higher. Such a column of water is about 33 feet in height. If a tube 40 feet long be closed at its upper end, filled with water, and then placed mouth downwards in a vessel of water, the water in the tube will fall till it stands about 33 feet above the level of that in the cistern. Such a tube may be seen in the hall of the Royal Society, where it was placed by the late Professor Daniell, forming, in fact, a *water barometer*.

(34) *The Barometer.*—If the tube were filled with a heavier liquid than water, a proportionately shorter column of it would be sustained by the pressure of the air, the length of the column being inversely proportioned to the specific gravity of the two fluids. Now as mercury is rather more than thirteen times as heavy as water, this fluid metal will rise to a height only about $\frac{1}{13}$ as great as that of water, or to a height of about thirty inches instead of thirty-three feet. This result is easily verified; for if a glass tube about three feet long, and closed at one extremity, be completely filled with mercury, the aperture closed with the finger, and it be placed mouth downwards in a basin of mercury, on removing the finger, the column of fluid metal will partially descend, and leave a void space of 5 or 6 inches in length in the upper part of the tube. But the most complete demonstration that the mercury is sustained solely by the pressure of the air upon that in the basin, is furnished by placing the whole apparatus under the receiver connected with the air-pump; as the air is exhausted, and consequently the pressure is diminished, the column sinks, but it recovers its former level on re-admitting the air from without. A tube, or *air-gauge*, acting on this principle, is usually attached to every air-pump, as a convenient means of judging of the perfection of the vacuum. If it were possible wholly to exhaust the air from the receiver, the mercury would rise in such a gauge (which is simply a tube open at top into the reciever, and dipping below into a basin of mercury) until it stood at the same level as in the barometer at the time of the experiment, but this result is never attained in practice; the elasticity of the portion of air remaining in the receiver always depresses the

metal a few hundredths of an inch in the gauge below this point. By means of the gauge the density of the air still remaining in the receiver, is readily ascertained, for the density is always exactly proportioned to the pressure. Suppose, then, the gauge showed a residual pressure of $\frac{1}{10}$ of an inch, the remaining air would have only $\frac{1}{300}$ of the density that it possessed at the commencement, if the atmospheric pressure shown by the barometer at the time were equal to a column of thirty inches in height.

M. Regnault employs a gauge, at the side of which an ordinary mercurial barometer plunging into the same cistern is placed, (fig. 15) so that the difference in height between the two columns of mercury is read off with the greatest accuracy by means of a graduated scale and verniers *v*, *v*.

FIG. 15.

A simple pressure gauge or *manometer* for estimating the rarity or condensation of air in a confined space, is made by bending a tube into the form shown in fig. 16, and pouring water into the bend; the apparatus is attached at *a* to the air vessel, the other limb, *b*, being open to the atmosphere; by the difference of level, the elasticity of the gas under experiment can be accurately estimated by a scale placed between the tubes. Where the pressures are considerable, mercury is used instead of water. A pressure gauge of this simple description is in constant requisition in coal gas works for estimating the pressure in the gasometer, in the street mains, or at any part of the services.

FIG. 16.

A simple inverted tube when filled with mercury, with due precautions to exclude every particle of air, and furnished with accurate means of measuring the height of the column above the level of the mercury in the cistern, constitutes one of the most indispensable philosophical instruments—*the barometer*. The diameter of the tube is of little consequence, but a tube, $\frac{1}{3}$ or $\frac{1}{2}$ an

Fig. 17.

inch wide, or wider, is preferable to one of smaller bore. A slight fixed correction for capillarity, varying with the diameter of the tube, is required for each instrument. In the best instruments of this description the whole scale is moveable by a rack and pinion, *p*, (fig. 17) and can be adjusted so that its lower extremity, which for convenience of observation is made to terminate in a fine steel point, *e*, can be brought exactly to coincide with the surface of the mercury in the cistern: unless this contrivance were adopted it would not be possible accurately to measure the height of the column of metal, as the level of the mercury in the cistern is continually undergoing slight variations; as the metal rises in the tube it falls in the cistern, and *vice versâ:* part of the cistern is constructed of glass, to allow this object to be accurately attained. The height of the mercurial column above the level of the mercury in the cistern when the instrument has been placed in a truly vertical position, is read off at the top by a vernier, *v*, which estimates differences of $\frac{1}{500}$ of an inch. The barometer has been constructed in a great variety of forms, but the simple inverted tube is the best for ordinary purposes.

Fig. 18.

(35) *The Syphon*, which is another instrument in frequent use in the laboratory, depends for its operation partly upon the principle of atmospheric pressure. The syphon is a bent tube, by means of which, liquids may be lifted above the level at which they stand, provided they are ultimately transferred to a lower level. Suppose it be desired to draw off a liquid, without disturbing a powder which has settled down to the bottom of a vessel; a bent tube or syphon (s fig. 18) one limb of which is longer than

the other, is filled with water, and closed by placing the finger at the end of the longer limb; the instrument is then inverted, and the short limb is rapidly plunged into the fluid to be decanted. On removing the finger from the longer limb, the liquid flows, and will continue to do so as long as the shorter limb remains below the surface of the liquid in the vessel. If the vessel v, however, be raised until the longer limb of the syphon is immersed in the liquid that has run over, and the fluid stands at the same level in both vessels, no further flow will take place; if v be again depressed, the flow through the syphon will again be renewed. When, as was effected by the expedient of raising the lower vessel till the fluid stood at the same level in both, the acting limbs of the syphon are of equal length, the column of fluid in each has the same perpendicular height, and the downward pressure of each column will be the same: neither column will preponderate over the other: but if the vertical column of fluid be longer on one side than on the other, this longer column will necessarily press downwards with more force on that side than the column in the shorter limb presses in the opposite direction; the atmospheric pressure, however, is equal on both sides; the heavier column therefore runs out of the tube, drawing with it the liquid in the shorter limb, and the place of this liquid is supplied from the fluid in the vessel, by the pressure of the atmosphere which drives it up into the space that would otherwise become empty.

(36) *Downward pressure of the Atmosphere.*—From what has been already stated, it must be obvious that we are living at the bottom of a vast aerial ocean, and subject to the pressure of the superincumbent mass,—a pressure which amounts to about fifteen pounds upon every square inch of surface, and as has been estimated, to about fourteen or fifteen tons upon the surface of the body of a man of average stature.

The existence of this downward pressure of the air is a matter of the highest importance to us in the economy of nature and of art. It admits of proof by experiment in a variety of ways. The receiver of the air pump may at first be lifted from the brass plate without difficulty, but after a few strokes of the pump in the ordinary process of exhausting, it becomes fixed by the pressure of the superincumbent air, uncompensated by that within the vessel. It is for this reason that an arched form is given to the external surface of vessels designed to bear exhaustion. If the hand be placed over the mouth of a receiver having an opening at the top of two or three inches in diameter, a very partial removal of the air will make this pressure painfully sensible; and if a piece of bladder be moistened and securely tied over the opening and then left to dry, its surface will, when a portion of the enclosed air is removed, become very tense and concave, and if the exhaustion be carried far enough, it will suddenly burst with a loud report.

But the question will naturally arise, how is it, that if our bodies are subjected to the enormous pressure above indicated, we are not only able to support it without being crushed or rooted to the earth, but are even insensible of its existence. The reason is, that the pressure is equal in all directions. The air upon the earth's surface being compressed by that above it, acquires an elasticity sufficient exactly to counterpoise that pressure, and it presses laterally and upwards, with a force exactly equal to that with which it is compressed. A very simple experiment will suffice to demonstrate the upward pressure. Take a glass jar with a smooth edge, (a common wine-glass will do), fill it with water, close the mouth with a card or with a bit of paper, retain the paper in its place with the hand, and turn the jar mouth downwards; the hand may be removed, the card will remain supported, and the water will not escape. Indeed, we might thus support a column of water thirty-three feet long (but not longer), as that would just balance the pressure of a column of air of equal diameter. It is this upward pressure, exerted by the portion of the air that is dissolved in our blood, and pervades every tissue of our frame, which renders us unconscious of the atmospheric pressure. If the pressure upon the surface of the body be decreased, as by ascending a lofty mountain, great inconvenience is often experienced; bleeding at the nose, and other unpleasant symptoms sometimes arising from the expansion of the air within the body when the external pressure is removed. Blood flows in the operation of cupping, by partially removing the atmospheric pressure over the wounds inflicted by the lancets.

(37) *Pneumatic Trough.*—Among the many useful applications depending on the pressure of the air, is a simple but invaluable contrivance of Dr. Priestley's, called the *pneumatic trough*, which enables us to confine air and gases in vessels, and to decant them from one to another with as much ease as liquids may be managed, and poured. The pneumatic trough consists merely of a vessel containing water, fig. 19, across which, at the depth of 2 or 3 inches from the top, a ledge or shelf is placed; the jars destined to receive the gas are filled with water, and placed with their mouths downwards upon the shelf, which is kept about an inch under water: into

FIG. 19.

these jars the gas is allowed to bubble up, and it may be transferred from one to another by an inverted pouring. When a jar has been filled, or partially filled with gas, it may be readily removed from place to place by sliding under its open mouth, still immersed in water, a plate or shallow tray, containing water, on which it may be lifted out of the pneumatic trough as at B.

(38) When large quantities of gas are to be stored up, a different apparatus, the *gas holder* is employed, and in this instrument also, advantage is taken of the upward pressure of the atmosphere. The gas holder is represented in fig. 20. It consists of a cylinder B, surmounted by a tray A, for holding water; this communicates with the cylinder by means of two pipes provided with stop-cocks, one of these pipes, *f*, proceeds nearly to the bottom of the vessel B, and is open at both extremities; the other pipe, *e*, only just enters the top of the lower cavity: at the lower part of the cylinder is a short, wide pipe, *c*, passing obliquely upwards, and furnished with a plug, which can be closed at pleasure. A third stop-cock is introduced at the upper part of the cylinder at *g*, to which a flexible tube may be attached for the

FIG. 20.

convenience of transferring the gas. Now suppose the gas holder to be full of atmospheric air and to be wanted for use; the pipe *c* at the bottom is closed, water is poured into the tray, and both stop-cocks in the vertical pipes are opened: the water descends through the longer pipe *f*, whilst the air escapes in bubbles through the shorter one *e*; when B is completely full the stop-cocks are closed, and the plug at the bottom removed; no water escapes, owing to the pressure of the atmosphere upon the surface of the liquid in the wide tube *c*, the water being retained just as in the ordinary bird fountain. The neck of the retort H, or other vessel for producing the gas, is introduced completely within the cylinder, and the water is displaced by the gas which rises and accumulates in the upper parts, whilst the water runs off into a vessel placed below. The progress of the experiment may be watched by means of the glass tube *d*, which is open both at top and bottom into the cylinder B; the level of the water within the instrument is thus always exhibited. In order to use the gas stored up, the plug is replaced at *c*, the stop-cock in the long pipe opened to allow the column of water to exert its pressure on the gas, which escapes on cautiously turning the stop-cock *e*, and may either be received in a jar placed in the tray over the short tube *e*, or it may be conveyed away through a flexible tube attached to the stop-cock *g*.

FIG. 21.

(39) Water dissolves all gases; some in small quantities, and others with very great avidity; such gases of course cannot be collected over water. Indeed, in all cases where great accuracy is requisite, some other fluid must be substituted in the trough and jars for water. Mercury is the fluid which offers fewest inconveniences, and it is usually employed for this purpose in a trough, the form of which is seen in fig. 21.

(40) *Correction of Gases for Pressure.*—The foregoing mode of collecting gases over mercury, leads us to consider a correction of great importance in all cases where an accurate measurement of the bulk of gases is requisite. In all cases a portion of air or gas which communicates with the atmosphere either through the walls of a flexible bag or bladder, or that is confined over water or mercury, is subject to the pressure of the atmosphere, transmitted to it either through the flexible material, or through the interposed

portion of fluid. If, in the pneumatic trough, the liquid within and without the jar stand at the same level, the pressure upon the included air will be exactly that due to the atmosphere at the time; if, however, the liquid within stand higher than that in the bath, the air will be subjected to a pressure less than that of the atmosphere at the time, by the amount necessary to support the column of liquid above the outer level of the fluid.

Observation has shown that the pressure of the atmosphere at the same spot is liable, from a variety of causes, to continual variation. The average pressure at the sea level, is equivalent to that of a column of mercury 30 inches in height; but in this climate it is sometimes so much diminished as to support a column of only about 28 inches; at other times the pressure will be equivalent to 31 inches of mercury. Now the same quantity of gas will, under these different circumstances, sometimes occupy a bulk considerably less, at others considerably greater, than the average.

It is necessary, therefore, in all experiments upon the weight or bulk of gases, to observe the height of the barometer, as this gives the pressure to which the gas is at the time subjected. This, however, is only true when the liquid in the bath, and that in the jar, are on the same level. In practice it is rarely possible to make them rigidly so. The liquid generally stands highest in the jar. Supposing the gas to have been collected over mercury, in order to allow for the dilatation occasioned by this inequality of level, the difference of the two heights must be accurately measured, and the measurement, so obtained, must be subtracted from the height of the mercurial column in the barometer at the time. A similar correction is required if the gas be standing over water, but it is smaller in amount, a column of water of 13·6 inches in height being equivalent to 1 inch of mercury. When the necessary measurements have been made, a simple calculation enables us to ascertain the bulk that any gas would have occupied, supposing it to have been measured under the pressure of 30 inches of the barometer, which in this country is taken as the standard.*

Let us imagine that having measured 10 cubic inches of

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* In other countries the standard pressure to which gases are corrected is generally that which has been proposed by the French; *viz.* that of a column of mercury 760 millimetres (or 29·922 English inches), in height: consequently 100 cubic inches, measured under the English standard pressure of 30 inches, would, under the French standard, fill a space of 100·261 cubic inches.

Strictly speaking, however, the observations should be reduced to the pressure of a column of mercury 29·922 inches in height at 32° F. Such a column, oxygen standing over mercury, the level of the metal in the jar being 1·5 inches higher than that in the bath, the barometer at the time standing at 29·75, it is desired to ascertain what bulk it would occupy under a pressure of 30 inches. By Marriotte's law (26) the bulk of a gas is inversely as the pressure to which it is subjected. Therefore—

Standard pressure.		Observed pressure.		Observed vol.		True vol.
30	:	$\left\{\begin{matrix} 28{\cdot}25 \text{ or} \\ 29{\cdot}75-1{\cdot}5 \end{matrix}\right\}$	::	10	:	$\left\{\begin{matrix} x(=9{\cdot}41 \\ \text{cub. in.)} \end{matrix}\right.$

In estimating the weight from the bulk of a gas, it is necessary to make a further correction for the temperature (95), as well as for the state of moisture or dryness which it may possess at the time.

(41) *Density of the Atmosphere at Different Heights.*—A remarkable consequence of the law of elasticity in gases is exhibited in the increasing rarefaction of the atmosphere in ascending from the surface of the earth. The air is subject to a pressure which gradually decreases with the progressive elevation above the sea level. This will be evident if we consider the atmosphere to be composed of a series of layers or strata: the lowest layer supports the pressure of the entire super-incumbent mass; the one next above this supports the pressure of all but the lowest; the third that of all but the two lower ones, and so in succession. In consequence of Marriotte's law —viz., that the bulk of elastic fluids is inversely as the pressure, it is found that if the air be examined at a series of heights, increasing according to the terms of an arithmetical progression, the density of the air decreases according to the terms of a geometrical progression. In the following table the heights above the surface are taken in arithmetical progression, increasing regularly by distances of 3·4 miles; the *bulk* of equal weights of air at these successive heights *increases* in geometrical progression, the volume being doubled for each step in the ascent; while the *density*, and the corresponding height of the barometer, *decrease* in the same geometric ratio, being at each successive elevation exactly half what it was at the preceding one:—

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owing to the expansion of mercury by heat, would be increased $\frac{1}{355}$ of its length, at the mean temperature of 60° F., and consequently would then measure 30·005 inches: and under this pressure 100 cubic inches, measured at a barometric pressure of 30 inches, would be reduced to 99·98 cubic inches, a difference so trifling, that it may almost always be neglected.

Density of the Air at increasing altitudes.

Miles above the Sea.		Bulk of equal wt. of Air.		Density.		Height of Barometer.
0	—	1	—	1	—	30·00
3·4	—	2	—	$\frac{1}{2}$	—	15·00
6·8	—	4	—	$\frac{1}{4}$	—	7·50
10·2	—	8	—	$\frac{1}{8}$	—	3·75
13·6	—	16	—	$\frac{1}{16}$	—	1·87
17·0	—	32	—	$\frac{1}{32}$	—	0·93

FIG. 22.

The annexed diagram, (fig. 22) slightly altered from one in Mr. Tomlinson's Treatise on Pneumatics is supposed to represent a section of the atmosphere; the left hand column shows the height in miles above or below the sea level; the right-hand column the corresponding heights of the barometer in inches; A indicates the altitude of the highest peaks of the Himalaya; B the altitude of 23,018 feet, the greatest height attained by a balloon (Gay Lussac, 17 Sept., 1804); C Dalkeith mine, Cornwall, 1440 feet; D the deepest sea sounding yet obtained, 7706 fathoms, 8¾ miles, (Capt. Denham) H. M. Ship Herald, Oct. 20, 1852, lat. 36° 49′ S., lon. 37° 6′ W.

It is obvious that a knowledge of the law of the decrease of density in the atmosphere furnishes the means of ascertaining the height of mountains by the employment of the barometer.

Dr. Young has calculated that if the air continued to diminish indefinitely in density, according to Marriotte's law, 1 cubic inch air of the mean density of that at the earth's surface would, at a distance of 4000 miles from the earth's surface (or at a distance equal to the earth's radius), fill the whole orbit of Saturn; and, on the other hand, if a mine could be dug 46 miles deep into the earth, the air at the bottom would be as dense as quicksilver.

The observations of astronomers upon the amount of refraction experienced by the light of the heavenly bodies in traversing the atmosphere, however, have rendered it probable that there is a limit to the upper surface of our atmosphere, as definite as that of the waters of the ocean, the repulsive force of the particles being at length exactly balanced by their gravitation towards the earth.

§ II. Cohesion.

(42) In the case of gases the predominance of elasticity is the leading characteristic; in the case of solids the opposite power of cohesion is that which first demands attention. Cohesion is the force which binds together into one mass the same kind of particles. It is this force which retains a bar of iron, a block of wood, or a lump of ice in a single piece. It is obvious that the cohesion of different bodies varies greatly. Cohesion, however, appears to be uniform between particles of the same kind placed under circumstances similar as to temperature and structure. Owing to the difficulty, even in the most compact substances, such as the metals, of securing uniformity in texture and freedom from flaws, it is difficult to estimate the amount of the coefficient of cohesion in any material with precision; although the general fact that iron is much tougher than copper, and copper than lead, is at once recognised. Two methods have been generally used to determine the cohesive power of solids; the first consists in estimating the weight required to stretch rods of a given diameter, of the substance under examination, until they give way; the second, in finding the amount of force required to crush a cube of the substance of, given dimensions.

The strength of materials, all-important as it is to the engineer and to the architect, has little to do with chemistry, although variations in cohesion and aggregation of the same substance exercise a marked influence on the rapidity of many chemical actions. Gunpowder, for example, is reduced to grains that each portion may quickly ignite, and contribute its expansive force to act upon the bullet. But the very same material, before it has been granulated and whilst in the form of hard compact masses, as it comes from the press, burns comparatively slowly, like a fusee or a portfire.

(43) Particles of a similar nature will, under the influence of cohesion, reunite, after complete separation, if brought sufficiently near to each other. This is shewn on pressing together two clean,

smooth, and freshly-cut surfaces of lead; they will cohere, and a force of some pounds will be required to separate them. In the same way, too, perfectly polished plates of glass cohere, sometimes so completely that they may be cut and worked as a single piece. This has not unfrequently happened in plate-glass manufactories.

According to the proportion that cohesion bears to other forces which, like heat and elasticity, tend to separate the particles of matter from each other, the body assumes the solid, the liquid, or the aeriform state. Considerable differences in physical properties are produced both in solids and in liquids, by variations in the degree of cohesion existing among their particles.

(44) *Cohesion of Solids.*—In solids, these variations give rise to differences in hardness, elasticity, brittleness, malleability, and ductility.

The *hardness* of a body is measured by its power of scratching other substances, and it consists in the degree of resistance which the particles offer to the slightest change of relative position. To the mineralogist, the variations in the degree of hardness presented by different crystallized bodies, often furnish a valuable physical sign, by which one mineral may be discriminated from others which resemble it. For the purpose of facilitating such comparisons, Mohs selected ten well-known minerals, which are enumerated in the following table, each succeeding one being harder than the one which precedes it; thus arranged, they constitute what he terms a *Scale of hardness*, which has been generally adopted. In the examples selected, each mineral is scratched by the one that follows it, and the hardness of any mineral may be determined by reference to the types thus selected. Thus, suppose a body neither to scratch, nor to be scratched by fluor spar, its hardness is said to be 4: if it should scratch fluor spar but not apatite, its hardness is between 4 and 5; the degrees of hardness being numbered from 1 to 10. The figures on the right indicate the number of minerals known of the same, or approximatively the same degree of hardness, as the substance opposite to which they stand—

Scale of Hardness of Minerals.

1	Talc	23	6	Felspar, any cleavable variety	26
2	Compact gypsum	90	7	Limpid quartz	26
3	Calcspar, any cleavable variety	71	8	Topaz	5
4	Fluor spar	53	9	Sapphire, or corundum	1
5	Apatite (crystallized)	43	10	Diamond	1

The cause of the varieties of hardness observed in different bodies is not well understood. Even in the same substance, trifling variations in the external circumstances to which the body is subjected often produce extraordinary differences in the degree of hardness which it exhibits. A piece of steel slowly cooled from a red heat is soft; it may be cut with a file; and under strong pressure, it will even take impressions from a die; whilst the same piece of steel, if heated to redness, and suddenly cooled, becomes as brittle as glass, and nearly as hard as the diamond.

Brittleness is exhibited by bodies the particles of which resist displacement with regard to each other, except within extremely narrow limits. It is generally observed in hard and elastic substances.

Malleability and *ductility*, or the property of extending under the hammer, and of fitness for drawing into wire, are the very opposite of brittleness, the molecules of the solid admitting of very considerable relative displacement without losing their cohesion. These modifications of cohesion are exhibited only by the metals, and by a few only of them.

(45) *Cohesion of Liquids.*—In liquids, notwithstanding the facility with which their particles slide one over the other, and the unlimited freedom of motion of each molecule within the mass of liquid, a very appreciable amount of cohesion still exists, and is displayed in the rounded form assumed by every detached drop. This same form of cohesion is also beautifully shown in the case of two liquids which do not mix with each other, but which have precisely the same specific gravity, as is the case with oil, and spirit of wine of a certain degree of dilution. If a little oil be poured into such a fluid, it remains suspended within it in the form of a perfectly spherical mass. In the drops of dew which fringe every leaf in a fine summer morning, we have an admirable natural illustration of this fact. A striking exemplification of cohesion in the particles of liquids is also afforded by blowing a large soap-bubble upon the end of a glass tube. Upon presenting the open end of the tube to a lighted taper, whilst the bubble is still attached at the other end, the contraction of the film expels the air with sufficient force to extinguish the taper. The researches of Donny (*Ann. de Chim. et de Phys.*, III. xvi. 167) have added many curious facts to our knowledge of the cohesion of liquids. The following form of one of his experiments, may be cited as an illustration. A tube, A, fig. 23, about 36 inches long and 1 inch in diameter, is bent at its middle to an angle of about 60°; it is sealed at one end, and filled with distilled water, which, when the tube is closed, is to occupy about two-thirds of its capacity; the water is thoroughly boiled for

an hour, and the tube is then hermetically closed whilst boiling. In this condition the tube contains only water and the vapour of water. After it has been carefully reversed, as at A, it may be brought into the position represented at B, and the water will nevertheless be supported by adhesion to the surface of the glass, and by the cohesion among its own particles, above the level of the fluid in the other limb. However, by inclining the tube in such a manner that a minute bubble of aqueous vapour is made to pass up into the full limb, the column of water, having its continuity broken at one point, immediately falls, and the level of the liquid in both limbs becomes the same.

FIG. 23.

Even amongst liquids, considerable differences are observed in the degree in which the cohesive force is exhibited. *Limpid* liquids are those which, like ether or spirit of wine, display great mobility of their particles. Bubbles produced in such liquids by agitation, quickly rise to the surface, break, and disappear. In oil, syrup, and gum-water, the particles move sluggishly; such liquids are termed *viscous*. The viscosity of fluids presents a certain analogy with the malleability of solids. In a few instances, whilst the solid is melting under the influence of heat, a viscous state is observed intermediate between the hardness of solids and the perfect mobility of liquids. Melted sugar, or barley-sugar, is a case in point. The occurrence of viscosity, as an intermediate state, is rare, except in the case of a mixture of two substances, one of which melts at a temperature a little higher than the other. Glass, which is a mixture of several silicates of different degrees of fusibility, offers a remarkable example of this kind; indeed to this condition it owes the plastic properties by which it is rendered capable of adaptation to the multifarious purposes to which it is now applied. A true chemical compound passes at once from the solid to the liquid form, as when ice, for example, by fusion, becomes water. A few of the simple bodies, however, present some remarkable cases of the occurrence of viscosity preceding fusion; such, for instance, as phosphorus, and those metals which, like iron and potassium, admit of being 'welded,' a process in which two pieces of the metal are united into one mass by hammering or pressing them together whilst they are in the soft condition which is observed before fusion.

(46) All analogy leads to the conclusion that cohesion would be entirely destroyed in every elementary body by a sufficient elevation of its temperature; though there are some bodies which have not as yet been liquefied, and many which have not been converted into vapour. The three conditions in which the same chemical compound may exist, exemplified by ice, water, and steam, according to the degree of heat to which it is exposed, are shown by a vast number of other bodies. Gold itself has been first melted and then volatilized by the intense heat of the sun's rays concentrated by a burning lens. On the other hand, by a sufficient reduction of heat, united with a certain degree of pressure, a number of gases have been reduced, first to a liquid, and several even to the solid condition. The force of cohesion, like that of heat, is therefore universal. If the repulsion exerted by heat could be carried sufficiently far, every known substance, not actually decomposable by heat, we have reason to believe, might appear as a gas; and, by a reduction of temperature sufficient to allow cohesion to exert its sway, every known gaseous substance would probably exist in the solid state.

In gases, cohesion appears to be entirely overcome, and it does not exert itself sensibly, except in cases where the gas is approaching the point at which, by pressure, or cold, it assumes the liquid form (182).

§ III. ADHESION—DIFFUSION OF LIQUIDS AND GASES.

(47) *Adhesion.*—Analogous to cohesion, or the power which holds similar particles together, is that of adhesion, which is exerted between the particles of dissimilar kinds of matter. It not unfrequently rises high enough to destroy cohesion, as when sugar or salt dissolves in water. A rod of glass or wood dipped into water or oil comes out wetted under the influence of this force. It is exerted between different bodies with very different degrees of force, as may be illustrated by the following experiment:—take two glass dishes, sift over the bottom of one, a layer of lycopodium or of finely powdered resin; over the other a layer of powdered glass: if a little water be sprinkled upon each, the drops of water in the dish of resin will be covered by a thin film of the powder, and when the

dish is inclined will roll about like shot, the cohesion of the particles of the fluid predominating over their adhesion to those of the solid: whilst on the powdered glass, from the superior adhesion of glass to water, the drops sink in and are absorbed.

If the solid is wetted, a certain preponderance of the force of adhesion over the cohesion of the particles is obviously necessary; for if the cohesive exceeds the adhesive power, as when glass or iron is plunged into mercury, the solid is not wetted. Extraneous circumstances, however, greatly modify the exertion of this force. If a film of air, of oil, or of any foreign matter be diffused over the surface of the solid, it is no longer the surface of the solid and the liquid which are concerned, but the liquid and the surface of air or oil with which the solid is covered. A clean glass is immediately wetted with water, but if the slightest film of grease exist upon its surface, the water runs off almost entirely.

Adhesion gives rise to a variety of important phenomena; it is mainly concerned in the production of capillary action, of solution, of the diffusion of liquids, in endosmosis, and less directly in the process of the intermixture and diffusion of gases. In this chapter some remarks will therefore be made upon each of these subjects in succession. Adhesion is the more especially worthy of attentive study by the chemist, as in its manifestations it is more nearly allied than any other force to chemical affinity.

Adhesion is exerted between bodies of all kinds, and when it occurs between solids, it is the principal cause of that resistance to motion which is termed *friction*. As a general rule, friction is greater between similar kinds of matter, less between those which differ in nature. An iron axle moving in an iron socket experiences under similar circumstances a greater amount of friction than if revolving in a brass socket; and the interposition of a substance like plumbago or grease, the particles of which have but very little cohesion, is a familiar mode of reducing the amount of friction in machinery.

Few substances admit of a greater variety of useful applications from their faculty of adhesion than caoutchouc; its perfect adhesion to glass adapts it admirably for stoppers, and enables the chemist to employ it for air-tight and flexible joints. This property of adhesion to the bodies which it touches further fits it for bands for driving machinery, and for numberless other purposes. One of its most ingenious applications is to the manufacture of the cards employed in the carding of cotton, preparatory to spinning it into thread: these cards consist essentially of a wire brush with a flexible back;

they were formerly made of a strip of leather, through which the wire teeth were passed; the holes, however, which allowed the passage of the wire, speedily became enlarged and conical from the strain on the bristles or wires during use, and the card ere long was unfit for its office. By making the flexible back of two pieces of woven fabric with a layer of caoutchouc between them, however, this difficulty is now entirely obviated; the caoutchouc adheres to the wire and follows it when deflected, whilst by its elasticity, it, as soon as the drag upon the wires ceases, restores each wire to its right position.

(48) The entire value of cements depends upon the operation of the force of adhesion; and in the variety of cements rendered necessary by the variety of materials to be united, we have additional proof that adhesion is exerted between different kinds of matter with very varying degrees of force. Glue or gum may be used for joining pieces of pasteboard or wood, while it totally fails as a cement for glass or china, either of which needs some resinous material to unite its fragments; whilst for the union of marble, stone, or brick-work with each, other the use of mortar or some calcareous cement is required. The thinner the layer of cement the more perfectly does it perform its task, as it more rapidly and completely adapts itself to changes of temperature, which, by causing it to expand unequally, would, if a thick mass were used, destroy the cohesion of its own particles.

A variety of cements are in continual requisition in the laboratory. Well boiled paste applied on bibulous paper forms an excellent covering for corks and other joints which are liable to be porous; it must be allowed to become nearly dry before it is used. Plaster of Paris made into a paste not too stiff, may often be used; when dry it may be washed over with oil to make it air tight. Strips of well soaked bladder may sometimes be employed advantageously; they form a firm joint when dry: but for most purposes where a temporary joint only is required, nothing is so convenient as a strip of sheet caoutchouc softened at the fire, and bound round the parts to be connected; when softened thus, it usually adheres perfectly without even requiring to be tied. When the joint is intended to be permanent, as when a brass cap is to be attached to the neck of an air-jar, for example, a resinous cement consisting of 5 parts of resin, 1 of yellow wax, and 1 of finely powdered Venetian red, forms a convenient mixture: the resin and wax are melted together and incorporated with the Venetian red by stirring. Before applying it, both the glass and the metal cap which are to be connected together must be warmed just sufficiently to melt the cement. When the joints are required to resist a considerable pressure without leaking, a mixture of equal parts of red and white lead ground into a paste with linseed oil, worked up with fibres of tow, and packed tightly into the joint, sets firmly, and is not liable to crack.

It not unfrequently happens that the force of adhesion between a cement and the bodies which it unites, surpasses the cohesion of the particles which compose the bodies themselves: from this cause we often see a film of wood split off, adhering to the surface of the glue when a fracture occurs near one of these joinings. The feat of splitting a bank note into two laminæ, which excited so much astonishment, was accomplished by cementing it firmly between two flat surfaces and afterwards separating them; the cohesion of the paper being feebler than the adhesion to the cement, the paper was split through the middle. This method of splitting paper had, however, been long known to the buhl cutter and inlayer.

(49) *Capillary Action.*—The existence of adhesion between solids and liquids is so well known as to need no further illustration; but it produces many very important results, some of which must be noticed.

It is to the adjustment of the forces of adhesion and cohesion between solids and liquids under the simultaneous influence of gravity, that the important phenomenon called *capillary attraction* is due. If a perfectly clean glass tube, with a fine bore and open at both ends, be plunged into water, or into a liquid capable of wetting it, the liquid will be found to rise in the tube considerably above the level of its surface in the vessel; the finer the tube the higher does the liquid rise. The surface of the liquid will also be seen where it approaches the outside of the tube, or the side of the vessel containing it, to stand above the general level. (fig. 24 A.) The phenomenon may also be examined by placing vertically in a shallow vessel containing a little coloured fluid, two plates of glass with parallel faces, which are in contact by two of their vertical edges, and slightly separated at the opposite edges. The liquid will rise between the glass plates, the height of the column being inversely

Fig. 24.

as its distance from the angle of contact between the plates. The upper boundary of the liquid will consequently describe a hyperbolic curve (fig. 24 B). The cause of the rise of the fluid is the adhesion between its particles and those of the glass; the limits to that rise are the action of gravity and the force of cohesion amongst the liquid particles. As the action of gravity is equal under ordinary circumstances upon all the particles of the fluid, it reduces the liquid surface to a uniform level. When a tube is introduced, the uniformity of this action is interfered with, as the following considerations will show:—the particles in immediate contact with the side of the tube are partially supported by adhesion to its surface; they therefore gravitate downwards with a diminished force, and a longer column becomes necessary in order to compensate for this diminution of downward pressure. Now let us conceive the particles of the elevated column of liquid to be arranged as a series of contiguous concentric cylinders; the particles of the outermost cylinder are sustained laterally by adhesion to the tube, those of the next cylinder are hung on to these, if the expression may be allowed, and supported solely by the cohesion of their fellows; those of the third cylinder are hung on to the particles of the second, and so on, till we reach the central rod of particles. The surface of the fluid is in consequence necessarily curved; the outer cylinder, or the portion of fluid in contact with the tube standing at the highest point. Now since adhesion is confined to the superficial layer, and between the same substances, is, *cæteris paribus,* constant in quantity fo ran equal extent of surface, the wider the tube the shorter will be the column sustained, as the contents of the column raised by cohesion increase more rapidly than the surface of the cylinder. The height of the column is inversely as the diameter of the tube.

(50) The elevation of the column of fluid in tubes of equal diameter varies with the nature of the fluid, the variation depending partly on the difference of cohesion between the particles of the fluid, partly upon the difference of adhesion between the fluid and the glass. In consequence of the decrease of both these forces by heat, the height of the column diminishes as the temperature rises.

The following table from the experiments of Frankenheim, shows the height at which the different liquids enumerated stand, at 32° F. in a tube 1 millimetre (about $\frac{1}{25}$ of an inch in diameter), with the coefficient of correction for temperature, which multiplied by *t*, the number of degrees centigrade above 0°, gives the amount to be deducted in millimetres from the number in column 3, in order to find the height of the capillary column at the temperature required.

Capillary elevation of Liquids at 32° F.

Liquid used.	Specific gravity at 32° F.	Height in Millimetres of the capillary column.	Height of the column in thousandths of an inch.	Coefficient for correction for Temperature.
Water	1·0000	15·336	604	$-\ 0{\cdot}02875t$
Acetic Acid . . .	1·0522	8·510	355	$-\ 0{\cdot}0097t$
Sulphuric Acid . .	1·8400	8·400	331	$-\left\{\begin{matrix}0{\cdot}0153t\ + \\ 0{\cdot}000094t^2\end{matrix}\right.$
Oil of Lemons . .	0·8380	7·23	285	$-\ 0{\cdot}0174t$
Oil of Turpentine .	0·8902	6·76	266	$-\ 0{\cdot}0167t$
Alcohol, (dilute) .	0·9274	6·41	242	$-\ 0{\cdot}0120t$
Alcohol	0·8208	6·05	238	$-\left\{\begin{matrix}0{\cdot}0116t\ + \\ 0{\cdot}000051t^2\end{matrix}\right.$
Ether	0·7370	5·40	213	$-\ 0{\cdot}0254t$
Bisulphide of Carbon	1·2900	5·10	201	$-\ 0{\cdot}0101t$

(51) In fluids, such as mercury, where the force of cohesion preponderates over their tendency to adhere to the sides of the tube, the capillary action is reversed; the surface becomes convex instead of concave, and the height of the column within the tube is depressed below the general level. In a mass of fluid each particle is maintained in its place by the mutual attraction of all the surrounding ones; but if a column be isolated from the mass of fluid by the interposition of the walls of the tube, the sides of which exert little or no equivalent adhesive force, the cohesion of the mass below draws down the upper particles and produces a depression of the column. This depression of mercury in glass renders a certain correction necessary in reading off the height of the mercurial column in the barometer, which, in consequence, always stands a little lower than the elevation due to the atmospheric pressure. The narrower the bore of the tube the greater is the depression. Experiment has shown that this capillary depression is nearly one half less in tubes that have had the mercury boiled within them than in unboiled tubes, as by this means a film of air, which in unboiled tubes adheres to the glass, is expelled. By employing a tube of $\frac{3}{8}$ or $\frac{1}{2}$ an inch in the bore, this correction becomes so trifling that it may be neglected. In a tube of $\frac{1}{4}$ inch in diameter in which the mercury has been boiled, the depression is 0·02 inch, while with a similar tube of $\frac{1}{2}$ inch diameter it is only 0·003. The capillary depression of mercury is slightly increased by elevation of temperature.

In reading off the level of mercury in a barometer, or in a graduated jar used for the measurement of gases, the height of the metal should be taken from the convexity of the curve; but in

Fig. 25.

estimating the volume of a liquid which wets the surface of the glass the determination should always be made from the bottom of the curve. The lines *a a*, *b b*, fig. 25, indicate the points in the two cases.

Mathematicians have shown that if the adhesion between the solid and the liquid be equal to half the cohesion of the particles of the fluid, the surface at the point of contact will neither be elevated nor depressed; if the adhesion between the two be more than half the cohesion, elevation of the liquid will occur, and if it be less than half, the surface will be depressed and convex.

(52) Capillary action plays an important part in the operations of nature, and in a variety of ways has been rendered subservient to the wants of man. A familiar illustration of its employment is seen in the wicks of lamps and candles, which being composed of a bundle of fibrous materials, furnish hair-like channels by which the oil or melted combustible is elevated to the flame, and supplied as fast as it is consumed. Capillary action influences the circulation of the fluids in the porous tissues of organized beings, and it is the principal mode in which water, with the various substances which it holds in solution, is supplied to the roots of growing plants. By its means, during the droughts of summer, fresh supplies of moisture are raised towards the surface for the maintenance of vegetable life; and in the same way, when during winter the surface is hard bound by a long dry frost, water is constantly finding its way from beneath, is solidified upon the surface, and remains stored up until a thaw ensues; then it is that the accumulated moisture mellows the soil and produces the well-known soft and plashy state of the ground which follows long-continued frosts, and which extends deeper, the longer the duration of the freezing temperature, although neither snow nor rain may have fallen.

A curious illustration of the action of the combined forces of cohesion and adhesion, in overcoming the force of gravity, is afforded by the following experiment:—Procure a small cylinder of fine copper wire-gauze, about 3 inches high and 2 inches wide, closed also above and below with the same material, and furnished with a stout wire to serve as a handle: plunge it under water; considerable difficulty will be experienced in expelling the air, owing to the formation of a film of moisture over its surface, which by the cohesion of the fluid particles composing it and by its adhesion to the wire, prevents the escape of the air; when about half filled with water, lift the cylinder out of the liquid, the fluid will be securely retained; water may even be allowed to fall in a gentle stream upon the top of the gauze, it will pass through and run out below, without, however, affecting the quantity of liquid within, but by giving the handle a slight jerk, the film of liquid which supported the pressure of the atmosphere will be broken, and the water will then immediately escape.

(53) *Influence of Surface on Adhesion.*—As adhesion takes place solely between the surfaces of bodies, it is evident that any circumstance which increases the extent of that surface must materially facilitate the exertion of this force. Minute subdivision, by thus increasing the extent of surface, greatly exalts the effect of adhesion; a cube of 1 inch in the side exposes a surface of 6 square inches, *i. e.*, there is a square inch upon each of its 6 faces. Suppose this cube, however, to be subdivided into a number of smaller cubes, each of which is only $\frac{1}{1000}$ of an inch in the side, 1,000,000,000 such cubes would thus be contained in the space of a cubic inch. Now as each little cube has 6 sides, the surface which it will expose is $\frac{6}{1000000}$ of a square inch, or 1,000,000 of them will expose 6 square inches; that is, as much surface as a solid cube of an inch in the side; the 1,000,000,000 cubes will consequently expose 1000 times as great a surface, or upwards of 41·6 square feet. The force of adhesion, therefore, by such a subdivision, should be increased somewhat in this proportion.

The influence of this kind of subdivision in exalting the effect of adhesion is strikingly exhibited in the case of charcoal. The structure of the wood from which the charcoal is procured is cellular; when heated in vessels from which air is excluded, the volatile constituents of the wood are expelled; and the charcoal, which does not fuse, remains behind in a very porous condition, retaining the form of the wood which furnished it. Mitscherlich calculates that a cubic inch of box-wood exposes a surface of not less than 73 square feet on the cells of which it is formed.

Adhesion occurs between charcoal and other bodies, with degrees of force that vary very much. For the colouring matters of vegetable and animal origin this adhesion is extremely energetic; so that if these bodies be dissolved in any liquid and agitated with charcoal, nearly the whole of the colouring matter will be retained by the charcoal on separating the latter by filtration, and the fluid will run through colourless. Ordinary vinegar and portwine may thus be obtained in a colourless condition. Advantage is taken of this fact extensively in the refining of sugar; the syrups are in this case deprived of colour by filtration through a column of charcoal 12 or 13 feet in thickness. The species of charcoal which is most extensively employed for this purpose is that obtained by burning bones in close vessels; and it is hence termed *bone black*, or *ivory black*, or frequently *animal charcoal*. The charcoal is in this case in a state of extreme subdivision; it does not constitute above a tenth or a twelfth of the weight of the mass; the remainder consists of earthy matters, chiefly phosphate and carbonate of lime. When bone black has been used for filtering liquids, and has ceased to take up any more colouring matter, it is thrown aside and allowed to ferment: if then it be well washed, and re-burned, it may be used again with nearly equal effect. Other animal matters, especially dried blood, furnish, when calcined and well washed, a charcoal which is still more efficacious. The addition of carbonate of potash to the mass before calcination still further increases the decolorizing power. Many other matters besides those possessed of colouring properties have likewise this peculiarity of adhering strongly to charcoal. Professor Graham has shown that metallic oxides in solution in potash or ammonia, arsenious acid in water, and bodies generally of feeble solubility, possess this property; a variety of vegetable matters, and especially the bitter principles, are thus affected. If porter be agitated with charcoal and filtered, it will not only be deprived of colour, but also of much of its bitterness. It was formerly the practice, after the active principles, of medicinal plants had been separated from the woody fibre and most of the extraneous matters with which they are associated, to free them from the colouring matters with which they were contaminated, by digestion with animal charcoal; so much of the active principles themselves, however, were found to be retained by the charcoal, that the plan was abandoned. In consequence of this property, animal charcoal has been administered with good effect in some instances of poisoning with vegetable matters: in such cases it can never be unsafe, and may often be of great value.

(54) *Solution.*—Adhesion is also manifested between solids and liquids with sufficient force to overcome the power of cohesion, and the substance is then said to dissolve, or to undergo solution. In this manner sugar or salt dissolves in water, camphor or rosin in spirit of wine, lead or silver in mercury. Anything that weakens the force of cohesion in the solid favours solution. Thus, if the

substance be powdered, it dissolves more quickly, both from the larger extent of surface which it exposes, and from the partial destruction of cohesion. In the same way, heat, by increasing the distance between the particles of the solid, lessens its cohesion, and probably thus contributes so powerfully to assist in producing solution. If a solid body be introduced in successive portions into a quantity of fluid capable of dissolving it, the first portions rapidly disappear, and as each succeeding quantity is added it dissolves more slowly, until at length a point is reached when it is no longer dissolved. When this occurs, the force of cohesion balances that of adhesion, and the liquid is said to be *saturated*. It is important to remark, that in cases of simple solution, the properties both of the solid and of the liquid are retained. Syrup, for instance, retains the sweetness of the sugar and the fluid form of water. So, when camphor is dissolved in spirit of wine, the resulting tincture partakes of the properties of both, having the smell and taste both of camphor and of spirit. Solution is, in this respect, distinguished broadly from cases in which a solid disappears under the influence of a liquid, owing to the exertion of a chemical force between the particles of the two bodies. Solution generally occurs more readily when the solvent and the body dissolved present some general resemblance in properties: thus, mercury dissolves many of the metals, alcohol dissolves resins, oils dissolve fatty bodies and each other. In cases of chemical action, on the other hand, that action is most energetic between bodies the properties of which are most widely different; the metals dissolve in acids, oils in the alkalies, and silica, if melted with potash or soda, becomes soluble in water. The extent to which different solids dissolve in the same liquid, varies almost indefinitely. In water sulphate of baryta is almost absolutely insoluble. Sulphate of lime or gypsum dissolves in the proportion of about 1 part in 700 of water, sulphate of potash in about 1 part in 16, while sulphate of magnesia dissolves to the extent of 2 parts of the crystals in 3 of water. Water, however, which is saturated with one salt, will still continue freely to dissolve others.

Many substances in which the cohesion amongst their particles is weak are extensively soluble in water, though they have but little adhesion to it. Such substances will often be displaced by adding a solution of another body which adheres more strongly to water. Prussian blue, for example, dissolves in distilled water, but is immediately precipitated by adding a solution of common salt, or of sulphate of soda, and leaves a clear colourless liquid above it, as the blue compound subsides on standing.

Although in the majority of instances the solubility of a substance is increased by heat, it is not uniformly so. Lime and several of its salts offer remarkable exceptions. Water, just above the freezing point, dissolves nearly twice as much lime as it does when boiling; so that if water, saturated with lime in the cold, be heated, it becomes milky, and recovers its transparency as it cools. Sulphate of lime is also slightly more soluble in water at about 100° F. than it is in boiling water. A compound of lime and sugar, very soluble in cold water, is separated from the solution almost completely, if heated to boiling. But the most remarkable case of the kind occurs in sulphate of soda. This salt (the Glauber's salt of commerce) when crystallized dissolves in about 10 times its weight of ice-cold water, and its solubility increases rapidly as the temperature rises, until it reaches 91° F. From this point until the solution boils, the solubility decreases; so that, when a portion of the liquid saturated at 91°, is heated more strongly, without allowing the water to evaporate, hard gritty crystals are deposited, and the boiling liquid retains only about $\frac{4}{5}$ of the quantity which was dissolved at 91° F. Seleniate of soda exhibits the same peculiarity; so also does sulphate of iron, although in a less degree. These anomalous results may be partly explained by the consideration, that heat diminishes the force of adhesion as well as that of cohesion. Generally speaking, cohesion is the more rapidly diminished of the two, although not uniformly so; and in the cases of which we are now speaking, it would appear that the adhesive force decreases in a greater ratio than the cohesion of the saline particles. This subject, however, has not yet been sufficiently examined. The composition of the salts just mentioned undergoes change at a temperature below that of boiling water. At the temperature of the air, these salts contain a certain quantity of water, known as *water of crystallization*; but this water is either wholly or partially expelled from the crystals at a boiling heat. The hard crystals of sulphate of soda which are deposited during the heating of the saturated solution contain no water.

Diffusion of Liquids.

(55) *Adhesion between Liquids.*—In the majority of instances adhesion between dissimilar fluids is very perfect; and from the complete mobility of the particles the two fluids become perfectly incorporated. A drop of vinegar or of ink may be perfectly mixed with a quart or any other quantity of water; or a drop of

water with a quart of vinegar or of ink. There are instances, however, in which this perfect solution does not take place. The cohesion of the particles of the two liquids may, at a certain point, balance their adhesion for each other, and they will become mutually saturated. Ether may, by agitation, be mixed with water, and the greater part will separate on allowing the mixture to repose. The ether will have dissolved $\frac{1}{8}$ or $\frac{1}{10}$ of its bulk of water, and the water will have taken up about an equal quantity of ether. In a similar way the essential oils dissolve only to a very small extent in water; oil of peppermint, for instance, if agitated with water, and then left to rest, will, for the most part, separate, although a sufficient quantity will have been dissolved to communicate the flavour and odour of the essence to the water. In other instances, the separation of the two fluids, as when oil and water are mingled, appears to be complete.

When chloroform is dropped into distilled water it gradually sinks, and the drops preserve their rounded outline. If a drop or two of an alkaline solution be added, the surface of the chloroform becomes flattened, and it resumes its rounded character on again adding a few drops of an acid. This experiment shews what slight circumstances may modify the cohesive powers of a liquid, and its degree of adhesion to others; the adhesion of water to chloroform being increased by the addition of an alkali, and being again diminished by neutralizing the alkali.

(56) *Diffusion of Liquids.*—If two liquids of different densities, which are susceptible of mixture with each other, be placed in the same vessel, they will gradually become intermixed: thus, if a tall jar be filled for about two-thirds of its capacity, with the blue infusion of litmus, and, by means of a long funnel, as shown in fig. 26, a quantity of oil of vitriol be cautiously poured in, so as to occupy the lower portion of the jar, it will be found, after the lapse of two or three days, that the acid has become diffused through the liquid, which will consequently have assumed a red colour throughout. If watched at intervals, the progress of the mixture may be traced by the gradual change of colour from below upwards.

FIG. 26.

Professor Graham, who has recently investigated this subject (*Phil. Trans.*, 1850, pp. 1 and 805), employs a very simple apparatus (fig.

27), by means of which he is enabled accurately to measure the rate at which this diffusion takes place. His experiments have been performed principally upon solutions of saline bodies, which have been allowed to diffuse into water. A number of small jars, of equal capacity (about 4 oz. each), were prepared, with the necks ground to an uniform aperture of 1·24 inches in diameter; into these jars the trial solutions were poured, to within half an inch of the top; the jars were then filled up with pure water. Thus charged, each jar was closed by a glass plate and placed in a cylindrical vessel containing about 20 oz. of distilled water, the mouth of the solution jar being at least one inch below the surface of the water in the exterior vessel. The glass plate was then cautiously removed. The apparatus was then set aside in an undisturbed place, and maintained at a steady temperature for several days. After a sufficient lapse of time, the mouth of the solution jar was again closed with a plate of glass, and the vessel withdrawn from the large jar. The water in the outer jar was evaporated, and the salt that had passed into it was easily determined by weight.

FIG. 27.

(57) From these experiments several important conclusions have been deduced:—

1. It is found that by employing solutions of the same substance, but of different degrees of strength, the quantities of the substance diffused in equal times are, *cæteris paribus*, proportioned to the quantity in the solution. For example, four different solutions of common salt, in water, were prepared, containing respectively 1, 2, 3, and 4 parts of salt to 100 parts of water. In eight days' time the quantities diffused were, in the first solution, 2·78 grains; in the second, 5·54 grains, or just double the amount; in the third, 8·37 grains, or three times the quantity; and in the fourth, 11·11 grains, or almost exactly four times the amount diffused from the first solution.

2. The quantities of the substance diffused from solutions containing equal weights of different bodies, vary with the nature of the substance, as will be seen by reference to the following table. The solutions in each case contained 20 parts of the solid, dissolved in 100 parts of water, and were exposed for eight days at a temperature of 60°·5 F.

Diffusion of Solids in Solution.

Substances used.	Sp.gr.of solution at 60°	Weight in grains diffused.
Chloride of Sodium . .	1·1265	58·68
Sulphate of Magnesia .	1·185	27·42
Nitrate of Soda . . .	1·120	51·56
Oil of Vitriol	1·108	69·32
Sugar Candy	1·070	26·74
Barley Sugar	1·066	26·21
Starch Sugar	1·061	26·94
Treacle (of Cane Sugar)	1·069	32·55
Gum Arabic	1·060	13.24
Albumen	1·053	3·08

The extreme slowness with which albumen diffuses is remarkable, and is no doubt connected with its functions in the animal system, where it is present so abundantly in the serum of the blood and in other important fluids.

On comparing together the times in which different substances are diffused in equal quantities, some remarkable numerical relations have been observed by Professor Graham, and a close parallelism has been found to hold between the phenomena of liquid diffusion and those which accompany the diffusion of gases (64).

It has been found that saline substances arrange themselves in groups, the members of each group being equi-diffusive, and the rates of diffusion in each group being connected with the rate of diffusion of the other groups by a simple numerical relation. At present seven such groups are known. Isomorphous salts, that is, salts which crystallize in the same form, and which have an analogous chemical composition, have generally equal rates of diffusion.

The first group contains hydrochloric, hydriodic, and hydrobromic acids; perhaps also nitric acid. These acids are the most diffusible substances known. The second group contains hydrate of potash, and probably ammonia. The third group, nitrate of potash, nitrate of ammonia, chloride of potassium, muriate of ammonia, and chlorate of potash. The fourth, nitrate of soda and chloride of sodium. The fifth, sulphate of potash, carbonate of potash, sulphate of ammonia, and ferrocyanide of potassium; probably also chromate and bichromate, bicarbonate and acetate of potash, and ferridcyanide of potassium. The sixth group contains sulphate and carbonate of soda; and the seventh, sulphate of magnesia.

On comparing together the *squares of the times* in which equal quantities of these different salts are diffused, these numbers exhibit a very interesting proportion to each other, which is illustrated by the following table. In the first column of figures the relative diffusibility of the different groups is given as compared with the hydrochloric acid group; the second shows the times required for the diffusion of equal weights of the individuals composing each group; and in the third is shown the ratio of the squares of those times of equal diffusion.

Groups.	Rate of Diffusion.	Times of equal Diffusion.	Ratio of Squares of times of = Diffusion.
1. Hydrochloric Acid . . .	1·000	3·960	2
2. Hydrate of Potash . .	0·800	4·950	3
3. Nitrate of Potash . . .	0·565	7·000	6
4. Nitrate of Soda . . .	0·462	8·573	9
5. Sulphate of Potash . .	0·400	9·900	12
6. Sulphate of Soda . . .	0·326	12·125	18
7. Sulphate of Magnesia . .	0·200	19·800	48

All experiments on the diffusion of liquids proceed with greater regularity in dilute solutions: as the liquid approaches the point of saturation, the uniformity of action is interfered with by the tendency to cohesion of the particles of the solid.

3. The quantity of any substance diffused from a solution of uniform strength increases as the temperature rises; but the ratio of diffusion between different bodies, if compared at the same temperature, remains constant, whatever the temperature at which the comparison is made.

4. It is found that if two substances which do not combine chemically, and which possess different degress of diffusiveness, be mixed in solution, and be placed in a diffusion cell, they may be partially separated by the process of diffusion, the more diffusible passing out the more rapidly; the salt which is least soluble having, however, its diffusiveness somewhat reduced in proportion to the other.

In some cases even chemical decomposition may be effected by the process of liquid diffusion. Thus, if a solution of ordinary alum (which is a compound of sulphate of potash and sulphate of alumina in fixed proportions) be placed so as to diffuse into water, the sulphate of potash will pass out more rapidly in proportion to the quantity present than the sulphate of alumina.

5. Provided that the liquids be dilute, it appears that one sub-

stance will diffuse into water already containing another body in solution, just as into pure water.

In comparing with these the phenomena of gaseous diffusion, it will be seen how closely all these points coincide in the two cases.

(58) *Endosmosis and Exosmosis.*—Intimately connected with the process of liquid diffusion are the changes which occur when the two liquids are separated by the intervention of a porous diaphragm. The phenomena here are, however, more complicated, from the part which the adhesion of the two fluids to the material of the diaphragm exercises upon the result. The process of mixture will go on in this case notwithstanding the direct opposition of gravitation. The following experiment exhibits this fact in a striking manner:—Provide a funnel, or a small jar, open at top and bottom, and furnished with a long, narrow stem; over the open mouth of the jar tie a piece of moistened bladder, fill the jar and a portion of the stem with spirit of wine (or with a solution of sugar in water), then place the jar, with its broad end downwards, in a shallow vessel containing water, noting the height at which the spirit or the solution stands in the stem. In the course of a few hours the column of liquid will be found to have increased in height, and if sufficient time be allowed, it will have risen to the top of the tube, and will at length overflow (fig. 28). This phenomenon has been explained in the following manner:—

FIG. 28.

Owing to its greater adhesion to water than to spirit, the membrane is easily moistened by the water in contact with its lower surface, whilst the spirit above wets the bladder with difficulty; the water rises into the bladder by capillary attraction and fills its pores; it thus reaches the upper surface where it comes into contact with the spirit; a true liquid diffusion of the water through the spirit then commences (owing to the adhesion between the two liquids); a fresh portion of water rises from below into the pores of the bladder to supply the place of that which has been removed, and thus the liquid within the funnel is constantly increasing in bulk, until at length, even in opposition to gravity, the liquid overflows: this *flowing in* of the liquid has been termed by Dutrochet, who first particularly observed it, *Endosmosis*. At the same time that this action proceeds from without inwards, a very small quantity of spirit is *passing out* by a similar process into the water below, and this flowing out of the vessel is designated *exosmosis*. Upon this view the essential conditions to the phenomenon are the more complete adhesion of the bladder to one liquid than to the other, and the existence of a certain degree of adhesion between the two liquids. Whenever these conditions are realized, no matter what the liquids may be, the liquid which most freely wets the membrane passes out more rapidly than the other passes in.

The foregoing explanation, although it is probably true for the particular experiment with alcohol and water, is however inadequate to explain the phenomenon generally, which is one of continual occurrence, and is of importance, especially when considered in its physiological bearings; and from the recent investigations of Professor Graham (*Phil. Trans.*, 1854, p. 177), it has acquired additional interest in a purely chemical sense.

FIG. 29.

(59) The instrument generally used by this gentleman in his experiments, and called by him the *osmometer*, is represented in fig. 29. It consists of a bell-jar, A, of a capacity of 5 or 6 ounces, over the open mouth of which a plate of perforated zinc is placed, and over this is securely tied a piece of fresh ox-bladder with the muscular coat removed, or else an artificial membrane formed by calico soaked in white of egg and dipped into boiling water to coagulate it; to the upper aperture of the bell-jar, a tube, $\frac{1}{10}$ of the diameter of the lower opening of the jar, is fitted. This tube is open at both ends, and is graduated into millimetres, so that each degree is equal to about $\frac{1}{25}$ inch. A rise or fall of liquid in the narrow tube amounting to 100 millimetres therefore represents the entrance or removal of a stratum of liquid of 1 millimetre in thickness over the whole surface of the membrane. In using the instrument, the membrane is well macerated in pure water, and the saline solution introduced into the jar A until it stands at a fixed mark in the narrow tube. The apparatus is then placed on a tripod stand in a tall cylindrical jar B, and distilled water poured in until it stands exactly at the level of the fluid in the tube. During the whole experiment this level is carefully maintained, by the addition or removal of water in the outer jar, as circumstances require.

The principal points ascertained by Professor Graham by experiments, conducted in this way, were the following:—

1. Neutral organic substances, such as urea, gum arabic, sugar of milk, gelatin, and salicin, exercise little or no osmotic action.

2. Strictly neutral salts, such as sulphate of magnesia, chloride of sodium, and chloride of barium, exercise no peculiar osmotic power, but appear to follow nearly the same rate of diffusion as that which is observed when no porous partition is used.

3. Alkaline solutions, and especially the solutions of the carbonates of potash and soda, on the contrary, produce endosmosis to a most remarkable extent. This effect is observed even in solutions which contain not more than 1 part of the salt to 1000 of water. Indeed, it was found generally that these osmotic phenomena were most strongly developed in dilute solutions, such, for instance, as did not contain more than 2 per cent. of the salt. In these experiments a large bulk of water entered the osmometer, whilst only a very small portion of the alkaline salt escaped into the water of the outer jar. For example, in five hours, when a solution of carbonate of potash containing 1 part of the salt in 1000 of water was placed in the osmometer, the liquid in the stem of the instrument rose through 192 divisions; and for each grain of carbonate of potash that diffused into the outer cylinder upwards of 500 grains of water entered the osmometer; but when a solution which contained 1 per cent. of carbonate of potash was used, not much more than 60 grains of water entered the instrument for each grain of carbonate that diffused into the outer cylinder. When the liquid *rises* in the osmometer, Professor Graham distinguishes it as *positive osmose.*

4. On the other hand, dilute acids, and solutions of acid salts generally, produce a current in the opposite direction; consequently the column falls in the stem of the osmometer. This effect is distinguished as *negative osmose.*

5. In every instance (except in the cases of alcohol and cane sugar), in which osmotic action is observed, a chemical action on the material of the septum, whether it consists of bladder or of earthenware, invariably occurs; and it is remarkable, that if porous materials, not susceptible of decomposition by the liquids, be made use of as a partition, the osmotic phenomena become insignificant:—thus a plug of gypsum, of washed unbaked clay, of tanned leather, or of compressed charcoal, although sufficiently porous, gave rise to little or no osmotic action. These two circumstances are especially interesting from their chemical bearings, as is also the next point, which is probably connected with them: viz.—

6. Two salts, when mixed, often have an osmotic action very different from that which they exercise separately. For example, perfectly neutral sulphate of potash has a feeble positive osmose, represented by a rise of 20 millimetres in five hours. The addition of 1 part of carbonate of potash to 10000 of the solution

raised it to nearly $100^{\mathrm{mm.}}$ in five hours, whilst an equally minute trace of hydrochloric acid stopped the osmose almost entirely. Similar results were obtained with sulphate of soda. Chloride of sodium, on the other hand, exhibits a remarkable power of reducing osmotic action in other salts. The osmose of a solution of carbonate of soda, containing $\frac{1}{1000}$ of the carbonate, was reduced from $179^{\mathrm{mm.}}$ to $32^{\mathrm{mm.}}$, by the addition of 1 per cent. of chloride of sodium. From other experiments, it appears further, that two different saline solutions, one placed in the osmometer, the other in the outer jar, each solution holding equal weights of the different salts dissolved in the same bulk of water, may also give rise to osmotic action, when separated by a suitable porous partition.

Phenomena of this description are constantly going on both in plants and in animals; for in their tissues, fluids of very different natures, sometimes acid, still more often alkaline, are circulating through vessels necessarily constructed of flexible and porous materials; and in the economy both of the vegetable and of the animal creation such actions are of the highest importance to the due performance of the vital functions. In fact, we as yet know not how intimately the entire processes of absorption, nutrition, and secretion, are connected with the operations of liquid diffusion and of endosmosis.

(60) *Flow of Liquids through Capillary Tubes.*—An interesting and close connexion exists between the subjects which have just been considered and the flow of liquids through capillary tubes. The most extensive and complete set of experiments hitherto made upon this branch of research, is due to M. Poiseuille. (*Ann. de Chimie et de Phys.*, III. xxi. 76.)

FIG. 30.

Fig. 30 will explain the method of conducting these experiments: A is a hollow conical metallic vessel, which can be attached by a screw joint to a capacious receiver of condensed air, the exact pressure of which can be regulated by means of a gauge attached to it. B is a glass globe, about half a cubic inch in capacity, which contains the liquid under experiment; it is connected with the metallic vessel A by a glass tube of narrow bore. A similar tube proceeds from the lower part of the globe, and to this is attached the capillary tube *c*, the diameter and length of which are carefully determined. The object of the little bulb, *d*, is merely to enable the observer accurately to define the termination of the capillary tube. G is a vessel which is filled with water, provided with an accurate thermometer, for regulating and observing the temperature. When an experiment is to be made, the end of the capillary, *c*, is introduced into the liquid, and the globe, B, is filled by attaching it to an exhausting syringe. When the liquid has risen a little above the line *e*, the syringe is detached, and the apparatus connected with the vessel of condensed air. The pressure of this confined air continues without appreciable change during the experiment. By opening a stop-cock, the condensed air exerts its force upon the liquid which is expelled through the capillary tube *c*, and the column descends in the tube *e f*. By means of a stop-watch, the time at which it reaches the line *e* is exactly noted, and the time is again observed when the globe has become emptied, and the fluid has reached the lower line *f*. The object of the conical metallic vessel, A, is to act as a trap or lodging place for any particles of dust that might be suspended in the compressed air, and which, by obstructing the capillary tube, would mar the result. From the inquiries of M. Poiseuille, it appears that when a tube exceeds a certain length (which is greater as the diameter increases), the following laws regulate the rate of efflux of the liquid: 1. The flow increases directly as the pressure, so that, with a double pressure, double the amount of liquid is discharged in equal times. 2. With tubes of equal diameter, the quantities discharged in equal times are inversely as the length of the tube. If from a tube 2 inches in length, 100 grains escape in five minutes, from a similar tube, 4 inches long, only 50 grains would flow out in the same time. 3. In tubes of equal lengths, but of different diameters, the flow is as the fourth powers of the diameters; for example, if two tubes, one of $\frac{1}{50}$, another of $\frac{1}{100}$, of an inch in diameter, be compared together, the efflux from the larger tube would be 16 times as great as from the smaller, being in the proportion of $1^4 : 2^4$, or as 1 : 16, although the diameter of the tube is only twice as great.

To the chemist, however, the most interesting part of these experiments is that which displays the effect produced by varying the kind of body which is allowed to flow through the capillary tube. The material of which the tube itself is made does not appear to influence the result; but the nature of the solution employed exercises the most marked effect. The materials used were, in most cases, solutions in water of various bodies, especially of salts. In the majority of instances the flow of the solution was slower than that of distilled water. All the alkalies produced this retardation. In a few cases, no sensible effect was produced. Thus, neither nitrate of silver, bichloride of mercury, iodide of sodium, iodide of iron, nitric, hydriodic, bromic, nor hydrobromic acid, seemed to have any influence; whilst the hydrosulphuric and hydrocyanic acids, and a few of the salts of potash and ammonia—viz., the nitrates of potash and ammonia, chlorides of potassium and ammonium, the iodide, bromide, and cyanide of potassium increased the rapidity of the flow: but it is remarkable, that concentrated solutions of iodide of potassium above a temperature of 140°, and of nitrate of potash above 104°, actually flow more slowly than distilled water does. Strict attention to the temperature at which these comparisons are made is absolutely necessary, for both with water and with dilute solutions generally, a slight elevation of temperature produces a great increase in the rapidity of efflux. Water, for instance, at 113° F., escaped through the same tube with a rapidity 2½ times as great as it did at 41° F.

Hitherto no connexion has been traced between the rate of efflux of the fluid and its density, capillarity, or fluidity. The capillarity of alcohol, as well as its density, increases in proportion as it is diluted with water, while its fluidity diminishes; but experiment has proved that a mixture of equal parts of spirit of wine and water flows out with considerably less than half the rapidity of pure alcohol, and with less than one-third of that of distilled water. The dilution of alcohol, therefore, to a certain point, retards its efflux, and beyond that point increases it: the minimum rate of efflux corresponds with that particular mixture of alcohol and water, which is attended with the maximum of contraction, after admixture of the two fluids. The solubility of the body in water appears also to exercise but a secondary influence on the phenomenon. M. Poiseuille shows it to be highly probable that the various solutions, when introduced into the blood of a living animal, provided they do not cause the serum to coagulate, produce effects of acceleration or retardation on the capillary circulation, corresponding with those which are observed with the same liquids, in capillary tubes of glass. He has proved this to be the case by direct experiment with the iodide of potassium when injected into the veins of the horse; and has shown that when various salts are mingled with serum, and the liquids are allowed to flow out through small tubes, retardation or acceleration occurs, as in the corresponding cases, with their aqueous solutions.

The following table contains several of the results which M. Poiseuille has obtained, numerically expressed. The solutions employed contained 1 per cent. of the various substances mentioned, except in the case of the last four liquids. They were exposed to a pressure equal to that of a column of water 1 metre (39·37 inches) in height, at the temperature of 52°·16 F., unless otherwise noted; and escaped through a tube 64 millimetres (2·48 inches) in length, and 0·24946$^{\text{mm.}}$ (0·0882 inch) in diameter. The numbers in the table indicate the time occupied in seconds, for the efflux of equal bulks of the liquids used—viz., 6·6 cubic centimetres (0·4 cubic inch).

Efflux of Liquids through Fine Tubes.

	Temperature 52°·16 F.					53°·42.	53°·24.
Distilled Water	575″·8	. . .	. . .	. . .	. . .	565″·0	566″·2
	Nitrate.	Sulphate.	Phosphate.	Arseniate.	Carbonate.	Chloride.	Oxalate.
Potash . .	564·5	578″·9	583″·4	583″·3	588″·3	560·8	571·1
Ammonia .	569·4	582·0	590·2			560·9	574·2
Soda . . .	575·9	590·3	588·6	588·0	592·5	569·4	578·4
Lead . . .	577·8						
Strontia . .	578·8						
Lime . . .	581·2					571·2	
Magnesia .	583·2	590·5				574·9	
Alum . . .		592·4	Tartar Emetic, 581·2				

Distilled Water . .	575″·8	Pure Serum, Ox .	1048″·5
Arsenious Acid . .	578·6	Madeira	1134·1
Phosphoric Acid . .	582·8	Sparkling Sillery .	1462·8
Oxalic Acid	582·9	Jamaica Rum . .	1831·9
Acetic Acid	585·5		
Citric Acid	586·0		
Arsenic Acid . . .	586·3		
Sulphuric Acid . . .	589·6		

(61) *Adhesion of Gases to Liquids.*—The adhesion of gases to liquids, although not quite so evident as that of solids to liquids, is yet attended with results almost equally important. It is exemplified in the pouring of liquids from one vessel to another, by the bubbles which are carried down with the descending stream, and which rise and break upon the surface of the liquid.

Adhesion, however, produces in the effects of solution which attend the mutual action of gases and liquids, results which are far more general in their operation. All gaseous bodies are in a greater or less degree soluble in water: some, as hydrochloric acid and ammonia, being absorbed by it with extreme rapidity, the liquid taking up 400 or 600 times its bulk of the gas; in other instances, as occurs with carbonic acid, water takes up a volume equal to its own; whilst in the case of nitrogen, oxygen, and hydrogen, it does not take up much more than from $\frac{1}{20}$ to $\frac{1}{50}$ of its bulk. As the elasticity of the gas is the power which is here opposed to adhesion, and which at length limits the quantity dissolved, it is found that the solubility of each gas is greater the lower the temperature, and the greater the pressure exerted upon the surface of the liquid. In consequence of this solubility of the air, all water contains a certain small proportion of air, and if placed in a vessel under the air-pump, so as to remove the pressure of the air from its surface, the dissolved gases rise in minute bubbles. Small as is the quantity of air thus taken up by water, it is the means of maintaining the life of all aquatic plants and animals; if the air be expelled from water by boiling, and it be covered with a layer of oil to prevent it from again absorbing air, fish, or any aquatic animals placed in such water, quickly perish.

The following table shows the solubility of some of the principal gases in water:—

Solubility of Gases in 100 *parts of Water.*

Hydrochloric Acid, above	50,000·
Ammonia, „	48,000·
Sulphurous Acid	5000·
Sulphuretted Hydrogen	300·
Chlorine	200·
Carbonic Acid	100·
Carbonic Oxide	6·6
Binoxide of Nitrogen	5·0
Oxygen	4·6
Nitrogen	2·5

All these gases, with the exception of hydrochloric acid, may be expelled from the water by long-continued boiling.

Other liquids besides water dissolve the gases with greater or less avidity.

(62) *Adhesion of Gases to Solids.*—When iron filings are gently dusted over the surface of a vessel of water, a considerable body of iron dust may be accumulated upon the surface, until at length it falls in large flakes, carrying down with it bubbles of air of considerable size. The adhesion of these bubbles caused the particles of iron to float, for such particles are nearly eight times as heavy as water. Contrasted with this result is the effect of dusting magnesia in fine powder over the surface of water; the particles although not one third of the density of the iron, immediately

become moistened and sink. In consequence of this adhesion of air to their surface, many small insects are enabled to skim lightly over the surface of water, which does not wet them. If a slip of clean platinum be placed in mercury, it is found on withdrawing it to come out dry, but if the mercury be boiled on the platinum, the film of air which separated the two metals is expelled, and the mercury will be found to have wetted the surface completely. It is this adhesion of air to the surface of glass which renders it necessary, in making barometers, to boil the mercury in the tubes after they have been filled, in order completely to expel the film of air with which the tube is lined. But the most striking instances of adhesion between gases and solids are exhibited when finely divided bodies are made the subject of experiment. We have already had occasion to notice the effect of charcoal when introduced into solutions (52). Its effects on gases are equally remarkable. If a piece of well burnt box-wood charcoal be plunged whilst red hot under mercury, and introduced without exposure to the air into a jar of ammonia or of hydrochloric acid, it will absorb these gases with great rapidity, and will indeed reduce them into a bulk less than that which they would occupy in the liquid form. A piece of freshly burned charcoal when exposed to the air rapidly condenses moisture within its pores, and has been observed to increase in weight from this cause nearly one-fifth, in a few days.

Owing to this property of charcoal, water saturated with many gases may be freed from them when filtered through a body of ivory black: sulphuretted hydrogen may thus be removed so completely, that it cannot be detected either by its nauseous odour, or by the ordinary tests. Saussure found that freshly burned box-wood charcoal absorbed different gases in very different proportions, as will be seen in the following tabular view of his results, where the bulk of the charcoal used in each experiment is taken as 1.

Absorption of Gases by Charcoal.

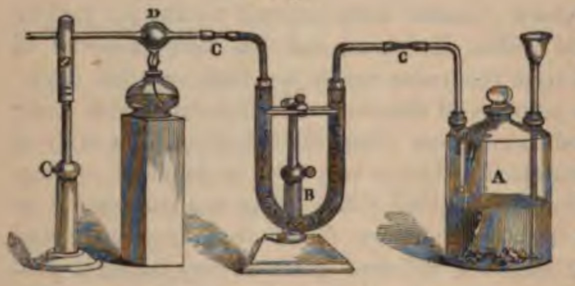
Ammonia	90	Bicarburetted Hydrogen	35
Hydrochloric Acid . .	85	Carbonic Oxide . . .	9·4
Sulphurous Acid . .	65	Oxygen	9·2
Sulphuretted Hydrogen	55	Nitrogen	7·2
Protoxide of Nitrogen .	40	Carburetted Hydrogen .	5·0
Carbonic Acid . . .	35	Hydrogen	1·7

It will be seen that these results follow an order almost exactly the same as that of the solubility of the gases in water (61).

Charcoal which is saturated with one gas, if put into a different gas gives up a portion of that which it had first absorbed, and takes in its place a quantity of the second. Finely divided metallic platinum also condenses in its pores a large quantity of many gases, amounting in the case of oxygen to very many times its own volume. If a jet of hydrogen gas be allowed to fall in the open air upon a ball of platinum in a fine state of subdivision the metal becomes incandescent; the oxygen and hydrogen rapidly combine within the pores of the metal, and the heat given out usually sets fire to the jet of hydrogen: ether and alcohol when dropped upon *platinum black*, another still more finely divided form of the metal, produce a similar appearance of incandescence. This property of platinum is turned to account in effecting many important chemical changes.

(63) *Desiccation of Gases.*—It frequently happens that in the course of his operations, the chemist requires the gases which are the subjects of his experiments to be in a perfectly dry state. They are usually prepared in contact with water, and hence become charged with a variable quantity of aqueous vapour, and whether he wishes to ascertain their specific gravity, or to submit other bodies to their chemical influence, it becomes necessary to remove this moisture completely. For this purpose, the property of adhesion which we are now considering is turned to account. The gas to be dried, which we will suppose to be in the act of formation in the glass bottle A, fig. 31, is allowed to pass slowly through a long tube, B, filled with fragments of fused potash, or of chloride of calcium, or of quicklime, or of pumice stone moistened with oil of vitriol, according to the nature of the gas. The gas will thus be in a dry state when it reaches the bulb D, which may contain the substance upon which its action is to be exerted; since all these bodies possess the property of adhering strongly to water and aqueous vapour, and if allowed a sufficient length of time, will completely remove every trace of moisture from the gases which are brought into contact with them.

FIG. 31.



As the different parts of the apparatus are connected by flexible tubes of caoutchouc, c c, sufficient freedom of motion is allowed to those parts which alter their position in the progress of the operation.

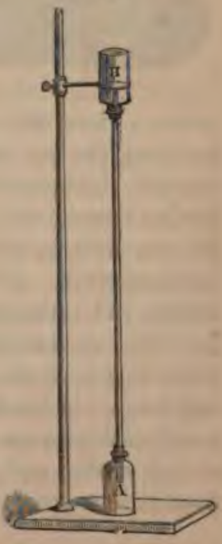
Diffusion of Gases..

The process of intermixture in gases and the motion of these bodies have been more completely investigated than the corresponding processes in fluids. The movements of gases may be considered under four heads.

1. *Diffusion,* or the intermixture of one gas with another.
2. *Effusion,* or the escape of a gas through a minute aperture in a thin plate into a vacuum.
3. *Transpiration,* or the passage of different gases through long capillary tubes into a rarefied atmosphere.
4. *Endosmosis,* or the passage of gases through diaphragms.

(64) *Diffusion of Gases.*—In consequence of the absence of cohesion among the particles of which gases and vapours consist, mixture takes place amongst these bodies very freely, and in all proportions. Very great differences in density occur amongst the gases. Chlorine is, for instance, 36 times as heavy as hydrogen, the lightest of the gases, so that there is nearly three times as great a difference between the relative weights of these two gases, as between those of mercury and water. But the mingling together of gaseous bodies of different densities produces a very different result from the mingling together of two fluids, such as mercury and water; for if these liquids be mixed by agitation, they separate the instant the agitation is discontinued. Chlorine and hydrogen, on the other hand, when once mixed, never separate, however long they may remain at rest. Indeed, if the gases be placed in two distant vessels and be allowed to communicate only by means of a long tube, the hydrogen or lightest gas being placed uppermost, as represented in fig. 32, the heavier chlorine will, in the course of a few hours, find its way into the upper jar, as may be seen by its green colour, whilst the hydrogen will pass downwards into the lower one, and ultimately the gases will be equally intermixed throughout. Indeed, if a sufficient interval of time be allowed, this equal intermixture occurs with all gases and vapours

Fig. 32.



which do not act chemically upon each other; and when once such a mixture has been effected it continues permanent and uniform. The rapidity with which this *diffusion* occurs, varies with the specific gravity of the gases; and contrary to what a superficial consideration might lead us to suppose, the more widely the two gases differ in density, the more rapid is the process of intermixture. If two tall narrow jars of equal diameter be about half filled, the one with hydrogen, the other with common air, which is more than fourteen times as heavy as the hydrogen, so that the water in both shall stand at the same level, and a small quantity of ether be thrown up into each jar, the ether will evaporate in both, and cause in each, ultimately, an equal depression, but the vapour of the ether will dilate the hydrogen at first much more rapidly than the air, for its vapour will become more quickly diffused through the lighter hydrogen. A very simple and striking illustration of the rapidity with which a light gas diffuses into a heavier one, is shown as follows. Take a tube ten or twelve inches long, one end of which is closed with a porous plug of plaster of Paris that has been allowed to become dry, and fill it with hydrogen gas, without wetting the porous plug: this is readily effected by introducing the shorter limb of an inverted syphon, *s*, into the jar *b*, fig. 33, till it reaches the top, and then lowering the jar in a deep vessel of water, A; when the air has escaped, the open limb of the syphon is closed with the finger, and the jar raised until the syphon can be conveniently withdrawn: the jar can now be filled with hydrogen prepared in a retort in the usual manner. If the jar be now supported so that the water within and without shall stand at the same level, the water in the jar will immediately begin to rise, and will continue to do so in opposition to gravity, until, in the course of three or four minutes, it will stand some inches higher than the surface of the fluid in the outer vessel, in consequence of the hydrogen passing out through the pores of the stucco, and diffusing itself into the air much more rapidly than the air passes in and diffuses itself through the hydrogen.

Fig. 33.

Any dry porous substance may be substituted for the plaster; a film of collodion on paper, as Professor Graham has informed me, gives excellent results.

By means of this simple diffusion tube, taking care to maintain the surface of the water within and without the jar on the same level as shown at B, in order that the results may not be interfered with by the disturbing force of gravity, Professor Graham has determined the law which regulates the rapidity of gaseous diffusion. Experiments so made show that the diffusiveness of a gas is in the inverse proportion of the square root of its density. Thus the density of air being 1, the square root of that density is 1, and its diffusiveness is also 1; the density of hydrogen is 0·0692, the square root of that density is 0·2632, and its diffusiveness $\frac{1}{0{\cdot}2632} = 3{\cdot}7994$; or as actual experiment shows, 3·83; that is to say, in an experiment conducted with due precautions, whilst 1 measure of air is passing into the diffusion tube, 3·83 measures of hydrogen are passing out of it.

In the case where different gases are mixed and then introduced into the diffusion tube, each preserves the rate of diffusion peculiar to itself. If, for instance, hydrogen and carbonic acid be mixed and placed in the diffusion tube, the hydrogen passes out with much greater rapidity than the carbonic acid: a partial mechanical separation of two gases differing in density may thus be effected.

Since all gases expand equally (128) by the action of equal additions of heat, their relative densities are preserved, and the relative velocities of diffusion are therefore preserved also, whatever the temperature, provided that both gases be heated equally. The rate of diffusion of equal volumes of different gases becomes, as we might expect, accelerated by a rise of temperature; for by heat all gases are rendered specifically lighter; but the rate of diffusion does not increase so rapidly as the direct expansion of gases by heat. Consequently the same absolute weight of any gas will be diffused more rapidly at a low than a high temperature.

The process of diffusion is one which is continually performing an important part in the atmosphere around us. Accumulations of gases, which are unfit for the support of animal and vegetable life, are by its means silently and speedily dispersed, and this process thereby contributes largely to maintain that uniformity in the composition of the aerial ocean which is so essential to the comfort and health of the animal creation. Respiration itself, but for the process of diffusion, would fail of its appointed end, in rapidly renewing to the lungs a fresh supply of air in place of that which has been rendered unfit for the support of life by the chemical changes which it has undergone.

The following table gives the specific gravity of several important gases, the square root of the density, the reciprocal of that square root, or calculated diffusiveness of the gas, and the actual numbers obtained by experiment.—(Graham, *Phil. Mag.*, 1833, vol. ii. p. 175.)

Diffusion and Effusion of Gases.

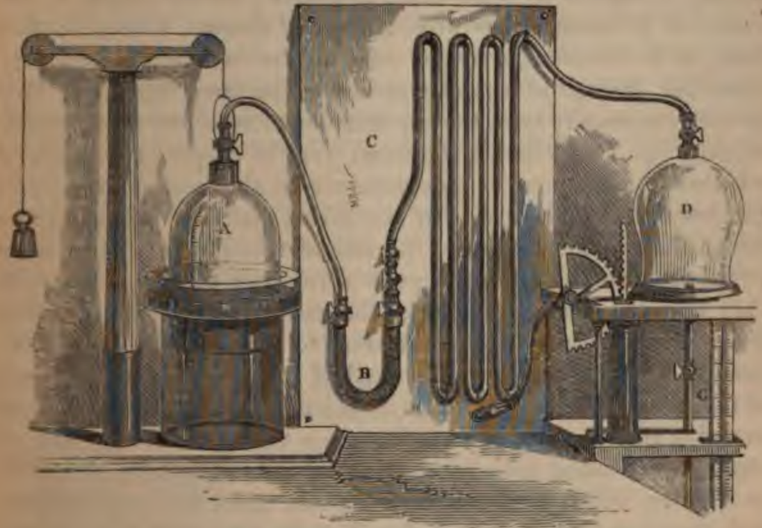
Gas.	Density.	$\sqrt{\text{Density}}$.	$\frac{1}{\sqrt{\text{Density}}}$.	Velocity of Diffusion.	Rate of Effusion.
Hydrogen	0·06926	0·2632	3·7994	3·83	3·613
Light Carbd. Hydrogen .	0·559	0·7476	1·3375	1·344	1·322
Steam	0·6235	0·7896	1·2664		
Carbonic Oxide	0·9678	0·9837	1·0165	1·0149	1·0123
Nitrogen	0·9713	0·9856	1·0147	1·0143	1·0164
Olefiant Gas	0·978	0·9889	1 0112	1·0191	1·0128
Binoxide of Nitrogen . .	1·039	1·0196	0·9808		
Oxygen	1·1056	1·0515	0·9510	0·9487	0·950
Sulphuretted Hydrogen .	1·1912	1·0914	0·9162	0·95	
Protoxide of Nitrogen .	1·527	1·2357	0·8092	0·82	0·834
Carbonic Acid	1·52901	1·2365	0·8087	0·812	0·821
Sulphurous Acid . . .	2·247	1·4991	0·6671	0·68	

(65) *Effusion.*—The numbers in the last column of the table headed 'Rate of Effusion,' are experimental results obtained by Professor Graham (*Phil. Trans.*, 1846, p. 574) upon the rapidity with which the different gases escape into a vacuum through a minute aperture, about $\frac{1}{300}$ of an inch in diameter, perforated either in a thin sheet of metal or in glass. It is evident that they coincide, within the limits of the errors of experiment, with the relative rates of diffusion of each gas; and that the velocities with which different gases pass through the same small aperture into a vacuum, are inversely as the square roots of the densities of the gases. The lightest gas enters the most rapidly. Change in the density of the gas has but little influence on the rate of effusion, the volume effused in a given time being nearly uniform. The same law is found to hold good also with liquids, when passing through an aperture in a very thin plate.

(66) *Transpiration of Gases.*—In passing through fine tubes, a very different result is obtained, corresponding with the effect already described in the case of liquids. (Graham, *Phil. Trans.*, 1846, p. 591; and 1849, p. 349.) In prosecuting a series of experiments on gases and vapours, analogous to those already referred to upon liquids by M. Poiseuille (60), Professor Graham soon found that the rate of

efflux for each gas, or the velocity of *transpiration* (as he terms this passage of gas through long capillary tubes) is entirely independent of its rate of diffusion. In the performance of these experiments the gas was placed over water, in a graduated jar, A fig. 34, so suspended that the fluid in the jar and in the bath could be readily kept at the same level. The gas was dried, by passing it through a tube B, filled with chloride of calcium, and then allowed to enter through a long fine capillary tube, C, into the exhausted receiver D, of the air-pump, which was sometimes kept vacuous by continued pumping; at others, the state of the exhaustion was ascertained, at intervals, by means of the gauge, G. In all cases, the quantities of gas that entered in a given time were carefully observed.

FIG. 34.



The following are the most important conclusions deducible from the researches hitherto made on this subject. It is necessary, in order to overcome the influence of effusion, and to furnish uniform results, to employ a certain length of tube, which increases with the diameter, and is not uniformly the same for all gases. If this precaution be observed, it appears, when the gases flow through capillary tubes into a vacuum—

1. That the rate of transpiration for the same gas increases, *cæteris paribus*, directly as the pressure; in other words, equal volumes of air, at different densities, require times inversely proportioned to

the densities. For example, a pint of air of double the density of the atmosphere will pass through the capillary tube into the vacuum in half the time that would be required for air of its natural density. This is a very remarkable result, and stamps the process of transpiration with a character quite unlike that of diffusion or effusion. 2. That with tubes of equal diameter, the volume transpired in equal times is inversely as the length of the tube: if 30 cubic inches were transpired through a tube 10 feet long, in five minutes, a similar tube, 20 feet in length, would only allow the passage of 15 cubic inches in the same time. 3. That as the temperature rises, the transpiration of equal volumes becomes slower. 4. That whether the tubes were of copper or of glass, or whether a porous mass of stucco were used, the same uniformity in the results was obtained. By comparing together different gases under similar circumstances, the rate of transpiration, or rapidity of passage into a vacuum through a capillary tube, was found to vary with the chemical nature of the gas. These velocities of different gases bear a constant relation to each other, totally independent of their densities, or indeed of any other known property of the gases. Professor Graham considers at present, that it is most probable that the rate of transpiration is the resultant of a kind of elasticity depending upon the absolute quantity of heat, latent as well as sensible, which different gases contain under the same volume, and therefore that it will be found to be connected more immediately with the specific heat than with any other property of gases.

Transpirability of Gases.

Gases.	Times for Transpiration of Equal Volumes.	Velocity of Transpiration.
Oxygen	1·0000	1·
Air	0·9030	1·1074
Nitrogen	0·8768	1·141
Binoxide of Nitrogen	0·8764	1·141
Carbonic Oxide	0·8737	1·144
Protoxide of Nitrogen	0·7493	1·334
Hydrochloric Acid	0·7363	1·361
Carbonic Acid	0·7300	1·369
Chlorine	0.6664	1·500
Sulphurous Acid	0·6500	1·538
Sulphuretted Hydrogen	0·6195	1·614
Light Carburetted Hydrogen	0·5510	1·815
Ammonia	0·5115	1·935
Cyanogen	0·5060	1·976
Olefiant Gas	0·5051	1·980
Hydrogen	0·4370	2·288

Of all the gases tried, oxygen has the slowest rate of transpiration; and hence that gas may be conveniently taken as the standard of comparison for the other gases, as has been done in the preceding table, which shows the relative times in which equal volumes of the different gases are transpired: their relative velocities are of course inversely as the times.

A mixture consisting of equal volumes of two gases which differ in their rates of transpiration, does not always exhibit a transpirability which is the mean of that of the two gases when separate. The transpiration-time of hydrogen is greatly prolonged by admixture with oxygen; equal volumes of these two gases had a rate of 0·9008 instead of 0·72, which would be the mean of the two.

In the following table the transpirability of some vapours is given. These results, however, from the necessity of experimenting upon the bodies in a state of mixture with some permanent gas, have not hitherto been determined with a precision equal to that attained in the gases above enumerated.

Transpirability of Vapours.

(Times required for equal volumes.)

Oxygen	1·0000	Chloride of Methyl	0·5475
Bromine (about)	1·0000	Chloride of Ethyl	0·4988
Sulphuric Acid (Anhydrous)	1·0000	Oxide of Methyl	0·4826
		Hydrocyanic Acid	0·460
Bisulphide of Carbon	0·6195	Ether	0·44

Some very simple relations in the transpirability of several of the foregoing gases may be observed.

1. That equal *weights* of oxygen, nitrogen, air, and carbonic oxide are transpired in equal times.
2. That the velocities of nitrogen, binoxide of nitrogen, and carbonic oxide are equal.
3. That the velocities of hydrochloric acid, of carbonic acid, and of protoxide of nitrogen are equal.
4. That the velocity of hydrogen is double that of nitrogen, of carbonic oxide, and of binoxide of nitrogen.
5. That the velocities of chlorine and of oxygen are as 3 : 2.
6. That the velocities of hydrogen and of light carburetted hydrogen are as 5 : 4.
7. That olefiant gas, cyanogen, and ammonia have each nearly double the velocity of oxygen.

That the transpiration-time of hydrogen is the same as that of the vapour of ether, and that of sulphuretted hydrogen is the same as the transpiration of the vapour of bisulphide of carbon.

Carbonic oxide and nitrogen have the same density and the same rate of transpiration; so have carbonic acid and protoxide of nitrogen. The rates of transpiration of atmospheric air, of oxygen, of nitrogen, and of carbonic oxide are likewise in direct proportion to their densities; but these seem to be concurrences rather than necessary consequences, as no regular connexion with the densities of the gas can be traced.

(67) *Passage of Gases through Diaphragms.*—As in the case of the diffusion of liquids, in which the results are often modified by the employment of a diaphragm, and the introduction of the disturbing force of adhesion to the material of which it consists, so it is also in respect to gases. This disturbance of the law of diffusion is especially seen in the case of soluble gases, when the diaphragm is moist. If a moist thin bladder, or a rabbit's stomach, be distended with air, and suspended in a jar of carbonic acid gas, the carbonic acid being soluble in the water with which the membrane is moistened, is conveyed by adhesion through its pores, and rapidly passes into the inside: the air in the interior is but sparingly soluble, and is transmitted very slowly outwards; the carbonic acid, consequently, notwithstanding its lower diffusive power, accumulates within, and at length often bursts the bladder. A similar phenomenon, arising from the same cause, is exhibited on placing a jar of air, the mouth of which is covered by a film of soapy water, in a vessel of protoxide of nitrogen. Where the diaphragm does not exert this solvent power, the usual law of diffusiveness prevails. This is strikingly exemplified by taking two similar small jars, shown at A and H, fig. 35, H being filled with hydrogen, A with air, and tying a sheet of caoutchouc over the open mouth of each. Over the one containing air invert a large jar full of hydrogen; leave the other exposed in a jar of air; in the course of ten days or a fortnight the caoutchouc over the jar filled with air will have become convex from the endosmosis of the hydrogen; over the other it will have become concave from its exosmosis; the motion of the hydrogen in both cases through the caoutchouc being more rapid than the simul-

Fig. 35.

taneous passage of the air through it in the opposite direction. Caoutchouc has, however, like charcoal, the power of condensing large quantities of many gases by the force of adhesion. For example, it rapidly absorbs ammonia, protoxide of nitrogen, and sulphurous acid. Indeed it is impossible to employ any diaphragm in which this disturbing force is not in a certain degree observable; even with plaster of Paris it is appreciable, and slightly modifies the experimental results of diffusion: where condensation occurs in the membrane to a large amount, the gas is frequently reduced in bulk as much as would be needed for its liquefaction; it then evaporates from the opposite surface of the diaphragm into the other gas, just as a very volatile liquid would do.

The phenomena of diffusion in gases were viewed by Dalton as a necessary consequence of the self-repulsive property of the particles of gaseous bodies. He considered that each gas ultimately dilates until the whole space through which the diffusion occurs is filled with an atmosphere of that gas, of a density proportioned to the quantity of the gas present. Observation shows that each gas diffuses itself through a limited space filled with any other gas, as it would do into a vacuum, the other gas only acting mechanically to retard the period at which such uniformity of diffusion is attained.

Professor Graham remarks, that if this view were true there should be, contrary to experience, a depression of temperature when two gases intermix. It does not, however, appear that this is a necessary consequence, since the particles of each gas may merely glide amongst those of the other kind, as the particles of water do amongst those of sand, the self-repulsion of the particles still being the power which determines the process of diffusion.

The phenomena of the diffusion of liquids seem, however, to be more easily reconciled with the supposition of a feeble superficial attraction between the particles of one liquid and those of another, and the supposition that an analogous attraction between the particles of one gas and those of a gas of different nature might sufficiently account for the process of intermixture in the case of elastic fluids.

It is to be remarked that in the intermixture of gases, the diffusive volume has no necessary relation to the chemical equivalent or supposed *atomic* weight of the body. The ratios which have been observed are dependent upon the relative density of the gases compared, quite irrespective of the combining proportion. In liquids a similar want of connexion between the equivalents and the diffusive volume is observed; the relation in this case is a multiple of the absolute weight diffused.

(68) *Separation of Bodies by Cold or Heat.*—It often happens, where adhesion has proceeded so far as to produce the solution of a solid in a liquid, as in the cases just considered, that the chemist has occasion to destroy this adhesion, and to obtain one or both substances in a separate form. This separation is generally effected with the aid of heat. Depression of temperature will sometimes cause the cohesion of the particles of the solid to acquire the ascendency over the force of adhesion. When, for example, brandy is exposed to intense cold, many degrees below that necessary to freeze water, the spirituous portion retains its liquid form and separates from the aqueous part, which solidifies as ice. An instance of this sort occurs in nature on a vast scale, in the pure fresh-water ice which is formed over thousands of square miles of ocean round the northern and the southern poles. Indeed water, in the act of freezing, separates completely from everything which it previously held in solution. It is owing to the separation of air previously dissolved in the water, that ice so often presents a blebby, honeycomb appearance. Faraday has shown that, even on a small scale, this complete separation of foreign matters from water may be easily effected by the process of freezing. If sulphuric acid, or a strong solution of indigo, or one of common salt, be mixed with 90 or 100 times its bulk of water, and this mixture be placed in a tube about an inch in diameter, and immersed in a freezing mixture (163), at the same time that the separation of the foreign matter is mechanically facilitated by stirring the liquid round and round briskly and constantly with a feather, the sides of the tube will, in a few minutes, be lined with a coat of transparent chemically pure ice, all the foreign matters having accumulated in the central portion, which still remains liquid.

In like manner, gases may be in great measure freed from condensible vapours by exposing them to a very low temperature. Air saturated with moisture may be rendered nearly dry by causing it to traverse a long tube, cooled down by immersion in a mixture of ice and salt.

Elevation of temperature is still more often resorted to for the separation of bodies in solution: when, for instance, common salt is dissolved in water, by exposing the solution to heat, the repulsive power of this agent overcomes the cohesion of the water as well as its adhesion to the salt; it assumes the aeriform state, passes off in steam, and leaves the salt behind in the solid state.

This process is termed *evaporation*. It proceeds rapidly in shallow, open vessels, in which case the liquid escapes into the air. If it be necessary to preserve the solvent, the operation is conducted in a closed vessel, such as a retort, and connected with a suitable condensing apparatus, so as to effect a *distillation* of the liquid. The same process may be applied to effect a partial separation of liquids of different degrees of volatility, and spirit of wine is thus more or less perfectly separated from water.

§ IV. CRYSTALLIZATION.

(69) It might be anticipated that when cohesion slowly recovers its ascendency, this force would exert itself throughout the mass equally in all directions, and that a globular concretion would result, as when oil separates from mixture with dilute spirit of a specific gravity precisely equal to its own. The fact, however, is quite otherwise, for as a general rule cohesion is not exerted equally in all directions in solids. In the majority of instances, where solid bodies are allowed slowly to separate from their solutions, they are found to assume regular geometrical forms. Each substance has its own peculiar form. Such regular geometrical solids are termed *crystals*.

By these differences in form, the materials which constitute the crystallized masses may often be distinguished from each other. For example, common salt crystallizes in cubes, alum in octohedra, saltpetre or nitre in six-sided prisms, Epsom salts in four-sided prisms, and so on. The more slowly and regularly the process is allowed to proceed, the larger and more regular are the crystals. The usual method of obtaining crystals is to form a strong solution of the salt in hot water, as most bodies dissolve in water more freely when it is at an elevated temperature than when cold. As the liquid cools, the cohesion of the salt resumes its ascendency, and the crystals shoot through the liquid; in this way crystals of nitre are easily procured. It is not necessary, however, that the liquefaction should in all cases take place through the intervention of an indifferent liquid such as water. Mere fusion of the substance, followed by slow cooling so as to allow it freely to obey the molecular attraction, is in many instances sufficient to produce crystals. If 8 or 10 lb. of sulphur or of bismuth be fused in a crucible, and, after it has cooled sufficiently to become solid upon the surface, the crust be broken through and the yet liquid sulphur or bismuth be poured out, the inner surface of the solid portion will be found to be lined with prismatic transparent crystals of sulphur or brilliant hollow cubes of metallic bismuth. Water on solidifying often shoots into beautiful crystals, as may be seen in the forms of snow flakes which fall during a hard frost, fig. 36. The forms of these flakes are all derived from the six-sided plate, No. 1; the separate crystals in the groups 2, 3, 4, 5, 6, 7, 8, all cross each other at angles of 60° and 120°, though they vary in the complexity of their arrangement.

Fig. 36.

In the bowels of the earth, temperatures which man can hardly attain in his furnaces, have been acting for ages; processes of cooling of the most regular and gradual kind have been proceeding, and a great variety of combinations have been effected under the pressure of the superincumbent strata: by the combined operation of these causes many crystalline substances of mineral origin have been formed, which we have not succeeded in imitating, although a closer examination of the slags of our iron furnaces reveals new artificial formations of this nature, and the number of those combinations, previously unattained by art, is gradually being diminished.

M. Ebelmen (*Ann. de Chimie et de Phys.*, III. xxii., 211) has succeeded in producing a variety of artificially crystallized compounds, which were before only known as natural minerals, by dissolving their constituents in boracic or in phosphoric acid, or in one of their salts, and then subjecting the mixture to an intense and long-sustained heat in a furnace used for baking porcelain; the acid or other compound employed as the solvent was thus very slowly volatilized, and various crystals were obtained, including spinelle, chrome iron, emerald, and corundum or ruby. The success that has attended these investigations offers every inducement, to those who have the opportunity, to pursue this interesting subject.

(70) Where the forces of cohesion and of adhesion are nearly balanced, as in saturated solutions, very slight causes may occasion the force of cohesion to preponderate; and when once this force has been set in action, its influence spreads rapidly through-

out the mass. Water, for example, in a still atmosphere, may be cooled 8 or 10 degrees below the freezing point, and yet continue liquid; but the slightest vibration of the vessel causes sudden crystallization of a portion of the liquid into ice. Sometimes, as in the case of Glauber's salt, the sudden admission of air to the solution of a salt saturated at a high temperature, from which, by boiling, the air has been expelled, produces a similar effect.

Adhesion to a solid body may be sufficient to disturb the balance; thus, the dropping in of a similar crystal, the insertion of a thread, or of a wire, or of a piece of stick, if not sufficient to cause sudden crystallization, will generally determine the spot upon which the crystals first form, especially if the foreign body or nucleus be rough and irregular in its outline. For this reason threads are stretched across the vessels in which the pure solution of sugar is set aside to crystallize in the manufacture of sugar candy; so also wooden rods are placed in solutions of acetate of copper, and copper wires are suspended in solutions of borax in order to facilitate the crystallization of the salt.

(71) The process of crystallization often affords a means of separating two salts of unequal solubility, the crystalline form of which is different, and which have no chemical action on each other. Nitrate of potash is thus purified from the common salt which always occurs mixed with it. This process is very generally resorted to as a means of purifying salts from small quantities of foreign admixtures, which may be soluble in water, but which either do not crystallize, or if they crystallize, do not do so in dilute solutions. Each crystallization diminishes the quantity of adhering impurity, and after the process has been repeated three or four times, by dissolving each successive crop of crystals in fresh portions of pure water, the product will in most cases be free from impurity. The crystallization of sea salt from sea water, thus separates the chloride of sodium from chloride of magnesium, and from various other salts which are present with it in small proportions. A single crystallization gives the salt sufficiently pure for commercial purposes, though it is in this state far from being chemically free from the bodies which accompany it in the waters of the ocean. Bodies, such as sulphate and chromate of potash, which possess the same crystalline form, cannot thus be separated.

(72) The volume of crystals is often influenced by circumstances apparently trivial. Muddy solutions generally yield the largest crystals, as is well seen in the manufacturing process for obtaining citric

and tartaric acid, where the impure acid always forms the finest crystals. Occasionally the presence of a substance in the liquid which does not crystallize with the salt, yet modifies the form which the latter assumes; urea, for instance, occasions the deposition of common salt in octohedra instead of its usual form of the cube. Under certain circumstances boracic acid also crystallizes in acute octohedra instead of in plates.

(73) Some change of bulk usually occurs at the moment of solidification; in many instances expansion is produced. Ice, for example, at the moment of congelation, increases in bulk about $\frac{1}{15}$ and expands so forcibly as to burst the vessel in which it is contained. Instances of this occur during severe frosts in the pipes used for conveying water. This expansive force is so enormous that no vessels have been found sufficiently strong to resist it. The most compact ice has a specific gravity of ·940: 1000 parts of water at 32° become dilated on freezing to 1063. It is owing to this expansion, which occurs at the moment of solidification in iron and fusible metal, that they answer so admirably for castings. Other solids, however, present equally remarkable instances of contraction, of which mercury, lead, and gold are illustrations, and hence the unfitness of the two metals last mentioned for the purposes of casting or moulding.

An interesting proof of the influence of mass upon cohesion is sometimes observed in the gradual conversion of small crystals left in the liquid into larger ones. In sulphate of nickel, for example, slight alternate elevations and depressions of temperature cause the alternate solution and re-crystallization of part of the salt; the smaller crystals, which offer the largest surface in proportion to their mass, dissolve most readily and crystallize again upon the surface of the larger ones, which thus gradually increase in size, whilst the small ones entirely disappear.

(74) It is not in all cases necessary that liquefaction should take place as a preliminary to crystallization: the deposition of a solid from the gaseous state sometimes occurs in crystalline forms: iodine, arsenious acid, sulphur, iodide of mercury, and camphor offer illustrations of this mode of crystallization.

By the slow action of solution, crystalline structure may often be made visible where previously no trace of it was apparent. The force of cohesion is strongest in certain directions, which depend upon the particular crystalline form, and a kind of dissection of the mass is thus effected.

On the surface of a tin plate these phenomena may be developed in a striking manner, by washing it over with a little weak acid; the crystalline forms thus displayed constitute, when the surface has been varnished, the ornamented tin plate termed *moirée métallique*. A bar of nickel placed in dilute nitric acid, becomes covered with tetrahedra, from the solution of the intervening uncrystallized portions of the metal, and the fibrous structure of the better kinds of iron is thus strikingly exhibited. Salts may be made to show the same kind of structure without having recourse to chemical solvents. A shapeless block of alum, when placed in a nearly saturated solution of the salt, becomes gradually embossed with portions of octohedra, so that its true crystalline structure is revealed to the eye. In all these cases the action of the solvent must be very weak, otherwise the force of adhesion will act too uniformly: the more slowly the solution takes place the more clearly is this difference in the amount of cohesion in different directions of the solid manifested.*

A remarkable molecular change sometimes takes place in bodies without their undergoing any alteration from the solid to the liquid state. Brass and silver, for example, when first cast or wrought, possess considerable toughness, and have no apparent crystalline structure; by repeated heatings and coolings, however, they often become so brittle as to snap off upon the application of a very slight degree of force, and the surface of the fracture then exhibits a distinctly crystallized appearance. In the same way it is found that constant vibration, such as that to which the iron shafts of machinery and the axles of railway carriages are subjected, gradually destroys the fibrous character to which the iron is chiefly indebted for its toughness, and renders it crystalline and brittle. A similar change sometimes occurs in crystallized bodies: in this way transparent prismatic crystals of sulphate of nickel or of seleniate of zinc, when exposed for a few minutes to the sun's rays, become opaque; they retain their form until touched, and then crumble down into a granular powder composed of octohedral particles. A somewhat similar alteration occurs in barley sugar, which, when first made from melted sugar, is amorphous and transparent; but it gradually becomes crystalline, opaque, and brittle.

(75) *Structure of Crystals: Cleavage.*—By the careful application of mechanical force, crystalline form may be often revealed

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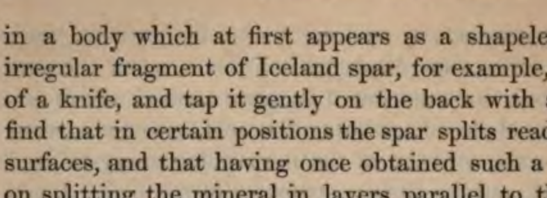
* This subject was particularly examined by Professor Daniell, *Quarterly Journal of Science*, i. 24, and *Royal. Inst. Journal*. i. 1.

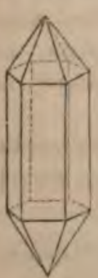
in a body which at first appears as a shapeless mass. If to an irregular fragment of Iceland spar, for example, we apply the edge of a knife, and tap it gently on the back with a hammer, we shall find that in certain positions the spar splits readily, leaving smooth surfaces, and that having once obtained such a surface, we may go on splitting the mineral in layers parallel to this surface. Upon applying the knife to the surface of a layer so detached, we find that this again is capable of cleaving in two directions, and that ultimately we obtain a rhombohedral crystal from the spar. Some bodies cleave with much greater facility than others; and very often cleavage occurs more readily in the direction of one of the planes than in that of the others. Selenite, or sulphate of lime, has three cleavages, but one of these is much more easily effected than the others; hence the mineral is readily split into laminæ.

FIG. 37.



The flat surfaces developed by cleavage are termed the *faces* or *planes* of a crystal (such as *p p*, fig. 37). The lines *e e*, formed by the junction of two of these planes are its *edges;* the junction of two edges a *plane angle;* and the point *a*, at which three or more planes meet constitutes a *solid angle*. These *planes* are said to be *similar*, when their corresponding edges are proportional, and their corresponding angles equal. *Edges* are *similar*, when they are produced by the meeting of planes respectively similar at equal angles; and *angles* are *similar* when they are equal, and are contained within edges respectively similar. Sometimes it happens that the crystal is bounded in all directions by perfectly equal and similar faces, as is seen in the cube, octohedron, and rhombohedron. Such forms are distinguished as *simple forms*, whilst those forms resulting from the combination of two or more simple ones are termed *compound, or secondary forms*. A crystal of quartz, consisting of a six-sided prism, terminated by two six-sided pyramids (fig. 37 *bis*), is a compound form. In figure 37, 2, is a compound form, the twelve edges of the octohedron *d d d*, being replaced by faces of the rhombic dodecahedron.

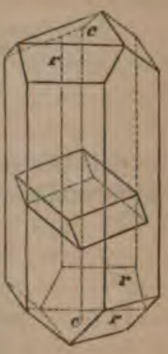
FIG. 37 (*bis*).



Although each substance has its own peculiar crystalline form, as, for example, alum the octahedron, common salt the cube, carbonate of lime the rhombohedron, it often happens that the regularity of the crystalline form is interfered with. Extra faces are often formed by the *replacement* of an edge, or the *truncation* of an angle. If the twelve solid edges of the octahedron were removed, a form intermediate between the octahedron and the rhombic dodecahedron would be the result, such as is seen in fig. 37, 2. If the four solid angles of the octahedron were removed, a form intermediate between the tetrahedron and the octahedron would result (fig. 37, 3.)

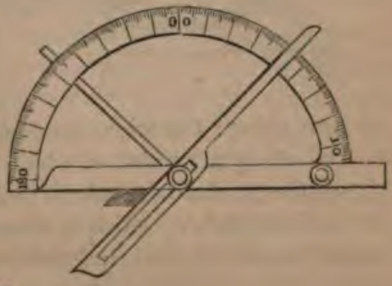
In the discovery of the simple form of crystals, the process of cleavage just alluded to is most valuable; and by its means, secondary forms, which at first sight present no resemblance to the original, may be readily traced to it. A striking instance of this kind is afforded by the cleavage of the six-sided prism of calcareous spar. By cleavage, the three alternate edges of the base may be removed, and three faces produced, as at *r r*, fig. 38, whilst a cleavage similar to that of the base may be effected upon the opposite extremity of the prism, except that the edges corresponding to those that before resisted, now yield, and that those which at the base yielded to cleavage now remain entire. The obtuse rhombohedron is thus obtained by pursuing the dissection, as shown in fig. 38.

Fig. 38.



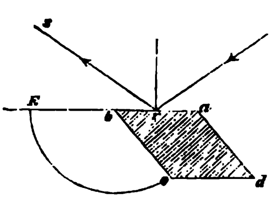
(76) *Goniometers.*—Since the number of geometrical solids is limited, whilst the number of crystallized bodies is very great, it necessarily happens that several different substances possess the same crystalline form, and the only difference observable between them consists in the different inclination of the planes to each other; or what is the same thing, in variations of the angles of the crystal. In order to detect this difference, the crystallographer requires instruments for measuring these angles. Such instruments are termed *goniometers.* Of these the simplest consists of a pair of double compasses, the pivot of which coincides with the

Fig. 39.



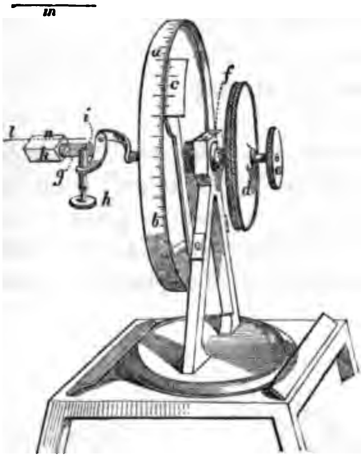
centre of a graduated semicircle; one limb is fixed, forming the diameter of the semicircle, the other is moveable on the pivot, and crosses the fixed limb at its centre, as shown in fig. 40. The external limbs of the compasses are pressed against the two planes of the crystal, the inclination of which is to be measured, so that they shall accurately touch those planes in directions perpendicular to the edge at which they meet; and the alternate and opposite angle, which of course coincides with that of the crystal, is read off in the degrees of the graduated arc.

FIG. 40.



(77) A far more elegant and accurate instrument is the *reflecting goniometer* of Dr. Wollaston. Let *a b c d* (fig. 40), represent a section of the crystal to be measured. A ray of light, *i r*, reflected as at *r s*, from the surface of the crystal, forms the radius of the arc which is to be measured. One plane, *a b*, of the crystal, is brought into a fixed position with regard to the graduated circle, and the inclination of the two planes *a b*, *b c* is ascertained by measuring the arc which the graduated limb of the instrument describes, in order to bring the second plane, *b c*, of the crystal into the same position as the first, *a b*. The *supplement, a b c, of this arc,* E *b c* measures the inclination of the two planes. The angle may, however, be read off at once, by attending to the following instructions:—

FIG. 41.



The instrument (fig. 41) consists of a brass disk, *a b*, supported in a vertical plane, and graduated on its outer edge to half degrees. By means of a milled head, *d*, this disk may be turned round in its own plane; the angle through which it has been made to turn is read off by a vernier, *c*, which is permanently fixed. The axis, *f*, of the graduated circle is pierced by a second axis, attached to the milled head, *e*, which is intended to give rotation to the parts supporting the crystal, independent, when necessary, of the movements of the graduated circle, *a b*.

"To use the goniometer, it should first be placed on a pyramidal stand, and the stand on a small steady table, placed about six to ten or twelve feet from a *flat* window. The graduated circular plate, *a b*, should stand *accurately* perpendicular from the window, the pin, *h i*, being horizontal, with the slit end, *i*, nearest the eye. Place the crystal which is to be measured on the table, resting on one of the planes whose inclination is required, and with the edge at which those planes meet the farthest from you, and parallel to the window in your front. Attach a portion of wax to one side of the small brass plate, *g*; lay the plate on the table with one edge parallel to the window, the side to which the wax is attached being uppermost, and press the end of the wax against the crystal, *k*, till it adheres; then lift the plate, with its attached crystal, and place it in the slit of the pin, *h i*, with that side uppermost which rested on the table.

"Bring the eye now so near the crystal, as, without perceiving the crystal itself, to permit your observing distinctly the images of objects reflected from its planes; and raise or lower that end of the pin which has the small circular plate, *h*, attached to it, until one of the horizontal upper bars, *m*, of the window is seen reflected from the upper or first plane of the crystal, and till the image of the bar, *n*, is brought nearly to coincide with some line below the window; as the edge of the skirting-board where it joins the floor. Turn the pin, *h i*, *on its own axis*, if necessary, until the reflected image of the bar of the window coincides accurately with the observed line below the window. Turn now the small circular plate, *e*, on its axis, and from you, until you observe the same bar of the window reflected from the second plane of the crystal, and nearly coincident with the line below; and having, in adjusting the first plane, turned the pin on its axis to bring the reflected image of the bar of the window to coincide *accurately* with the line below, now move the lower end of that pin *laterally* either towards or from the instrument, in order to make the image of the same bar reflected from the second plane coincide with the same line below.

"Having assured yourself, by looking repeatedly at both planes, that the image of the horizontal bar reflected successively from each, coincides with the same line below, the crystal may be considered as adjusted for measurement. Let the 180° on the graduated circle be now brought opposite the 0° of the vernier, by turning the middle plate, *d*, and while the circle is maintained accurately in this position, bring the reflected image, *n*, of the bar, *m*, from the first plane, to coincide with the line, *l*, below, by turning the small circular plate, *e*. Now turn the graduated circle from you, by means of the middle plate, *d*, until the image of the bar reflected from the second plane is also observed to coincide with the same line." (Brooke's *Crystallography*, p. 30.) In this position, the reading of the vernier gives at once the inclination of the two planes to each other. It is almost superfluous to remark, that the reflecting goniometer can only be applied in cases in which the surfaces of the crystal have sufficient polish and brilliancy to reflect the image of the line by means of which the angle is read off.

(78) *Symmetry of Crystalline Form.*—The study of the geometrical relations of different crystalline forms to each other belongs to the science of crystallography. It will be sufficient for the present purpose to indicate the general principle upon which the classification of crystals is founded. This principle is the symmetrical arrangement upon which every crystalline form is constructed. Symmetry, or a complex uniformity of configuration (that is, similarity in the arrangement of two or more corresponding forms round a common centre), is the general law of creation, both in the vegetable and animal kingdoms, and it at once attracts the notice of every observer. The same law holds good still more rigidly, though not so obviously, in the constitution of every crystal. If one of the primary planes or axes of a crystal be modified in any manner, all the symmetrical planes must be modified in the same manner.

The imaginary line which thus governs the figure, and about which all the parts are similarly disposed, and with reference to which they correspond exactly, is termed the *axis of symmetry* in a crystal. If a rhombohedron of Iceland spar be held with one of its obtuse angles uppermost, the vertical line which joins that angle to the opposite obtuse angle is the axis of symmetry of the crystal. Each extremity of the axis is formed by the meeting of three planes, each similar to the others, and all inclined to the axis at an equal angle. If any internal molecular force produce the replacement of any of the edges of one of those faces, the same cause must act with similar intensity upon the corresponding edge of the other faces, and produce a corresponding modification. The variation thus introduced in the form of the crystal has a symmetrical character; and the alteration which is experienced by each of the divisions of which the crystal consists is consequently similar, three in each case.

There are, however, crystals that possess more than one axis of symmetry; and an arrangement of crystalline form, first proposed by Weiss, and which is now universally adopted, is based upon the relation which these axes bear to each other. These axes, it must be remembered, are *imaginary* lines, which connect the opposite angles or faces of a crystal, and all of them intersect each other in the centre of the figure. In the regular system, to which the cube, the regular octahedron, and rhombic dodecahedron belong, there are three axes which are all equal, and cross each other in the centre of the crystal at right angles. If one of the faces or edges upon any of these equal axes be modified, not only are all the faces or edges upon that axis similarly modified, but all the faces and edges of the entire crystal experience a similar modification; since the symmetry of all the axes is alike, and the molecular modifying force acts equally upon all. This rule, though of very general application, is not without exception. If, for instance, a crystal rest upon one face during its formation, the mechanical obstacle to its symmetrical development is frequently the cause of considerable interference with the regular growth in this direction, but this interference does not operate upon the upper and exposed faces. This interference of causes external to the crystal is very generally observed in crystalline masses artificially obtained. The crystals of which the mass is composed cross each other in all directions, and form a confused structure, from the surface of which project isolated crystals, one extremity of which only is developed regularly.

(79) *Classification of Crystals.*—Crystals are subdivided into six clssses or systems, founded upon the relation of their axes of symmetry to each other. These relations exert an influence not only upon the geometrical connexion of the forms of the crystals, but also upon their optical and physical properties. It is necessary in studying crystalline forms, the relations of which are often very complicated, always to place the crystal in a definite position. It will be found most convenient to place the principal axis in a vertical direction. The observance of this rule greatly facilitates the comparison of the compound with the simple forms.

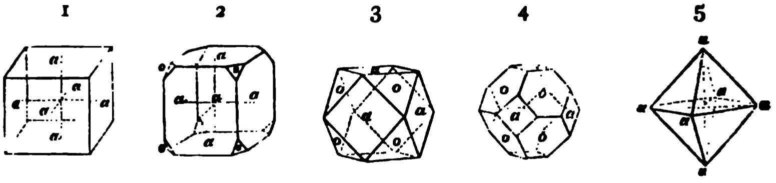
The six classes into which crystals are subdivided are the following:—1st, the regular or tessular system; 2nd, the right square prismatic, or pyramidal; 3rd, the rhombohedral; 4th, the prismatic; 5th, the oblique; 6th, the doubly oblique.

1. *The Regular*, or *Tessular*, or *Cubic System*, is characterized by three equal axes, *a a*, *a a*, *a a*, figures 42, 43, 44, around which the crystals are symmetrically arranged; they cross each other at right angles. Crystals belonging to this system expand equally in all directions when heated, and refract light simply. The most important varieties of simple forms are the cube, as shown in fluor spar, common salt, and iron pyrites (fig. 42, 1); the octahedron

(fig. 42, 5), exemplified by alum and magnetic iron ore; the tetrahedron (fig. 44, 3), sometimes seen in copper; and the rhombic dodecahedron (fig. 43, 3), as in the garnet and sulphide of cobalt. Upon the geometrical relations of these forms, a single instance, showing one of the simplest cases of such a connexion, will suffice.

From the cube may readily be deduced the three other allied forms of the regular system. By truncating each of the eight solid angles by planes equally inclined to the faces of the cube, we obtain the *octahedron*, in which the three axes of the cube terminate in the six solid angles of the figure, one of which consequently corresponds to the centre of each side of the cube. (See fig. 42.)

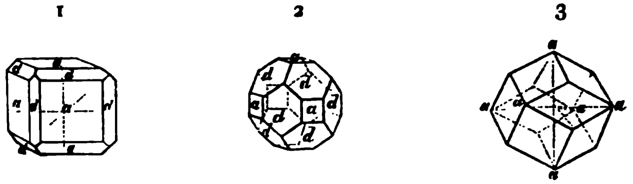
Fig. 42.



Passage of the Cube to the Octahedron.

By replacing each of the twelve edges of the cube, we arrive at last at the *rhombic dodecahedron*. (Fig. 43.)

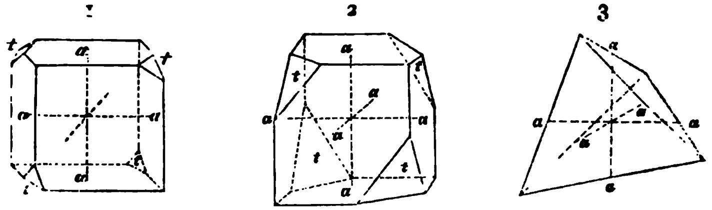
Fig. 43.



Passage of the Cube to the Dodecahedron.

By truncating the alternate angles, we obtain the *tetrahedron*, as shown in fig. 44.

Fig. 44.



Passage of the Cube to the Tetrahedron.

Homohedral, or *Holohedral* forms, are those which, like the cube and octahedron, possess the highest degree of symmetry of which the system admits. *Hemihedral* forms, on the other hand, are those which may be derived from a holohedral form, as the tetrahedron is from the octahedron (fig. 37), or from the cube (fig. 44), by supposing half the faces of the holohedral form omitted, or its alternate angles or edges replaced, according to a certain law.

These relations will be readily traced, even by those unacquainted with geometry, by cutting out two or three cubes in soap, or some other sectile body, and paring down the angles or edges in the manner above described.

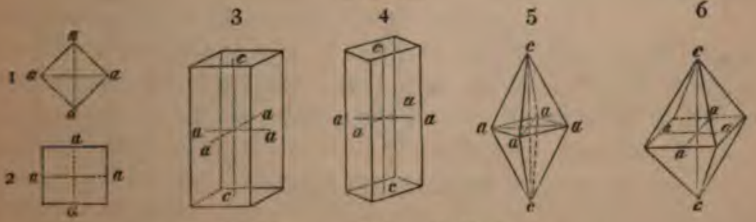
In a similar manner, by inserting wires into an apple, (fig. 45), we may represent to the eye the direction assumed by each of the axes of a crystal, and by winding a piece of string round each point of the wires, and stretching the thread across from one wire to another, the outline of an octahedron belonging to any of the systems is readily obtained.

Fig. 45.

2. *The Right Square Prismatic*, or *Pyramidal System.*—In this system there are three axes, all at right angles to each other, but two only, *a a*, *a a* (fig. 46), are equal; the third, *c c*, being either longer or shorter than the others. Generally there is no simple relation between the length of this axis and that of the other two. Expansion by heat is equal in two directions. The crystals of this system, as well as those of the four other systems not yet described, exert double refraction on light, and have only one axis of single refraction.

Four principal varieties of this system may be mentioned; two prisms with a square base, and two octahedra. The prisms differ from each other according as the equal axes, *a a*, *a a*, terminate in the angles of the base, as seen in fig. 46, 1; or in the sides of the base,

Fig. 46.

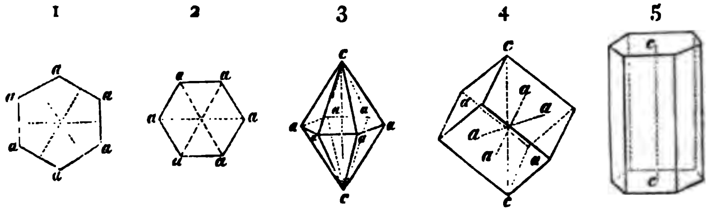


Right square Prismatic System.

as at 2. Similar differences exist in the two octahedra. The octahedron is said to be *direct*, when the axes end in the angles,—*inverse*, when they end in the edges. 3 represents a right square prism, the axes of which terminate in the sides of the crystal. In 4 the axes terminate in the edges of the prism; 5 is the direct octahedron, with its axes in the solid angles; 6 the inverse octahedron, with the axes in the edges. To this system belong ferrocyanide of potassium, cyanide of mercury, oxide of tin, and anatase. In consequence of the absence of any fixed relation in length between the principal axis, $c\,c$, in the four different prismatic systems, these prisms may vary in length indefinitely. In some cases, the axis, $c\,c$, is so short that the crystal assumes the form of a flattened plate, when it is said to be a *tabular* crystal; at others it forms a long prism of indefinite length. Even in the octahedron of the various prismatic systems, the principal axis, $c\,c$, is not always of the same length *in the same compound*; though in these various octahedra the axis, $c\,c$, always bears some simple ratio in length to those of the other octahedra of the same body.

3. *The Rhombohedral System.*—In this system there are four axes; three of them, $a\,a$, $a\,a$, $a\,a$, are of equal lengths, are situated in the same plane, and cross each other at angles of 60°; whilst the fourth, $c\,c$, is perpendicular to these, and may vary in length. The crystals of this class produce, in a very marked manner, the effects of double refraction on light. They have one axis, $c\,c$, of single refraction; and by the application of heat expand equally in two directions. A section which passes through the principal axis, $c\,c$, and any one of the secondary axes $a\,a$, is termed a *principal section*; in each crystal of this system there are three such sections, corresponding with the three secondary axes, $a\,a$. In this system the principal forms (fig. 47, 4) are the bi-pyramidal dodecahedron 3, (of which there are two varieties, according as the axes terminate in the sides of

FIG. 47.

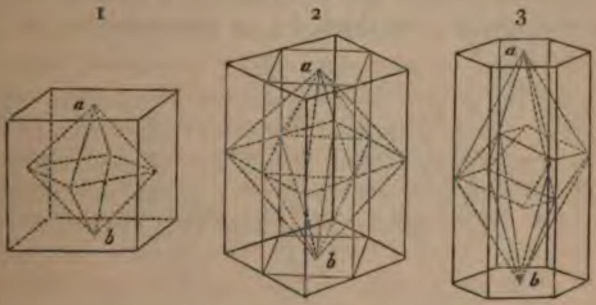


Rhombohedral System.

the base 1, when it constitutes an inverse dodecahedron; or in its angles 2, when the dodecahedron is said to be direct;) the rhombohedron 4, and the six-sided prism 5. Of each of these forms there are likewise two varieties, depending upon the position of the axes. 4 is an inverse rhombohedron. Ice, quartz, beryl, Iceland spar, and nitrate of soda, belong to this system. The relations of the first three systems are simple, and easily traced; the other three systems are more complicated, owing to the variety introduced by the irregular lengths and obliquities of the axes.

Figure 48 represents, in one view, the manner in which the principal forms in each of the first three systems can be described about the crystallographic axes. 1 exhibits the octahedron inscribed in the cube; 2 shows both varieties of the octahedron and of the square prism; 3 the six-sided prism, containing the rhombohedron and the bi-pyramidal dodecahedron.

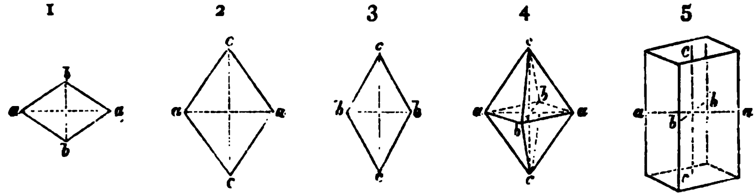
FIG. 48.



4. *The Right Rectangular Prismatic*, or *Prismatic System.*—The crystals of this system have three axes, *a a*, *b b*, *c c* (fig. 48), all at right angles to each other; they are all unequal, and usually bear no simple proportion in length to each other. In this and in the two remaining systems, by the application of heat, the crystals expand unequally in the three directions of these axes, and they have two axes in which there is no double refraction.

The principal varieties of the prismatic system are the right octahedron with a rhombic base (fig. 49, 4), or right rhombic octahedron; and the right prism with a rhombic base, or right rhombic prism 5. Both these figures have a rhombic base 1; the axes terminate in the solid angles of the octahedron, and in the edges of the prism. Owing to the inequality in the lengths of the axes, the sections of the octahedron, through *a b a b*, 1, *c a c a*, 2, and *c b c b*, 3, though all rhombic in form, are each different in dimensions. The faces of the octahedron are all similar, but the length of each side of its triangular faces is different. To this class belong nitre, aragonite, topaz, sulphate of baryta, and sulphur obtained by evaporation from bisulphide of carbon.

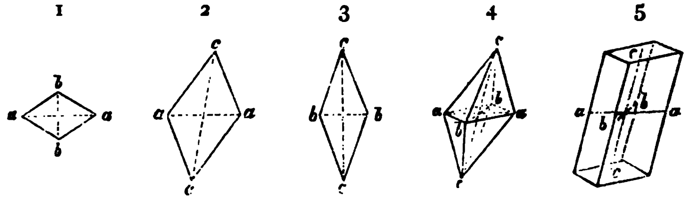
Fig. 49.



Right Prismatic System.

5. *The Oblique System.*—The three axes of this system may all be unequal in length; two of them, *c c*, *a a*, cross each other obliquely (fig. 51, 2); the third, *b b*, is perpendicular to both the others; generally there is no simple proportion between the lengths of the different axes. The principal forms are the oblique octahedron with a rhombic base 4, in which the axes are in the angles of the crystal. The base of this figure is a rhomboid, 1, in which the axes *a a*, *b b*, cross each other at right angles. The section through the two oblique axes, *a a*, *c c*, 2, is also a rhomboid, and it is termed the *principal section* of the crystals. The axis, *c c*, crosses the third axis, *b b*, perpendicularly, and a section through these axes produces the rhomboid shown in 3. The octahedron of this system is not perfectly symmetrical. The three sides forming its triangular faces are unequal in length, and the faces are of two kinds. The two upper front faces of 4, fig. 50, correspond to the two lower back faces, and the other four faces are alike. Besides the oblique rhombic octa-

Fig. 50.

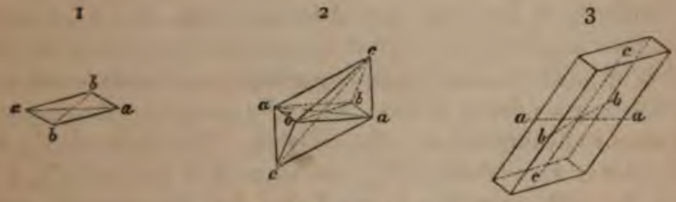


Oblique Prismatic System.

hedron, there are three forms of the oblique rhombic prism; the kind of prism being defined by the axis to which the long axis of the prism is parallel. Sulphate of soda, phosphate of soda, sulphur crystallized by fusion and slow cooling, borax, and sulphate of iron, offer examples of crystals belonging to this class.

6. The *Doubly Oblique*, or *Anorthic System.*—In this system all

Fig. 51.



Doubly Oblique System.

three of the axes are unequal in length, and all cross each other obliquely. The principal varieties are the doubly oblique octahedron (fig. 51, 2), the base of which is seen at 1, and the doubly oblique prism 3. The octahedron is not symmetrical in its form. The four upper faces are all unlike, but each face corresponds to the lower face which is parallel to it. Comparatively few crystals occur in this class. Sulphate of copper and nitrate of bismuth offer examples. Some of the varieties which it includes are very complicated, and difficult to define.

Isomorphism—Dimorphism—Allotropy.

(80) Owing to the comparatively small number of forms which belong to the regular system, and to the perfect symmetry which characterizes them, it necessarily happens that a variety of bodies, very dissimilar in properties and in chemical composition, assume crystalline forms which are not distinguishable from each other, since they coincide exactly in their angular measurements. For example, the elements,—carbon, gold, and copper, and the compounds,—sulphide of lead, bisulphide of iron, fluor spar, alum, and spinelle, all crystallize in cubes or octahedra which perfectly resemble each other; yet these substances present no resemblance to each other, either in properties or chemical composition.

Crystals which belong to the other systems, however, do not present so frequently this exact similarity in form; for though they may crystallize in similar prisms or octahedra, yet a measurement of the angles will suffice to show considerable differences in the length of the axes; and, in the case of the two oblique systems, in the inclination of the axes to each other. But in these systems, likewise, as well as in the regular system, cases occur in which an exact, or almost exact identity in crystalline form, even in these respects, is found. In the larger number of these instances, as Mitscherlich has proved, the chemical composition of the substances which thus correspond in form is analogous. Bodies which possess this similarity in form are termed *isomorphous*. The term isomorphous, etymologically considered, means equal or similar in form; but it is by most chemical writers restricted to such substances as exhibit not only similarity in form, but at the same time, the analogy in their chemical composition just alluded to. The diamond (C), magnetic oxide of iron (FeO, Fe_2O_3), and alum ($KO, SO_3 + Al_2O_3, 3\ SO_3 + 24\ Aq$), all crystallize in octahedra, yet they are not usually cited as instances of isomorphism: but the spinelle-ruby (MgO, Al_2O_3), magnetic oxide of iron (FeO, Fe_2O_3), and chrome iron ore (FeO, Cr_2O_3), not only crystallize in the same form, but have a constitution perfectly analogous, and are therefore truly isomorphous. Mitscherlich, indeed, endeavoured to show that crystalline form is independent of the chemical nature of the atoms, and that it is determined only by their grouping and relative position; the same number of atoms combined in the same way, always producing the same crystalline form.

This statement is not strictly true: the elementary bodies have by no means all of them the same crystalline form; and it is found that even when the chemical constitution is the same, though there may frequently be a close similarity in the form assumed, yet a careful measurement of the angles indicates differences in the length or inclination of the axes. For example—the carbonates of manganese, of lime, of magnesia, of iron, and of zinc, all crystallize in rhombohedra; but the corresponding angles of these several crystals are all different, as the following table shows:—

Carbonate of manganese	103° 0′
Calcareous spar	105° 5′
Carbonate of iron	107° 0′
Carbonate of magnesia	107° 25′
Carbonate of zinc	107° 40′

These differences are in all probability partially due to differences in the crystalline arrangement of the elementary molecules of some of the components; and, as Kopp has shown, in the atomic volume or space occupied by these ultimate molecules. The crystals of metallic zinc and iron, for instance, belong to different systems, so that it is not surprising that some difference should be observed in the form of their corresponding compounds; and if Mitscherlich's law be confined to compound bodies, these very differences which have been supposed to militate against it will prove a remarkable corroboration of its truth, as they show that the number and collocation of the atoms may overcome the tendency of some of the atoms of the elementary components to assume different forms. It also shows, moreover, that it is unsafe to infer isomorphism in the elements simply from the occurrence of isomorphism in the compounds which they form.

(81) This discovery of the coincidence of similarity in crystalline form, where the chemical composition is also similar, is one of the most important generalizations yet arrived at in the science of crystallography. It has rendered important services to chemistry by facilitating the classification of compounds, and it has often called attention to analogies in composition which might otherwise have been overlooked. In determining the chemical equivalent of a substance it is frequently of essential value; but its application to these purposes will be more advantageously examined at a future period.

Bodies which thus closely approach each other in crystalline form frequently occur mixed together in variable proportions in regularly crystallized minerals. Such isomorphous compounds cannot be separated by the method of crystallization. Indeed, it is quite possible to obtain crystals consisting of alternate layers of different isomorphous salts, if they have nearly the same degree of solubility in water. An octahedral crystal of ordinary alum, if transferred to a solution of chrome alum (a compound isomorphous with ordinary alum, and which differs from it in containing two equivalents of chromium in the place of two equivalents of aluminum), will continue to increase in size regularly, and a layer of the metallic salt will be deposited on the common alum. If the crystal be transferred again to the original solution of alum, a fresh layer of colourless alum will form upon the chrome salt, and so on in succession. Sulphate of copper and sulphate of iron may, by similar treatment, be also obtained in alternate layers upon the same crystal.

A large number of metallic oxides are found to be isomorphous when united with the same acid. The sulphates of magnesia, of oxide of copper, of oxide of zinc, of protoxide of iron, of oxide of nickel, of oxide of cobalt, of oxide of manganese, and of oxide of cadmium, all crystallize in similar forms. The isomorphism of many acids, when united with the same base, such as potash or soda, is not less evident. Sulphate, seleniate, chromate, and manganate of potash, all have the same form. and the isomorphism of the corresponding phosphates and arseniates of soda is equally striking.

(82) The following table exhibits some of the more striking of the groups in which the existence of isomorphism has been distinctly ascertained:

ISOMORPHOUS GROUPS.

(*A.*) *Elements.*

1

Diamond
Lead
Iron
Copper
Silver
Gold

2

Arsenic
Antimony
Tellurium

(*B.*) *Compounds.*

3

Alumina	Al_2O_3
Sesquioxide of Iron .	Fe_2O_3
Oxide of Chromium .	Cr_2O_3
Ilmenite	$FeTi, O_3$

4

Arsenious Acid . .	AsO_3
Teroxide of Antimony	SbO_3

5

Sulphides Arsenides Antimonides	2 Eq. of Sulphur are isomorphous with 1 Eq. of Arsenic, or 1 Eq. of Antimony.

6

Potassium—compounds of

Chlorine	KCl
Iodine	KI
Bromine	KBr
Fluorine	KFl

Acids in Combination, or Salts of the following Acids when united with the same base.

7

Phosphoric Acid (Tribasic)	PO_5
Arsenic Acid	AsO_5

8

Sulphuric Acid	SO_3
Selenic	SeO_3
Chromic	CrO_3
Manganic	MnO_3

9

Molybdic Acid . . .	MO_3
Tungstic	WO_3
Columbic	TaO_3
Chromic (in the unusual form of Chromate of lead)	CrO_3

10

Perchloric Acid	ClO_7
Permanganic Acid . . .	Mn_2O_7

Bases in Combination, or Salts of the following bases when united with the same Acid.

11

Magnesia		MgO
Lime (in Calc Spar) . . .		CaO
Zinc (oxide of)		ZnO
Cadmium	Do.	CdO
Iron	(Protoxide of) . .	FeO
Manganese	Do. . . .	MnO
Cobalt . .	Do. . . .	CoO
Nickel . .	Do. . . .	NiO
Copper . .	Do. . . .	CuO
Lead (in Plumbo-calcite) .		PbO

12

Baryta	BaO
Strontia	SrO
Lime (in Aragonite)	CaO
Lead	PbO

13

Double Chlorides of

Platinum	$KCl, PtCl_2$
Osmium	$KCl, OsCl_2$
Iridium	$KCl, IrCl_2$

14

Potash	KO
Oxide of Ammonium	NH_4O

15

Alumina	Al_2O_3
Sesquioxide of Iron	Fe_2O_3
Sesquioxide of Chromium	Cr_2O_3
Sesquioxide of Manganese	Mn_2O_3

(83) *Dimorphism.*—Another very remarkable fact connected with crystallization has been observed in a few bodies. Some substances, sulphur, for example, are capable of assuming two dissimilar forms, according to the temperature at which the crystals are produced. Sulphur, as it is found crystallized in nature, or as it is obtained by the spontaneous evaporation of its solution in bisulphide of carbon or in chloride of sulphur, is deposited in the form of octahedra with a rhombic base, which is one of the forms of the 4th, or prismatic system. When obtained by the slow cooling of a melted mass of sulphur, beautiful amber-coloured prismatic crystals are obtained, belonging to the 5th, or oblique system. These oblique prisms, in the course of a few days, at the usual atmospheric temperature, become opaque, lose their cohesion, and are gradually converted into a congeries of octahedra. A similar change is produced in the octahedral crystals by exposing them for some time to a heat of about 230°, but the opacity is in this case due to the formation of prismatic crystals. The crystalline axes of the two forms differ, and consequently the crystals belong to different systems. Bodies capable of thus assuming two forms geometrically incompatible are said to be *dimorphous*.

Many other instances might be mentioned. Carbon, in its pure state, as it occurs in the diamond, is crystallized in the 1st, or regular system, in octahedra, or in allied forms; in graphite, as it separates from cast iron when fused, it assumes the shape of six-sided plates, which belong to the rhombohedral system. Carbonate of lime usually occurs in forms of the 3rd system, reducible by cleavage to rhombohedra, like those of Iceland spar, and it is thus formed by crystallization at low temperatures; but occasionally it occurs in the rectangular prisms of the 4th system, as in the mineral aragonite; and the microscopic crystals which form when the carbonate of lime is deposited from its solution by carbonic acid in water, on the application of a heat of 212°, have also this form. (G. Rose.) Another beautiful instance of this kind is afforded in iodide of mercury. When this body is heated, it fuses, boils, and is converted into vapour, which condenses upon the side of the tube as a yellow crystalline crust, composed of minute rhombic plates. The application of a slight mechanical force, such as a mere scratch upon a single point, changes the form from the rhombic tables to an octahedron with square base, and the change is rendered visible to the eye by the accompanying substitution of a bright scarlet for the yellow colour.

Some substances are even trimorphous, that is, they crystallize in three different systems. Both the seleniate of zinc ($ZnO, SeO_3 + 7Aq$) and sulphate of zinc ($ZnO, SO_3 + 7Aq$), and the seleniate of nickel ($NiO, SeO_3 + 7Aq$) and sulphate of nickel ($NiO, SO_3 + 7Aq$), according to Mitscherlich, exhibit this peculiarity. Sulphate of nickel crystallizes below 59° F. in right rhombic prisms; between 59° F. and 68° F. in acute square-based octahedra; and when the temperature is above 86° F. in oblique rhombic prisms. In the first case the crystals belong to the prismatic, in the second to the pyramidal, and in the third to the oblique system. If the right rhombic crystals be placed in the summer's sun for a few days they become opaque, but still retain the form of the prism, which is found when broken to consist of a mass of octahedra.

It is not unlikely that the change of tenacity produced in some of the metals by elevation of temperature, and exhibited in a marked degree by zinc, is produced by some modification of their crystalline form under the action of heat.

The influence of temperature in thus subverting the direction of the molecular forces under which crystals are formed, has as yet scarcely been made the subject of systematic research; its further prosecution, however, cannot fail to throw much additional interesting light upon our knowledge of the operation of molecular force.

(84) *Allotropy.*—Independently of dimorphism, the particles of many solids are capable of other modes of arrangement, which, without altering the chemical composition of the body, yet produce a very important modification of many of its properties, both chemical and physical.

There appear to be four different conditions in which solid bodies may exist. They may be—1st, *crystalline*, as diamond, garnet, felspar; 2nd, *vitreous* or glassy, as glass itself, transparent arsenious acid, and barley-sugar; 3rd, *amorphous*, or destitute of crystalline form altogether, as tinder, chalk, or clay; 4th, *organized*, or arranged in masses, consisting of cells, fibres, or membranes, like the tissues of animals or vegetables, as hair, muscle, skin, wood, bark, leaves, &c. To these organized structures, no further allusion will for the present be made, as they are producible only by the living organism.

Now, many substances are capable of assuming indifferently any one of the first three of these conditions. Sulphur, for example, often occurs naturally in beautiful octahedral crystals, and may always be obtained in this form by allowing its solutions to evaporate spontaneously in the air. These crystals are very hard and brittle, and they easily dissolve again in the bisulphide of carbon. But if a quantity of these crystals be melted and heated considerably beyond the boiling point of water, and then suddenly cooled by pouring into cold water, a tough, flexible, transparent substance, of an amber colour, is procured, which may be kneaded in the hand or drawn out into long threads, and is less easily inflamed than ordinary sulphur. This forms vitreous sulphur; but if this is left for a few days it becomes brittle, opaque, and partly crystalline. However, it is not all crystallized, for if digested with bisulphide of carbon, part only will be dissolved; the crystallized portion is taken up, and a buff-coloured powder is left, which is insoluble. It has no crystalline appearance, and is amorphous sulphur. This, if melted by heat, becomes as soluble as before.

In addition to these alterations in consistence, colour, inflammability, and solubility, differences in the density are observed.

Octahedral sulphur	has a specific	gravity of	2·05
Prismatic sulphur	,,	,,	1·98
Vitreous sulphur	,,	,,	1·751

Corresponding differences in the specific heat have been observed in these different conditions.

Now these three different forms of sulphur are called *allotropic* modifications of sulphur, and the existence of the same substance in different forms, each endowed with different properties, is called *allotropy.*

Phosphorus affords another excellent instance of this singular series of modifications. Phosphorus, when first prepared and as sold in the shops, is in the form of transparent, flexible, waxy-looking sticks, which are of the vitreous variety. In this form it is freely soluble in bisulphide of carbon, melts in warm water at a heat very little above that of the human body, and is so inflammable, that if left exposed to the air, even for a few minutes, in warm weather, it takes fire and burns with great violence. Phosphorus has also been obtained in crystals, which are equally inflammable with the common form. But if phosphorus be put into a flask filled with nitrogen or carbonic acid gas, to prevent it from taking fire, and be heated with various precautions, to avoid accident, up to the melting point of tin (442° F.), or rather higher, in a few hours it will be changed into a red powder which, when properly purified, may be exposed to the air without any danger of taking fire. In this condition it does not melt until heated to 500°, or even beyond that temperature; and it is quite insoluble in bisulphide of carbon. Yet it is pure phosphorus, although in the amorphous condition. By heating it in a retort or vessel, from which the air is excluded, to between 500° and 600°, it melts, and then cannot be distinguished from the original phosphorus that furnished it. In addition to the alterations in solubility, colour, inflammability, and external appearance, differences in the specific gravity and in specific heat have been observed.

Many other elementary bodies exhibit these allotropic modifications, and their number will no doubt be increased as researches in this direction become multiplied. It is probable, indeed, that such modifications exist in all the elements, although the properties of the different forms certainly are not always so dissimilar as in the cases already quoted. Even in permanent gases we have indications of allotropy, the remarkable substance ozone having been ascertained to be oxygen in a particularly active condition. The consideration of special instances of allotropy will be deferred until the properties of the bodies themselves are detailed. Allotropy does not appear to be confined to elementary bodies; but in compounds it is not always easy to determine whether the corresponding modifications may not be due to alterations in chemical composition, arising from a change in the mode of combination of the different component elementary bodies with each other.

It is certain, whatever be the causes which thus influence molecular arrangement, that the particular arrangement which such causes may produce in any given case, has a very material influence in modifying the physical properties of the body. Where a body is homogeneous, or when it is symmetrically arranged, as in the crystals belonging to the regular system, the transmission of light, the expansion by heat, and the conducting power of the body for heat, is uniform in every direction; but when the molecular forces, as shown by the form of the crystal, are more powerful in one direction than in others, immediately a corresponding irregularity in the action of the body on light, and in its expansive and conducting powers for heat, may be traced: probably similar irregularities would be found in its power of transmitting sound, and in allowing the passage of electricity andmagnetism.

CHAPTER IV.

LIGHT.

Nature of Light—Undulations—Reflection—Refraction—Production of Colour—Interference—Double Refraction—Polarization.

(85) The force of light which, operating through the eye, gives exercise to the sense of vision, is one which, until within the last few years, would have been thought to have little connexion with chemistry. Now, however, the case is otherwise, and an acquaintance with the fundamental laws and properties of light is indispensable to the chemist. The physical characters of an object, revealed by its action on light, are often of the greatest chemical value. Differences in refractive power, for example, furnish in many cases the most rapid and satisfactory proof of the genuineness of an essential oil. Varieties in the amount and direction of circular polarization afford the best means in certain cases of arriving at a knowledge of the varieties and proportions of sugar in complex saccharine liquids. By the action of polarized light, the diamond and other precious gems may be distinguished from spurious imitations.

But besides the assistance thus afforded to chemistry, the researches of the last fifty years have been gradually developing the vast importance of light as an agent in producing the chemical changes which are continually in operation upon the surface of the earth, and they have at length shown that this wonderful emanation from the sun, is, conjointly with heat, the mainspring which maintains the chemical actions, and with them the existence, of all the varied forms of organic life which teem around us. The fixation of carbon in the vegetable creation, the accumulation of materials for our habitations and for fuel, and the maintenance of a uniform composition in the atmosphere, may be mentioned in illustration of the importance of its chemical actions; whilst the new and fascinating art of photography, gives proof of the rapidity and the variety of changes which it produces.

The investigation of the laws of light belongs to the science of optics: in the following pages, therefore, reference will only be made to some of its principal properties, which will be a necessary preparation to the study of its chemical effects.

(86) *Sources of Light.*—Besides the great sources of natural light which exist in the sun and the heavenly bodies, there are several modes of procuring light by artificial means. Whenever any solid object is raised to a high temperature (beyond 900° or 1000° F.), it becomes luminous. A current of gaseous matter may have a temperature of upwards of 2000° F. without becoming luminous. If, however, a solid be introduced into such a current, it becomes luminous and throws off light in all directions. The colour of the light varies with the intensity of the heat. When first perceptible it is of a dull red colour, and as the temperature rises it passes through orange and yellow into a full white, which, when the heat becomes extremely intense, assumes something of a violet tinge. All our artificial lights depend upon such an ignition of solid matter, in the intense heat developed by the chemical changes attendant on combustion. One of the most remarkable instances of the production of light in this manner, is afforded by directing an ignited jet of mixed oxygen and hydrogen gases upon a piece of lime; the burning gas alone gives scarcely any sensible light, but the moment the lime becomes thoroughly heated, the brilliancy of the light becomes too great for the eye to bear.

Some substances of mineral origin, when gently heated, emit a feeble light, which in a short time ceases, and cannot be again renewed until after the body has been exposed to the light of the sun, or to that emitted by the discharge of a Leyden jar. Native phosphate of lime, or phosphorite, and a variety of fluor spar, known as chlorophane, exhibit the phenomenon very distinctly.

The existence of phosphorescence may be recognised in the animal kingdom. The waters of the ocean in different parts of the globe, and at different times, appear to be entirely luminous from the presence of countless hosts of luminous animalculæ. Most usually the light of the sea appears to be developed only by agitation, and the crest of every wave may often be seen to be tipped with a beautiful fringe of pale green light. The glow-worm and the fire-fly offer other familiar instances of the same nature. Some kinds of scolopendra, in passing over the ground, leave a luminous trail behind them. Within certain limits, this power of emitting light appears to be under the control of the animal, and it ceases in a few hours after vitality is destroyed.

Sea fish, in general, soon after death, exhibit a luminous appearance, and in particular whiting, herring, and mackerel; the light is most intense before putrefaction commences, and gradually disappears as decomposition proceeds. In order to observe the phenomenon more distinctly, the fish should be gutted, the roes and scales removed. The entire fish, and especially the soft roe, exhibits the light. By placing such luminous fish in weak saline solutions, such as those of Epsom salts, Glauber's salts, or common salt, they likewise become luminous, and the appearance continues for some days; it is particularly visible when the liquids are agitated. The light is quickly extinguished by the addition of pure water, of lime water, of fermented liquids, of acid and alkaline liquids, and of strong saline solutions in general; these saline solutions, however, on being diluted recover their luminosity. If the fish be exposed to a cold sufficient to freeze it, the luminosity disappears, but it returns when it is thawed.

The same fact has been observed of luminous wood. A temperature of about 100° seems to be that most favourable to the appearance of this remarkable light; considerably below 212°, it disappears, and the faculty of again becoming luminous is speedily destroyed by the continuance of the heat. (Hulme, *Phil. Trans.*, 1800.)

The transient light of the electric spark is familiarly known; but electricity may likewise be made to give a continuous and abundant supply of light. The ignition of charcoal points between the wires of a voltaic battery, may be made to yield a light which dazzles the unprotected eye. Attempts have been made recently to apply this light to the purposes of illumination on a large scale, though as yet with very imperfect results. Other less important sources of light, such as the friction of two pieces of quartz or of loaf sugar, may also possibly be of electrical origin.

Light is likewise developed, under certain circumstances, in the act of crystallization. When the transparent form of arsenious acid is dissolved in hot hydrochloric acid, the liquid as it cools deposits crystals of opaque white arsenious acid. If the process be watched in a darkened room, the separation of each crystal will be seen to be accompanied by a faint flash. Fused sulphate of soda, and one or two other vitrified salts, when dissolved in water and crystallized, exhibit the same phenomenon, which appears to accompany the transformation of a vitreous into a crystalline solid.

(87) *Theories of Light—Undulations.*—Two hypotheses have been proposed to account for the phenomena of light. Upon the first of these, the theory of *emission*, it is imagined that all luminous bodies are constantly throwing off into space a luminous matter, the particles of which are inconceivably minute, and are projected with a velocity equally inconceivable. These particles, when they fall upon any object, are reflected more or less completely from its surfaces; and, entering the transparent portions of the eye, form images upon the retina or expanded termination of the optic nerve, and are by it transmitted to the brain; the result enabling us to see the object from which the light was reflected.

Upon the second hypothesis, that of *undulation*, recourse is had to the supposition of an elastic medium or ether of inconceivable tenuity, filling all space and the interstices of all material objects. This medium is not light itself, but it is susceptible of being thrown into vibration by impulses incessantly emanating from all luminous objects. Portions of the vibrations thus excited are collected by the lenses of the eye, and thrown upon the retina. Upon this theory, therefore, the phenomena are explicable upon a mechanism similar to that by which the vibrations of elastic media are known to be propagated; such, for example, as that by which the undulations of the atmosphere are conveyed to the ear and excite the sensation of sound. The ether by means of which light is transmitted, though possessed of inertia, is not, like the atmosphere, affected by the force of gravity.

At present, the theory of undulation is all but universally adopted, as it affords the most complete explanation of the facts upon which the science of optics is based. The analogies between light and sound are not the least striking and interesting amongst the proofs adduced in its support.

Indeed, it will greatly facilitate the comprehension of the mechanism by which light is propagated, if we first examine some of the phenomena of sound, which admit of being traced in a manner more directly appreciable to common apprehension.

(88) *Illustrations of Undulations from the Phenomena of Sound.*—In the first place, we have abundant evidence of the fact that sound, whenever produced, arises from a series of vibrations which are occasioned by any sudden impulse, such as a blow communicated to any substance possessed even of a very slight degree of elasticity.

In other words, the impression which we receive is due to the vibration into which the particles of the sounding body are thrown; these vibrations react upon an elastic medium, such as the air: the impulses are communicated by the motions of the particles of air to the ear, and by reaction upon the auditory nerves, they excite the sense of hearing.

These motions of sounding bodies are frequently not too rapid to be traced by the eye; for example, a stretched string whilst sounding may be easily seen to be in rapid vibration. Again; if a goblet be dusted over with a little sand or any fine powder, and a violin bow be drawn across its edge so as to elicit a sound, the particles of dust will be briskly agitated. And in the common experiment of half filling a finger-glass with water, and producing a sound by drawing the moistened finger along its edge, the water within, whilst the sound lasts, is beautifully rippled to an extent corresponding with the loudness of the tone. These motions are also distinctly visible in the prongs of a tuning fork whilst it is in the act of producing sound (fig. 52). These vibrations, however, to render them audible require the intervention of an elastic medium to convey them to the ear. If a bell be suspended in the receiver of the air-pump, and struck, it will be distinctly heard whilst the vessel is full of air; but as the exhaustion proceeds, on repeating the stroke, it will gradually become feebler, and at last will be inaudible, or nearly so.

FIG. 52.

Other media besides air may, however, be employed for the transmission of sound. A bell, for instance, may be rung under water, and will be heard by a person under water at even a greater distance than in the air. Wood will also transmit sound freely, and to still greater distances than atmospheric air.

These impulses require time for their propagation, and the rate of propagation varies in different bodies. Sound travels, for example, at the rate of 1130 feet in a second, through air, of 4900 feet through water, and of 17,400 feet per second along a deal rod.

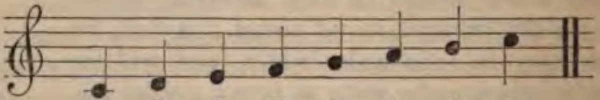
The intensity of sound, like that of all forces radiating from a centre, diminishes as the square of the distance; and as it is propagated in waves or undulations, it is subject to reflection from obstacles interposed in its course, producing the various kinds and forms of echo.

(89) Sounds differ from each other in *loudness, quality,* and *pitch.* The loudness of a sound depends upon the extent of the vibration. A tuning fork vibrating freely in the air produces only a feeble sound; but if the handle be placed upon a table whilst the prongs are vibrating, the wooden surface is thrown into powerful simultaneous vibration, and a loud sound is emitted. *Quality,* or *timbre,* depends on the form of the sounding body, and the nature of the material composing it. Successive impulses rapidly following each other at irregular intervals, constitute a noise or continued sound, like the rumbling of carriages in the street, or the rattle of machinery; but when they follow at regular intervals, with a velocity exceeding sixteen vibrations in a second, they produce a musical note; the pitch of the note depends on the frequency of these vibrations; the more rapid the vibrations the sharper does the sound become.

These facts may be readily verified by pressing a card against the edge of a toothed wheel, which is made to revolve at first slowly; the distinct strokes of the card against each cog are heard at first; but by increasing the rapidity of rotation, a low humming note is given out, and as the velocity increases the sound becomes more acute.

Musical notes all have a fixed numerical relation to each other, each octave as the scale ascends having twice as many vibrations in equal intervals of time as the corresponding note of the octave immediately below it. These ratios are exhibited in the annexed table.

Ratio of Harmonic Sounds.



C	D	E	F	G	A	B	C
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

	Vibrations per second.	Interval.
C	256	
D	288	32
E	320	32
F	$341\frac{1}{3}$	$21\frac{1}{3}$
G	384	$42\frac{2}{3}$
A	$426\frac{2}{3}$	$42\frac{2}{3}$
B	480	$53\frac{1}{3}$
C	512	32

In this table, a tuning-fork is considered to have made one vibration whilst the prong is passing from *a* to *b* (fig. 52), the return motion from *b* to *a* being reckoned as a second vibration, as in counting the beats of the pendulum.

The further consideration of this subject would, however, be irrelevant in a work on chemistry, as it falls under the physical science af acoustics.

It rarely happens that all the particles of a sounding body are simultaneously vibrating. A sounding body generally divides itself into portions vibrating in opposite directions; the intermediate points or lines are quiescent, and these quiescent portions are termed *nodal* lines or points. If a flat plate of glass be held horizontally by the point of the finger and thumb about its centre, and its surface be sprinkled with sand, on eliciting a musical note by drawing a violin bow across its edge, the sand will accumulate on the stationary parts, and clearly show the position of the nodal lines. By altering the points at which the glass is held, the nodal lines, and the note elicited, may be made to undergo a variety of interesting changes.

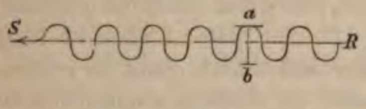
The amount of force exerted by the accumulation of these minute molecular motions is extraordinary. A feat occasionally performed by a powerful singer is to crack a glass by swelling his voice upon the note to which the glass responds. Savart has made some important experiments in relation to this subject. (*Ann. de Chimie*, II. lxv. 384.) He found that a copper band 10 feet long, $\frac{3}{10}$ inch wide, $\frac{1}{25}$ inch thick, will sustain a weight of 90 lb. without becoming perceptibly lengthened, but if made to vibrate it will become lengthened 6 or 7 inches. In the same way, a cylinder of brass 1·37 inch in diameter, lengthened during vibration by as much as would have required the application of a direct strain equal to 4000 lb. It is needless to insist on the important practical bearing of these facts on the construction of metallic machinery liable to regular partial oscillation, however slight or apparently trivial such vibrations may be.

The experiments just detailed, will show in what way it has been clearly ascertained that it is by successive regularly recurring motions, or undulations, that sound is propagated. A similar principle has been with great success applied, with certain modifications, to trace the yet more interesting and complicated phenomena exhibited by light.

(90) *Mechanism of Undulation.*—The mode in which the undulations of light are transmitted may be illustrated by loosely stretching a long cord and striking it near one end: the motion

will be propagated in successive waves from one extremity to the other, each portion of the cord becoming alternately first higher and then lower than the position which it assumes when at rest. In the passage of a ray of light, the motions of the particles of ether interposed between the eye and the luminous object, will, like those of the cord, be at right angles to the track of the ray, or to that line in which the wave is advancing, and in the same plane as that in which the impulse was given. If the cord be struck from above downwards, the waves will be upwards and downwards; if laterally, the waves will occur from side to side. Let R S (fig. 53) be the direction of the ray, the motion of the particles of ether will be in the direction *a b*, at right angles to the course of the ray.

Fig. 53.



A similar movement takes place in water when a stone is dropped into it, or when its surface is ruffled by a breeze. Though the motion is propagated from the point struck towards the edges, in circles continually widening, the particles of the fluid themselves do not travel onwards from the centre towards the circumference, but are alternately elevated and depressed, as may be seen by watching the movements of a cork or other light floating object; each vertical line in succession receiving and transmitting the motion produced by the first impulse, which gradually diminishes in intensity as the squares of the distance increase, and as the circle becomes more extended. In elastic media like air, the propagation of force is also effected by undulation, as in the phenomena of sound; but in them the particles undergo alternate condensation and rarefaction in the same direction as that in which the motion is communicated.

(91) Bodies through which light passes freely, such as glass or air, are termed *transparent*; they allow objects to be seen through them, whilst the majority of substances which, like wood, metals, &c., do not allow its passage, are designated as *opaque*. No substance, however, is perfectly transparent. The purest air arrests a portion of light. Dr. Young estimates that the horizontal sunbeams which pass through about 200 miles of atmospheric air before they reach the eye, possesss only $\frac{1}{2000}$ of their original intensity. A column of the clearest water seven feet in depth, arrests one half of the light which falls upon it. On the other hand, there is no such thing as perfect opacity. Gold, which is one of the densest metals, may be hammered out into very thin

leaves, which transmit a green light if the metal be pure, and a purplish light if it be alloyed with silver. Between the extremes of opacity and transparency are innumerable gradations. Bodies vary greatly in *translucency*, that is, in their power of transmitting light. Porcelain is a translucent body; it breaks up the rays, but transmits a softened light, though it does not allow the form of an object to be seen if interposed between that object and the eye.

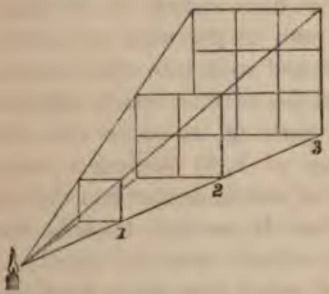
Light proceeds through all homogeneous transparent media in straight lines from the object, and these lines radiate in all directions from a luminous point. The path of the rays in a direct line may often be traced across a darkened room into which a sunbeam is admitted, by the floating particles of dust which reflect a small portion of the light in different parts of its course into the eye of the observer. The mere passage of light through a transparent object does not excite the sense of vision, neither can the eye track its direction, unless the vibrations be carried towards the observer by reflection from the surface of some material object.

The impression of light upon the retina lasts for a brief interval, varying in different persons from $\frac{1}{10}$ to $\frac{1}{8}$ of a second after the light itself has ceased, and gives rise to many curious effects: for instance, the act of blinking produces no impediment to correct vision; a bright point made to revolve rapidly in the dark is seen as a luminous circle, and the jets of flame which in fireworks are whirled round before the eyes of the spectator, assume the form of wheels or stars of fire.

(92) *Law of Diminution of Light by Distance.*—When light diverges from a luminous centre, its intensity, like that of all radiant forces, diminishes not directly as the distance, but as the square of the distance. A little consideration will render the reason for this obvious. Suppose the flame of a candle or any luminous point to be placed in the centre of a hollow sphere 2 feet in diameter, its light will fall upon the whole internal surface of the sphere, and the candle will be 1 foot distant from each point. A square inch of that surface will receive a given amount of light. The same candle, placed in the middle of a globe 4 feet in diameter, will be 2 feet distant from each point of the surface, or double the distance that it was in the first globe, but its light will still illuminate the whole of the interior. The surface of the second globe, however, is four times greater than that of the first, because the surfaces of spheres are to each other as the squares of their radii; in this case as $1^2 : 2^2$, or as 1 to 4. Consequently each point, or each inch of the surface of the larger

sphere will only receive one-fourth of the light that fell on an equal space in the smaller globe, and yet the candle is only twice as far from it; so, if the globe were 8 feet across, the distance of the candle being now 4 times as great as in the first globe, the surface to be illuminated is 16 times as large, and consequently a square inch of the 8-foot globe would receive only $\frac{1}{16}$ of the light that fell on a square inch of the 2-foot globe. A board at 1 yard from a candle receives a certain amount of light, at 2 yards it receives $\frac{1}{4}$ of that amount, at 3 yards $\frac{1}{9}$, at 4 yards $\frac{1}{16}$; and experiment shows that, at 1 yard distance, a board 1 foot square would cast a shadow that would cover a board exposing 4 times the surface, or 2 feet in the side, at a distance of 2 yards, as shown in fig. 54.

FIG. 54.



(93) An application of this law affords a ready means of approximatively determining the relative intensities of two lights, which do not differ greatly in colour. Suppose, for instance, it were necessary to ascertain the illuminating power of a gas-light burning 5 cubic feet of gas per hour, as compared with that of a sperm candle burning 132 grs. of spermaceti per hour. Place at the distance say of 100 inches from the gas-light, a vertical screen of white paper, and in front of this, at an inch distance, a narrow strip of wood or metal, so as to cast a definite shadow. Between the gas-light and the screen place the candle, at such a distance that the shadow of the same object cast by the candle upon the screen shall have as nearly as possible the same intensity as that produced by the gas. Say that the distance of the candle from the screen is 27·75 inches. The shadow from each light is illuminated by the rays proceeding from the other light. If the shadows be sensibly equal, the light falling upon the screen from each source must at that distance be equally also; the relative intensities of the two lights are then found by squaring the distances of each light from the screen; the gas-light will consequently cast a light which bears the same proportion to that of the candle as $100^2 : 27{\cdot}75^2$; or as 16 to 1.

Reflection.

When light falls upon any object it may be disposed of in three different ways. 1st, it may either be bent back or *reflected;* 2nd, it may be allowed to pass on in an altered direction, that is, it may be *transmitted* and *refracted;* or, 3rd, it may disappear altogether, and be *absorbed.*

(94) *Reflection.*—If a ray of light fall obliquely upon a flat polished surface, a large proportion of the *incident* rays, or rays which fall upon the surface, is reflected or thrown off obliquely, at an equal angle formed on the other side of a perpendicular to the point of incidence. Fig. 55 is intended to illustrate the law of reflection. If in this figure I N represent the incident ray, M M the mirror, P N a perpendicular to the point of incidence, P N I will be the angle of incidence, N R the reflected ray, and P N R the angle of reflection formed between the same perpendicular and the reflected ray.

The law which regulates the reflection of light is expressed by saying that the angle of reflection is equal to the angle of incidence: the incident and the reflected ray are always in the same plane, and that plane is perpendicular to the reflecting surface. When the incident ray is perpendicular to the surface, the reflected ray is therefore also perpendicular, and coincides with the incident ray, but it does so in no other position.

FIG. 55.

In fig. 55, the angle of reflection P N R, is equal to the angle of incidence P N I, but they are on opposite sides of the perpendicular. A person looking into the mirror at R, would see the candle behind the mirror. An object always appears to lie in the direction of the line which the ray last traversed when it reaches the eye.

The power of reflecting light varies very greatly in different bodies. In some, as in the metals, reflection is almost perfect; in others, as in charcoal, or in black velvet, it is almost wanting; but whenever light passes out of one medium into another, no matter how transparent such media may be, reflection more or less complete, takes place at their common surface.

With the exception of metals, in which reflection is most complete at the smaller angle of incidence, it is found that the greater the incident angle the more complete is the reflection; so that the surface of a body, such as plaster of Paris, or hot-pressed writing-paper, may thus afford a tolerably perfect image of a luminous object, if the reflection be effected under a great angle.

Bodies in general do not possess surfaces actually flat; to common observation they may be flat, but optically examined, their surface is found to consist of an indefinite number of minute planes inclined to each other at all possible angles, and therefore receiving and reflecting light in all possible directions. If a beam of light admitted into a dark room fall upon a bright metallic surface, in one particular position a brilliant spot of light will be perceived, the direction of which can be varied by altering the inclination of the mirror to the ray, but the mirror will be nearly invisible in all other directions, and the room will remain dark; but if for the mirror a sheet of white paper be substituted, the paper will be almost equally visible in every direction, and a general, though slight illumination of the apartment will be perceived. It is this irregular reflection or *scattering* of the light in all directions, which renders non-luminous objects distinguishable in the light. The light of the moon and of the planetary bodies are instances of this kind. A further evidence of the value of this scattering or secondary radiation, is afforded by the difference between the mild and softened light which is reflected from the heavens when partially covered with clouds, and the strong lights which fatigue the eyesight in a cloudless summer's day. It is entirely to this secondary radiation that we owe the generally diffused and subdued light of day, even when the sun itself may be invisible; and the morning and evening twilight, while the great luminary itself is below the horizon, is due to the same cause, each illuminated particle of the atmosphere contributing its share in producing this effect.

(95) When light is received upon a regular curved surface, it undergoes reflection according to the usual law; the reflection from each point of the curved surface being in fact, the same as from a plane tangent to the curve at the point of incidence. If, therefore, the form of a parabolic concavity be given to a mirror, all the reflected rays will be directed towards a point at which they will cross each other, and continue their progress as before, the upper ray now becoming undermost, and *vice versâ*. This point of intersection is called the *focus* of the mirror (fig. 56.)

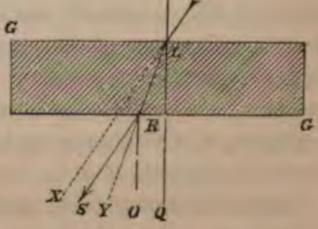
Fig. 56.

Let M M, fig. 56, represent the section of the curved surface, each of the rays L R, L R, will be reflected from it as from planes T T T_1T_1, T_2T_2, tangent to the curve at the points of incidence of the respective rays; they will consequently meet at the focus F, cross there, and subsequently diverge. P R, P R represent the lines perpendicular to the tangents.

Refraction.

(96) When a ray of light falls upon the surface of an uncrystallized transparent substance of uniform density, one portion of the light is regularly reflected, and another portion is scattered, by which the surface is rendered visible, whilst a third portion is transmitted. We will confine our attention to that portion of the light which is transmitted. If the ray be incident upon the surface of the body in a perpendicular direction, it continues its course unchanged; but if it fall upon the surface obliquely, its direction is suddenly altered as it enters the transparent object, or *medium* as it is called in optical language; it then passes on in its new direction in a straight line, and on quitting the medium it is again abruptly bent back to its original course, provided the surface of entrance and the surface of exit be parallel to each other. This change in the course of the ray is termed *refraction*. If, in fig. 57, G G represent a plate of glass with parallel sides, a ray of light I L incident upon it, will not pass straight on in the direction L X, but will be deflected to L R, towards the perpendicular P Q; on quitting the medium at R it is again bent, towards S, but this time the refraction is from the perpendicular O R, and the ray R S becomes parallel to its original

Fig. 57.



direction. On passing from a rare medium like air, into a dense one like glass, the ray is bent towards a line perpendicular to the common surface of the two media; on again passing out from glass into air, it is bent from the perpendicular to the same amount. Different media vary greatly in refractive power; combustible bodies in general having the highest refracting energy. It was upon this general observation that Newton founded his conjecture that diamond was 'probably an unctuous substance coagulated:' the combustibility of the diamond has been since fully verified. The more obliquely the light falls upon the surface of the refracting body the greater is the amount of refraction which the ray experiences. The extent of the refraction, therefore, varies with the angle of incidence, but by a knowledge of the following law it may easily be calculated for all angles, if its amount for any one angle has been carefully determined. This law of refraction may be expressed by stating that when light passes from one medium into another, for the same two media the sines of the angles of refraction and of incidence, always bear the same proportion to each other. This proportion expresses the *index of refraction* of the substance, when obtained by dividing the sine of the angle of incidence *in vacuo* by the sine of the angle of refraction. The incident and the refracted ray always lie in the same plane, and this plane is perpendicular to the surface of the refracting medium.

FIG. 58.

(97) *Law of Refraction.*—Fig. 58 may assist in explaining this important law. Let W W represent a section of the refracting medium, I L the incident ray, and L R the refracted one. Let P L Q be the perpendicular to the refracting surface, passing through the point of incidence L. With any radius L R, describe from the centre L the circle R M P; from M let fall the perpendicular M N on P Q; M N will then represent the sine of the angle of incidence I L P, and R Q the sine of the angle of refraction, R L Q; $\frac{\text{M N}}{\text{R Q}}$ gives the index of refraction, which is uniformly the same for the same substance, whatever the angle of refraction. In the diamond, for instance, M N is always $2\frac{1}{2}$ times as long as R Q; in water it is $1\frac{1}{3}$ times the length of R Q.

The following table contains the *refractive powers* of a few substances; the light being supposed to pass from atmospheric air.

Diamond	2·439	Alcohol	1·372
Phosphorus	2·224	Ether	1·358
Rock Salt	1·557	Water	1·335
Quartz	1·548	Ice	1·308
Castor Oil	1·490	Tabasheer	1·111

MM. Biot and Arago have given the following values for the refractive power of certain gases; the second column furnishes the absolute value under a pressure of 29·92 inches of mercury, and at a temperature of 32°, as compared with the refracting power of water at the same temperature; the third column shows the relative refracting power of the different gases, air being taken as 1·00000.

Air	0·00058971	1·00000
Oxygen	0·000560204	0·86161
Nitrogen	0·000590436	1·03408
Hydrogen	0·000285315	6·61436
Ammonia	0·000762349	2·16851
Carbonic Acid	0·000899573	1·00476
Carburetted Hydrogen	0·000703669	2·09270
Hydrochloric Acid	0·000879066	1·19625

Many familiar phenomena receive an easy explanation from the law of refraction. If a coin be placed in an opaque vessel, and the observer retire until the edge of the basin just hides it from his view, the coin will again become visible if water be carefully poured in without disturbing its position; the rays of light proceeding from the coin which before passed above the eye of the observer, are now abruptly bent downwards from the perpendicular, as they emerge into the air, and the image of the object is conveyed to the eye. The coin appears raised, but never displaced to the right or to the left of its true position; the refracted ray, notwithstanding its change of medium, continues in the same plane, which is vertical to that which forms the common surface of the refracting media. For a similar reason, a straight stick plunged obliquely into water appears bent upwards abruptly where it enters the liquid.

(98) As the refractive action is exercised at the surface of junction between the two media, and is governed by the inclination of the ray to a perpendicular to that surface, it is manifest that by altering the inclination of the surface at which the ray passes out of the medium, the inclination of the emerging ray may be altered; so that instead of continuing its passage in a direction parallel to the one which it possessed on entrance, it may be made permanently to deviate from this to a greater or less extent.

If G G G (fig. 59), represent the section of a *prism*, or bar of glass,

FIG. 59.

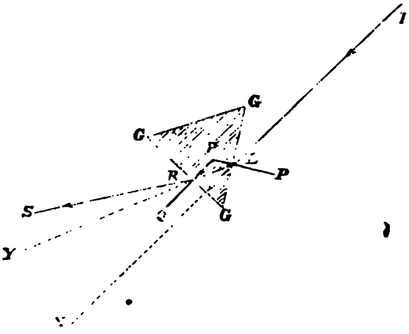
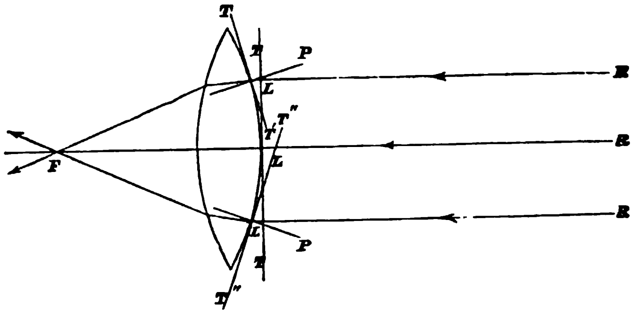


FIG. 60.

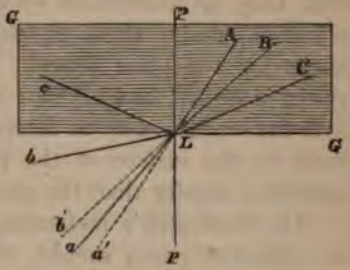


the incident ray I L on entering this medium is bent towards the perpendicular P P: on quitting it at R, it is bent from the perpendicular Q P, and assumes a course R S, permanently deflected from its new direction L Y, and from its original direction I X. This deflection is always towards the thick part of the prism. By employing two such prisms set base to base, the rays may be refracted towards one common line, where they would cross and diverge; and by using a lens of glass (fig. 60), with two convex surfaces, which are segments of spheres, the incident rays R L R L, may be caused to converge to a common focus, F; each portion of the curved surface refracting the ray in the manner of a plane, T T, T T, T T, tangent to the curve at that particular spot or point of incidence.

(99) In the passage of light from a denser into a rarer medium, as when light passes from glass into air, the obliquity of the refracted ray increases as the angle of incidence increases, until at length it becomes parallel to the common surface of the two media. Light incident at an angle more oblique than this ceases to be refracted; refraction becomes impossible, and it is wholly reflected within the denser medium. The angle at which this phenomenon first shows itself is termed the *angle of total reflection*. In fig. 61, let G G represent a plate of glass with parallel sides, P L P a perpen-

dicular at the point of incidence. The incident ray A L, instead of passing to *a′*, would be refracted from the perpendicular P P to L *a* on emerging into the air, B L would be still more refracted from L *b′*, the refracted portion L *b* would be nearly parallel with the surface of the glass, whilst C L would be incapable of refraction at all, and would be wholly reflected as to L *c*. This phenomenon is easily seen by placing the back to the light and holding a glass of water a little above the level of the eye; on looking obliquely up through the water, a spoon, or other object placed in the glass, will appear to be perfectly reflected upon the surface where the liquid and the air meet. The same thing is seen by holding a glass prism horizontally before a window, and turning it slowly round; on looking down into the prism, the internal surface of each face in succession, as it becomes undermost, reflects the light with the brilliancy of a mirror.

FIG. 61.



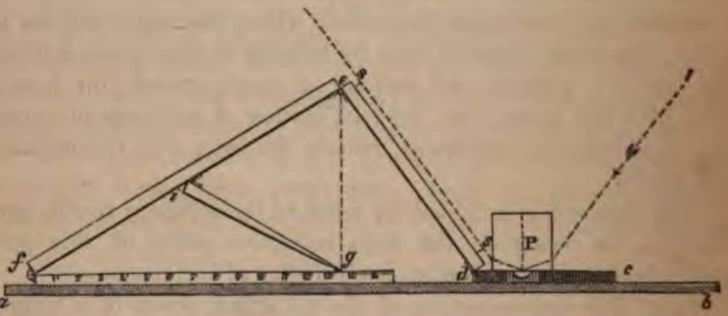
The diamond is indebted for much of its brilliancy to this total reflection, as owing to the high refractive power of this gem, total reflection commences at small angles of incidence.

(100) The determination of the refracting power of a body is often a valuable guide in estimating its chemical purity. The adulteration of essential oils may thus be often detected with ease, where it would otherwise be difficult to ascertain it.

Dr. Wollaston contrived a very simple means of determining the refractive power of a body in air, dependent upon the measurement of the angle at which total reflection commences. If this angle be measured in a glass prism, we are furnished with the means of determining its refractive power in air. Say that the angle of total refraction of the prism is found to be 39° 10′, the refractive power of the prism in air is calculated by dividing the sine of the angle of refraction by the sine of the angle of incidence: the angle of refraction at which total reflection begins is 90°; the refractive power therefore is $\frac{\text{Sine } 90^\circ}{\text{Sine } 39^\circ\, 10'}$ or $\frac{1{\cdot}000}{0{\cdot}631} = 1{\cdot}583$. Now cause a drop of any fluid to adhere to the under surface of the prism; provided the refractive power of the fluid be less than that of glass, the angle of total reflection will be increased: suppose the prism be moistened with water, the angle of reflection will now be $57\frac{1}{2}^\circ$. The water has a higher refractive power than air, consequently, the difference in refractive power between glass and water being less than that between glass and air, the angle of incidence required to produce total reflection is greater. The refractive power of the substance under trial may be ascertained by dividing the sine of its angle of total reflection, under these circumstances, by the sine of the same angle for the glass prism. In the case of water the refractive power is $\frac{\text{Sine } 57^\circ\ 30'}{\text{Sine } 39^\circ\ 12'}$ or $\frac{0{\cdot}8434}{0{\cdot}631} = 1{\cdot}336$. The refracting power of solids with flat surfaces may be determined in the same way by cementing them to the surface of the prism with some material of higher refracting density than the glass, such as balsam of tolu.

Dr. Wollaston's instrument, fig. 62, gives at once the sine of the refractive power sought, without any calculation.

FIG. 62.



On a board, *a b*, is fixed a piece of flat deal, *c d*, to which, by a hinge at *d*, is jointed a second piece, *d e*, 10 inches long, carrying two plane sights at its extremities; at *e* is a second hinge connecting it with *e f*, 15·83 inches long; at the other extremity of *e f* is a third hinge by which *f g* is connected with it; at *i* also is a hinge uniting the rod *i g*, which is half the length of *e f*, to the middle of *e f*; and then, since *g* moves in a semicircle, a line joining *e* and *g* would be perpendicular to *f g*. The piece *c d* has a cavity in the middle of it, so that when any substance is applied to the under surface of the rectangular glass prism, P, the prism may continue to rest horizontally on its extremities. When *e d* has been so elevated that the yellow rays in the fringe of colours, observable where perfect reflection terminates, are seen through the sights, the point *g*, by means of a vernier which it carries, shows upon the rule *f g*, which is graduated to fractions of an inch, the sine of the refractive power sought. The pieces *e f* and *d e* are proportional to the sines that represent the refractive powers of the prism and of air. If the dotted line at P be a perpendicular to the reflecting surface, *l* P will represent the incident ray.—(*Phil. Trans.*, 1802, p. 367.)

The following table contains some of the results obtained by Dr. Wollaston with this instrument.

Refractive Power of Flint Glass Prism, P, = 1·583.

Oil of Sassafras	1·536	Oil of Turpentine	1·475
Oil of Cloves	1·535	Rectified Ditto	1·470
Canada Balsam	1·528	Oil of Almonds	1·470
Capivi Balsam	1·507	„ Olives	1·469
Oil of Amber	1·505	„ Peppermint	1·468
„ Nutmeg	1·497	„ Lavender	1·467
„ Linseed	1·485	Melted Spermaceti	1·446
„ Lemons	1·476	Sulphuric Acid	1·435

Dr. Wollaston mentions that genuine oil of cloves had a refractive power of 1·535, but that some of inferior quality, which had probably been adulterated, had a refractive power of only 1·498.

(101) *Prismatic Analysis.*—Upon examining light that has undergone refraction by a prism, it is found that mere change in direction is only one of the phenomena observable. Suppose a beam of light, as represented in fig. 63, S L, be admitted through a small slit, S, into a darkened room, and be there received upon a prism, P; if the light, after transmission through the prism, be allowed to fall upon a white screen, V R X, placed at a distance of eight or ten feet,—instead of a narrow slit of white light, X, corresponding to the aperture, an elongated coloured image of the refracted beam is seen, as at V R, terminated by parallel ends, and exhibiting the brilliant hues of the rainbow. This elongation

FIG. 63.

occurs in the plane of the reflected and refracted rays.
coloured image is termed the *prismatic spectrum*.

Newton, who first carefully investigated this remark
distinguished seven different colours, which gradually shade
into the other, viz. violet, indigo, blue, green, yellow, orange,
White light may therefore be regarded as the result of a
of rays of different colours, which are unequally acted upo
prism. Each colour has its own peculiar refrangibility;
which deviates the least from its original course, is least refr
and the violet the most so; whilst the intermediate colours
intermediate degrees of refrangibility. Having once been s
by refraction, no second refraction is capable of further
posing any of these colours. They may, however, be rec
by using a second prism, in an inverted position (as shown
dotted lines at Q, (fig. 63), or by employing, what amount
same thing, a convex lens, in which case white light is rep
at the focus of the lens. The composition of white light
illustrated by dividing a circular disk of paper into seven
each of an extent corresponding with the extent of the
the spectrum, and painting each with its appropriate colo
causing the disk to rotate rapidly upon an axis passing
through its centre, the seven impressions will be given simult
to each point of the retina, and the paper will appear of a
white. The impossibility of obtaining pigments of th
hue, or of the brilliancy of the coloured light, renders a pu
unattainable by this means.

(102) *Theory of Colours.*—Upon this decomposability
light Newton founded his explanation of the colours of
objects. The objects are themselves devoid of colour, bu
placed in white light they absorb the rays of one or more
and reflect the rest: the object therefore appears to be
colour that would result from the ray or mixture of rays
reflects; green objects, for example, absorb the red rays an
the yellow and the blue; purple absorb the yellow, and ref
red and the blue. The rays thus absorbed are said to be
mentary to those that are reflected; a complementary colou
always that tint which when added to the primary colou
the eye would constitute white light. This theory of
may be illustrated by placing any coloured object in
one tint, or *homogeneous light* as it is called, such as th
isolated portion of the spectrum. A green object, for in
placed in the blue rays will appear blue; if placed in the

rays it will appear yellow; and a white screen which has the power of reflecting all the colours will take any tint in succession, according to the colour of the incident ray. An object of a pure red, on the contrary, will appear black in any but the red ray, because it absorbs all the other colours as perfectly as charcoal or black velvet absorbs white light or rays of all colours.

Hence it appears that white light may be decomposed by absorption as well as by refraction or prismatic analysis. By transmitting white light through transparent coloured media, we may obtain rays of any given tint: the light thus obtained is not always the same as that produced by prismatic analysis; by transmission through a coloured medium, a green, for instance, may be obtained, which is identical with the green separated by the prism, and then it cannot further be separated into blue and yellow; or it may be a compound colour resulting from the intermixture of rays of different degrees of refrangibility, and in this case it is susceptible of further decomposition: the coloured light that is obtained by absorption, is seldom so pure as that furnished by prismatic decomposition.

In artificial flames it is very generally the case that certain colours are present in smaller proportion than others, and are sometimes altogether wanting. Nitrate of strontia, for instance, gives a red tint to burning bodies; and the prism shows that in such light the blue and violet, or more refrangible rays, are singularly deficient. Common salt produces in burning bodies a nearly pure and homogeneous yellow light, which may be used to illustrate the observations just made upon the cause of colour in natural objects. The brilliant colours of insects or the plumage of birds strike strangely on the eye when seen in this yellow light.

The prismatic analysis of white light, which has just been considered, is not due entirely to the refractive power of the body by which it is effected. Another element of great importance is the *dispersive* power, which is independent of its refraction. Two substances may possess an equal amount of refracting power, in consequence of which the mean deviation of the rays transmitted will be the same, and yet the spectra which they furnish may be of very unequal lengths. If a hollow prism be made of plates of glass, and filled with oil of cassia, the spectrum which it produces will be more than double the length of that furnished by a similar prism of flint glass. The dispersive power of oil of cassia is much greater than that of flint glass, especially for the more refrangible rays from F to H, and hence the difference in the length of the two spectra. The comparative lengths of these spectra, as obtained from prisms of equal angles, are given in fig. 64.

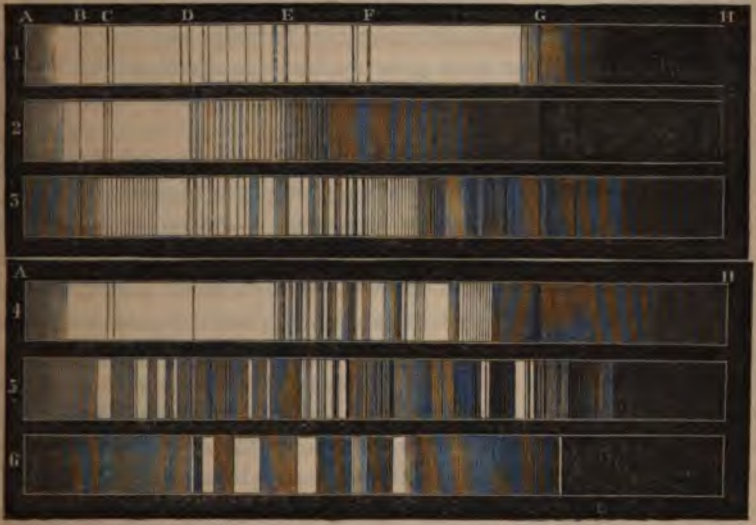
Fig. 64.

The mean refractive powers of the two media do not differ materially. No. 1 is the spectrum of oil of cassia; 2 that of flint glass. In the construction of *achromatic* lenses, two media which differ in dispersive power are employed; by this means the fringe of colours, which is always perceptible around the margin of an object viewed by an ordinary lens of high magnifying power, is removed.

(103) *Lines in the Solar Spectrum.*—When the solar spectrum is received in the usual way upon a white screen, it appears like a continuous band of coloured light; by taking due precautions, however, it may be seen that this luminous band is traversed in the direction of its breadth by several hundred black lines, varying, in different parts, in width and distinctness. They are independent of the nature of the refracting medium, and occur always in the same colour, and at corresponding points of the spectrum. No satisfactory explanation has yet been found for the cause of this remarkable phenomenon; but these lines have afforded fixed points of the greatest value to optical research, by enabling the observer to determine with rigid accuracy the refractive indices of a great variety of bodies. A few of the more important lines are seen in 1, fig. 65. It is found that the position of these lines varies with the source of the light: each of the fixed stars has a system of lines of its own, and every artificial light shows some peculiarity in this respect; for instance, the green light produced by burning a solution of boracic acid in alcohol gives a system of lines, fig. 65, 6, which differs widely from that produced by the green light obtained by the combustion of an alcoholic solution of chloride of copper shown at 5. In short, the chemical nature of the substance has a very important influence on the kind of light which it emits. Each of the metals, in burning, gives out light of a peculiar and distinctive colour; and in each case certain portions of the spectrum are wanting; in

these points dark and perfectly well-defined lines cross the luminous band. Solar light, when transmitted through vapours of different colours, and analysed by the prism, exhibits lines which vary in position and intensity with the nature of the vapour which it has traversed. In fig. 65, No. 1 shows the principal dark lines of the pure solar spectrum; 2 represents the effect of bromine on the solar ray; while 3 shows the very different result furnished by peroxide of nitrogen, which in colour can scarcely be distinguished from the vapour of bromine; 4 shows the effect of transmitting the sun's rays through the green-coloured perchloride of manganese. These lines do not alter their position when a different source of light is employed; the system of lines peculiar to the source of light occurs without interfering with those produced by the absorptive action of the vapour.—(*Phil. Mag.*, 1845, xxvii. 81.)

Fig. 65.



(104) *Change in the Refrangibility of Light.*—A remarkable discovery was made by Professor Stokes, whilst engaged in pursuing the observations of Sir John Herschel upon the effect of light upon an acid solution of sulphate of quinine. This liquid is colourless when viewed by transmitted light, but if placed in a glass and looked at from above, it exhibits, when exposed to direct light, a beautiful and intense blue upon its front surface; but the light which has passed through one vessel containing the sulphate

exhibits no such appearance on the front face of a second vessel of the liquid which is similarly exposed to it. Now, the rays which produce this beautiful blue colour are not the ordinary blue rays, but have been found to be those of the most refrangible portion of the spectrum, which, under ordinary circumstances, are not perceptible to the eye, but which are remarkable for their powerful chemical action, and which show their presence by their chemical effect upon a surface coated with chloride of silver, or with some other photographic preparation.

Professor Stokes (*Phil. Trans.*, 1852, p. 468) found that if a tube filled with a solution of sulphate of quinine were placed successively in each of the colours of the prismatic spectrum, 'throughout nearly the whole of the visible spectrum the light passed through the fluid as it would have done through so much water, but on arriving nearly at the violet extremity, a gleam of pale blue shot across the tube; on continuing to move the tube, the blue light at first increased in intensity, and afterwards gradually died away; it did not, however, cease to appear until the tube had been moved far beyond the violet extremity of the spectrum visible on a screen.' On examining by a second prism the dispersed light thus obtained, it was found that it contained rays extending over a considerable range of refrangibility within the limits of the visible spectrum; but the least refrangible rays, or those of the red end of the spectrum, were wanting.

Pursuing these experiments, Professor Stokes found that the phenomenon of a change of refrangibility is by no means uncommon, especially amongst organic substances, most of which show it in a degree more or less marked. The change in the refrangibility is not confined to the invisible rays, but extends also to those already visible. It is however, to be remarked, that as yet, in every instance, the altered ray gives rise to others which are *less* refrangible. The change is never to rays of greater refrangibility.

Amongst the bodies in which this phenomenon is most strikingly exhibited, may be mentioned, decoction of the bark of the horse-chestnut, which contains the vegetable principle termed *esculin,* an alcoholic tincture of the green colouring matter of leaves, tincture of the seeds of stramonium, and tincture of turmeric. Many of these substances, when spread upon paper, form surfaces which, if used as a screen for receiving the solar spectrum, exhibit a prolongation of the more refrangible end far beyond the violet and lavender rays which are visible on ordinary white paper; and with due precaution the fixed lines of this prolongation may be distinctly seen.

A slip of ivory makes a very good screen for this purpose. Glass, coloured yellow with oxide of uranium, also exhibits these phenomena in a very striking and beautiful form.

The light of many artificial flames which are of feeble illuminating power often contains beams which exhibit this kind of reduction in refrangibility in a remarkable manner. The flame of a common spirit lamp, and that of burning sulphur, are especially remarkable. A weak infusion of horse-chestnut bark poured into a tall jar of water, exhibits, when illuminated by burning sulphur, beautiful waves of phosphorescent light as the two liquids mingle, owing to the dispersion of the light rendered visible by the esculin in solution. In the same way, characters traced with tincture of stramonium on white paper, and nearly invisible in daylight, when exposed to the light of burning sulphur, appear distinctly upon the paper in lines of a pale blue phosphorescent light.

These highly refrangible rays do not readily pass through glass. By employing a prism of quartz and lenses of the same material, Professor Stokes has found, in artificial lights, rays which extend far beyond the limits of the solar spectrum. The invisible rays in the solar spectrum, for example, extend beyond the violet extremity of the spectrum for a distance about equal in length to that of the luminous portion; but in the electric light obtained by the ignition of charcoal points, the invisible spectrum can be traced nearly six times as far. By interposing a coloured absorbent medium, such as chlorous acid gas, in the track of the beam before it is transmitted through the prism, fixed dark lines can be traced at different points through this greatly elongated spectrum.

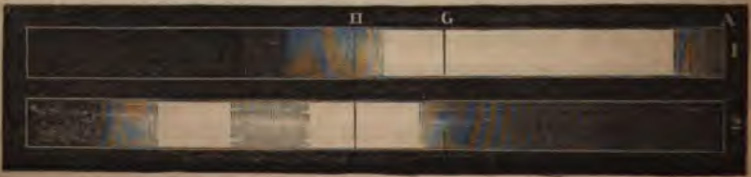
(105) Prismatic analysis of the solar beam, however, discloses to us other phenomena besides the separation of light into portions of different colours. The radiations from the sun contain not only luminiferous rays, but they are accompanied by a large amount of heat, and these rays of heat are susceptible of refraction, like those of light; though, as they are for the most part less refrangible than the rays of light, the calorific or heating rays are most abundant near the red end of the spectrum; and a large proportion of the rays of heat are less refrangible than any of the rays of light, and fall in the dark space beyond the red. Besides the rays of heat and light, the spectrum contains rays which exert a powerful chemical effect on growing plants, and on many metallic and other compounds; these occur in greatest abundance in the more refrangible portions, in and beyond the blue and violet rays.

The complex nature of the solar spectrum may be further illustrated by its action upon phosphorescent bodies.

(106) *Phosphorogenic Rays.*—A few chemical compounds are known which, although they do not, under ordinary circumstances, emit light in the dark, yet after exposure to the solar ray continue to be faintly luminous for some hours after having been removed to a darkened room, without undergoing any perceptible chemical change. Amongst these bodies may be mentioned *Canton's phosphorus*, or sulphide of calcium; *Baldwin's phosphorus*, or fused nitrate of lime; and *Bologna stone*, which is a sulphide of barium. If one of these phosphori, sulphide of calcium, for instance, after it has ceased to emit light in the dark, be sprinkled over a piece of paper and submitted to the action of the solar spectrum, phosphorescence will be produced in it, but by the more refrangible rays only. There are two maxima of illumination, one of which is within the blue and violet portion of the spectrum; the other is beyond the termination of the violet (fig. 66). The flash of an electric spark made to pass so that its light shall fall upon a piece of paper thus prepared, is sufficient to render the whole exposed surface of the sulphide phosphorescent. If, however, the paper be partially covered by a plate of the most transparent glass, the screened portion will not exhibit any phosphorescence. A screen of rock crystal, however, produces no such absorbent effect, all the portions of the prepared surface being in this latter case equally luminous. The light emitted from charcoal points, ignited by a voltaic current, if it be only instantaneous in duration, is equally unable to penetrate glass so as to produce phosphorescence, although it traverses rock crystal readily. The solar rays, however, traverse either medium equally, without loss of *phosphorogenic* power. A long continued voltaic light produces a similar result. Glass is only less perfectly permeable than rock crystal to the phosphorogenic rays that accompany the luminous ones.—(E. Becquerel, *Ann. de Chimie*, III., ix. 314.)

In fig. 66, the stripe 1 represents the diffusion of light in the

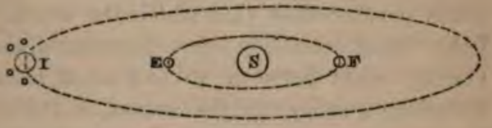
Fig. 66.



solar spectrum, whilst 2 gives the points of maximum phosphorescence corresponding to the luminous spectrum.

(107) *Velocity of Light.*—It is certain that light is the result of a series of progressive actions, since it requires time for its propagation. Astronomers have ascertained from observations on the eclipses or *occultations* of the satellites of Jupiter, the periods of which are accurately known, that these occultations appear to occur when the earth is situated at its greatest distance from that planet, as at F, fig. 67, about a quarter of an hour later than they do when nearest to it, as at E; consequently, between 15 and 16 minutes are required by light in traversing the width of the earth's orbit (a space of about 190,000,000 miles). Light would therefore describe a space equal to the circumference of the earth in about the eighth part of a second of time.

FIG. 67.



The velocity of light, however, appears to vary with the *medium*, or body through which it passes; in a denser medium its velocity is retarded, but in a medium of uniform density, if it travel in a uniform direction, its velocity is also uniform. It is remarkable that upon the hypothesis of emission, the velocity ought to be quickened in a denser medium, but on the undulatory view it should be retarded; the decision of this question, therefore, affords an *experimentum crucis* between the two theories.

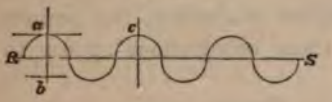
MM. Foucault (*Annales de Chimie et de Phys.*, III., xli. 129) and Fizeau, have, independently of each other, by a beautiful application of the revolving mirror suggested by Professor Wheatstone, each succeeded in solving this important question; by direct measurement they find that light is retarded in the denser medium; the relative velocity being inversely as the refracting indices of the media compared.

Whichever theory of light we adopt, the conclusions forced upon us of the exceeding minuteness of the magnitudes with which we are dealing, and the extraordinary rapidity of the motions which they imply, are of the most startling kind, conclusions that nothing but the completeness of mathematical demonstration, as confirmed by experimental research, would justify us in admitting.

(108) The undulatory hypothesis accounts for differences in the intensity of the light R S, by differences in the amplitude or

excursion *a b* of the undulation (fig. 68); and for the phenomena of colour by differences in the length *a c* and in the frequency of the undulations; just as in the phenomena of sound, the pitch of the note is proved to depend upon the number of vibrations in a given time: but the extent through which the ear appreciates proportionate differences of rapidity in the undulations which produce sound, is much greater than that which the eye can estimate in the case of light. Most persons can perceive musical sounds in which all possible variety exists between 16 and 2048 vibrations in a second, *i. e.*, including a range of eight octaves, in the highest of which the vibrations are 128 times more numerous than in the lowest. With light the range is much more limited, and extends not quite so far as from 1· to 1·75. The average length of a wave of white light is $\frac{1}{50000}$ inch; but the length of the wave, as well as its frequency, differs in the different colours; in red light it is longer, being about $\frac{1}{34000}$ of an inch, while in violet it is only $\frac{1}{60000}$. The number of vibrations is estimated at five hundred million millions per second (500,000000,000000) in white light; in red light at 482,000000,000000; and in violet light at as much as 707,000000,000000.

Fig. 68.



Interference.

(109) One of the simplest, and at the same time most beautiful proofs of the analogy in the mechanism by which sound and light are produced, is exhibited in the phenomena included under the term *interference*.

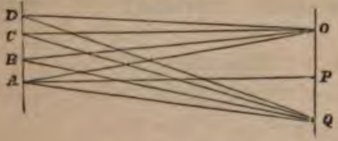
It is well known that when two stretched strings, not in unison with each other, are struck simultaneously, each gives its own note, and the compound sound produced, instead of gradually and uniformly dying away, is subject to a succession of alternate maxima and minima of intensity; the sound alternately dies away and revives several times in succession before it finally becomes inaudible; it thus produces what are termed *beats* in the notes. These beats are due to the interference with each other of the vibrations from the two strings. As one string is vibrating a little faster than the other, it must happen that the direction of the vibrations in the two strings at certain moments must coincide: at this point we have the maximum of sound; the periods of vibration will then gradually recede, and ultimately oppose each other and produce a momentary silence.

Again, when two equal impulses are given at a little distance from each other upon the surface of a still sheet of water, each becomes the centre of a system of waves, which ultimately cross each other, and alternately increase and diminish the effect of each other. For example: if in fig. 69 the concentric circles represent two equal systems of waves in water, setting out simultaneously, they will intersect each other; the length of the wave is in each system the same: where the crests of the waves coincide, the elevation will be doubled; but where the crest of one wave coincides with the depression of the other, the water will retain its level surface. These points will occur in regular succession, and form 'lines of double disturbance and no disturbance.' The lines of double disturbance, indicated in the diagram by the points where *the circles touch or cut each other*, occur at distances which differ by the *entire width* of one or more waves. The intermediate points, or points of no disturbance, are situated at distances from the centres differing by an odd number of *half waves;* the first will occur at the distance of half a wave; the second at a wave and a half; the third at two waves and a half, and so on. Now these phenomena of undulation in water and in air, have an exact counterpart in the case of light.

Fig. 69.

If a beam of light of one colour be admitted into a darkened room by two small apertures, such as pin-holes, placed very near each other, and the light which enters be allowed to fall upon a screen just beyond the point where the outermost rays of the two cones intersect each other, a spot of increased brightness is seen where the screen is intersected by a line at right angles to it, and which also bisects at right angles the line joining the two pin-holes; on either side of this bright spot will be a series of bands, alternately dark and light, although the dark bands as well as the bright spots are receiving the rays from both apertures. The addition of light to light has here produced darkness. Let O Q, fig. 70, represent the two pin-holes, and A B C D a section of the screen; let P A bisect the distance between the apertures at right angles, and fall vertically on the screen. If the spots A B C D each represent the centre of a bright band, O A, Q A, will be formed of rays the paths of which are equal; O B, Q B, will differ by the length of one wave; O C, Q C, by two waves; O D, Q D, by three waves; and the black bands between the bright ones will be formed by the interfering of rays, the paths of which differ in length successively by half a wave, a wave and a half, two waves and a half, &c.—(Lloyd's *Lectures on the Wave Theory of Light.*)

FIG. 70.



The length of the paths traversed by the rays from each aperture is equal in the central spot A, and the intensity of the light is therefore increased; as the path of the rays on either side of this becomes more or less oblique by regular increase or decrease, the lengths of those paths must necessarily be gradually and progressively augmented or diminished; consequently the number of undulations in each will be proportionately increased or diminished. When the lengths differ by entire undulations, a bright band results; when they differ by an odd number of half undulations, darkness ensues. Now as the inclination is progressive, there is necessarily a progressive passage from the brightest light to the most complete darkness: by intercepting the light from one aperture, all the dark bands disappear. The measurement of the breadth of one of these bands affords one means of determining the length of a wave of light of that particular colour, if the length of A P be known. Further, as the length of a wave of light differs in lights of different colour and refrangibility, being longest in the red or least refrangible, and shortest in the violet or most refrangible ones, the coloured bands are broadest in the red and narrowest in the violet; and if the experiment illustrated by fig. 70 be performed with white light instead of with light of one colour, the overlapping of the bands of the different colours produces a succession of iridescent or *coloured* bands, instead of mere alternations of light and darkness.

The phenomenon of interference is one of the most fundamental properties of light: it, indeed, takes place with common light under all circumstances; but the disturbing causes in ordinary cases exactly compensate each other, and it is only by intercepting part of a pencil of rays, so as to remove one-half of the compensating system, that the disturbance produced by the remaining half becomes manifest, as in the experiments just described. If upon a brilliant plane reflecting surface, such as a polished plate of steel, a number of very fine lines be traced at equal intervals, so that there may be from 1000 to 20,000 per inch, a surface is obtained which reflects a multitude of diverging cones of light, in consequence of the absence of reflection at regular intervals corresponding to the grooves; these cones of rays interfere at their edges without compensation, and a series of colours of the most brilliant tints is perceptible. A variety of natural objects owe the beautiful iridescent play of colours which they exhibit, to a structure of this kind: as is shown in the feathers of many birds. The hues of mother of pearl and other shelly structures are also due to their mode of formation in successive extremely thin laminæ, the edges of which form a series of grooves upon their surfaces and thus produce the phenomenon; impressions of these grooves may often be taken in sealing-wax or in fusible metal, and the same play of colours is then obtained in the impressions.

(110) *Colours of Thin Plates.*—A different set of colours, also dependent for their origin upon interference, are those termed the colours of *thin plates.* By dipping the mouth of a wine glass into a solution of soap in water, or still better, into gum-water, a bubble may be formed across it; if the glass be laid upon its side, the film becomes gradually thinner and thinner from the action of gravity, and if viewed by reflected light a series of iridescent tints is developed, increasing in brilliancy until the bubble becomes reduced to a state of extreme tenuity; it then appears black at the thinnest point, and speedily bursts. These colours are due to the interference of a part of the light which is reflected from the second surface of the film, with that which is reflected from the first surface. Any transparent object, such as glass, thin films of metallic oxides, mica, &c., if reduced to laminæ of sufficient thinness will produce the same effect. The particular colour is dependent on the thickness of the film. In tempering steel its surface becomes covered with a film of oxide, and the workmen judge of the heat by the colour produced; the higher the temperature which is applied the thicker does the film become.

The laws which regulate this phenomenon were traced with great ingenuity and success by Sir I. Newton. He placed a convex lens, of a very long radius of curvature, upon the flat surface of a plano-convex lens. Fig. 71 shows a section of both lenses, the curvature of which is much exaggerated. Around the point of contact the rings developed themselves with a black spot

FIG. 71.

FIG. 72.

in the centre, in an order dependent upon the thickness of the film of air included between the two plates (fig. 72). Knowing the convexity of the upper lens, he was able to calculate the thickness of the film required to produce any given tint. He thus found that there is a limit to the thickness of all transparent objects, beyond which they cease to be visible in reflected light, and another thickness above this, beyond which they reflect only white light: between these two points the phenomena which we are now considering take place. The thicknesses of these films vary with the nature of the reflecting plate, being in the inverse ratio of its refractive index. At and below the thickness of $\frac{1}{2000000}$ of an inch the film of air exhibits a black spot, and above $\frac{72}{1000000}$ it reflects white light. In water at $\frac{3}{8}$ of a millionth of an inch a black spot forms; above $\frac{58}{1000000}$ the reflected light is white. Glass produces the same result at all thicknesses below $\frac{1}{3000000}$ of an inch, and reflects white light at all thicknesses above $\frac{50}{1000000}$ of an inch.

The order of succession of the colours constitutes what is termed *Newton's scale*. Six or seven series of coloured bands may thus be distinctly traced. These rings when produced by homogeneous light appear alternately bright and black; the width of the ring is dependent upon the colour, and is greatest in the least refrangible light. The overlapping of the narrow rings by the broader ones in the mixed light of day, is thus, as in the case of the coloured bands produced by interference, the cause of the brilliant succession of colours.

A similar, but fainter series of colours, may be seen in the light that is transmitted through the film, but the tints are in this case complementary to those of the reflected rays. By increasing the obliquity of the incident rays, the breadth of the rays is increased in both transmitted and reflected light. The tints of the transmitted rays are much paler than those seen by reflection; they are produced by the interference of a portion of light twice reflected within the plate, with the beam directly transmitted.

In fig. 73, I R represents a beam of light incident upon the film, F F; part of the light, R Y, is reflected, and part, R S T, transmitted; at S, the second surface of the film, a portion of the light is again partially reflected to U; at U part is transmitted,

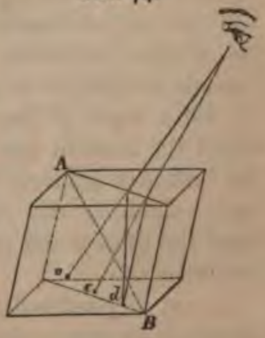
Fig. 73.

and interferes with the reflected portion, U X, of the beam K U, which falls upon the upper surface of the film at the spot where S U emerges. Now, since the lengths of the paths of the rays, I R S U, and K U differ by a fraction of an undulation, owing to the refraction and reflection of the portion R S U within the film, interference between the two rays results, and colours are produced in the reflected beam; in addition to this action, a part, U V W, of the beam, I R, is a second time reflected, and passing out on the lower surface of the film, interferes with the portion of K U, which is directly transmitted, and thus the colours in the transmitted light are occasioned. The dotted line, V Z, represents the track which is taken by the portion of the ray K U V, which undergoes reflection from the internal lower surface of the film.

Double Refraction—Polarization.

(111) *Double Refraction.*—The law of refraction (97), which is true for water, for glass, and for other homogeneous uncrystallized media, does not extend to all transparent bodies. In all transparent crystals, excepting those belonging to the regular system, the refracted ray is subdivided into two portions, and hence such bodies are said to possess the property of *double refraction.*

Fig. 74.



This remarkable action upon light is best exhibited in the transparent crystallized variety of carbonate of lime, known as *Iceland spar*. Place upon a dot, *d*, made upon a sheet of white paper a rhombohedron of Iceland spar, as A B, fig. 74, and look down upon the dot through two of the parallel faces of the rhomb: two images, *o*, *e*, of the dot will be seen instead of a single one; and if the crystal be turned round upon the paper, keeping the eye steadily fixed, one of the images will appear to rotate round the other which preserves its fixed position. The line which joins the two images of the dot is, under all circumstances, parallel to the diagonal, A B, connecting the two obtuse angles of the crystal: around this line the different parts of the crystal are symmetrically arranged. Upon varying the obliquity of the incident ray upon the surface, it is found that the refracted ray which was stationary during the movement of rotation, preserves the constant ratio of the sines, and, as in ordinary cases of refraction, falls always in the plane of the incident ray, whilst in the other ray the ratio of the sines varies at different obliquities of the incident ray; and, excepting in two positions of the crystal, this refracted ray never occurs in the plane of incidence. One of the refracted rays follows nearly the usual law of refraction, and is hence termed the *ordinary* ray; while the other follows a different law, and is called the *extraordinary* ray. There is one remarkable direction in the crystal, in which this splitting of the ray does not take place, a direction parallel to the line which connects the two obtuse angles of the rhombohedron; this line is called the *optic axis* of the crystal. To render this obvious, a slice of the mineral may be cut in a direction perpendicular to the optic axis, *a b*, fig. 75; it will be found on looking at a minute object perpendicularly through such a plate, that a single image of it only will be seen. In all other positions, a double image will be visible. The separation of the two images increases with the obliquity of the incident light to the optic axis, until, when at right angles to it, it attains its maximum. The point at which the difference between the two rays attains its maximum, is selected for determining the index of refraction for the extraordinary ray. In the case of Iceland spar, the extraordinary ray is refracted less powerfully than the ordinary ray; such crystals are termed *negative* doubly refracting crystals. Instances however are not wanting in which the extraordinary ray undergoes the greater refraction of the two, as in quartz and ice. Such crystals are said to be *positive* or *attractive*.

FIG. 75.

Both rays, if they emerge from a surface parallel to that on which the incident ray entered, are parallel to each other; but if the surface be inclined, both rays proceed with increasing divergence, each exhibiting the colours of the prismatic spectrum. In all cases the thicker the crystal the greater is the separation of the two images.

(112) Crystallized substances may be divided into two classes, according to their action upon light; and their optical properties are intimately related to their crystalline form. Thus we have:—

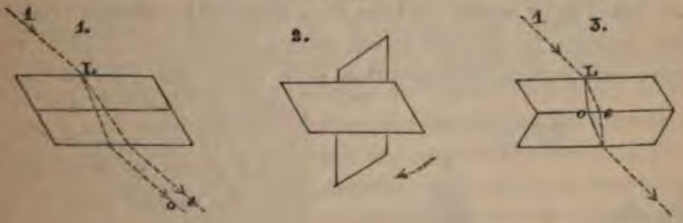
1. Singly refracting crystals:—These all belong to the regular system.

2. Doubly refracting crystals:—These may be subdivided into two classes. The *first* sub-class, like Iceland spar, presents only one optic axis in which no double refraction occurs, and it includes all crystals of the rhombohedral and right square prismatic systems; such crystals are termed *uniaxal*. The *second*, of which aragonite and nitre are examples, comprises all crystals of the three remaining systems,—namely, the right rectangular, the oblique prismatic, and the doubly oblique prismatic systems: they have two optic axes, which, however, do not coincide with any of the crystalline axes, but occur in resultant directions between them. Such crystals are said to be *biaxal*.

In biaxal crystals, both the doubly refracted rays obey extraordinary laws of refraction.

(113) *Polarization.*—Light that has been transmitted through a doubly refracting prism, has undergone a remarkable modification. If received upon a second crystal of Iceland spar of equal thickness, placed in a similar position to the first (fig. 76, 1), both rays pass through it unchanged, except that they are separated further from each other in proportion to the thickness of the crystal, but the extraordinary ray will still be refracted extraordinarily, and the ordinary ray ordinarily; the *principal sections*[*] of the two crystals are parallel. On causing the second plate to describe a quarter of a revolution, so that the principal sections shall be at right angles, as shown at 2, still but two images will be seen; but now the ordinary ray is refracted extraordinarily, the extraordinary ray is refracted ordinarily. When the second crystal describes

FIG. 76.



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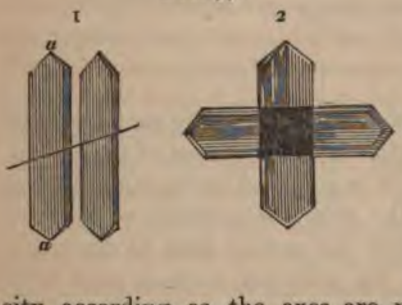
[*] In uniaxal crystals a *principal section* is a plane which passes parallel to the optic axis, and perpendicular to any face of the crystal, natural or artificial, upon which the light is incident.

another quarter of a revolution as at 3, only one image is visible, the rays separated by the first are reunited by the second; in all other intermediate positions, each ray is doubly refracted, and four images become visible: the intensity of the images taken together is constant, one pair fading as the other increases in brightness, and *vice versâ*. Each ray, therefore, on emerging from a crystal of calcareous spar, has acquired new properties; it is no longer subject to further subdivision by a second crystal when placed in particular positions. The rays in fact appear to have acquired sides, and to have new relations to certain planes within the crystal; such rays are said to be *polarized*.

Many crystals when cut into plates parallel with their axis, allow light to pass through them, which on emerging is found to be similarly affected; some kinds of tourmaline exhibit this phenomenon in a very marked manner. Tourmaline is a doubly refracting crystal, through which the extraordinary ray alone passes, the ordinary ray being absorbed. If a plate of this mineral, cut from a brown or green specimen, parallel to its axis, *a a*, (fig. 77, 1), be placed between the eye and a candle, a considerable portion of light will traverse the plate, and the amount of light will be in no way affected on turning the plate round in its own plane; but if light which has been thus transmitted through one plate of this mineral, be allowed to fall upon a second similar plate, it will traverse this without interruption only when the axes of the two plates are parallel (fig. 77, 1); but it will be completely interrupted where the plates overlap, when the second plate is made to describe a quarter of a rotation in its own plane (2); the axes of the two plates are then at right angles to each other: in all intermediate positions, light will be transmitted with greater or with less intensity, according as the axes are nearer to the parallel, or to the perpendicular directions.

FIG. 77.



If the two pencils emerging from a rhomb of Iceland spar be examined by means of a plate of tourmaline, it will be found that the ordinary image is most intense when the axis of the tourmaline is perpendicular to the principal section of the rhombohedron, and that it is extinguished when the axis of the tourmaline is parallel to the principal section, whilst the opposite results occur with the extraordinary ray. Both rays are therefore polarized, but under different circumstances.

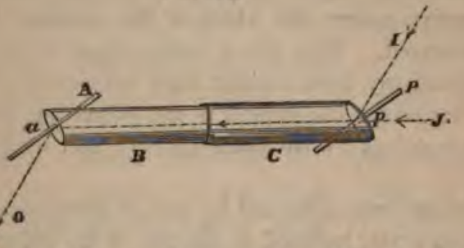
(114) Polarization may also be effected by means of reflection. Whenever light is reflected from the surface of a transparent medium, a certain portion of such light undergoes this remarkable change; and at a particular angle, varying with each medium according to its refractive power, the whole of the incident light that is reflected is polarized. This effect takes place when the reflected and the refracted ray form a right angle with each other: the higher the refracting power the greater is the polarizing angle: with glass this angle is 56° 45′, with water 53° 11′, and with Iceland spar 58° 51′.

When light which has been polarized by any of these means is examined by a reflecting plate, inclined to the ray at the polarizing angle, other remarkable properties are observed. Common light will be reflected indifferently, whether the reflecting plate be placed above or below the ray, to the right or to the left of it, though the inclination of the plate to the ray continue to be the same. It is not so with polarized light: suppose a beam thus affected to fall upon any transparent reflector inclined to the ray at the polarizing angle; if the light be completely reflected when the mirror is placed below the ray, it will not be reflected at all but be wholly transmitted when the plate is placed on either side, and when placed above it will again be wholly reflected; at intermediate points part will be reflected and the remainder transmitted; the proportion which is reflected is greater the more nearly the plane of the second reflection coincides with that of the first, the light being wholly transmitted when the two are at right angles to each other.

FIG. 78.

These facts admit of easy experimental proof. Provide two tubes, B C (fig. 78), which are fitted so as to allow of their being turned round one within the other. Fasten obliquely to the end of each tube a flat transparent plate of glass, P, A, so as to form an angle of 56° 45′ between the line *p a*, and a perpendicular to the point at which *p a* falls upon the surface of each plate. The tube B, with its attached plate A, can now be turned round on the tube C, without altering the inclination of the plate to a ray passing along the axis of the two tubes, but the plate A, according to its position will reflect the ray upwards or downwards, to the right or to the left. We can therefore alter the plane in which the reflection is produced without altering the angle of the reflector to the ray. If the light be common light, such as that from a candle placed as at J, no matter whether the plate A be placed below the ray as in fig. 78, or above it as in fig. 79, or to the right or to the left, an observer placed in the direction which the reflected ray, O, would follow, would see the candle distinctly: but the case would be different if the candle were placed as at I, where the light would be reflected from the plate P, along the axis of the tubes; by reflection at this particular angle it would be polarized. So long as the plate A retains the position represented in fig. 78, the reflected ray would fall in the same plane as that in which polarization took place, and the candle would be seen by an observer stationed in the direction of the reflected ray. But suppose the tube B to be turned slowly round the ray; by following the image as the tube is turned, the light of the candle will be seen gradually to become fainter and fainter, until, when the tube has been turned a quarter of the way round, it will be almost invisible; the plane of reflection is now at right angles to that of polarization, and the light which falls upon A is almost wholly transmitted; on turning it further, the light again becomes more and more distinct, till, when the tube has been turned half round, the candle is seen as brightly as at first; the plane of reflection again coincides with that of polarization; if it be turned still further, at the third quadrant the light again disappears, until, on completing the revolution, it is as distinctly visible as at first.

FIG. 79.



The plane of reflection in which the polarization was produced, is called the *plane of polarization*. The original plane of polarization may be easily ascertained in a ray, by whatever means it may have been polarized, as it is always at right angles to the plane of extinction. In this manner it is proved not only that the doubly refracted rays transmitted by Iceland spar are each polarized, but that they are polarized in planes at right angles to each other, the ordinary ray being polarized in the plane of emergence: in the case of tourmaline, it is found that the emergent ray is polarized in a plane perpendicular to the axis of the crystal.

When the condition of polarization has once been impressed upon a beam of light, it continues to be permanent, whether the subsequent course of the ray be long or short, provided it continue in a homogeneous medium.

(115) *Distinction between Common and Polarized Light.*—Every beam of *common light* appears to consist of a rapid succession of systems of waves, each system undulating in a determinate plane, always at right angles to the direction pursued by the ray, but the inclination of this plane in one system varies at all possible angles with the plane of vibration in the preceding and succeeding systems. As a resultant of these various motions, common light may be regarded as composed of two beams of light which are vibrating in planes at right angles to each other. *Polarized light* differs from ordinary light in being produced by vibrations in a single plane only, that plane being coincident with the plane of polarization; 'and the phenomenon of polarization consists simply of the resolution of the vibrations of common light into two sets, in two rectangular directions, and the subsequent separation of the two systems of waves thus produced' (Lloyd, *op. cit.* part ii. p. 29). The effect of a crystal of Iceland spar upon common light will be best understood by considering its action upon a beam which has been already polarized. When a beam of light polarized in any given plane falls upon a crystal of Iceland spar, it is split into two portions, the intensity of which varies with the inclination of the plane of polarization to the principal section of the crystal, one beam vanishing altogether when the other is at a maximum. Now common light consists of successive systems of waves, each system during the minute fraction of a second, which forms the period of its duration, being in the condition of a polarized beam; for its vibrations occur in one definite plane. When the undulations belonging to one of these systems fall upon the spar, they are divided into two pencils of unequal intensity, but owing to the extremely brief duration of each system, the pencils produced by several hundred of these systems in succession are *simultaneously* (so far as the eye can perceive) thrown upon the same spot; the greater intensity of the light produced by some of these systems compensates for the feebler intensity of others, and the resultant effect is the

production of two beams which are of equal intensity whatever be the position of the spar. The result of the analysis is the same as that which would have been yielded by a compound ray, consisting of two other rays polarized in planes at right angles to each other, one plane coinciding with the principal section of the crystal, and the other being at right angles to it.

Since the vibrations of a polarized ray always occur in the same plane, we may, with the assistance of a rude illustration, form some idea of the reason why it appears to be possessed of sides. If we imagine the reflecting surface to be made up of a series of parallel fibres lying only in one direction, these fibres would allow the passage of all the rays in common light which undulate in a plane parallel to their direction, and would reflect the rest; whilst polarized light, if undulating in a plane parallel to the fibres, would be wholly transmitted; but if its undulations were in a plane at right angles to the fibres it would be wholly reflected.

FIG. 80.

(116) Light may also be polarized at other angles by a series of successive reflections from several plates; a pile of glass plates, as shown at fig. 80, is often made use of for this purpose: the light polarized by reflection is always equal in quantity to that which is polarized by transmission, and it is polarized in a plane at right angles to it.

(117) In all cases where a polarized beam is received on a reflecting or *analysing* surface, the plane of reflection of which does not coincide with the plane of polarization, the plane of polarization becomes changed. The rotation of the plane of polarization is always towards that of reflection, and the amount of this rotation depends upon the angle of incidence which the ray forms with the analysing plate. If the light be incident upon the analysing plate at the polarizing angle, the plane of polarization is brought to coincide with that of reflection: but the rotation of the plane of polarization is less in proportion as the angle of incidence differs more from the polarizing angle: a corresponding alteration in the plane of polarization is effected by refraction, but in an opposite direction.

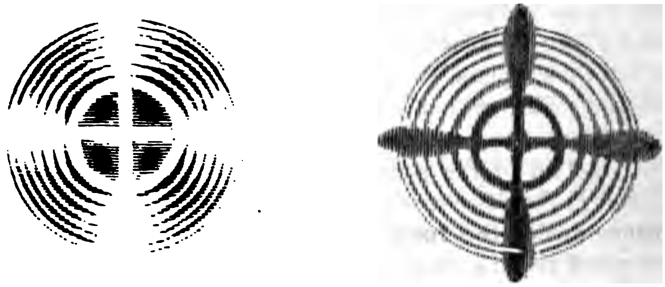
(118) *Colours of Polarized Light.*—When a beam of polarized light is transmitted in particular directions through plates of doubly refracting bodies, a series of splendid phenomena are observed, dependent upon the production of colours which vary with the circumstances of the experiment. The simplest method of rendering these

colours visible consists in adjusting two reflectors, so that the image polarized by reflection from the first may be extinguished in the second. The first is called the *polarizing*, the second the *analysing plate*. By introducing a thin plate of any doubly refracting substance, such as mica, quartz, or sulphate of lime, cut parallel to the optic axis, the image suddenly reappears in the analysing plate, but it is tinged of a particular colour. If while the ray falls perpendicularly on the interposed plate, the plate be turned round in its own plane, two positions will occur in which the image completely disappears; these positions are at right angles to each other. In one, the principal section of the plate coincides with the plane of polarization, and in the other it is perpendicular to it. The colour does not change during this rotation, but only varies in intensity. But if the crystal remain fixed, and the analysing plate be made to rotate, the colour will pass through every grade of the same tint, into the complementary colour, and at each succeeding quadrant the hue is exactly complementary to that which was exhibited in the preceding one. This remarkable phenomenon is most distinctly seen by substituting a rhombohedron of calcareous spar for the analysing plate, so as to obtain two images of the polarized beam; on turning the spar round, the two images will be seen tinged of complementary hues in all parts of the revolution; and if the two images be allowed to overlap a little, the overlapping portions will in all positions be white. By varying the thickness of the interposed crystalline laminæ, the tints will vary according to the thickness, and the succession of tints will follow the same order as in Newton's rings, so that when the laminæ exceed a certain thickness the light is white. The production of these colours is not confined to crystallized minerals, but they are obtainable in a less degree with substances of animal origin, such as quill, horn, or membrane.

(119) If the crystallized plate interposed between the polarizing and analysing surfaces be cut *perpendicular* to the optic axis of a uniaxal crystal, the transmitted ray will still be coloured, but the phenomenon is different, and still more beautiful. A series of coloured rings will be observed, intersected by a cross, which in one position of the analysing plate will be white (fig. 81, 1); on rotating the analyser through an arc of 90°, the white cross will be succeeded by a black one (fig. 81, 2), and the rings of colours will exhibit tints complementary to those before observed; at the next quadrant the colours of the first reappear, whilst at the succeeding quadrant they are again complementary.

Rotation of the crystal on its own axis produces no change in the tints or in the position of the cross.

FIG. 81.

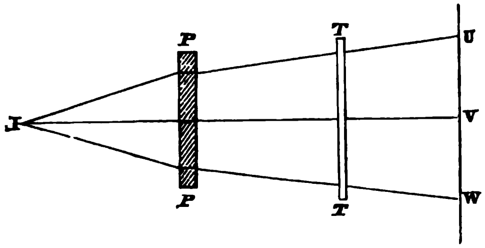


1

2

The general explanation of these facts is not difficult:—

FIG. 82.



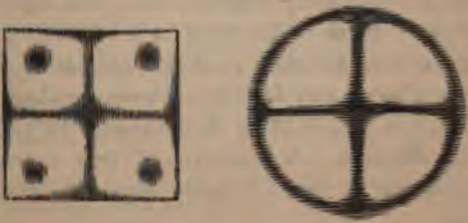
If P P (fig. 82) be a section of the interposed plate, I the diverging polarized beam, T T the tourmaline, U V W a section of the screen on which the image is received, it is obvious that the rays, I V, which traverse the plate P P, parallel to the optic axis, will suffer no change; but all the lateral rays, I U, I W, which fall upon P P more or less obliquely according to their distance from the line I V, will be doubly refracted in opposite planes; one of these rays will thus be retarded upon the other, and as soon as they are brought into the same plane by the action of the analysing tourmaline, they interfere, and give rise to the brilliant colours which are observed. The formation of the cross is occasioned by the absence of any change in the plane of polarization of those rays which traverse the principal section of the crystal which either coincides with the plane of polarization, or is perpendicular to it; these rays consequently do not interfere when analysed by the tourmaline. The arms of the cross are alternately white or black, according as the axis of the tourmaline is parallel to the original plane of polarization, or is at right angles to it.

ith biaxal crystals, such as aragonite, carbonate of lead, and borax, the phenomena are even more beautiful, a double of rings being formed, in which the curves are of a nt order, owing to the more complicated phenomena ng from the mutual action of the optic axes; the surface of tion being oblique to both these axes; the greater the angle l with each other by the axes, the further will the rings be er. The two axes are inclined to each other in nitre at an angle 20′; in aragonite at an angle of 18° 18′; in borax at an angle °; and in topaz the angle is between 49° and 50°: the n of the intersecting cross varies when the crystalline plate is to rotate; and the colours become complementary when the er is turned round. The general outline of these figures is ented fig. 83.

FIG. 83.

peculiarly interesting connexion has been established en these phenomena and the state of molecular tension in lid, by the discovery that these appearances may at will be ced in uncrystallized media, such as glass, or in regular ls, whenever homogeneity is interfered with in regular pro- on. This fact is rendered evident by the application of pressure lly to a strip of glass, which previously exerted no doubly tive influence. The parts compressed acquire a negative double tion, separated by a neutral line, where the particles of the retain their nor- condition, from on the opposite which have be- dilated, and show ve double refrac- This want of geneity exists nently in glass has been im-

FIG. 84.

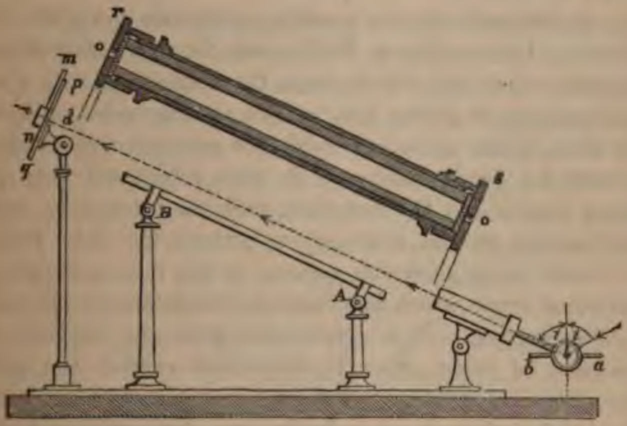


perfectly annealed, and according to the form given to it by grinding, it is possible to alter the tension of the particles in different directions, and produce the phenomena of uniaxal or biaxal crystals; thus a square, or a circular plate, belongs to the uniaxal system (as shown in fig. 84), while an elliptic plate occasions rings referable to the biaxal form.

(120) *Coloured Circular Polarization.*—There are, however, cases in which the plane of polarization of the ray is continually changing during its entire progress: in some substances it revolves from left to right (like the hands of a clock); in others from right to left. Rock crystal is the substance in which this effect was first observed. If through a plate of rock crystal, cut perpendicular to its axis, a polarized ray be transmitted, the plane of polarization undergoes rotation in a degree proportioned to the thickness of the plate. The amount of this rotation differs for each colour, and increases according to the increase of the refrangibility of the ray. If the incident light be white, the emerging light, when examined by an analysing plate, is therefore seen to be coloured. The central portion only of the pencil of light (which traverses the axis of the crystalline plate vertically) exhibits these phenomena; at oblique incidences, the usual law of interference prevails, and coloured rings are formed. In left-handed quartz the central colours ascend in the scale, when the analyser is turned in the direction of the hands of a watch, the succession being red, orange, yellow, green, &c., and the rings appear to expand with the revolution of the analyser. When homogeneous light is employed, each colour disappears at a particular angle of the analyser. In crystals of quartz, in which the secondary planes of the crystal are arranged differently from those of the left-handed variety, the same phenomena occur, but in the opposite direction. There are also some liquids which produce similar effects. Solution of sugar-candy, for example, gives a left-handed rotation; oil of lemons does so likewise. Certain varieties of oil of turpentine produce a right-handed rotation. In all these cases the degree of the rotation effected by liquids is much less than that produced by quartz; and, consequently, the light must traverse a much greater depth of the fluid to produce the effect. Turpentine has a power not exceeding $\frac{1}{72}$ of that of quartz. Dilution with an inactive liquid does not destroy or even weaken the power, provided the depth of the column be increased in proportion to the extent of the dilution. A mixture of two substances acting oppositely produces a result exactly equal to the difference between the two.

M. Biot, who discovered the phenomenon of circular polarization, has applied it to chemical purposes. It may be used, for example, to ascertain the purity of syrups; crystallizable cane sugar causes a left-handed rotation, while the molasses, or uncrystallizable syrup, rotates the ray to the right. The observation is, however, too delicate to admit of practical application to the purposes of the refiner. In order to measure the extent of the rotation, the solution for trial is placed in a long glass tube shown at o o (fig 85), closed at the two ends by flat plates of glass. This tube is placed within a metal tube, *r s*, for the purpose of excluding stray light. A beam of homogeneous light, obtained by transmission through red glass, is polarized by reflection from the mirror *a b*. A Nicol's prism,* or other polarizing eye-piece, *n*, is so mounted as to admit of rotation around the line *d i*; this eye-piece is provided with a vernier, *m*, which traverses a circle, *p q*, divided to degrees,

FIG. 85.



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* Nicol's prism is a convenient means of obtaining a polarized beam, depending upon the principle of total reflection (99). It is prepared in the following manner: A long rhomboidal prism of Iceland spar is divided in half by a plane perpendicular to the plane of the longer diagonal of the base; the line of section passing through the opposite obtuse solid angles of the prism, so as to divide it obliquely into two equal portions; the two halves of the prism are then re-united by means of Canada balsam. When light is transmitted through the prism parallel to its length, the incident light falls very obliquely upon the layer of Canada balsam, and as the balsam has a smaller refractive index than the ordinary ray, this ray experiences total reflection, whilst the extraordinary ray alone is transmitted, because the refractive index of the balsam being greater than that of the extraordinary ray, total reflection does not occur in its case.

for the purpose of measuring the angular rotation of the eye-piece. The eye-piece is then so adjusted, that when the polarized beam becomes no longer visible, the vernier stands at 0°. Now, if the tube, o o, full of solution, be placed on the supports, A, B, so that it shall be traversed by the reflected ray, *i d*, light becomes visible to the observer at *n*; but on rotating the eye-piece (to the right or to the left, according to the nature of the solution) the image again disappears; the amount of the movement to the right or to the left expresses the amount of rotatory power exerted by the liquid under the circumstances.

An experienced observer usually substitutes the white light of day for that of the red glass. In this case the zero is first adjusted to a particular violet tint, which, from the suddenness with which by a slight rotation it passes into red on the one side, or into blue on the other, is the most favourable for accurate observation. The tube, with its liquid contents, is then interposed between the polarizing mirror and the eye-piece, and the rotation is estimated by the angular motion necessary to restore the violet tint. Dr. Bence Jones has applied this process to the determination of the proportion of sugar which has escaped fermentation in the different wines of commerce. It is remarkable that the vapours of turpentine and of some other liquids which exhibit the power of circular polarization, display the phenomenon when seen through very long tubes, though more feebly than the liquids themselves.

(121) Dr. Faraday has discovered a new modification of this peculiar form of polarization which homogeneous transparent solids and liquids assume, with various degrees of intensity, when subjected to magnetic power of very exalted degree. Some of these singular results will be more particularly described at a future point (272).

The study of the chemical effects of light will be postponed until after the chemical properties of the elementary bodies have been described.

CHAPTER V.

HEAT.

§ I. *Expansion—Measurement of Heat.* § II. *Means of Maintaining Equilibrium of Temperature.* § III. *Heat of Composition.*

(122) Upon the due understanding of the principles and applications of heat, much of the successful prosecution of chemical research depends. There is scarcely a chemical operation in which heat is not either emitted, absorbed, or purposely applied to produce the required result. Heat in one mode of its manifestation presents the closest analogy with light, which it very generally accompanies. In this condition it is known as radiant heat; and it is in this form that the main supply of heat is transmitted from the sun to the surface of the earth.

It is, however, after heat has fallen upon the surface of an object and has become absorbed, that its most important effects are manifested. It is only then that the sensation of warmth is experienced; then it is that expansion takes place in the heated body; and it is then only that the phenomena of liquefaction or of evaporation may ensue. Heat may also, after its absorption, be again transmitted from the heated body, by secondary radiation, to other objects around, or it can be propagated more slowly by conduction from particle to particle through the mass.

Heat likewise is susceptible of entering for a time into the composition of a body, and of altering its physical state. When a solid becomes liquid, it unites for the time with a quantity of heat, which is perfectly definite; for instance, a pound of ice in undergoing liquefaction, always requires a uniform quantity of heat to produce this effect; the water obtained appears no warmer than the ice; and the heat, though it for a time ceases to affect the senses, is not lost, but is again given out when the water passes back into the state of ice. The heat which disappears in liquefaction is said to have become latent; and it again becomes sensible as the solid condition is resumed.

In considering the relations of heat, the subject may therefore naturally be subdivided into three sections:—

The first of these embraces the phenomena of *expansion,* and

their application to the measurement of temperatu
principles of the thermometer and the pyrometer:
to the modes in which the *equilibrium of temperat*
or restored—viz., by conduction, by convection, a
and the third relates to *heat in combination*, includ
the processes of congelation and liquefaction, and t
and evaporation.

Before passing to the immediate consideration o
it will be advantageous briefly to review the princip
command for procuring a supply of the heat by ar

(123) *Sources of Heat.*—(*a*) The sun obviou
main supply of warmth to the globe, but there
sources whence it may be procured.

(*b*) *Friction* is one of these sources. It is rem
supply of heat from this source is apparently un
savage nations employ the friction of two pieces
means of obtaining fire; and it is known among ou
axles of wheels, and other parts of machinery e
motion combined with pressure, are liable to b
heated as to char or ignite the woodwork in t
vicinity.

In order to obtain some idea of the amount of
by friction, the following experiments were instit
Rumford (*Phil. Trans.*, 1798, p. 80):—A brass ca
113 lb., was made to revolve horizontally with a pr
10,000 lb. against a blunt steel borer at the rate
revolutions per minute; in half an hour the temp
metal had risen from 60° to 130°; this heat wo
sufficient to have raised 5 lb. of water from 32° t
experiment was subsequently varied by placing the
vessel of water, and friction was again applied; in th
of water at 60° were actually made to boil in 2½ hou
thus obtained was calculated by Count Rumford to
greater than that given out during the same period b
of nine wax candles each ¾ inch in diameter.

One of the most curious proofs of the extricatio
friction was afforded by an experiment of Sir H. Dav
two pieces of ice, made to rub against each other i
temperature below 32°, were melted by the heat dev
surfaces of contact.

The experiments of Mr. Joule (*Phil. Trans.*, 1
appear to show that the actual quantity of heat

friction is dependent simply upon the amount of force expended, without regard to the nature of the substances rubbed together. He found, as a mean of forty closely concordant experiments, that when water was agitated by means of a horizontal brass paddle-wheel, made to revolve by the descent of a known weight, the temperature of 1 lb. of water was raised 1° F. by the expenditure of an amount of force sufficient to raise 772 lb. to the height of one foot. When cast-iron was rubbed against iron, the force required to raise 1 lb. of water 1° F. was found, as a mean of twenty experiments, to be about 775 lb.; and by the agitation of mercury by means of an iron paddle-wheel it was found to be 774 lb.

(*c*) Percussion, which is a combination of friction and compression, is a method of eliciting heat which is frequently practised, as is seen in the use of the common steel and flint, where the compression extricates heat enough to set fire to the detached portions of steel. It is not an uncommon practice among blacksmiths, to show their agility and dexterity by hammering a piece of cold iron on the anvil until it becomes red-hot from the heat extricated by compression. It is, however, remarkable that iron once heated in this way cannot again be made red-hot by hammering until it has been again heated in the forge. Many other similar instances might be adduced: in the rolling of brass and of copper, the bars, as they issue from the rollers, between which they have been subjected to enormous pressure, become much heated, although they were quite cold when they entered the rolling-mill.

(*d*) Another source usually resorted to for procuring heat artificially is chemical action. Whenever this occurs with high intensity, heat is evolved, and it is very generally accompanied by extrication of light, of which our common fires afford the best practical illustration. The chemical actions which are constantly going on in the animal economy are also never-ceasing sources of a regulated emission of heat, and they differ only from those of the furnace in the more moderate and subdued amount of heat emitted in a given time and in a given space.

(*e*) Accumulated electricity is another source of intense heat.

(*f*) In addition to the above-mentioned sources of heat, M. Pouillet (*Ann. de Chimie*, II. xxvi. 141) has shown that the simple act of moistening any dry substance is attended with slight yet constant disengagement of heat. With bodies of mineral origin, when reduced to a fine powder with a view of increasing the extent of surface, the rise of temperature does not exceed from half a degree to 2° F.; but with some vegetable and animal

substances, such as cotton, thread, hair, wool, ivory, a
paper, a rise of temperature varying from 2° to even
has been observed.

(124) The effect of a hot or of a cold substance u
sations enables us to distinguish the one from the ot
impression thus produced is only comparative, and aff
criterion of the amount of heat, the sensation produ
ferable to the temperature of that part of the body t
applied at the particular moment. Heat and cold
merely relative terms; cold implying not a negativ
tagonistic to heat, but simply the absence of heat in
less degree. It is singular that intense cold produ
sensation as intense heat, and a freezing mixture, as w
water, will blister the part to which it is applied.

§ I. Expansion—measurement of temperat

(125) *Difference between Heat and Temperature.*-
duces no alteration in the weights of bodies; conse
balance cannot be employed as a measure of its a
bodies, however, when heated, acquire an increase i
return to their original dimensions in cooling, and
of the amount of expansion is universally employed
sure of temperature. It is necessary to draw a distincti
the terms *heat* and *temperature*, which are applied to i
different things. By the term heat is meant, in philos
guage, the power, whatever it be, which excites in us th
of warmth: by temperature is meant the energy with
heat in a body tends to transfer itself to other bodies.
words, the temperature of a body is that modification of
is perceptible to the senses or can be measured by th
meter. Where two or more masses of matter, of the s
different kinds, such as mercury, oil, water, or spirit of
brought into contact with a thermometer, cause the merc
it contains to stand at the same point, they are said t
same temperature. The temperature of a body afford
cation of the actual quantity of heat which it con
pint of spring water may raise a thermometer to
degree as a gallon of the same water; but it is obviou
larger quantity of the liquid contains the greater amoun
Again, suppose a thermometer to stand in water at 5
instance, and at 100° in another, in equal quantities of the

would be a mistake to suppose that in the latter case the water was twice as hot as in the former. The zero of the thermometer scale is entirely arbitrary, and does not indicate the entire absence of heat, which may be abstracted continuously from bodies even though they may have been already cooled to 0°.

(126) *Expansion of Solids.*—Solids, as might be expected from the exertion of cohesion among their particles, expand less for equal elevations of temperature than either liquids or gases. Solids generally expand uniformly in all directions, and on cooling return to their original shape. Lead, however, is so soft that its particles slide over each other in the act of expansion, and do not return to their original position. A leaden pipe used for conveying steam, permanently lengthens some inches in a short time (Graham), and the leaden flooring of a sink which often receives hot water becomes, in the course of use, thrown up into ridges and puckers.

Mitscherlich (*Poggendorff, Ann.* x. 137) has discovered that all those crystals which possess a doubly refracting action upon light, expand unequally in different directions when heated. The shape of a crystal of calcareous spar, for instance, is slightly altered when heated: the obtuse angles become more acute, and the inclination of the faces of the crystal to each other becomes altered 8½′ by an elevation of temperature from 32° to 212° F. The crystal elongates most in the direction of the optic axis, and indeed it actually contracts at the same time in directions at right angles to this. Such crystals, however, form no exception to the general rule that the bulk of bodies is increased by heat. It has been ascertained, for instance, that a crystal of calc spar increases in bulk between 32° and 212°, to the extent of 1 part in 510.

Different solids expand very unequally for equal additions of heat: zinc, for example, dilates much more than iron, and iron more than glass. The total expansion of a body may be obtained very nearly by multiplying the linear expansion (or expansion in length) by three. The following table gives some measurements of the expansion both in length and bulk which is experienced by various solid bodies.

Expansion of Solids.

1,000,000 parts at 32° F.	At 212° F. become,	Expansion.		Authority.
		In length.	In bulk.	
English Flint Glass	1·000,811	1 in 1248	1 in 316	Lav. & Laplace
Glass tube (French)	1·000,861	1 in 1148	1 in 382	Dulong and Petit
Platinum	1·000,884	1 in 1131	1 in 377	
Palladium	1·001,000	1 in 1000	1 in 333	Wollaston
Tempered Steel . .	1·001,079	1 in 926	1 in 309	Lav. and Lapl.
Antimony	1·001,083	1 in 923	1 in 307	Smeaton
Iron	1·001,182	1 in 846	1 in 282	Dulong & Petit
Bismuth	1·001,392	1 in 718	1 in 239	Smeaton
Gold	1·001,466	1 in 682	1 in 227	Lavoisier and Laplace
Copper	1·001,718	1 in 582	1 in 194	
Brass	1·001,866	1 in 536	1 in 179	
Silver	1·001,909	1 in 524	1 in 175	
Tin	1·001,937	1 in 516	1 in 172	
Lead	1·002,848	1 in 351	1 in 117	
Zinc	1·002,942	1 in 340	1 in 113	Smeaton

The addition of heat beyond a certain point overcomes the cohesion of the solid, and it assumes the liquid form. The quantity of heat required to effect this varies greatly with the nature of the substance; some solids melting at a much lower temperature than others.

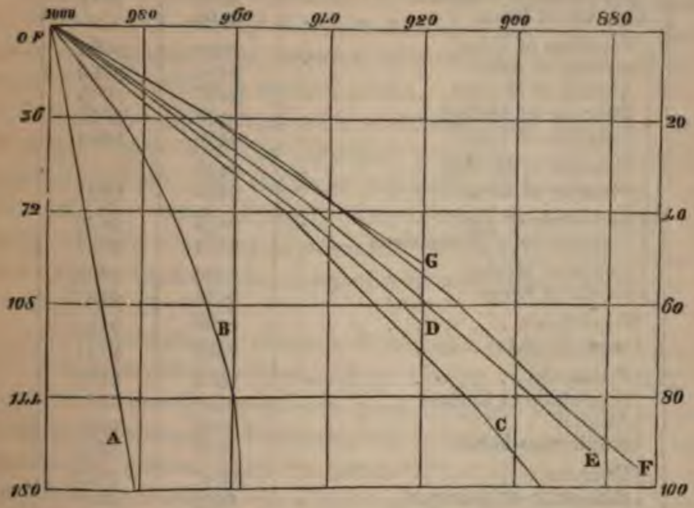
(127) *Expansion of Liquids.*—Liquids expand proportionately much more rapidly than solids. They differ, also, in expansibility to a much greater extent; generally the most volatile are most expansible. This is remarkably shown in the case of the liquids obtained by the condensation of the gases (182), which are even more rapidly dilated by heat than aeriform bodies.

Between 32° *and* 212° *F.*

1,000,000 parts of Mercury become	1,018,153	1 in 55	Regnault
,, Water ,,	1,046,600	1 in 21·3	Dalton
,, Oil ,,	1,080,000	1 in 12·5	
,, Alcohol ,,	1,111,000	1 in 9	

In the annexed diagram (fig. 86), the curves show the variation in the rate of expansion offered by some important liquids. In each case, 1000 parts of the liquid at the boiling point serves as the starting point of the comparison. The horizontal lines from above downwards indicate the bulk of each liquid at temperatures below the boiling point; these temperatures are represented on Fahrenheit's scale in the left hand column, and in Centigrade degrees on the right hand. For instance, B represents the curve of water: the curve commences at 1000 in the left hand upper corner of the table. 1000

Fig. 86.



parts of water at 212° when cooled 36° F. below the boiling point, or to 176° F., occupy a bulk of 986 parts; at 144° F. below boiling, or at 68°, these 1000 parts will have become 960 parts, the curve cutting the vertical line marked 960. A indicates the contraction of mercury; B, water; C, alcohol; D, wood-spirit; E, formic ether; F, terchloride of silicon; G, ordinary ether. It has, however, been found by comparing together liquids, not at the same temperature, but at equal distances from the boiling point (the point at which cohesion is just about to yield to the repulsive action of heat), that in many liquids of analogous chemical composition the expansion is very nearly uniform. The same thing has also been observed between some liquids which present no analogies in their nature. A valuable and elaborate series of experiments has been made upon this subject by M. Pierre (*Ann. de Chimie*, III. xv. 325; xix. 193; xx. 5; xxi. 336). Some of the results which he has obtained are embodied in the following table. The bulk of each liquid at its boiling point is taken as 10,000. The numbers in the table indicate the volume of the liquid, first at 72° F. below the boiling point of each liquid, and again at a still lower temperature, 126° below that point; the contraction being greatest in the liquids first enumerated in the table.

Liquid used.	Volume at 72° F. below boiling.	Volume at 126° F. below boiling.
Ether	9384	
Terchloride of Silicon	9393	9027
Chloride of Ethyl	9419	
Formiate of Ethyl	9430	9064
Acetate of Ethyl	9424	9053
Acetate of Methyl	9431	9065
Butyrate of Methyl	9438	9075
Butyrate of Ethyl	9446	9065
Bromide of Methyl	9438	
Bromide of Ethyl	9452	9091
Bichloride of Tin	9475	9130
Terchloride of Phosphorus	9484	9157
Iodide of Methyl	9494	9163
Iodide of Ethyl	9514	9187
Wood Spirit	9488	9153
Dutch Liquid	9499	9171
Fousel Oil	9503	9192
Bisulphide of Carbon	9521	9201
Alcohol	9536	9225
Sulphurous Ether	9536	9215
Bromine	9547	9247
Bichloride of Titanium	9553	9247
Terchloride of Arsenic	9560	9250
Bromide of Elayl	9562	9264
Bromide of Phosphorus	9621	9353
Terbromide of Silicon	9627	9340

The expansion of the different liquids used in these experiments was determined by inclosing in tubes similar to those employed for thermometers, known bulks of the liquid at a particular temperature, and measuring the expansion experienced in each case, making the necessary correction for the dilatation of the glass envelope. In fact, a number of thermometers were prepared, in each of which one of the various liquids under experiment was substituted as the expansible material in place of mercury.

In comparing corresponding compounds obtained from wood-spirit and from alcohol (two homologous organic liquids), a remarkable parallelism in their rates of expansion has been observed. The acetates of oxide of ethyl and of methyl correspond closely with each other, and with the butyrates of the same substances. Formiate of oxide of ethyl is isomeric with acetate of oxide of methyl (that is to say, it is composed in 100 parts of the same chemical elements, in precisely the same proportions), and both expand also in exactly the same ratio. The bromides of ethyl and of methyl also correspond. So do the iodides of ethyl and of methyl. Wood-spirit and alcohol do not differ greatly from each other, or from an allied compound produced during fermentation, which has received the name of fousel oil. In like manner a close correspondence is observed between the expansions of the bromides of phosphorus and of silicon.

Two elements, however, such as chlorine and bromine, which are most closely allied in chemical properties, and which form compounds which have the same crystalline form, may yet combine with the same element, and produce liquids which have totally different rates of expansion. No correspondence, for instance, exists between the expansion of terbromide of silicon and of terchloride of silicon.

(128) *Expansion of Gases.*—When the temperature rises beyond a certain point in liquids, they change their state, cohesion is entirely overcome, repulsion predominates, and the aeriform condition supervenes. Expansion for equal increments of heat is in gases far greater than in solids or in liquids. If the open extremity of a tube, on the other end of which a bulb is blown, be plunged into water, the heat of the hand will be sufficient to dilate the air in the bulb so as to cause a part to escape. In gases, as cohesion is entirely overcome, no such variety in expansion is exhibited as in the case of liquids and of solids; it may, without sensible error, be assumed that in gases, and also in vapours at some distances above their points of condensation, the expansion is alike in all. From the freezing to the boiling point of water, they increase more than one third of their bulk. 1000 parts at 32° become 1366 at 212° F.*

(129) *Thermometers.*—Whether the body be in the solid, the liquid, or the gaseous condition, the expansion is always proportionate to the heat employed; and the same body, with the same initial temperature, always expands to the same extent by the addition of the same amount of heat: for example, a substance at the temperature of 50° will, however often it be heated to 100°, always expand to the same bulk; and on cooling to its

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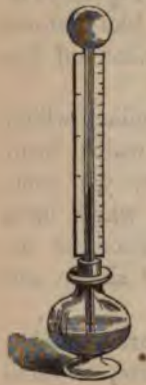
* Regnault (*Annales de Chimie*, III. iv. 1, and v. 52), and Magnus (*Ib.* III. iv. 330), have published independent and elaborate investigations on the expansion which various gases undergo by the application of heat. According to their experiments, the coefficient of expansion is not rigidly uniform for all gases; the expansion being greatest for those which are most readily condensible, whilst for the gases which have resisted all efforts to liquefy

original temperature of 50°, it will always return to its original bulk, however often the heat is applied or withdrawn.

FIG. 87.



By ascertaining exactly the extent of this expansion, a ready and available measure of temperature is afforded; and accordingly an instrument termed a *thermometer* has been constructed for this purpose.

Air, from the delicacy of its indications, and the regularity of its expansion, would seem to be the material best fitted to measure changes of temperature, and indeed it was the substance first tried; the *air thermometer* consisted simply of a bulb of glass, with a narrow elongated stem dipping into some liquid (fig. 87); as the bulb became heated the air expanded, and depressed the liquid in the stem; as it cooled the air contracted, and the liquid rose; a scale attached to the stem gave the amount of the expansion or contraction. But the size of the instrument and the extreme delicacy of its indications limited the range through which it could be employed, and impaired its utility. It was also soon observed that differences of atmospheric pressure, entirely independent of temperature, caused an alteration in the bulk of the air; this may be seen by introducing such an instrument under the receiver of an air pump, and moving the handle; the slightest motion causes great altera-

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them, scarcely any appreciable differences are observed. The following table contains a summary of the results of these important experiments:—

Expansion of Gases by Heat.

Between 32° and 212° F. 1000 parts become,

	Regnault.	Magnus.
Of Hydrogen	1366·13	1365·659
Carbonic Oxide	1366·88	
Atmospheric Air	1367·06	1366·508
Nitrogen	1366·82	
Hydrochloric Acid	1368·12	
Carbonic Acid	1370·99	1369·087
Protoxide of Nitrogen	1371·95	
Cyanogen	1387·67	
Sulphurous Acid	1390·28	1385·618

For ordinary purposes, sufficient accuracy is, however, attained by assuming the expansion of gases and vapours by heat, between 32° F. and 212° F., at $\frac{11}{30}$ of the volume at 32°; this is equal to about $\frac{1}{490\cdot9}$ for each degree of Fahrenheit.

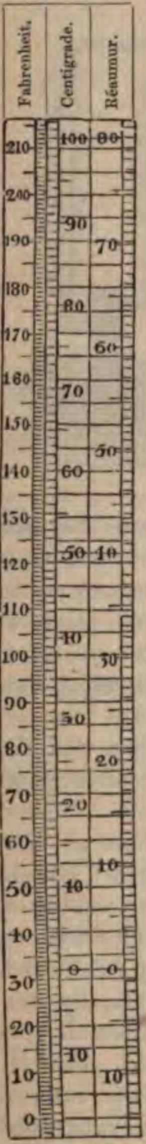
tion in the height of the column of fluid in the thermometer. This difficulty was obviated by a modification of the instrument in which atmospheric pressure was altogether excluded: two bulbs were blown at the extremities of a stout tube, which was bent twice at right angles, and a liquid was included in the stem (fig. 88). The instrument in this form, however, would not indicate general changes of temperature, but only differences between the temperature of the two bulbs; if one were warmer than the other the air expanded in that bulb and drove the liquid in the stem towards the other bulb; it was hence termed the *differential thermometer* or *thermoscope*, and formed, in a limited number of cases, an instrument of great delicacy and utility.

Fig. 88.

(130) The next great improvement in the thermometer was made by the Florentine academicians: they substituted the expansion of a liquid for that of air, employing spirit of wine for this purpose, and they divided the stem of the instrument, arbitrarily as before, by means of small dots of enamel, placed at equal distances upon the tube. As the scales of different instruments were not divided upon any uniform principle, the results which they furnished did not admit of direct comparison. This evil was, however, removed by Newton, who applied Hooke's observation, that the melting point of ice always occurred at a fixed temperature; and finding that the boiling point of water under certain standard circumstances was equally uniform, he proposed these as fixed points, between which the scale should be divided into a certain number of equal parts; the scale being continued above and below, with similar divisions as far as might be necessary. Unfortunately, this interval has in different countries been differently subdivided. In England, Fahrenheit's division into 180° is principally employed; the zero, or 0°, upon this scale, being 32 of these degrees below the freezing point of water. In France, and generally on the continent, the Centigrade division prevails; the interval between the freezing and the boiling points being subdivided into 100°, the degrees being counted upwards and downwards from the freezing point, which is reckoned 0°; the lower temperatures being indicated by the prefix of the negative algebraic sign —.

Réaumur, whose division is still used in Germany and Russia, divided the same interval into 80°, making his zero at the freezing point of water.

Fig. 89.



The conversion of degrees upon one scale into those of another is easily effected by the use of the following formula.

Fahrenheit to Centigrade $\frac{5}{9}(F^\circ - 32) = C^\circ$
Centigrade to Fahrenheit, $\frac{9}{5}\ C^\circ + 32 = F^\circ$
Réaumur to Fahrenheit, $\frac{9}{4}\ R^\circ + 32 = F^\circ$
Fahrenheit to Réaumur, $\frac{4}{9}(F^\circ - 32) = R^\circ$

The annexed cut (fig. 89) exhibits the three scales placed side by side, and shows the corresponding values through a considerable range of temperature.*

The employment of spirits of wine as the expansible liquid for measuring temperature, is attended with advantages where low temperatures are concerned, inasmuch as spirit of wine has never yet been solidified by cold. But owing to the low temperature at which the spirit boils, it cannot be applied for high ranges of temperature; the heat of boiling water would be sufficient to burst the thermometer in consequence of the generation of the vapour of alcohol within the instrument. For most purposes mercury is a more convenient thermometric liquid; it embraces a considerable range of temperature, freezing at 39° below 0° F. and not boiling under 600° F. It has also the advantage of not adhering to the sides of the tubes.

(131) A good mercurial thermometer should answer to the following tests: when immersed in melting ice, the column of mercury should indicate exactly 32° F.; when suspended with its scale immersed in the steam of water boiling in a metal vessel, as represented in fig. 90 (the barometer standing at 30 inches), the mercury should remain stationary at 212°. When the

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* A table of the degrees of the Centigrade scale, with their comparative values on that of Fahrenheit, will be found in the Appendix.

instrument is inverted, the mercury should fill the tube, and fall with a metallic click, thus showing the perfect exclusion of air. The value of the degrees throughout the tube should be uniform: to ascertain this a little cylinder of mercury may be detached from the column by a slight jerk, and on inclining the tube it may be made to pass from one portion of the bore to another. If the scale be properly graduated the column will occupy an equal number of degrees in all parts of the tube.

FIG. 90.

The expansion of which a thermometer thus takes cognizance, is not the entire expansion of the mercury, but the difference between the expansion of the mercury and of the glass: both expand, but the mercury expands the more rapidly of the two, and the column of metal, therefore, rises in the stem of the instrument.

If a thermometer be graduated immediately after it has been sealed, it is liable to undergo a slight alteration in the fixed points of the scale, owing to the gradual contraction of the bulb, which does not attain its permanent dimensions until after a lapse of several months. This contraction is probably due to the pressure of the atmosphere. From this circumstance the freezing point may become elevated from $\frac{1}{4}$ to $\frac{1}{2}$ a degree; and thus the graduations throughout the scale indicate a temperature which is higher than the true one by the amount of the error. In some thermometers, the bulb, as Pierre has shown, does not at once contract in cooling to its proper dimensions; and thus a temporary displacement of the graduation is caused every time such instruments are heated to 212°.

The expansion of liquids is best measured by instruments which resemble the thermometer in shape, but all experiments upon expansion require precautions of the most minute and scrupulous description. For particulars the reader is referred to the papers of Regnault and of Pierre, previously quoted, or to 'Dixon's Treatise on Heat.'

(132) The variety of circumstances under which thermometers are used necessarily demands a considerable variety in their form. It is desirable, for delicate experiments, to reduce the mass of

the instrument, in order to diminish the amount of heat required to raise its temperature to that of the bodies with which it is brought into contact; but where minute subdivisions of a degree require notice, it is better to employ a thermometer with a large bulb and a fine bore. A useful form of the instrument is the self-registering *maximum and minimum thermometer*. The maximum thermometer consists of a mercurial thermometer, with a horizontal stem, in the bore of which a small piece of steel wire is included above the mercury. As the mercury expands it pushes the steel before it, and when the mercury contracts, and recedes towards the bulb, the wire does not follow it. The minimum temperature is observed by a spirit thermometer, arranged like the mercurial one, but the index consists of a small piece of enamel, sunk below the surface of the liquid column. As the fluid descends, it carries the index with it by capillary adhesion, as soon as its extremity reaches the surface of the fluid; but the liquid, on expanding, readily passes by the enamel, and leaves it at the lowest point to which the column had retreated. *Six's thermometer* is constructed upon a somewhat similar principle, but it is less portable, and more liable to derangement. A simpler form of maximum thermometer has been constructed by Negretti and Zambra; it is merely an ordinary thermometer, placed horizontally, with a contraction in the tube, just above the bulb, so that it allows the mercury to pass when it expands, but owing to the narrowing, the metal does not recede when the temperature falls. It therefore indicates the highest temperature attained since the last observation. The true place of the mercurial column is restored by placing the instrument vertically, and giving it a slight swinging motion.

(133) *Increase of the Ratio of Dilatation with Rise of Temperature.*—A scale divided upon the principles already described evidently depends for accuracy on the supposition that equal increments of heat produce an equal amount of expansion. With due precautions, a pound of water, at 32°, mixed with a pound of water at 212°, should yield a mixture in which the thermometer should stand at 122°, the exact mean. In the mercurial thermometer, for temperatures between freezing and boiling water, it may be assumed, without sensible error, that equal increments of heat raise the thermometer through an equal number of degrees. The increase in the capacity of the glass bulb, especially if the thermometer be made of crown glass, almost exactly compensates for the increasing rate of the expansion of mercury: for temperatures above this point the compensation is not so exact. The general result is, that for all bodies, in proportion as the temperature rises, the expansion in-

creases; the distance between the particles augments with the heat, and consequently their mutual cohesion is more readily overcome. The total expansion of mercury, for example, for 3 progressive intervals of 180° F., according to Regnault, is the following: between 32° and 212° it is 1 part in 55·08; between 212° and 392° it is 1 in 54·61; and between 392° and 572° 1 in 54·01. Platinum is more equable in its expansion than any of the metals, but it exhibits a similar increase in the rate of its expansion as the heat rises.

The following table embodies some experimental results obtained upon this point by MM. Dulong and Petit:—

Increase of Mean Dilatation in Bulk by Heat.

	Expansion for each degree F.			
	Between 32° and 212°.	Between 32° and 392°.	Between 32° and 572°.	Between 32° and 662°.
Glass	1 in 69660	1 in 65340	1 in 59220	
Platinum	1 in 67860		1 in 65340	
Iron	1 in 50760		1 in 40860	
Copper	1 in 34920		1 in 21060	
Mercury	1 in 9990	1 in 9665	1 in 9518	
Do. (Regnault)	1 in 9915·7	1 in 9776	1 in 9647·6	1 in 9582·7
Mercury in Glass	1 in 11664	1 in 11480	1 in 11372	

The temperature of 572° F., as measured by an air thermometer, if measured by the expansion of mercury, in an ordinary thermometer, would be indicated as 586°, because the apparent dilatation of the mercury increases as the temperature rises.

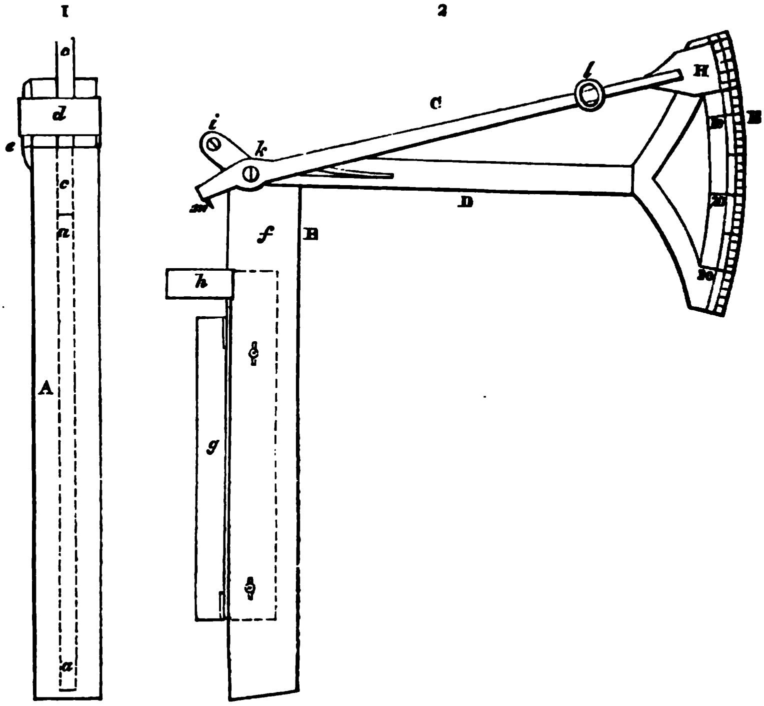
The following results, which were obtained by Professor Daniell, with bars heated in a cylinder of baked black lead ware, and measured by his pyrometer scale (134), show this increasing dilatability of solids, for equal increments of heat, as the temperature rises.

1,000,000 Parts, at 62° F.	At 212°.	At 662°.	At Fusing Point.
Black Lead Ware	1000244	1000703	
Wedgewood Ware	1000735	1002995	
Platinum	1000735	1002995	1009926 maximum, but not fused
Iron (Wrought)	1000984	1004483	1018378 to the fusing point of cast iron
Iron (Cast)	1000893	1003943	1016389
Gold	1001025	1004238	
Copper	1001430	1006347	1024376
Silver	1001626	1006886	1020640
Zinc	1002480	1008527	1012621
Lead	1902323		1009072
Tin	1001472		1003798

(134) *Pyrometers.*—Since the expansion of dissimilar metals for equal additions of heat is unequal, it is evident that if a compound bar, consisting of two such metals as brass and steel, be formed by riveting equal plates of each metal together, the application of heat would occasion curvature of the bar; the concavity being upon the side of the steel, the metal which expands least. On this principle, a very delicate solid thermometer has been constructed by M. Breguet. It consists of a compound ribbon of three metals, platinum, gold, and silver, which are rolled out into a very thin lamina and coiled into a cylindrical spiral, to the lower extremity of which an index is attached, the upper end of the spiral being fixed. The silver expands much more than the platinum, so that the coil twists and untwists as the temperature rises and falls. The value of the degrees is ascertained by comparison with a standard thermometer.

For the estimation of high degrees of temperature, such as the heat of furnaces, and the fusing points of many metals, instruments of a different description, usually termed *pyrometers*, are required.

Fig. 91.



The most accurate of these is Daniell's *register pyrometer*, which is shown in fig. 91. It consists of two parts, the *register*, 1, and the *scale*, 2. The register is a solid bar of black lead earthenware, A, highly baked. In the axis of this a hole is drilled, reaching from one end of the bar to within half an inch of the other extremity. In this cylindrical cavity a rod of platinum or iron, *a a*, six inches long, is placed. Upon the top of the bar a cylindrical piece of porcelain, *c c*, sufficiently long to project a short distance beyond the extremity of the black lead bar, is placed, to serve as an index. It is confined in its position by a ring or strap of platinum, *d*, passing round the top of the black lead tube, which is partly cut away at the top; the ring is tightened by a wedge of porcelain, *e*. When exposed to a high temperature, the expansion of the metallic rod, *a a*, forces the index forward to a distance equal to the difference in the amount of expansion between the metallic rod and the black lead bar, and when cool, it will remain protruded to the same distance, which will be greater or less, according to the temperature; the exact measurement of this distance is effected by the 'scale,' 2. This scale is independent of the register, and consists of two rules of brass, *f g*, joined together by their edges accurately at a right angle, and fitting square upon the two sides of the black lead bar. Near one end of this double rule a small brass plate, *h*, projects at a right angle, which, when the instrument is used, is brought down upon the shoulder of the register, formed by the notch cut away for the platinum strap. To the extremity of the rule nearest this brass plate, is attached a moveable arm, D, turning at its fixed extremity upon a centre *i*, and at the other end carrying an arc of a circle, E, the radius of which is exactly five inches, accurately divided into degrees and thirds of a degree. Upon this arm, at the centre, *k*, another lighter arm, C, is made to turn, carrying upon the extremity of its longer limb a nonius, H, which moves on the face of the arc, and subdivides the graduation into minutes. The shorter arm crosses the centre, and terminates in an obtuse steel point, *m*, turned inwards at a right angle.

To use the instrument, the metallic rod is placed in the register, the index is pressed firmly down upon its extremity, and secured tightly by the platinum strap and the wedge. The position of the index is then read off on the scale, by placing the register in the re-entering angle for its reception, with the cross-piece firmly held against the shoulder, and the steel point, *m*, resting on the top of the index, in a notch cut for it, which coincides with the axis of the rod. A similar observation, made after the instrument has been heated and allowed to cool, gives the value of the expansion. The scale of the pyrometer is compared with that of the mercurial thermometer, by observing the amount of expansion between two fixed points, such as the freezing of water and the boiling of mercury.

Wedgwood's pyrometer, which is now disused, depended in principle upon the contraction which clay undergoes when heated in consequence of partial vitrification, a contraction which the inventor believed to be proportioned to the temperature, but which later experiments have shown to depend rather on the duration than on the intensity of the heat. The instrument consisted of a number of pieces of fire clay, cut to a uniform size by a punch, the contraction which these pieces of clay experienced by heat being measured by the depth to which they entered between two brass rulers converging at a very small angle.

(135) A combination of the thermometer with the pyrometer gives a range of temperature extending through extensive limits. The means of attaining very elevated temperatures are much more under command than those of procuring great degrees of cold.

The following table gives, in degrees both of Fahrenheit's and of the Centigrade scale, some remarkable points of temperature:—

	° Fah.	° Cen.
Greatest artificial cold produced by a bath of Protoxide of Nitrogen and Bisulphide of Carbon in vacuo (Natterer)	—220	—140
Greatest cold by a bath of Carbonic Acid and Ether in vacuo (Faraday)	—166	—110
Greatest natural cold recorded (Sabine). .	— 56	— 49
Mercury freezes	— 39	— 39·4
Freezing mixture of Snow and Salt . . .	— 4	— 20
Ice melts	32	0
Maximum Density of Water	39·2	4·0
Mean Temperature of London (Daniell). .	49·7	9·9
Blood Heat	98	36·6
Boiling point of Water	212	100·
Mercury boils	662	350
Red heat . . . . Daniell.	980	526
Silver melts	1873	1022
Cast-Iron melts.	2786	1530
Highest heat of wind furnace .	3280	1804

(136) The amount of force exerted by expansion or contraction from the effects of heat or of cold is enormous; for it is equal to that which would be required to elongate or compress the material to the same extent by mechanical means. According to the experiments of Barlow, a bar of malleable iron, of a square inch section, is stretched $\frac{1}{10000}$ of its length by a ton weight; a similar elongation is pro-

duced by about 16° F. In this climate a variation of 80° F. between the cold of winter and the heat of summer is frequently experienced. In that range, a wrought-iron bar, ten inches long, will vary in length $\frac{5}{1000}$ of an inch; and will exert a strain, if its two extremities be securely fastened, equal to fifty tons upon the square inch.

In many instances in the arts this effect is turned to useful account. With this view the wheelwright makes the iron tire of his wheels a little smaller than the wheel itself, and applies the tire in a heated state; on cooling, it contracts, and binds the parts firmly together. For the same reason, in fastening together the plates of steam-boilers, the rivets are used whilst red-hot. But, on the other hand, this force of expansion requires often to be carefully guarded against. Iron clamps built into furnaces frequently destroy by their expansion and contraction, the masonry which they are intended to support. In laying down pipes for the conveyance of gas and water, it is necessary to fit the lengths into sockets where the material used as stuffing to tighten the joint allows sufficient play for the alterations in length of the metal by changes of temperature. For the same reason, a small interval is left between the ends of the iron bars in laying down a line of rails. Each tube of the Britannia Bridge, across the Menai Straits, is liable, from changes of temperature, in the course of twenty-four hours, to an elongation and contraction varying from half an inch to three inches.

Brittle substances, such as glass and cast-iron, often crack on the sudden application of heat, because a sudden dilatation is produced upon the surface before the heat has time to reach the interior, and thus the cohesion is destroyed. The thicker the plate the greater is its liability to fracture. Sudden cooling, by inducing unequal contraction, has a similar effect.

A knowledge of these effects of expansion explains why the wires of certain metals, such as iron and platinum, may be soldered into glass; whilst other metals, such as silver, gold, or copper, separate and crack out as the joint cools. The expansion of iron or of platinum differs from that of glass by a very small amount, whereas other metals vary from it greatly, and contract far more in cooling.

(137) A remarkable exception to the law of contraction by the removal of heat, exists in the case of water. Water follows the regular law until it reaches a point between 39° and 40° F.; then, instead of contracting, it begins to expand, and continues to do so till it reaches the freezing point. About 39° it is at its point of

greatest density, and just before it freezes it
great as it did at 48°. If water at 39°·2 be ta
has a density of 0·99988 (Pierre).

By dissolving table salt in water, the point o
is lowered, and the solution goes on contractin
peratures considerably below 39° F., until, in sea-
disappears, the maximum density occurring at a
the point of congelation. Various other sal
salt (chloride of sodium) have the effect, when
of lowering its point of maximum density ;
numerous liquids examined by M. Pierre, no o
water was found thus to expand whilst the
falling.

(138) *Correction of Gases for Temperature.*—
mentioned that air expands more than other bod
tions of temperature, and that the rate of expa
and vapours is equal and uniform, at all degrees
all varieties of pressure. It becomes, therefore
portance to estimate the amount of this expans
ments where the quantities of gases require to b
where their weight is inferred from measureme
Provided that the temperature of the gas be known
easily made. Experiment has shown that for eve
upon Fahrenheit's scale, an amount of expansion
to $\frac{1}{491}$ of the bulk that the gas occupied at 32° F
that a quantity of any gas which, at the tempe
measures 491 parts, for every additional degree i
1 part ; so that at 33° it will occupy 492 parts, at
499, at 60° 519 parts. In England, all comparis
referred to the temperature of 60° F. Suppose i
ascertain the volume which 9·2 cubic inches of co
at 70°, would have when reduced to 60°:—since
491 parts of any gas at 32° would at 70° ha

standard temperature of 60° F.; since $50 - 32 = 18$, the gas, which occupied 491 parts at 32°, would have expanded to 509 at 50°. The proportion to the volume at 60°, which would, as before, be 519, is given as follows:

$$509 : 519 :: 9{\cdot}2 : x \ (= 9{\cdot}380 \text{ cubic inches}).$$

In this case, the observed volume is less than the corrected one; before, it was greater. An additional and independent correction of the volume of the gas for the deviation of the barometric pressure from the standard is needed after the correction for the temperature has been made.

(139) Liquids and gases immediately adjust their bulk to the alteration of temperature; but, according to observations made in the Arctic Expeditions, solids do not immediately do so in all cases: it was frequently observed in the metallic scales of many of the instruments, that full contraction did not occur until a concussion had been given to the apparatus; it then contracted suddenly and completely.

(140) *Process for Taking the Specific Gravity of Gases.*—The principal corrections required in the delicate operation of taking the specific gravity of a gas with accuracy, have now been pointed out. M. Regnault, in his recent elaborate investigations, has reduced the number of corrections ordinarily required, by counterpoising the globe in which the gas is to be weighed by a second globe of equal size, made of the same glass; a practice which was also adopted by the late Dr. Prout, in his careful investigations on the density of the atmosphere. The film of hygroscopic moisture which always adheres to the glass is equal in both globes; and as the bulk of air displaced is also equal in both cases, the calculation for its buoyancy may be dispensed with. The following is a brief description of the method adopted by M. Regnault:

FIG. 92.

A balance, capable of weighing two pounds, and sufficiently delicate to turn with the $\frac{1}{100}$th part of a grain when loaded, is placed upon a chest provided with folding doors, within which the glass globes, each of the capacity of about 600 cubic inches, attached to the scale-pans, are freely suspended. The globe B, fig. 92, is hermetically sealed; the globe A, for weighing the gases, is provided with a stop-cock; the air is exhausted from A as perfectly as possible, and it is connected with an apparatus which supplies the gas to be weighed, the gas having been carefully purified and dried. The globe is again exhausted very completely, the last portions of air being thus displaced by the gas, and it is a second time filled with the gas; this process must be repeated a third time, and the gas will then be free from atmospheric air. To avoid the need of any correction for temperature, the globe is this time placed in a vessel of melting ice (fig. 93), in order to cool the gas to 32° F., which, by the French, is always taken as the standard. When the globe is filled with gas, and sufficient time has elapsed for it to acquire the temperature of the ice, the vessel of mercury, M, into which the escape-tube dips, is removed, so as to equalize the pressure within the globe with that of the air; the stop-cock is closed, and the globe withdrawn, wiped carefully with a damp cloth, to avoid rendering the surface electric, and it is then suspended to the scale-pan. It is not weighed, however, until after the lapse of a couple of hours, by which time the equilibrium of its temperature with the atmosphere is restored, and the production of currents (146) around it is obviated. The weight is then accurately noted; the globe is again plunged in ice, the gas removed by the air-pump, and the elasticity of the included gas measured accurately by the gauge attached to the air-pump. The empty globe is again withdrawn from the ice and weighed as before; the difference of the two

Fig. 93.

weights will give the weight of a bulk of gas, the elasticity of which is equal to that of the atmosphere, as marked by the height of the barometer, diminished by the elasticity, *h*, of the remaining gas, as measured by the gauge. If the capacity of the globe has been previously accurately determined, the corrected weight of the gas will be obtained by the following proportion: in which H′ represents the height of the barometer at the time of the experiment, and *h* the elastic force of the gas which remains in the globe after exhaustion.

	The standard pressure.		The observed pressure.		The observed weight.		Corrected weight.
As	H	:	$H^1—h$	: :	W^1	:	W

M. Regnault has in this manner determined the weights of 1 litre of each of the following gases, at 32° F., and under a pressure of 29·922 inches of mercury at 32°.

				Grammes.
Of Air, ·	mean of 8 Expts.	. .	=	1·293187
Oxygen,	„ 3 Expts.	. .	=	1·429802
Nitrogen,	„ 6 Expts.	. .	=	1·256167
Hydrogen,	„ 3 Expts.	. .	=	0·089578
Carbonic Acid,	5 Expts.	. .	=	1·977414

From these data it is easy to determine the weight of 100 cubic inches of each gas in grains. The litre has a capacity of 61·024 cubic inches; the gramme is equal to 15·433 grains; and the expansion of air between 32° and 60° by heat is such, that 100,000 parts become 105,701. The barometric pressure of 29·922 inches at 32° would be equal to a column, at 60°, of 30·005 inches of mercury. Calculating from these numbers, the weight in grains of the under-mentioned gases under a pressure of 30 inches of mercury (the column being measured at 60° F.) is as follows:

100 Cubic Inches	At 32° F.	At 60° F.
	Grains.	Grains.
Air	32·698	30·935
Oxygen	36·153	34·203
Nitrogen	31·762	30·119
Hydrogen	2·265	2·143
Carbonic Acid	50·000	47·303

(141) *Determination of the Specific Gravity of Vapours.*— different method of procedure is required in taking the specifi gravity of a vapour. This is an operation which the chemist h frequently occasion to perform, as it often throws light upon th composition of the body. Two methods have been proposed f attaining the object; one, devised by Gay Lussac, is suitable for liquids which boil at a temperature approaching the boiling point of water: the other is applicable not only to these liquids but to all that boil below the boiling point of mercury. This latter method, contrived by Dumas, is the only one that will be here described.

A thin glass globe or balloon (A, fig. 94) of 3 or 4 inches in diameter, is drawn off at the neck into a capillary tube, 5 or 6 inches in length; the open extremity of this tube is attached to a desiccating tube filled with chloride of calcium (63), and this is connected with the air-pump. The air is exhausted from the apparatus, and then slowly re-admitted, repeating the process three or four times. By this means any film of moisture which might be adhering to the interior of the globe is removed, and it is filled with air in a dry state: the temperature and pressure of the atmosphere at the time are noted down. The balloon having been detached from the air-pump, it is accurately weighed: this weight represents that of the balloon and the air which it contains. The capillary tube is then inserted into the liquid which is designed to furnish the vapour, the specific gravity of which is required: by gently warming the globe, the enclosed air expands, and a small quantity of it is expelled. As the globe cools the air again contracts and the liquid rises. 100 or 150 grains of the liquid having been thus introduced, the globe is next firmly attached, by means of copper wire, to a wooden handle, *c*, and by its means is depressed, as represented in fig. 94, completely beneath the surface of a liquid (water, oil, or chloride of zinc, according to the temperature required), which is gradually heated till it is 30° or 40° F. above the boiling point of the liquid of which the vapour-density is required. The liquid in the globe is thus made to boil briskly,

FIG. 94.

and is converted into vapour, which expels the air and takes its place.

After the vapour ceases to escape from the aperture of the capillary tube, the temperature of the bath is maintained steady for a few minutes, to allow the balloon and its contents to acquire the temperature of the liquid in which they are immersed. The temperature is then observed by the thermometer *t*, and at the same moment the capillary tube is sealed by the flame of the blowpipe. The balloon is then removed from the bath, and allowed to cool; it is thoroughly cleaned, and a second time accurately weighed. The weight thus obtained represents that of the balloon with that of the liquid which remained within it in the form of vapour at the moment of the sealing. The capillary neck is now plunged beneath the surface of water (or of mercury), and is then broken off. If the operation be successful, the vapour condenses, and the liquid enters the globe, so as either completely to fill it or to leave only a small bubble of air. The globe, with the water which it contains, is then carefully weighed, and the capacity of the balloon is thus ascertained, since 252·5 grains of water are contained in the space of a cubic inch. The bubble of air is then decanted into a graduated tube, and its bulk measured; or the globe may be completely filled up with water and again weighed; the difference of the last two weighings will represent the weight of a quantity of water which corresponds to the bulk of the bubble of air.

All the data necessary for calculating the specific gravity of the vapour are thus furnished, as will be seen from the following example:

Determination of the Density of the Vapour of Alcohol.

BY EXPERIMENT.

	Grains.
(1) Weight of the balloon full of air, at a pressure of 29·1 inches barometer, and a temperature of 57° F.	1187·20
(2) Weight of the balloon full of vapour, sealed at 212° F., barometer at 29·1 inches	1189·20
(3) Weight of the balloon with the water that entered on opening the capillary neck under water	8102·0
	Cubic Inch.
(4) Residual air	0·200

BY CALCULATION.

	Grains.
By (3) the weight of the balloon full of water was .	8102·0
By (1) the weight of the balloon full of air was .	1187·2
Difference: weight of the water	6914·8
Add $\frac{1}{817}$ for the weight of air displaced by the water .	8·4
	6923·2
	Cubic Inches.
Dividing 6923·2 by 252·5, we obtain, as the contents of the balloon, in cubic inches . .	27·419
Add to this the bulk of the residual air . .	0·200
(5) The sum gives the capacity of the balloon at 57° F.	27·619*
Add the increase of volume due to expansion at 212° .	0·043
(6) The capacity of the balloon corrected to the temperature of 212° becomes	27·662
27·619 cubic inches of air measured at 57° F., with barometer at 29·1 inches, would become at 60° with barometer at 30 inches . . .	27·083
	Grains.
And would weigh	8·37
Now (by 1) the weight of the balloon filled with dry air was	1187·20
Deduct the weight of the air	8·37
(7) The difference gives the weight of the empty balloon.	1178·83
	Cubic Inch.
The 0·2 cubic inch of residual air measured at 57° F., and at 29·1 inches barometer, would become at 212° F. and 29·1 barometer . . .	0·252

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* Where rigid accuracy is desired, it is necessary to calculate the difference between the capacity of the globe at the temperature of the air, and that at the temperature at sealing, and to add this difference to the capacity as calculated above. When the temperature at sealing is very elevated, this correction acquires some importance; but it is insignificant in most cases, more especially as the vapour densities obtained by experiment never coincide accurately with the theoretical results, and a fair approximation is generally all that is required to indicate the state of condensation of the constituents of the compound. Since the expansion of flint glass between 32° and 212°, is equal to 0·00228366 of its bulk, the increase in capacity of the balloon in the foregoing experiment between 57° and 212° is 0·043 cubic inch.

	Grain.
(8) And would weigh	0·06
	Cubic Inches.
But (by 6) the capacity of the balloon at 212° was .	27·662
Deduct dilated residual air	0·252
The difference gives the space occupied by alcohol vapour, at 212° F. and 29·1 barometer .	27·410
Now 27·41 cubic inches of vapour, measured at 212° and 29·1 barometer, if they could exist uncondensed as vapour, at 60° F. and at 30 inches barometer, would become	20·565
	Grains.
But (by 2) the united weight of the balloon, the vapour, and the residual air was found . .	1189·20
Deduct the weight of the residual air (8) . .	0·06
The difference gives the weight of balloon and vapour	1189·14
Deduct the weight of the empty balloon (7) . .	1178·83
The difference gives the weight of 20·565 cubic inches of alcohol vapour at 60°	10·31

100 cubic inches of alcohol vapour would, therefore, weigh 50·123 grains at 60° F. and 30 inches barometer. Now, 100 cubic inches of air weigh 31 grains, at 60° F. and 30 inches barometer; therefore, 50·123 divided by 31 gives 1·617 the specific gravity of the vapour of alcohol.

§ II. On the Equilibrium of Temperature.

(142) All bodies, when heated, return sooner or later to the temperature of surrounding objects; the tendency of heat being constantly to preserve an equilibrium. This balance is restored either by transmission from particle to particle, in which case the process is termed *conduction:* or by *convection,* or the motion amongst the particles of liquids or gases: or by *radiation* between bodies at a distance from each other.

Conduction.

(143) If we place the end of a short strip of glass and of a strip of metal, of equal length, in the flame of a lamp, we shall

soon be sensible that heat reaches the fingers more rapidly through the metal than through the glass; and shall have a clear proof that these two substances differ greatly in their power of conducting heat. Of all known substances metals possess the greatest amount of conducting power, but they differ considerably when compared with each other. It may be taken as a rule, although it is liable to numerous exceptions, that the denser the body the better it conducts heat. M. Despretz (*Ann. de Chimie*, II. xxxvi. 422) made a series of experiments to determine the conducting power of a variety of solids: he formed them into bars of 0·826 inch square, and drilled holes in the bars at distances of 3·93 inches asunder, for receiving the bulb of a thermometer; a steady heat was then applied to one end of the bar, and the temperature of each thermometer was recorded as soon as the temperatures ceased to rise. The following table shows the results which he obtained:—

Conduction of Heat by Solids.

Gold	1000·0	Tin	303·9
Silver	973·0	Lead	179·6
Copper	898·2	Marble	23·6
Iron	374·3	Porcelain	12·2
Zinc	363·0	Fire Clay	11·4

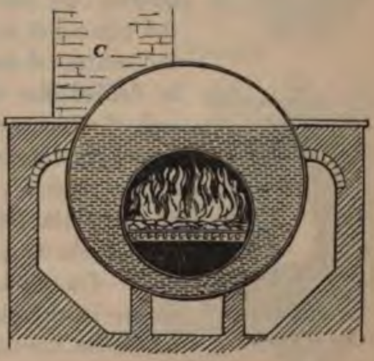
It is principally owing to differences in conducting power that bodies at the same temperature excite when touched very different sensations of heat or of cold. A piece of metal feels much hotter or colder than a piece of wood heated to the same degree, because the metal, from its superior power of conduction, according as it is above or below the temperature of the hand, imparts heat or receives it more quickly than the wood.

This property of conduction is possessed by liquids in a very limited degree. On filling a test tube with water, and holding it by the lower part, whilst the top of the tube is placed across the flame of a spirit lamp, the water at the top of the tube may be kept boiling for many minutes without occasioning the slightest inconvenience to the person who holds it. Gases are inferior even to liquids in conducting power; hence it is that porous bodies, such as wool, fur, and eider-down, which imprison large bodies of air within them, are so well adapted for winter clothing, by preventing the escape of the heat of the body outwards. For the same reason, chiefly, the employment of double doors and windows, which include a layer of air between them, is so useful in preventing the heat of our apartments from escaping outwards; or, as in the case of fire-proof boxes and icehouses, from penetrating from the outer atmosphere. In a similar manner snow preserves the warmth of the earth during the rigour of winter.

The rapid change of particles of air which are in contact with the body, by the action of a wind, renders the human frame much less able to bear cold in a windy, than in a still atmosphere. Voyagers in the Arctic regions found that if properly clad, they could endure in a still air, a temperature of $-55°$ F.; while at 0° with a brisk wind, it was impossible to face the breeze with safety. A parallel case occurs in liquids: the hand may with impunity be kept stationary in water of a temperature so high, that if the hand were in motion, severe pain would be occasioned.

Many familiar contrivances for preventing the escape of heat and for facilitating the employment of hot bodies, depend upon the use of inferior conductors of heat; thus a layer of charcoal is generally interposed between the case of the furnace and its fire-clay lining, in order to confine the heat. The kettle-holder is for this reason used to protect the hand from the heat of the metal; whilst the handles of teapots are insulated from the hot metal by non-conducting pieces of ivory. Wicker-work or matting is placed under hot dishes to separate them from the dinner table by badly conducting substances.

Fig. 95.



Much of the economy of fuel depends upon a judicious application of these principles. An instructive illustration of their importance is exhibited in the manner in which heat may be economized by an appropriate construction of the boiler of a steam-engine. The form which answers this purpose most perfectly is that which is known as the Cornish boiler. Fig. 95 shows a transverse section of this boiler; it consists of two cylinders placed one within the other; between the two is the space for the water: the interior cylinder contains the fire-grate, ash pit, and the first portion of the flue: the heat, which would otherwise be conducted away by the fire bars and by the masonry of the ash pit, is thus economised, and the heated products of combustion pass through the boiler for its whole length, which is sometimes as much as forty or even sixty feet; the hot air then returns along the outside of the boiler towards the fireplace, and once more passes underneath the boiler before it finally reaches the chimney. Loss of heat from the outer surface of the boiler is prevented by covering it with a layer of badly conducting material. In the boiler of the locomotive, where a stronger draught is necessary, the fireplace is surrounded at top and on its two sides by a double casing containing water, and the hot air from the furnace passes through the length of the boiler by a number of small tubes, which open at one end into the fireplace, at the other into the chimney. Loss of heat from the external surface is here also prevented by casing the boiler in some non-conducting material, which is frequently covered with wood.

(144) *Inequality in the Rate of Conduction in Different Directions.*—The researches of Senarmont (*Ann. de Chimie,* III. xxi. 457, and xxii. 179,) have shown that although the conducting power of solids which are homogeneous throughout, and of crystals which belong to the regular system, is uniform in every direction, yet that in all crystals which do not belong to the regular system the conducting power varies in different directions, according to the relation of the direction to that of the optic axis of the crystal. The fundamental fact is easily demonstrated by taking two slices of quartz, one cut parallel to the axis of the prism, the other cut at right angles to that axis; through the centre of each plate a small conical aperture is drilled for the reception of a silver wire, one end of which can be heated in a flame, and which by its conducting power acts as an uniform central source of heat. If previously to the application of heat the surfaces of the crystal be coated with bee's-wax, the wax will be melted in the form of a circle, of which the wire occupies the centre in the plate cut across the axis (fig. 96, 1); whilst on the other plate the wax will melt in the form of an ellipse, the two diameters of which are as 1000 : 1312, the long axis coinciding with the direction of the optic axis of the crystal (fig. 96, 2) showing that the conducting power is greater in this direction than in one at right

FIG. 96.

ngles to it : whilst the circular form of the melted wax in the first xperiment shows the uniformity with which heat is propagated in ll directions around, and parallel to, the axis of symmetry. In rystals with two optic axes, the results, although more complicated, resent the same intimate connexion with the direction of those nes within the crystal.

FIG. 97.

Delarive and Decandolle have shown hat similar differences in conducting ower occur in wood, which conducts uch better with the grain than across ; that is, better in a direction parallel o the fibres, than across them. Dr.Tyndall as not only confirmed this fact, but has lso proved that heat passes rather more apidly in a direction from the external urface towards the centre, *a b* (fig. 97), han it does in a direction parallel with the ligneous rings, *c d*. *Phil. Trans.* 1853, p. 226.)

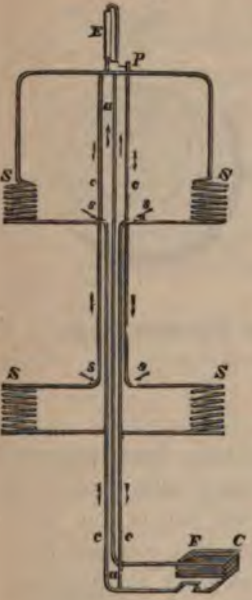
Convection of Heat.

(145) Although the power of conducting heat possessed y liquids and gases is very small, yet they admit of being apidly heated by a process of circulation or convection, which epends upon the free mobility of the particles that compose them. Vhen heated, each particle expands, and becomes for the time pecifically lighter. If the heat be applied at the bottom of a arge flask nearly filled with water, into which a little bran has een thrown to enable the eye to follow he motion occasioned, the heated and ighter particles will be seen by the motion f the bran to ascend, while their place is upplied by fresh particles from the sides ; hese in turn come into contact with the eated glass at the bottom, and they gain make way for colder portions. An scending current, as shown in fig. 98, s thus established up the middle, and de-cending currents flow down the sides of he flask, which are kept cool by the air. nything that checks this free circulation, and occasions viscidity n the liquid, impedes the distribution of heat. Porridge or starch uring the boiling requires to be constantly stirred, for the pur-

FIG. 98.

pose of presenting fresh surfaces to the source of heat, and to prevent the portions in contact with the hot bottom of the vessel from becoming overheated and 'burned.'

FIG. 99.



The motion thus communicated by heat to liquids, has been ingeniously applied to the warming of buildings, by the circulation of hot water in pipes. One of the most effective methods will be understood by examining fig. 99, which represents Perkins's arrangement for heating by means of hot water at a high pressure. In its simplest form it consists of a continuous wrought-iron pipe, one inch in diameter externally, with a bore half an inch in diameter. The pipe is completely filled with water at P and closed by a plug. The apparatus is provided with a chamber at E, of about $\frac{1}{5}$ or $\frac{1}{6}$ the capacity of the entire tube, to allow for expansion; this chamber being left empty. About $\frac{1}{6}$ the entire length of the pipe is coiled up at F C, and is heated by a furnace, which is of necessity placed in the basement of the building. At S S, S S, other coils are formed upon the pipe as it passes through the different apartments which are to be heated. The course of the water is indicated by arrows. The hot water, mixed with bubbles of steam, passes off from the upper part of the coil, F C, ascends by the pipe, *a a*, to the highest part of the building; it then flows off on either side through the coils, S S, S S, and returns by the pipes, *c c*, which unite into one before delivering the cooled water to the bottom of the coil, F C. *s s*, *s s* are stop-cocks for arresting the current through any one of the heating coils, S S, S S.

The importance of the exception in the case of water to the regularity of expansion (137), in connexion with these circulatory movements will now be perceived. During the frosts of winter a rapid process of cooling goes on from the surface of the earth, and of our lakes and rivers: the colder water sinks to the bottom, fresh portions being supplied from below, until the whole has reached the temperature of 40°; below this point the colder water being the lighter remains at the top, thus protecting the mass beneath from further reduction of temperature by its inferior conducting power, and preventing such a reduction at any considerable depth as would be fatal to the animals which it contains. Ice, too, being lighter than water, floats upon the surface, and thus the bottoms of our rivers are protected from the accumulations of frozen water, otherwise inevitable; and which no subsequent summer heat would ever suffice to melt, or even to reach from the surface. In the ocean, where the maximum of density occurs below 32°, the depth is so great that, excepting near the polar circles, the low temperature does not last sufficiently long to reduce the entire mass to a degree injurious to animal life.

(146) *Currents in Gases—Ventilation.*—The motions produced in gases by the expansive action of heat are still more obvious and extensive than those occasioned by it in fluids. The tapering form of flame is due to an expansion of the air, accompanied by a powerful upward current, produced by the heat with which it is attended. A body of heated air confined in a light envelope possesses considerable ascensional power, and constitutes the ordinary fire-balloon; it was, indeed, by means of such a balloon that the first recorded aeronautic excursion took place.

The application of the currents produced in air by differences of temperature to the ventilation of our dwellings is a subject of great practical importance. The *draught* produced in the chimney is due to the heat derived from the fire, which dilates the air in the flue above it, and renders it specifically lighter: it consequently rises in the shaft, and the longer the chimney the more powerful is the draught. Suppose the temperature in the chimney to be on the average of its length 25° above that of the outer air, which may be assumed to be at 41° F.; the dilatation of air for each 1° F. is $\frac{1}{500}$ of its bulk at 41°, the column of air in the chimney will therefore be dilated $\frac{25}{500}$, or $\frac{1}{20}$. A column of such heated air, 21 feet high, which we will assume as the length of the chimney, would therefore only balance a column of the temperature of the outer air 20 feet in height, and the ascensional force of the heated air would be that due to the difference in weight between the 21 feet of warm air and 21 feet of colder air, or equal to the pressure of a column of the colder air 1 foot in height. Air must, however, be supplied to the lower opening, in order to allow the equilibrium to be restored; and if the communication of the apartment with the outer air be insufficient (as when the doors and windows are carefully closed, and listed down, to exclude the draughts of cold air that rush in at every crevice to furnish that required to feed the chimney), air will enter at the top of the chimney, just as when a bottle full of air is plunged, with its mouth upwards, under water, the water enters at the mouth, whilst the air escapes in gushes or bubbles. The consequence of cold air entering at the top of the chimney will be, that it pours down into the room, and, as a necessary result, the chimney smokes. If the door or the window be opened, however, the annoyance ceases. In a room properly ventilated, the requisite supply of fresh air will enter freely, without the necessity of setting the door open.

In ventilating a room, it must be remembered that the air which has been used, and which requires renewal, has become heated by respiration and by the burning of lamps or candles; it therefore rises and accumulates in the upper part of the room. This is easily seen by opening the door of a heated apartment, and holding a candle near the upper part of the door-way; if the window be not open, a current will generally be found blowing the flame from the room. Midway down the flame will be stationary, while near the floor it will be blown strongly into the room. In this experiment the lighter heated air flows out above, while the heavier cold air supplies its place, by entering at the lower part of the room. It is for this reason advisable always to make apertures for the escape of heated air near the ceiling; at the same time, no ventilation can be effectual which does not provide for the entrance of fresh air, which may be previously warmed or not, and which is best admitted at the lower part of the room. In cases where there is a sufficient height of chimney, a contrivance of Dr. Arnott's is a valuable auxiliary to the ventilation; it consists of a balanced valve, opening into the chimney, as near the ceiling as practicable. The heated air passes off through this aperture into the chimney, whilst any momentary downward draught occasioned by the sudden shutting of the door, or otherwise, causes the valve to close, and thus to prevent the escape of smoke into the room.

The velocity of the currents produced by heat, and the rate of cooling effected by them upon a thermometer heated up to a determinate point, vary in different gases, being more rapid the lighter the gas. In hydrogen the rate of cooling is much more rapid than in air, while in carbonic acid it is considerably less rapid.

(147) *Trade Winds.*—The processes of circulation produced by heat in liquids and gases, which have just been described, occur upon a vast scale in the atmosphere and in the ocean. The important phenomena of the trade winds arise from movements which origi-

nate from these causes. The temperature of the surface of the earth not being uniform, but being highest within the tropics and lowest at the poles, the warm air of the equator, as it rises in temperature, becomes expanded, grows specifically lighter, and therefore ascends, its place being supplied by cooler air from the parts adjacent, but nearer to the poles. The heated equatorial air rises to a certain point, and then falls over to supply the place of the cooler air just conveyed from the neighbouring regions. In consequence of these actions, the air upon the surface of the earth is continually moving from the poles towards the equator, and above this current is another proceeding in the contrary direction, from the equator towards the poles. The lower current, which is steadily felt on each side of the equator, through at least 30° of latitude, is of the utmost importance to navigation, and forms what are called the *trade winds*. The upper current does not admit of being so accurately traced, but there is satisfactory proof of its existence. The summits of many inter-tropical mountains, such as the Peak of Teneriffe, 12,180 feet high, and Mouna Kea, in the Sandwich Islands, 18,400 feet in height, are sufficiently elevated to reach into the upper current; and at the top of these mountains a strong south-westerly wind blows continually, whilst the north-east trade wind is blowing at the base. If the earth were stationary, these currents would set due north and south. The surface of the globe, however, is revolving from west to east, at the average rate of 980 miles per hour in its equatorial part, and the rapidity of motion gradually diminishes towards the poles, at which points the motion almost vanishes. Air, therefore, which flows towards the equator from the poles, is moving more slowly than those regions of the earth towards which it advances. Since, however, the objects upon the surface partake of the motion of the earth at the particular spot on which they rest, and as therefore the earth's motion is not perceptible, the effect of a wind travelling more slowly in the same direction as that in which the earth is moving would be precisely the same as that of a current blowing in the opposite direction, with a velocity equal to the difference between the rates of the two motions, supposing the earth to be at rest: consequently the wind from the north has an easterly set, which diminishes as it approaches the equator, where the motion of the successive portions of the surface becomes more uniform. From the operation of these causes the north-east is one of the most prevalent winds in our climate. For similar reasons, the equatorial current towards the poles sets in a westerly direction, and retains its course when it comes down to the surface, which it does at and about our latitude, occasioning the westerly winds which prevail in these islands so generally at certain seasons.

The land and sea breezes which occur morning and evening along the coasts of tropical countries, are due to the action of analogous causes. During the early part of the day the earth, from the action of the sun's rays, becomes more heated than the ever-moving ocean; the air above it expands and rises, whilst its place is supplied by cooler air from the ocean—this constitutes the *sea breeze:* whilst in the evening, after sun-set, the land cools more rapidly than the ocean, and the air resting upon it contracts in bulk, and becoming heavier, flows out during the night upon the sea, and produces the *land breeze.*

(148) *Gulf Stream.*—Similar currents, of equal constancy and regularity, exist in the ocean, but they are modified in their direction by the general distribution of land and water on the earth's surface. That part of the ocean which is immediately under the tropics, and between the eastern and western hemispheres, for example, becomes highly heated; the water flows off on either side, towards the poles, acquiring a westerly direction as it passes south of the coast of Guinea, and, striking the promontory of Cape St. Roque, on the South American coast, is split into two streams; the smaller one continues southwards, towards Cape Horn; the larger current maintains a northwesterly course into the Gulf of Mexico, where it receives further accessions of heat, and is gradually changed in its direction; it passes along the southern shores of North America, and finally emerges northward, in the narrow channel between the peninsula of Florida and the Bahama Islands, where it assumes the name of the Gulf Stream. The temperature of this current is found to be 9° or 10° higher than that of the neighbouring ocean. The current passes on, gradually widening and becoming less marked, till it is lost on the western shores of Europe. A less accurately defined under-current, from the poles, is constantly setting in towards the equator, to supply the place of the heated water which takes the course already described. Besides rendering important aid to the navigator, these currents assist in maintaining an equilibrium of temperature on the earth, moderating the severity of the polar frost, and tempering the sultry heats of the tropics.

Radiation of Heat.

(149) A person placed in bright sunshine, or before a blazing fire, must perceive that in addition to the gradual mode of propagation from particle to particle, heat is endowed with the faculty of traversing space, and transparent media such as the atmosphere. This transmission of heat occurs in right lines, with a velocity equal to that of light itself; in fact in its propagation it follows the same laws as light, and like all radiant forces it diminishes in intensity as the square of the distance from the active centre.

The great supply of heat to the earth from the sun is transmitted by the process of radiation. Some idea of the amount of heat thus received by the earth may be formed from a rough calculation made by Faraday, to the effect that the average amount of heat radiated in a summer's day upon each acre of land in the latitude of London, is not less than that which would be emitted in the combustion of sixty sacks of coal.

Heat in its radiant state does not raise the temperature of the media which it traverses; a tube full of ether may be held in the focus of a burning mirror without becoming sensibly hotter; but the moment the absorption of the rays is caused in any way, as by introducing a bit of charcoal into the liquid, the ether enters into ebullition and is dissipated in vapour.

(150) *Reflection of Heat.*—Polished objects reflect the greater part of the heat which falls upon them; the reflected and incident rays are always in the same plane, and the angles which they make with a perpendicular to the reflecting surface are always equal. By means of concave mirrors, the rays of heat, like those of light, may be brought to a focus, and, if sufficiently intense, they will ignite combustible substances placed there. The law of the reflection of heat may be roughly demonstrated by holding a flat sheet of tin plate in such a position before a common fire that the light of the fire may be reflected from it; the sensation of heat will be perceptible upon the face the moment that the reflection of the fire is seen. The same fact may be shown in a still more striking manner by means of two similar concave parabolic mirrors (fig. 100, page 200) arranged opposite each other, at the distance of ten or twelve feet or more. If a lighted candle be placed in the focus of one of the mirrors, the rays will fall upon its concave surface, and thence be reflected in parallel lines to the surface of the second mirror, from which they will be a second time reflected, and will converge at its focus; a luminous spot being

formed upon a piece of paper held in this position. If for this paper one of the balls of a differential thermometer be substituted, the expansion of the air in that bulb will afford evidence that the heat as well as the light is reflected. That the rays take the course described, and which is represented in the diagram, and that they do not act upon the instrument by direct radiation, is shown by interposing a small tinplate screen between the second mirror and the thermometer: in this case the fluid immediately becomes stationary; while if the screen be placed between the instrument and the candle, no sensible effect is produced.

If, instead of a candle, a red-hot ball be placed in the focus of the first mirror, paper may be scorched, and gunpowder or phosphorus inflamed in the focus of the second. Heat, however, is emitted in the form of rays from bodies, whether such bodies be luminous or not. A canister of boiling water may be substituted for the candle or the red-hot ball, and the heat which it emits, although less intense, will be equally well concentrated by the opposite mirror.

(151) *Absorption of Heat.*—Different substances reflect heat unequally. Polished metals possess the power of reflection in the highest degree, but even the metals differ considerably in reflecting power. Melloni, from his experiments, has concluded that of 100 rays

Silver reflects	90
Bright lead reflects	60
Glass reflects	10

By scratching the surface of a body it reflects heat irregularly, in the same way that a sheet of white paper scatters the light which it reflects; and by coating the surface more or less completely with lamp-black, the amount of heat which is reflected may be diminished in a degree proportioned to the alteration of the surface. In this case, that portion of the heat which is not reflected is absorbed. When the heat is all reflected, the temperature of the body remains unaltered; but when absorption takes place, the temperature rises in proportion to the quantity of heat which is absorbed. This difference may be exhibited by placing a lighted taper in the focus of one of the mirrors, and employing in the second focus a differential thermoscope, one ball of which is gilt, and the other ball covered with lamp-black. On placing the gilt ball in the focus, scarcely any motion of the fluid in the stem is perceived; but on reversing the balls, although no more heat falls on the instrument than before, the liquid rapidly descends: in the first case, the heat is for the most part reflected; in the second it is absorbed, and the temperature consequently rises.

A similar result may be obtained by taking two bright tin plates, and coating one surface of one of them with lamp-black. On placing them in a vertical position, with a hot iron ball midway between them, the blackened surface being directed towards the source of heat, it will be found that the blackened plate becomes heated by absorption, while the other remains cool: this may be shown by causing a cork to adhere to the outer surface of each plate, by means of a little wax or pomatum; the wax will melt upon the blackened plate, and the cork will fall from it, much sooner than on the bright one.

The power of reflection seems to reside almost exclusively in the surface of the body. A film of gold leaf, not exceeding $\frac{1}{200000}$ inch in thickness, answers the purpose of a reflector nearly as well as a mass of solid gold; since a sheet of paper partially gilt, if held within a short distance of a mass of red-hot metal, will become scorched, excepting in those points which are protected by the metallic film. The absorbing power of a substance is inversely proportioned to its power of reflecting heat; the best reflectors are the worst absorbents, and *vice versâ*. As is the case with light, so it is found with radiant heat, that the greater the angle of incidence the more complete is the reflection.

(152) *Connexion between Absorption and Radiation.*—The experiments of Leslie have established an important connexion between the absorbent and the radiating powers of the same substance; they are in all cases directly proportioned to each other. The great diversity of radiating power possessed by different substances may be exemplified by the following experiments. Let a cubic canister of tin plate have one of its sides covered with lamp-black, and a second side with writing-paper, let a third be scratched in various directions, and let the fourth remain polished. On placing the canister, filled with hot water, in the focus of one mirror, and a thermoscope in the focus of the other, it will be found, on presenting each side in succession to the mirror, that a different temperature is indicated. The heat radiated will be found to be greatest from the lamp-black, less from the paper, still less from the scratched face, and least of all from the polished surface.

In consequence of the more rapid radiation from blackened than from polished surfaces of the same metal, a given quantity of a hot liquid placed in a blackened vessel will sooner reach the temperature of the surrounding air than if it be placed in a vessel with a polished surface.

In the economical applications of heat, constant scope is afforded for the employment of the powers of reflection, radiation, and absorption. The meat screen and the Dutch oven, when kept bright, are instances of the application of the reflection of heat to beneficial purposes, in directing the heat upon the objects between them and the fire. Tea made in a silver teapot, which, owing to its polished surface, long retains its high temperature, is superior in flavour to that made in black earthenware, which rapidly loses its heat by radiation. Pipes for the conveyance of steam should be kept bright until they reach the apartment where the heat is to be distributed, and there the surface should be blackened, in order to favour the process of radiation.

(153) *Formation of Dew.*—The distribution of heat by radiation is not confined to bodies highly heated. All substances, whatever be their temperature, are constantly radiating a certain portion of heat, the amount of which depends upon their temperature. If the bulb of a thermometer be placed in the focus of a parabolic mirror, which is turned towards a perfectly cloudless sky, in such a direction that the sun's rays shall not fall upon the mirror, the temperature will sink several degrees; at night, frequently as much as 15° or 18°. The thermometer, like all other objects, is constantly radiating heat; the mirror cuts it off from the rays proceeding from surrounding objects, and the portion of space towards which it is presented not returning the heat radiated towards it from the instrument, the temperature of the thermometer necessarily falls. A similar experiment is easily made with the conjugate mirrors. If in the focus of one mirror, a cage filled with ice (c, fig. 100) be supported, and in the focus of the opposite mirror, the bulb, B, of the differential

FIG. 100.

thermoscope, which has been blackened to favour radiation, and which is screened from the radiation of surrounding objects by a second small mirror, as at A, the liquid will soon rise in the stem connected with the blackened bulb, because the bulb radiates towards the ice, which only partially returns the rays which it receives; and the radiation from surrounding bodies upon the thermoscope being prevented, its temperature falls.

The principles of radiation were applied by Dr. Wells to the explanation of the phenomenon of dew. Dew forms most copiously during a calm, clear night succeeding a hot day: it is deposited in exposed situations and upon the leaves of plants, and on filamentous objects in general. As soon as the sun dips below the horizon, and in shady places even before sunset, radiation from the earth is no longer compensated by the solar rays; the temperature of the surface is, therefore, speedily reduced below that of the stratum of air in contact with it; this stratum being charged with moisture, is no longer able to support so much vapour in the elastic form, but deposits it (just as when a glass of cold spring water is brought into a warm room, it becomes bedewed with moisture on its outside); and the force of cohesion collects the water into the pearly drops that stud the herbage and sparkle in the sloping rays of the sun. On cloudy nights little or no dew is deposited, because the masses of suspended vapour intercept the rays from the earth, and return them to its surface. Overhanging buildings, or the projecting branches of trees in a similar way, return the heat to the objects beneath them, and prevent the reduction of temperature which necessarily precedes the deposition of dew. On windy nights, the equilibrium is rapidly restored by the contact of fresh surfaces of air with the radiating crust of the earth, and little or no dew is formed. Upon metallic bodies, which are bad radiators, and upon the hard-beaten path or road, where the heat is conducted rapidly from the strata beneath, little or no dew is deposited; while upon the branching shrub, the tufted grass, and the downy leaf, abundance of moisture is collected, these being precisely the objects which derive most benefit from its presence.

In India, near the town of Hoogly, about forty miles from Calcutta, the principle of radiation is applied to the artificial production of ice. Flat shallow excavations, from one to two feet deep, are loosely lined with rice straw, or some similar bad conductor of heat, and upon the surface of this layer are placed shallow pans of porous earthenware, filled with water to the depth of one or two inches. Radiation rapidly reduces the temperature below the freezing point, and thin crusts of ice form, which are removed as they are produced, and stowed away in suitable ice-houses until night, when the ice is conveyed in boats to Calcutta. Winter is the ice-making season—viz., from the end of November to the middle of February.

The fundamental fact of cooling by radiation of the bodies on which dew is forming, is easily verified. If a thermometer be laid upon a grass plat, on a clear night, it will be found to indicate a temperature several degrees below that shown by a second thermometer, suspended two feet or more from the surface.*

(154) *Law of Cooling by Radiation.*—The rapidity of the cooling of any body by radiation depends upon the excess of its temperature over that of the external air. The hotter the body the more rapidly does it cool; and as it approaches the temperature of the air, the more slowly does it lose its excess of heat.

Newton assumed that the quantity of heat lost by a hot body, for equal intervals of time, was proportioned to the excess of its temperature above that of the surrounding air; so that if a body heated to 100° in an atmosphere at 0°, lose 10° in one minute, the same body heated to 50° would lose 5° per minute, the air being also at 0°. Later experiments, however, have shown that this assumption is not exact, even for low temperatures, and becomes very inaccurate at high ones.

MM. Dulong and Petit have published a series of researches upon the rate of cooling by radiation. They employed a hollow sphere of thin brass, blackened in the interior, and furnished with arrangements for exhausting it of air. For the heated body they used a thermometer with a large bulb, heated to a determinate degree, and supported in the centre of the hollow sphere. They then placed the apparatus in water which was maintained at a constant temperature, and they observed that the rate

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* A curious formation of ice at the bottom of some rapid, clear, and rocky streams, is occasionally seen under the influence of radiation, during the prevalence of bright frosty weather. The water cools down to 40° F. as usual, but below this point the colder water no longer forms a protecting layer, as in still sheets or gently moving streams; the agitation produced by the passage of the water through its precipitous and irregular channel makes the temperature uniform throughout, till it arrives at the freezing point; radiation meantime proceeds through the water from the weeds and rocky fragments in the bed of the stream. These become now the coldest points, and to them the ice attaches itself in silvery, cauliflower-shaped, spongy masses, sometimes accumulating in quantity sufficient to dam up the stream, and cause it to overflow; at others, as the ice increases in bulk and buoyancy, it rises in large flakes, raising to the surface portions of rock, and even iron itself; it has indeed been productive of serious inconvenience, by lifting and transporting to a considerable distance the heavy masses of iron which are used to prevent the removal of the buoys employed to indicate the navigable channels of rivers.

of cooling differed with the nature of the gaseous medium contained in the globe. If the temperature of the sphere continued constant whilst the experiments were made *in vacuo* upon the heated body, at temperatures ascending according to the terms of an arithmetic progression, the rapidity of cooling increased according to the terms of a geometric progression, diminished by a constant quantity; this constant quantity being the heat radiated back upon the cooling body, from the inner surface of the sphere. If the temperature of the sphere and that of the heated body were *both* raised according to the terms of an arithmetical progression, so that the difference between the two was always constant, it was found that the rate of cooling increased as the temperature rose, according to the terms of a geometric progression.

(155) Radiation takes place more freely *in vacuo* than in air. It is calculated that the solar rays, in traversing a column of air 6000 feet high, are deprived of $\frac{1}{8}$ their heat in consequence of the imperfect transparency of the air. The absorption of heat is, however, influenced by an important cause, to which no allusion has yet been made, and which was first placed in its true light by the experiments of Melloni.

If a number of sources of heat be employed different in kind and in intensity, such as the naked flame of an oil lamp, a platinum wire heated to redness in the flame of a spirit lamp, a sheet of copper heated to between 700° and 800° F., in a current of heated air which is rising from a lamp placed beneath it, and a copper canister filled with boiling water,—the ball of a thermoscope covered with lamp-black may be placed at such a distance from each of these sources of heat that the liquid shall stand in each case at the same point; that is, the temperature to which the thermoscope is exposed shall be equal in each case. Now, if these distances be noted, and if the ball of the thermoscope be covered with a variety of other substances in succession, instead of with lamp-black, the thermoscope when exposed to each of the different sources of heat in succession, will appear to receive different proportions of heat, although placed at the distances at which, when it was coated with lamp-black, the heat appeared to be equal. Thus, suppose that the heat absorbed, when the lamp-black was used, in each case were equal to 100: if the thermoscope were coated with white lead, it was found that, at the same distance from the naked flame as before, it indicated a heat of only 53; opposite to the red-hot platinum the heat was 56, instead of 100 as with the lamp-black. With the copper at 700° F., a heat of 89 instead of 100 was indicated; while opposite the canister of boiling water the thermoscope showed a heat of 100, corresponding exactly with the effect upon it when lamp-black was used.

The following table exhibits some of the results which Melloni obtained by operating in this way:—

Relative Absorbability of different kinds of Heat.

	Naked Flame.	Incandescent Platinum.	Copper at 750° F.	Copper at 212°.
Lamp-black	100	100	100	100
White Lead	53	56	89	100
Isinglass	52	54	84	91
Indian Ink	96	95	87	85
Shell Lac	43	47	70	72
Polished Metal . . .	14	13·5	13	13

Lamp-black appears to absorb all the rays that fall upon it, from whatever source they may have originated; and the amount absorbed by metallic surfaces, although smaller, is nearly uniform, whatever be the source. It has also been observed, that the less intense the source of heat, the greater is the proportion absorbed.

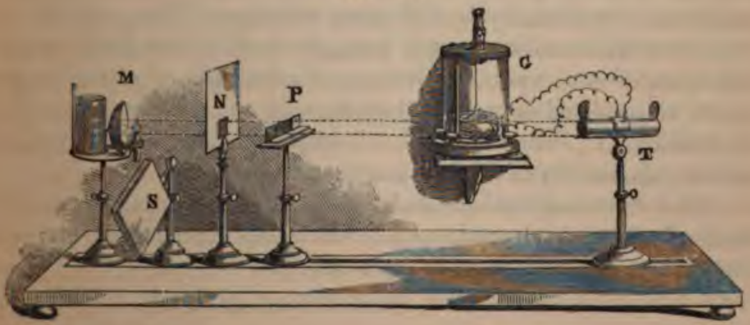
Franklin, nearly a century ago, made the observation that solar heat is absorbed with greater or less facility according to the colour of the object upon which the rays fall, but that little or no such difference exists with the heat of a lamp or of a candle. He took pieces of cloth, similar in texture and size, but different in colour, and placed them in the sunlight, upon newly-fallen snow, and he found that the snow melted under the pieces of cloth with greater rapidity the darker the tint—the absorption being greatest under the piece of black cloth, then followed the blue, then the green, purple, red, yellow, and white pieces, in the order enumerated.

(156) *Transmission of Heat through Screens.*—The cause of these remarkable differences will be best understood by a consideration of the phenomena attending the transmission of heat through bodies which allow it to pass unobstructed, as glass allows light to pass. Melloni terms those bodies which thus transmit heat *diathermanous*, or *diathermic*—those which do not allow this transmission of heat being termed *athermanous* or *adiathermic*.

Bodies that are transparent to light are by no means equally so to radiant heat. This arises from two causes, which require to be carefully distinguished from each other, and which may be separately illustrated by a parallel action on the rays of light. A glass containing pure water absorbs very little light, and transmits almost all that it does not reflect: if the attempt be made to measure its transparency by ascertaining the distance at which a page printed in small type is legible when the vessel of water is interposed, and afterwards, when it is removed, the difference in the two cases is hardly appreciable. If a few drops of a mixture of Indian ink and water be added, the transparency will be diminished, and the characters will be legible at a smaller distance; a further addition of ink will diminish the transparency more and more, until the letters can be no longer discerned. The light that is transmitted, however, although diminished in quantity, is of the same character as the incident light; and a prismatic analysis shows that both consist of the same colours in the same proportion: if indigo be substituted for Indian ink, the legibility of the page is diminished to an extent nearly equal; but the prism shows that certain of the rays have been absorbed more completely than others. Similar effects are produced with the rays of heat. There are, however, a number of substances which are almost perfectly transparent to light—viz., among solids, glass, diamond, Iceland spar, ice, and a great number of crystals; amongst liquids, water, spirit of wine, ether, turpentine, and a multitude of other bodies; and among aeriform bodies, atmospheric air, and the greater number of gases. For heat, on the contrary, there is only one known solid that is perfectly diathermic, and that is rock salt; colourless gases possess the property also in a very high degree; but no liquid has yet been discovered which is free from absorptive action on the thermic rays.

The more important parts of the apparatus employed by Melloni in these researches are represented in fig. 101. One of his

Fig. 101.



four principal sources of heat—viz., naked flame, ignited platinum, blackened copper, heated to 750°, or copper heated to 212°, was placed as at M, on a moveable support, behind the perforated screen N, the rays being concentrated, when necessary, by the concave mirror, M, and were received at a suitable distance from this upon the thermoscope or thermo-multiplier, T.* If a double screen, S, of polished copper were interposed between the source of heat and the thermoscope, the rays of heat were entirely intercepted. Having placed the thermoscope at such a distance as always to indicate, when the copper screens were removed, a constant given elevation of temperature, a plate of some substance, the *diathermacy* of which was to be ascertained, was then introduced at P; and on observing the difference of temperature, as marked by the instrument, the proportion of heat which the plate transmitted was at once ascertained. In this manner Melloni proved that plates of rock salt of great transparency, varying in thickness from the $\frac{1}{12}$ of an inch to 2 or 3 inches in thickness, transmitted 92 out of every 100 rays incident upon them, whatever were the source of heat employed; the loss of 8 per cent. being due to a uniform quantity which is reflected at the two surfaces of the plate; rock salt, therefore, is to heat what pure colourless glass is to light. The following experiment shows the independence of diathermacy and transparency:—If a cast-iron ball heated to about 400° F. be placed midway between the blackened bulbs of a thermoscope, each bulb will receive an equal amount of heat, and the liquid will remain stationary; but if a plate of rock salt be interposed between the iron and one of the bulbs, and a plate of glass of equal thickness be placed between the hot ball and the other bulb, it will be found that although both plates are almost equally transparent to light, yet the bulb next the rock salt will rise in temperature much more rapidly than the one next the glass. In liquids, the independence of transparency and diathermacy is still more striking. Thus, out of 100 rays that fell from an argand lamp, on each of four fluids equally transparent—viz., water, sulphuric acid, ether, and oil of turpentine, water transmitted only 11, sulphuric acid 17, ether 21, and oil of turpentine 31; while chloride of sulphur, which is of a reddish colour, allowed 63 of the incident rays to pass.

The following table includes some of the results obtained by Melloni, for several solid bodies: in these experiments plates of equal thickness were used in each case.

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* In these inquiries a peculiar and very delicate thermometric apparatus, termed a *thermo-multiplier* (267), was generally employed.

Diathermacy of different Solids.

Each plate was 0·102 inch thick.	Naked Flame.	Ignited Platinum.	Copper 750° F.	Copper 212° F.
Rock Salt (limpid)	92·3	92·3	92·3	92·3
Sicilian Sulphur (yellow)	74	77	60	54
Fluor Spar (limpid)	72	69	42	33
Rock Salt (cloudy)	65	65	65	65
Beryl (greenish yellow)	46	38	24	20
Iceland Spar (limpid)	39	28	6	0
Plate Glass	39	24	6	0
Quartz (limpid)	38	28	6	3
Quartz (smoky)	37	28	6	3
White Topaz	33	24	4	0
Tourmaline (dark green)	18	16	3	0
Citric Acid	11	2	0	0
Alum	9	2	0	0
Sugar-Candy (limpid)	8	1	0	0

Diathermacy of Liquids contained in Glass—stratum of liquid 0·362 inch. The source of heat in each case was an argand oil lamp.

Bisulphide of Carbon (colourless)	63
Bichloride of Sulphur (red brown)	63
Terchloride of Phosphorus	62
Essence of Turpentine	31
Colza Oil (yellow)	30
Olive Oil (greenish)	30
Ether	21
Sulphuric Acid (colourless)	17
Do. (brown)	17
Nitric Acid	15
Alcohol	15
Distilled water	11

It by no means necessarily follows that a body which is transparent to light is also able to allow the passage of heat, and *vice versâ;* sulphate of copper, which permits the passage of blue light abundantly, arrests the rays of heat entirely. Again, the opaque black glass, used for the construction of polarizing mirrors, transmits a considerable portion of the thermic rays. Smoked rock salt and black mica also exhibit the same power.

Mechanical arrangement appears to have even more influence upon diathermacy than chemical composition. Common table salt is perfectly adiathermic. A solution of rock salt is scarcely superior to pure water in diathermacy, and a solution of alum is equally diathermanous with a solution of rock salt. This is perfectly consistent with the effect which alteration of structure produces on the action of bodies on light. Common loaf-sugar is opaque and of dazzling whiteness, but pure sugar-candy (the same body only in larger crystals) is colourless and transparent: the most transparent glass, by pulverization, may be reduced to a white opaque powder.

As already mentioned, pure colourless rock salt is the only solid substance the diathermacy of which is perfect. All other bodies upon which M. Melloni has made experiments, transmit a quantity of heat which varies with the nature of the source, from a second cause, which has been termed *thermo-chrosis*, or calorific tint, which is analogous to a difference in colour for objects transparent to light; to this cause must be attributed the remarkable differences in the amount of absorption (155), according to the source from which the heat emanates.

(157) *Refraction.*—Radiant heat, like light, is susceptible of refraction: a large convex lens, or a concave mirror, placed in the sun's rays, not only gives a focus of intense light, but, as is well-known, constitutes a powerful burning-glass. Inflammable objects are easily ignited by this means, and the focus of heat is found to correspond with that of the greatest light. Further, if a solar beam be subjected to the action of a prism of transparent rock salt, and the coloured spectrum so obtained be examined by means of a small but sensitive thermometer, it is found that the rays of heat, like those of light, possess unequal degrees of refrangibility; hence, the rays of heat are not all accumulated in one spot, but are distributed over the entire spectrum. There are, in fact, differences in the rays of heat corresponding to those of colour in the rays of light. The greater portion of the rays of solar heat are even less refrangible than the red rays, for the maximum of temperature in the solar spectrum is found at a distance below the extreme red rays as great as the brightest yellow is above them. By the employment of different sources of light, spectra are obtained in which the intensity of the light varies in different parts, according to the prevailing colour of the luminous rays,—the yellow light of common salt giving a spectrum most intense in the yellow rays, and the red light of nitrate of strontia giving a spectrum in which the red rays possess the greatest intensity. In the same manner, by varying the source of heat which is employed, the position of maximum temperature in the refracted beam is found to vary: the less intense the source of heat, the smaller is the refrangibility of the heat radiated. The flame of a naked lamp, for example, emits rays of heat of all degrees of refrangibility, its maximum of intensity being about the middle of the spectrum; from the ignited platinum, the maximum heat falls nearer to the red; from copper at 750° nearer still; and the heat radiated from a surface at 212° contains scarcely any of the more refrangible rays. Now it is obvious, that a mixed pencil of heat, which falls upon a diathermanous medium, which absorbs certain of the rays of heat

and not others, will be altered in a manner similar to that which a ray of light experiences in traversing a coloured glass.

With a knowledge of these facts there is no difficulty in understanding how it is that the sun's rays can traverse a plate of glass and experience but little absorption, and can be brought to a point by a convex lens, or by a glass concave mirror, either of which remains cool while intense heat is developed at its focus; whereas, if the same lens or concave mirror be held opposite to a common fire, a bright spot of light will be obtained at the focus, but little or no heat; whilst the glass of which the lens or mirror is composed will become strongly heated. The rays which glass transmits most readily are those which abound in solar light, but these are precisely the rays which are least abundant in incandescent bodies. Advantage has long been taken of this fact by those who have occasion to inspect the progress of operations carried on in furnaces; they are able by the use of a glass screen to protect the face from the scorching rays which the glass absorbs, although it offers no impediment to the transmission of light.

This absorption of radiant heat by glass is easily demonstrated by placing a canister of hot water in the focus of one of the conjugate mirrors (fig. 100) and a thermoscope in the focus of the other: the air in the acting ball of this instrument ceases to dilate the instant that a glass screen is interposed anywhere between the two mirrors: the glass absorbs the rays, and becomes heated itself.

(158) *Probable Independence of Light and Heat.*—A consideration of the preceding facts led M. Melloni to the discovery that by a combination of screens which allow light of a given colour to pass, radiant heat may be entirely arrested; and thus a separation of the two forces may be effected. By transmitting the solar rays, first through a glass vessel filled with water, which arrests the less refrangible rays, and then through a plate of a peculiar green glass tinged by means of oxide of copper, which stops the more refrangible rays, a greenish beam was obtained, which was concentrated by lenses, and furnished a greenish light of great intensity, but yet produced no heating action, when it was allowed to fall upon the face of a delicate thermoscope. A similar separation of light and heat is effected in nature, in the light reflected by the moon. Melloni concentrated the rays of the moon by means of an excellent lens of forty inches in diameter, and obtained a brilliant focus of light of 0·4 inch in diameter; upon directing this focus of light upon the face of a very sensitive thermo-multiplier, only an extremely feeble indication

of heat was obtained.*—(Melloni, *Thermochrose*, Part I. note, p. 251).

The foregoing observations show that in the analysis of radiant heat, prisms and lenses of glass should not be used, since they lead to results as incorrect as those which would be furnished by studying the phenomena of light by means of coloured prisms and lenses. Rock salt furnishes the only known material of which such apparatus can properly be constructed, and by its means, rays proceeding even from the human body may readily be concentrated and made to act upon a thermoscope. These researches of Melloni explain the cause of the contradictory results obtained in the earlier experiments on the refraction of heat.

In all experiments on radiated heat it has been observed that heat when once absorbed, whatever may have been its original source, acts in the same manner in producing expansion; and when radiated again it does not retain the peculiarities of the source from which it originated: the refrangibility of the re-radiated heat depends solely upon the temperature of the surface that emits it a second time; so that it is immaterial whether it were originally derived from the sun, from a lamp flame, from ignited platinum, or from non-luminous bodies; although it is well known that the refrangibility decreases with the temperature of the source from which it is derived. This alteration in the refrangibility of radiant heat corresponds with the discovery made by Mr. Stokes of a similarde gradation of refrangibility in light (104). Heat of low refrangibility may, however, be converted into that of higher refrangibility: for example, a jet of mixed oxygen and hydrogen gases furnishes a heat nearly as intense as any which art can command, yet it does not emit rays which have the power of traversing glass in any considerable quantity,

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* It ought, however, to be stated, that influenced by theoretical considerations, Melloni, in opposition to these experiments and to his earlier opinions, maintained, during the latter years of his life, the identity of the agent that produces light and heat. Traces of heat, he says, are found in every luminous ray; he supposes that the rays of heat may be invisible just as the chemical rays beyond the violet end of the spectrum are invisible, because the structure of the retina is not susceptible of undulations, the frequency of which exceeds or falls short of a certain amount. No doubt there exists an average limit to the power of the retina to receive luminous impressions from solar radiations; the boundary between light and darkness being almost imperceptible. In certain individuals the retina is insensible to the extreme rays at the red end of the spectrum, which are plainly discerned by others. A parallel case occurs in the audibility of sounds: in some individuals the ear is unable to perceive notes in which, as in the chirp of a cricket, the vibrations exceed a certain number per second, though such sounds are plainly audible to the majority of persons.

even though a lens be employed for their concentration. Upon introducing a cylinder of lime into the jet of burning gases, though the amount of heat is not thus increased, the light becomes too bright for the unprotected eye to endure, and the thermic rays acquire the property of traversing glass, as is shown by their action upon a thermometer the bulb of which is placed in the focus of the lens.

(159) By the employment of tourmalines, and by transmission through bundles of mica placed at suitable obliquities to the incident ray, it has been further shown that radiant heat is also susceptible of polarization; since the rays are transmitted and reflected alternately, according as the reflecting planes of the mica bundles coincide, or cut each other at right angles: Knoblauch (*Poggendorff, Annal.* lxxiv. 9) has also recently obtained distinct evidence of the diffraction and interference of the rays of heat. The parallelism in the mechanical properties of radiant heat and of light is thus shown to be complete.

§ III.—HEAT OF COMPOSITION.

(160) *Specific Heat.*—It has been already stated (125) that the temperature of a body affords no indication of the actual quantity of heat which such a body contains. The thermometer does not even give the proportionate amount of heat which equal bulks of the same substance contain, if they be compared at different temperatures. It may, however, be made to furnish an estimate of the relative quantities of heat contained in two different masses, either of the same substance or of different substances. The mode in which this is effected we proceed now to illustrate.

Equal bulks of different kinds of matter, at the same temperature, contain very different quantities of heat. When equal volumes of water, or of oil, or of any liquid, at different temperatures, are mixed with due precautions, they yield a mass the temperature of which is exactly the mean of the two. Thus, a pint of water at 40° F., added to a pint of water at 100° F., gives 2 pints of water at 70°. But if two dissimilar liquids be used, the result is different. A pint of water at 40° mixed with a pint of mercury at 100°, gives a mixture the temperature of which is only 60°; but a pint of mercury at 40° mixed with a pint of water at 100°, gives a mixture having a temperature of 80°. Mercury is therefore said to have less capacity for heat than water. It requires a smaller amount of heat to raise it a given number of degrees in temperature than is required to produce an equal elevation of temperature in the same measure of water. If equal weights of the two bodies be employed instead of equal volumes, the difference is still more striking. A pound of mercury at 40°, agitated with a pound of water at 156°, gives a mixture the temperature of which is = 152°·3. The water loses 3°·7, while the mercury gains 112°·3. The quantity of heat which would be required to raise any substance 1° F. in temperature compared with the quantity of heat required to raise an equal weight of water 1°, is called its *specific heat:* therefore, taking the specific heat of water as 1, that of mercury will be 0·033:—since 112°·3 : 3°·7 :: 1 : x (=0·033).

The specific heat of liquids may be determined by the process of mixture just described. If the body be in the solid form, the specific heat may be ascertained by heating equal weights of the different solids which are to be compared, to the same degree, then immersing each in an equal bulk of water and observing the elevation of temperature produced in each case. Experiments conducted in this manner, show that great differences in specific heats exist. Researches of this nature are necessarily attended with great difficulty, owing to the variety of sources of error, and the number of precautions required in order to ensure accuracy. Full particulars upon these points are given in the papers of Dulong and Petit and of Regnault upon this subject in the *Annales de Chimie.*

Another mode of ascertaining differences in specific heat is founded on the different rates of cooling exhibited by equal masses of dissimilar composition, those which have the greatest specific heat cooling most slowly. Suppose the different bodies to be compared have all been heated to 212°, placed in the same vessel, and allowed to cool down 50°, under exactly similar circumstances; by noting the time occupied by each in cooling through this interval, and by comparing this with the time required by an equal weight of water to cool through the same thermometric interval, a series of numbers would be obtained which would represent approximatively the specific heats of the bodies in question; making the time occupied by water in cooling, the unit of comparison, or 1.

Lavoisier and Laplace determined the specific heats of a variety of substances, by ascertaining the quantity of ice which equal weights of the different bodies were able to melt in falling from the temperature of 212° to that of 32°. This process is excellent in principle, but in practice the difficulties which attend it render the results inaccurate.

The following table gives a few of the latest results of Regnault upon specific heat (*Ann. de Chimie,* II. 73, p. 64), obtained by the process of mixture or immersion.

Specific Heats of Equal Weights between 32 *and* 212°.

Water	1·0000
Oil of Turpentine	0·4259
Charcoal	0·2411
Glass	0·1976
Arsenic	0·0814
Cadmium	0·0567
Palladium	0·0592
Mercury	0·0333
Gold	0·0324

Any circumstance which alters the relative distances between the particles of which a body is composed, at the same time alters its specific heat. Mechanical compression sufficient to produce a permanent alteration in density is attended by a corresponding decrease in specific heat. A piece of soft, well annealed copper, gave M. Regnault a specific heat of from 0·09501 to 0·09455; the same copper, after hammering, had a specific heat of from 0·0936 to 0·0933; on being again thoroughly annealed, so as to recover its former density, its specific heat was from 0·09493 to 0·09479, or almost exactly the same as at first. To this diminution of specific heat by compression may be partially due the heating of cold metallic bars observed during the operation of rolling. They become denser, and consequently have less capacity for heat.

In like manner the sudden compression of aeriform bodies is attended with the evolution of a very large amount of heat, which may even rise high enough to ignite tinder and other inflammable substances. On rarefying air the opposite effects result. One evidence of the fact is afforded by the mist which forms within a glass receiver while it is undergoing exhaustion. On first working the pistons of the air-pump, the sudden expansion deprives the moisture which all air contains, of part of the heat necessary for its existence in the gaseous form, and it condenses in minute drops, which speedily evaporate again as the equilibrium of temperature is restored. If compressed air be allowed suddenly to expand, by escaping into the atmosphere, a similar phenomenon is produced; a demand for the heat which the air had lost in compression suddenly arises, and moisture is deposited as before.

These facts will enable us to understand the general distribution of temperature in any vertical column of the atmosphere of our globe. Suppose the atmosphere, without being altered in weight or quantity, to be reduced to a stratum of uniform density throughout, with a uniform temperature of 80°; it would extend to a height of about 28,000 feet. Now if this air, throughout the entire thickness of the stratum, suddenly took the adjustment due to its elasticity—owing to the alteration in the capacity for heat of the dilated air, the temperature would fall in every part of the column, except at its base, where it would remain stationary; at 15,000 feet it would be about 32°, and at 30,000 feet it would be about —30° F. Owing to the cause just explained, a progressive diminution of the temperature is experienced, as the altitude of the observer above the surface of the earth increases; and this depression of temperature is such, that even in tropical climates, the summits of lofty mountains are always crowned with snow. The limit of perpetual snow gradually descends (subject, however, to irregularities, from local causes) towards the level of the sea, according as the place of observation approaches towards either pole. A blast of cold air, therefore, in descending from a lofty height would have its temperature elevated without any supply of heat from extraneous sources by the mere condensation which it experiences as it approaches the surface of the globe; and the danger arising from its chilling influences would be thus simply and effectually averted. Observations have shown that the average depression of temperature in ascending from the sea level amounts to 1° F. for every 300 feet; and the following table is given by Daniell (*Meteorology*, vol. i. p. 41) as an approximative estimate of the distribution of heat in the atmosphere due to this cause, supposing, as indicated in the second column, that the initial temperature of 80° F., is that of the surface of the earth near the equator, and that the initial temperature of 0° F. indicated in the third column is that towards the poles.

Decrease of Temperature in the Atmosphere from Elevation.

Altitude in feet.	Temperature.	Temperature.
0	80°	0°
5000	64·4	—18·5
10000	48·4	—37·8
15000	31·4	—58·8
20000	12·8	—82·1
25000	—7·6	—109·1
30000	—30·7	—140·3

As the expansion of bodies by heat increases in an increasing ratio for equal increments of heat, as the temperature rises, so also as the space between the particles of bodies continues to increase with the temperature, the amount of the specific heat gradually increases as the body becomes hotter. A few of the results obtained by experiments on this subject by Dulong and Petit are given in the annexed table.

Rise of Specific Heat with Rise of Temperature.

	From 32° to 212° F.	From 32° to 572° F.
Mercury	0·0330	0·0350
Platinum	0·0335	0·0355
Antimony	0·0507	0·0549
Silver	0·0557	0·0611
Zinc	0·0927	0·1015
Copper	0·0949	0·1013
Iron	0·1098	0·1218
Glass	0·1770	0·1900

(161) A body in the liquid state has a higher specific heat than the same substance when it is in the solid form. This is remarkably shown in the case of water, in which the specific heat is double that of ice. Contrasting together the specific heats, as obtained for the following solids, by Regnault, with the numbers obtained by Person, (*Ann. de Chimie*, III. xxi. 295) for the same bodies when liquefied, the amount of this difference will be seen to be liable to great variation:—

Specific Heat of the same Substances, both in the Solid and in the Liquid State.

	Solid. between 32° and 212° F.	Liquid.	
			°F.
Ice	0·505 between 32° and —22°	1·0000	between
Nitrate of Soda .	0·2782	0·4130	788 and 806
Nitrate of Potash .	0·2387	0·3318	662 and 815
Sulphur	0·2026	0·2340	248 and 296
Phosphorus . .	0·1787 (between 45° and —6°)	0·2045	122 and 212
Tin	0·0562	0·0637	464 and 644
Lead	0·0314	0·0402	644 and 824
Bismuth	0·0308	0·0363	536 and 716

Of all solids and liquids water is that which possesses the largest amount of specific heat. This circumstance contributes in no small degree towards moderating the rapidity of transitions from heat to cold, or from cold to heat, owing to the large quantity of heat which the ocean absorbs or emits in accommodating itself to the variations of external temperature. Mercury, on the hand, has a very low specific heat, which much enhances its sibility to changes of temperature and increases its fitne thermometric purposes.

The determination of the specific heats of gases is at with so many difficulties that, although researches on the have been conducted by many philosophers distinguished f perimental skill, yet the statements which have been mad the subject are most discordant and unsatisfactory.

An important relation between the specific heat elementary body and its chemical equivalent, or the propor which it enters into combination with a fixed quantity of has been pointed out by Dulong and Petit, from which it that if the specific heat of a body in the solid state be mul into the chemical equivalent of the same body, it gives a which (allowing for errors of experiment) coincides almost with the product obtained by multiplying together the heat and the equivalent of any other elementary substance. subject, however, will be more advantageously examined he

Latent Heat.

(162) *Disappearance of Heat during Liquefaction.*—When passes from the solid into the liquid state, or from the liqu the aeriform state, heat in large quantity disappears, and ce the time to affect the thermometer; hence, this modification is called *latent heat*. For example, when a lump of ice at brought into a warm room, it gradually thaws and is con into water; but neither the ice, nor the water in contact rises in temperature. So long as any portion of the ice r unmelted, the water continues to indicate the temperature as does also the ice. Again, a pound of water at 212°, with a pound of water at 32° gives two pounds of water at 122°, is the mean temperature; but a pound of ice at 32°, mixe a pound of water at 212°, gives two pounds of water, of whi temperature is only 51°.

In this case the water has lost 161°, whilst the ice has only 19°; so that 142° have disappeared, or have become Thus, in order to convert a pound of ice at 32° into water a heat sufficient to raise 142 lb. of water from 32° to 33° is ne Water, therefore, may be regarded as ice in combination certain quantity of heat. This heat, however, is not lost, for progressive cooling of water be observed in an atmosphere degrees below the freezing point, it will be found that the temperature of the liquid sinks regularly until it reaches 32°, when it becomes stationary, and freezing begins; the heat being supplied from that which is latent in the water. As soon as the whole has become solid, the thermometer again shows that the temperature of the mass sinks, until at length it reaches that of the surrounding air. Some idea of the quantity of heat that is required to convert ice into water, without any apparent rise in temperature, may be formed from the fact that the simple conversion of a cube of ice three feet in the side into water at 32°, would absorb the whole heat emitted during the combustion of a bushel of coal. (Faraday.)

This large amount of heat latent in water, which is given forth as it freezes, furnishes a source of heat of the greatest value in mitigating the severity of any sudden setting in of frost, as the very act of freezing moderates the effect of the depression of temperature on surrounding objects, and renders the transition from heat to cold, and of course the converse from cold to heat, more gradual and uniform. Another very important purpose is attained by this gradual liquefaction of ice: but for this contrivance the ice that had accumulated during a long winter would at the first breeze from the south be instantly converted into water, and sweep before it, not merely the habitations of man and their tenants, but trees, rocks, and hills. Such fearful catastrophes do now and then occur, when a volcano such as Etna pours forth a stream of lava over its snow-clad sides; the flood that then ensues is even more destructive than the fiery torrent itself. The latent heat of water is greater than that of any other body, but in all cases of liquefaction there is a similar disappearance of heat; the quantity which becomes latent varying with the nature of the substance.

Person (*Ann. de Chimie et de Phys.*, III. xxi. 295, and xxiv. 265) has determined the latent heat absorbed during the fusion of a considerable number of bodies, and he concludes that the latent heat of fusion is obtained by multiplying the difference between the specific heat of the substance in its liquid and its solid form by a number obtained by adding the number 256° (an experimental constant furnished by researches upon the latent heat of water) to the melting point °F. of the substance in question.*

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* If l = the latent heat, d the difference of the specific heat in the liquid and in the solid state, t the melting point on Fahrenheit's scale, the latent heat may be calculated by the formula

$$(256 + t)\ d = l.$$

The results obtained with the metals do not accord with Person's theory, *Table of Latent Heat.*

	° F.	Water = 1.
Water	142·65	1·000
Nitrate of Soda . . .	113·34	0·794
Nitrate of Potash . .	85·26	0·598
Zinc	50·63	0·355
Silver	37·92	0·265
Tin	25·65	0·179
Cadmium	24·44	0·171
Bismuth	22·75	0·159
Sulphur.	16·85	0·118
Lead	9·65	0·067
Phosphorus	9·05	0·063
Mercury	5·11	0·035

The numbers in the second column of the table represent the number of degrees of temperature that an equal weight of water would be raised by the passage of each of the bodies enumerated, from the liquid to the solid state, or they may be taken as the number of pounds of water that would be raised 1° of Fahrenheit by the heat emitted during the congelation of one pound of each of the substances included in the table.

(163) *Freezing Mixtures.*—The chemist avails himself of the fact that heat disappears during liquefaction, for the purpose of procuring artificial cold: the action of freezing mixtures depends upon this principle. Many salts while undergoing solution produce a very considerable reduction of temperature. For example: 4 ounces of nitre and 4 of sal ammoniac, each in fine powder, mixed with 8 ounces of water, reduce the thermometer from 50° to 10° F. So, likewise, equal parts of water, of powdered crystallized nitrate ammonia, and of carbonate of soda also crystallized and in powder effect a reduction from 50° to —7°.

The most convenient mixture, however, when procurable, consists of equal weights of pounded ice (or better still of fresh snow) and common salt. A steady temperature of —4° F. can by its means be maintained for many hours. Again, a mixture of three parts of crystallized chloride of calcium and two parts of snow will produce a cold sufficient to freeze mercury:—if before making the mixture the vessel in which the experiment is to be performed and the chloride be cooled to 32°, such a mixture will sink a thermometer to –50° F.

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as the difference of their specific heats in the solid and liquid states is very trifling; for other bodies the result calculated corresponds pretty closely with that furnished by experiment. If M. Person's view be correct, a consequence which he ingeniously draws from it is, that the absolute zero of temperature would fall at —256° F.

Even during the liquefaction of a metallic alloy by quicksilver, the same fact is observed: thus an alloy may be formed by melting together 207 parts of lead, 118 parts of tin, and 284 parts of bismuth; if this be granulated, by pouring it, when melted, into water, it may be dissolved in 1617 parts of mercury, and will cause a thermometer, which is immersed in it, to sink from 63° to 14°.

It is owing to this absorption of heat during the liquefaction of solids, that not only in the melting of ice, but in the much higher temperatures required for the fusion of many of the metals, the temperature remains stationary as long as any portion of the mass remains unmelted; the excess of heat is transferred to the unmelted solid by conduction, and is rapidly absorbed by it during its liquefaction.

The following table contains the temperatures at which several substances, metallic and non-metallic, enter into fusion:—

Table of Fusing Points.

	° F.	Authority.
Mercury	—39	
Oil of Vitriol	—30	Regnault
Bromine	—4	
Ice	32	
Phosphorus	111·5	Schrötter
Potassium (about) . . .	131·	
Yellow Wax	143·6	Person
Sodium (about)	190·	
Iodine	224·6	
Sulphur	239·	Person
Tin	451·	
Bismuth	512·	
Nitrate of Soda	591·	
Lead	620·	
Nitrate of Potash	642·	
Zinc	773·	Daniell
Antimony (about) . . .	900	
Silver	1773	
Copper	1996	
Gold	2016	
Cast Iron	2786	
Wrought Iron	above 3280	

The melting point of ice is perfectly stationary* at 32° F.; but water which contains salts in solution has a lower point of

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[*] Prof. W. Thomson of Glasgow states, that in confirmation of the results anticipated from a mathematical investigation made by his brother, and communicated to the Royal Society of Edinburgh, January, 1850, he finds experimentally that the freezing point of water, a liquid which expands

congelation. Sea water, for example, freezes at 28°, the salt separating, and pure water floating in the form of ice; whilst water which is saturated with sea salt sinks as low as —4° F. before freezing.

(164) *Evolution of Heat during Solidification.*—When liquids return to the solid form, their latent heat, or *heat of fluidity*, as it is sometimes called, is again given out. Water, if undisturbed, may be cooled down in a narrow tube even 20° F. below the freezing point without congealing; but the least agitation causes a portion suddenly to solidify, and the latent heat emitted at the moment by the portion which freezes raises the temperature of the whole mass to 32°.

A similar extrication of heat occurs where a supersaturated solution of sulphate of soda (70) is made suddenly to crystallize by agitation, the mass becoming sensibly warm to the hand. The solidification of metallic bodies is attended with a like evolution of heat:—a fluid alloy of sodium and potassium may be easily made by kneading the two metals together; with mercury they form a solid amalgam, and in the act of uniting with it they emit sufficient heat to set fire to the naphtha that may be adhering to their surfaces.

(165) *Disappearance of Heat during the Formation of Vapour.*—In the change from the liquid to the gaseous state, the disappearance of heat is found to occur to an extent still greater than in the former cases. A vessel containing water, such as the boiler of a common still, placed over a source of heat which is tolerably uniform in temperature, receives equal accessions of heat in equal times; the water at first rises steadily in temperature, but at length the water boils and the thermometer becomes stationary; no matter how much the heat be urged, provided the steam be allowed to escape freely, the temperature of the boiling liquid cannot be raised beyond a certain point: if the vapour be made to pass through the worm of the still, which is cooled by immersion in water, the steam will

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at the moment of congelation, is *lowered* to a minute but measurable extent by exposing the water to pressure. Some preliminary experiments showed, that for a pressure of 8·1 atmospheres, the point of congelation was lowered 0°·106 F.; by a pressure of 16·8 atmospheres it was reduced 0°·232 F. Bunsen, on the other hand, found the melting point of paraffin and of spermaceti to be raised by increasing the pressure. Spermaceti, for instance, solidified at 117°·9 under the atmospheric pressure, but under a pressure of 150 atmospheres it solidified at 123°·6 F.; both these bodies *contract* at the moment of solidification, and, as had been anticipated by Professor Thomson, the melting point was *raised*.

transfer part of its heat to the water in the condenser, which rapidly rises in temperature, whilst the vapour returns to the liquid form; but the quantity of water that is raised in the worm-tub, to nearly 212°, is very much greater than the quantity that condenses in the form of liquid in the receiver of the still.

The large amount of latent heat contained in steam, renders it possible to use steam as a convenient and economical mode of warming buildings and apparatus which do not require to be raised to a temperature beyond that of boiling water. In practice it is found convenient in warming a building which is used for domestic purposes, to allow one square foot of radiating surface in the steam-pipe for every 200 cubic feet of space to be heated. This estimate, however, is liable to modification, as the greater the extent of radiating and conducting surface exposed by the windows in proportion to the cubic contents of the apartment, the more rapid is the loss of heat.

The maintenance of a steady temperature which cannot rise above 212°, is often required in the laboratory in the prosecution of various inquiries, especially in such as relate to organic chemistry, and for this purpose a small steam bath, such as is represented at 1 fig. 102, is extremely useful; it may also be employed to assist in effecting the filtration of hot liquids, where it is important to maintain their high temperature. In drying organic substances, a kind of double oven, or hot closet, made of copper, as exhibited at 2, is a convenient mode of applying heat; the interval between the internal and external plates of copper is filled with water which is heated by the gas flame below; if a higher temperature than this be required, the interval may be filled with oil; the temperature in the latter case may be regulated by a thermometer, introduced

FIG. 102.

at *a;* at *b* is a tube for the escape of vapour; this tube communicates with the drying chamber.

(166) *Ebullition.*—The gradual absorption of heat in the passage from the liquid to the gaseous state is not less essential to the comfort, and even to the existence of man, than the corresponding absorption in the passage from the solid to the liquid condition. Were it otherwise, every attempt to boil a saucepan or a flask of water or other liquid, would be attended with explosion, from the sudden formation of vapour, the moment the boiling point was attained.

Although the boiling point of each liquid, *cæteris paribus,* is always fixed, yet different liquids vary quite as much in the temperature at which this change occurs, as solids do in their points of liquefaction. This is shown by a glance at the following table, which contains the boiling points of a number of liquids, recently determined with very great care, reduced to the atmospheric pressure of 29·92 inches of mercury: the specific gravities of the liquids at 32° F. are also given.

Table of Boiling Points and Specific Gravities of Liquids.

	Boiling Pt. ° F.	Sp. Gr. at 32° F.	
Sulphurous Acid . . .	17·6	1.4911*	*a*
Chloride of Ethyl . . .	51·9	0·9214	
Bromide of Methyl . .	55·5	1·6644	
Aldehyd	69·4	0·8009	*b*
Formiate of Methyl . .	92·1	0·9984	
Ether	94·8	0·7365	
Bromide of Ethyl . . .	105·8	1·4733	*a*
Iodide of Methyl . . .	111·4	2·1992	
Bisulphide of Carbon . .	118·5	1·2931	
Formic Ether	127·7	0·9357	
Acetone	133·3	0·8144	*b*
Acetate of Methyl . .	133·3	0·9562	
Terchloride of Silicon .	138·2	1·5237	*a*
Bromine	145·4	3·1872	
Wood Spirit	149·9	0·8179	*b*
Iodide of Ethyl . . .	158·5	1·9755	*a*
Acetic Ether	164·9	0·9069	
Alcohol	173·1	0·8151	
Terchloride of Phosphorus	173·4	1·6162	
Benzole	176·8	0·8991	*b*
Dutch Liquid	184·7	1·2803	*a*
Butyrate of Methyl . .	204·6	0·9209	*b*
Water	212·0	1·0000	
Formic Acid	221·5	1·0267†	*b*
Butyric Ether	238·8	0·9041	

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* At 4°. † At 56°·6. *a* Pierre. *b* Kopp.

Table of Boiling Points and Specific Gravities of Liquids—(continued.)

	Boiling Pt. ° F.	Sp. Gr. at 32° F.	
Bichloride of Tin	240·2	2·2671	*a*
Valerianate of Methyl . .	241·1	0·9015	*b*
Acetic Acid	243·1	1·0619[‡]	
Fousel Oil	269·8	0·8721	*a*
Bromide of Elayl . . .	270·9	2·1629[‖]	
Terchloride of Arsenic . .	273·0	2·2050	
Bichloride of Titanium . .	276·6	1.7609	
Terbromide of Silicon . .	308·0	2·8128	
Butyric Acid	314·6	0·9886	*b*
Sulphurous Ether . . .	320·0	1·1063	*a*
Terbromide of Phosphorus.	347·5	2·9249	
Mercury	662·0	13·596	*c*

The process of ebullition may be beautifully shown in a common glass flask, heated from below. At first, bubbles of vapour are formed at the bottom of the vessel; these bubbles are condensed and disappear with a peculiar vibratory sound before they reach the surface; at length the temperature of the whole mass of fluid becomes nearly uniform, and the bubbles of steam as they form rise to the surface and break, emitting a perfectly transparent, invisible vapour, which only condenses into the cloudy form, which is commonly, but erroneously, designated as steam, when its temperature has been sufficiently reduced by the external air, to bring it back to the liquid form in exceedingly minute globules.

(167) *Influence of Adhesion on the Boiling Point.* — Adhesion of the fluid to the surface of the vessel that contains it has a marked effect in raising the boiling point. In consequence of this action, water sometimes boils at 214° in a glass vessel, but falls to 212° if a pinch of metallic filings be dropped in. If the interior of the vessel be varnished with shell lac, the boiling will often not occur till a temperature of 221° is reached, and then will take place in bursts, the temperature at each gust of vapour falling to 212°. So again the presence of a little oil elevates the boiling point of water three or four degrees. The experiments of Donny have thrown light upon some of the causes by which ebullition is facilitated. He has found that the presence of air in solution singularly assists the evolution of vapour. From the increased elasticity which the dissolved air acquires by the addition of heat

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[‡] At 62°·6. [‖] At 69°·4. *a* Pierre. *b* Kopp. *c* Regnault.

minute bubbles are thrown off in the interior of the fluid, especially where it is in contact with a rough surface; and into these bubbles the steam dilates and rises. By long boiling of the water, the air becomes nearly all expelled; in such a case the temperature has been observed to rise even as high as 360° F. in an open glass vessel, which was then shattered with a loud report, by a sudden explosive burst of vapour. In this case the force of cohesion retains the particles of the liquid throughout the mass in contact with each other, in a species of tottering equilibrium; and when this equilibrium is overturned at any one point, the repulsive power of the excess of heat stored up in the mass, suddenly exerts itself, and the explosion is the result of the instantaneous dispersion of the liquid. The difficulty of completely expelling air, even from a small bulk of water, can be adequately conceived by those only who have attempted it. Ebullition *in vacuo* for a very considerable period is not sufficient. Where the latent heat of the vapour is low, and the liquid has comparatively little adhesion to air, as is the case with alcohol, with ether, and with sulphuric acid, frequent bumping or irregular boiling occurs, endangering the vessel and its contents.

(168) *Influence of the Solution of Solids in a Liquid, on its Boiling Point.*—Any force that acts in opposition to the repulsive energy of heat produces a corresponding rise in the boiling point; thus the solution of a salt in water, by the influence of adhesion, always elevates the point of ebullition, and the more so the larger the quantity of salt added. Indeed it has been supposed that the quantity of salt required to produce a certain rise of temperature might be employed as a measure of the amount of adhesion between the liquid and the salt in solution. M. Legrand, (*Ann. de Chimie*, II. lix. 423), has made a series of careful experiments upon seventeen different salts, and the results which he has obtained possess considerable interest. It might be supposed, since the elasticity of vapour increases with the temperature, that the addition of a larger quantity of salt would be required to raise the boiling point from 213° to 214° than from 212° to 213°. In only three cases, however, was this effect produced; these three salts stand first in the following table. In six instances the effect produced was exactly the reverse; whilst in the seven instances which stand lowest in the table, the successive quantities of salt which it was requisite to add in order to produce a successive rise in the boiling point of 1° decreased up to a certain point, and beyond this steadily increased. The salts employed

were all used in the anhydrous state, that is to say, they were dried so as to be entirely deprived of their water before being dissolved.

Influence of Salts in Solution on the Boiling Point of Water.

Name of the Salt.	Quantity of salt required to raise the boiling point of 100 parts of liquid.		Boiling point °F. of a saturated solution.	Quantity of salt in 100 parts of water in saturated solution.
	From 212° to 213°·8 F.	From 213°·8 to 215°·6. F.		
Nitrate of Soda	9·3	9·4	250	224·8
Nitrate of Ammonia . .	10·0	10·5		unlimited
Nitrate of Potash . . .	12·2	14·2	240	335·1
Chlorate of Potash . . .	14·6	14·6	220	61·5
Chloride of Sodium . .	4·4	3·3	227	41·2
Chloride of Potassium . .	4·7	4·3	227	59·4
Carbonate of Soda . . .	7·5	6·9	220	48·5
Acetate of Soda	9·9	7·7	256	209·0
Chloride of Barium . .	11·0	8·6	220	60·1
Tribasic Phosphate of Soda and Water .	11·0	10·0	224	112·6
Sal Ammoniac	7·8	6·1	238	88·9
Chloride of Calcium . .	10·0	6·5	355	325·0
Acetate of Potash . . .	10·5	9·5	336	798·2
Carbonate of Potash . .	13·0	9·5	275	205·0
Nitrate of Lime	15·0	10·3	304	362·2
Chloride of Strontium .	16·7	8·5	244	117·5
Tartrate of Potash . . .	26·9	20·3	275	205·0

Notwithstanding their high boiling point, the vapour which rises from such solutions, immediately adjusts itself to the atmospheric pressure, and is not hotter than the steam of boiling water.

On comparing together equal weights of different salts it will be found that the most soluble are by no means uniformly those which produce the greatest elevation of the boiling point. A solution containing 40 per cent. of common salt (very nearly saturated) boils at 226°·5; whilst in the case of nitre (a far more soluble salt) a solution of the same strength boils at 219°.

(169) *Influence of Pressure on the Boiling Point.*—Ebullition consists essentially in the rapid formation of vapour of an elasticity equal to that of the atmosphere which exerts its pressure on the surface of the liquid; any diminution of that pressure should therefore be attended with a corresponding depression of the boiling point; and it is a fact that water which has long ceased to boil under the usual atmospheric pressure, may be at once made to enter into ebullition by placing it under the receiver of the air-pump, and exhausting the air; by this means water may be made to boil at

a temperature of 70° F. Indeed, liquids in general boil *in vacuo* from 60° to 140° below their ordinary point of ebullition, when under a barometric pressure of thirty inches. This result may be shown by boiling some water in a Florence flask, and whilst the steam is rapidly escaping, corking up the flask. Upon pouring cold water over the upper part of the flask the steam is condensed, its pressure is removed, and the water begins to boil rapidly; but in this case the bubbles nearly all rise from the surface, not from the bottom of the liquid. A simple proof that steam from boiling water possesses an elasticity equal to that of the atmosphere is obtained by repeating the last experiment with a tin canister, instead of a globular flask. On corking up the canister and pouring cold water over it the steam within is suddenly condensed, a vacuum is produced, and the canister is crushed in, from the pressure of the external air.

The reduction of temperature at which boiling takes place is advantageously applied in the preparation of vegetable extracts, the medicinal properties of which would be impaired by the ordinary temperature of 212°, and by exposure to the air. The apparatus consists of a still and a receiver, which are connected by an air-tight joint, and are filled with steam to expel atmospheric air, and then hermetically sealed; on cooling the receiver the evaporation is thus rapidly conducted at a temperature much lower than the usual boiling point of the liquid. A modification of this process is used in the manufacture of sugar, both in the concentration of the cane-juice and in the subsequent evaporation of the syrup.

(170) *Measurement of Heights by the Boiling Point.*—As might be expected in consequence of the diminution of atmospheric pressure, it is found that on ascending from the earth's surface, the temperature at which water boils becomes gradually lower. Saussure observed that on the summit of Mont Blanc, which is 15,650 feet (nearly three miles) above the sea-level, water boiled at 185°·8 F.; and M. Wisse recently determined the boiling point upon Mount Pichincha, at an altitude of 15,940 feet, to be 185°·27 F., whilst the barometer stood at 17·208 inches.

In descending mines a reverse effect takes place, the boiling point being proportionately elevated. This observation admits of a very simple application to the measurement of heights; a difference of about 596 feet of ascent, producing a variation of 1° F. in the boiling point of water.

The following table shows the temperature at which water boils at the corresponding heights of the barometric column, calculated by M. Regnault, and confirmed by direct observation. (*Ann. de Chimie,* III. xiv. 206.)

*Boiling Points of Water at different Pressures.**

Boiling Pt. ° F.	Barometer. Inches.	Boiling Pt. ° F.	Barometer. Inches.	Boiling Pt. ° F.	Barometer. Inches.
184	16·676	195	21·124	206	26·529
185	17·047	196	21·576	207	27·068
186	17·421	197	22·030	208	27·614
187	17·803	198	22·498	209	28·183
188	18·196	199	22·965	210	28·744
189	18·593	200	23·454	211	29·331
190	18·992	201	23·937	212	29·922
191	19·407	202	24·441	213	30·516
192	19·822	203	25·014	214	31·120
193	20·254	204	25·468	215	31·730
194	20·687	205	25·992		

The necessity of attending to the height of the barometer at the time of making a careful observation upon the boiling point of any fluid will be obvious. It has been ascertained that a variation of one-tenth of an inch makes a difference of more than a twentieth of a degree F.; so that within the range of the barometer in this climate, the boiling point of water may vary 5°.

(171) *High Pressure Steam.*—As a reduction of the pressure lowers the boiling point, so an augmentation of the pressure raises it. To demonstrate this fact an apparatus has been contrived, consisting of a small iron boiler, (fig. 103), furnished with three apertures in the lid, through one of which a thermometer stem is passed air-tight; through the second, a long glass tube open at both ends is inserted; the lower extremity of this tube plunges below the surface of mercury placed in the boiler. Water is introduced through the third aperture, which must be furnished with a stop-cock. It will be found on applying heat that so long as free communication with the atmosphere is permitted through the open stop-cock, the temperature of ebullition continues steady at 212°; but by closing

Fig. 103.

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* For an extended table of this kind, vide Dixon *On Heat,* p. 269.

the cock, the steam may be confined, and as fresh portions of steam continue to rise from the water, the pressure on the surface increases, as is shown by the rise of the mercury in the open tube; the boiling point also becomes higher; until when the mercury stands at 30 inches, and the pressure on the surface is equal to that of an additional atmosphere, the thermometer marks a temperature of 249°·5. By continuing the heat without allowing the steam to escape, the boiling point rises still higher, and the elasticity of the steam increases with increasing rapidity as the temperature rises, as is shown by the following table extracted from Regnault's work :—

Temperature of Steam at High Pressures.

Pressure in atmospheres of 30 inch. mercury.	Temp. ° F.	Pressure in atmospheres of 30 inch. mercury.	Temp. ° F.
1	212·	11	364·2
2	249·5	12	371·1
3	273·3	13	377·8
4	291·2	14	384·0
5	306·0	15	390·0
6	318·2	16	395·4
7	329·6	17	400·8
8	339·5	18	405·9
9	348·4	19	410·8
10	356·6	20	415·4

These results differ but little from those obtained, under the direction of Dulong and Arago, by a commission appointed for the purpose many years ago by the French government. They found the temperature of steam of twenty atmospheres to be 418°·4.

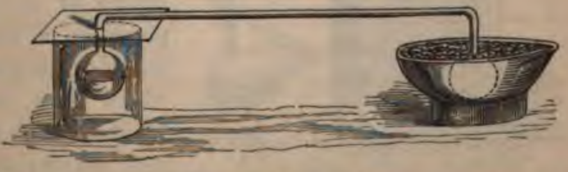
It will be observed that as the temperature rises by equal additions of heat, the increase of elasticity is more rapid at high than at low temperatures, and this circumstance (in addition to the greater simplicity of construction of the machinery in high pressure engines) is one of the principal reasons for the greater economy of power obtained in employing high pressure steam as a motive power, when compared with that furnished by the use of low pressure engines. But it is only when in contact with a body of water from which fresh steam is constantly rising, that the elasticity augments in this manner, and thus produces a force sufficient to rend asunder the strongest vessels. If dry steam alone be heated, it follows the law which regulates the expansion and elasticity of gaseous bodies in general (128).

High pressure steam whilst confined is always of the temperature of the water from which it is produced; it is, therefore, often used in the arts to supply a steady temperature above that of 212°. It is found that the solvent powers of water are much increased by the elevation of temperature caused by preventing the free escape of the steam. Papin's digester is an apparatus designed to effect this object; it is simply a strong iron vessel, furnished with a safety-valve for regulating the pressure at which the steam is allowed to blow off. The water may thus be kept steadily at any required temperature above 212° as long as is requisite. The gelatine of bones may by this means be easily extracted from the earthy matter, although the bones may be boiled for hours in water at 212° without exhibiting any such effect.

(172) *Production of Cold by Vaporization.* — In all cases, whether volatilization occur above the usual boiling point, or below it, heat is absorbed in large quantity. A few drops of ether if allowed to fall on the hand disappear rapidly in vapour, and produce the sensation of cold. Indeed, the boiling of one liquid may be attended with the freezing of another which is brought into its vicinity. Place, for example, a drop or two of water between two watch-glasses, pour a little ether into the upper glass, and having introduced them into the receiver of the air-pump exhaust the air; the ether will speedily boil, and the water between the two glasses will be frozen by the rapid abstraction of heat, which it has experienced during the conversion of the ether into vapour. Water, as Leslie has shown, may even be frozen by the rapid absorption of heat produced by its own evaporation. This experiment may be performed by supporting a watch-glass containing water, over a dish of oil of vitriol, under the receiver of the air-pump: as shown in fig. 115 (page 246). On exhausting the air, the water quickly evaporates, the steam being removed with great avidity by the oil of vitriol as fast as it is formed; and in two or three minutes the water which remains in the watch-glass becomes converted into ice.

Water is also frozen by its own evaporation in the *Cryophorus* of Dr. Wollaston, in which the condensation of the vapour is effected by the application of a freezing mixture, at a distance from the evaporating surface. The apparatus consists of a long glass tube bent twice at right angles, and terminating

FIG. 104.



in a bulb at each extremity, as shown in fig. 104. In making the instrument, one of these bulbs is partially filled with water, which is then made to boil rapidly; the steam thus generated expels the atmospheric air through a capillary opening which is left in the other bulb, and when the instrument is thus freed from air and filled only with water and vapour of water the aperture is sealed. To make use of it, the water is all collected into one bulb, and the empty bulb is plunged into a freezing mixture; the aqueous vapour which it contains is thereby condensed, and evaporation occurs rapidly from the surface of the liquid in the other bulb; its sensible heat is thus diminished, and the water in a few minutes begins to freeze.

(173) *Measurement of the Latent Heat of Vapours.*—Equal weights of different liquids require very different amounts of heat to convert them into vapour. The amount of heat which is thus rendered latent, may be determined by distilling over a given weight of the liquid, and condensing it in a large volume of water; the temperature of which is noted before and after the experiment. Suppose the latent heat of steam to be 966°, a pint of water converted into steam would on recondensation raise the temperature of 10 pints 96°·6. It is found that a gallon of water, if converted into steam of 212°, and condensed again into the liquid form, would raise about 5½ gallons of water from 32° to 212°.

FIG. 105.

We owe to Dr. Andrews (*Quart. Jour. Chem. Soc.* vol. i. p. 27), a careful determination of the latent heat of a number of vapours: fig. 105 shows the mode of procedure which he adopted. The liquid to be tried is placed in the flask A, the neck of which has a very short bend, and is connected with a glass receiver, B, furnished with a spiral condensing tube, terminating at *d*; this receiver is placed in a vessel, C, with a considerable quantity of water, which has been accurately weighed. The liquid is distilled over into B; the quantity that condenses is carefully weighed, and the rise of temperature experienced by the water used for condensation is estimated by a very sensitive thermometer, *t*. The whole is enclosed in an outer tin plate vessel furnished with a lid, which acts as a screen, and is further protected from the radiation of the lamp by the tin-plate screen R; *s* is a light glass tube for agitating the water. The result obtained has, however, to be corrected by other experiments for the heat absorbed by the metallic parts of the apparatus, and for that which is lost by radiation during the time that the experiment lasts: allowance has also to be made for the heat which the condensed fluid has given out while in the liquid form, in cooling down from the boiling point to the temperature of the water used in the condenser.

The results obtained in this delicate branch of inquiry by M. Despretz, and M. Brix, which, however, embraced a much smaller number of liquids, agree pretty closely with each other and with the experiments of Dr. Andrews. These results, with some of those obtained by MM. Favre and Silbermann are given in the following table:

Latent Heat of Vapours.

		Equal Weights.	Equal Volumes.
Water (Regnault)		966·6	8881
Water	A.	964·6	
Wood Spirit		474·6	7393
Alcohol	F.S.	374·9	8624
Fousel Oil		218·4	11734
Formic Acid		217·3	
Formiate of Methyl	A.	210·7	6321
Butyric Acid	F. S.	205·4	
Acetate of Methyl	A.	198·3	7337
Formic Ether		189·5	7011
Valerianic Acid	F. S.	186·3	
Acetic Acid		183·4	
Acetic Ether	A.	166·8	7337
Ether	A.	162·8	6023
Bisulphide of Carbon		156·1	5931
Oil of Lemons	B.	144·0	9792
Oil of Turpentine		133·2	9051
Oxalic Ether	A.	130·8	9548
Terchloride of Phosphorus		92·5	6975
Iodide of Ethyl		84·3	6870
Iodide of Methyl		82·9	5844
Bromine		82·0	6560
Bichloride of Tin		54·9	7190

Those marked A. are by Andrews; F. S., by Favre and Silbermann (*Comptes Rendus*, xxiii. 524), B. by Brix (*Pogg. Ann.* lv. 351).

The numbers which represent the latent heat of equal volumes of each vapour are obtained by multiplying the numbers in the third column by the weight of a bulk of each vapour equal to that occupied by nine grains of steam. The numbers contained in the third column indicate the quantities of water in pounds which would be raised 1° F. in temperature, by condensation of a pound weight of the vapours of each of the various liquids mentioned at the temperature at which each boils, into the liquid form; the liquid condensed being supposed in each case to be at the temperature of its own boiling point. For instance, the conversion of one pound of steam at 212° into water at 212° would raise 964·6 pounds of water from 60° to 61° F. So the condensation of one pound of the vapour of alcohol at 173° into liquid alcohol at 173° would heat 374·9 pounds of water from 60° to 61° F.

(174) The density, that is to say, the weight of a given volume of steam increases directly as its elastic force. Watt concluded from his experiments that the same weight of steam, whatever its density may be, contains the same quantity of heat, its latent heat being increased in proportion as its sensible heat is diminished or absorbed.

For instance,

A certain weight of steam at 212° F. condensed at 32°, gives out . .	180° of sensible heat, and 950° of latent heat.
Amounting together to	1130°
The same weight of steam at 250°, condensed at 32°, gives out . .	218° of sensible heat,
But only	912° of latent heat.
Still amounting together to	1130°.
The same weight of steam at 100°, condensed at 32°, gives out . . .	68° of sensible heat,
But now as much as	1062° of latent heat.
Making together, as before	1130°

M. Regnault, by a series of laborious experiments, has, however, shown, that although the assumption of this rule may not lead to serious errors in practice, and although, consequently there is but little saving of fuel in performing evaporations at a low temperature, yet that it is not strictly correct. In reality, the sum of the latent and of the sensible heat increases as the temperature rises, for each degree F., by a constant quantity, equal to 0°·305: this may be seen in the subjoined table, in which it is assumed that the sensible heat of steam may be neglected for all degrees below the zero of Fahrenheit.

Latent and Sensible Heat of Steam at different Temperatures.

0·00746
0·00603

Pressure in atmospheres.	Temperature.	Latent heat.	Sum of latent and sensible heat.
0·044	0°	1114°	1114°
0·18	32°	1091°·7	1123°·7
1·	212°	966°·6	1178°·6
8·	339°	877°·3	1216°·8

It must be borne in mind that equal bulks of different liquids produce very different quantities of vapour. Water furnishes, bulk for bulk, a much larger amount than any other liquid, a cubic inch of water at 212° expanding to nearly a cubic foot of steam at 212°, or more accurately to 1696 times its volume. The following table shows the volume of vapour which is furnished by a cubic inch of four different liquids, at their respective boiling points:—

A cubic inch	of Water	expands to	1696	cubic inches of vapour at the boiling point.
,,	of Alcohol	,,	528	,, ,,
,,	of Ether	,,	298	,, ,,
,,	of Oil of Turpentine	,,	193	,, ,,

Equal volumes of different vapours, taken at the boiling points of their respective liquids, consequently possess very different weights; for example:—

46·6	cubic inches	of Steam weigh	9	grains.
46·6	,,	of Alcohol vapour weigh	23	,,
46·6	,,	of Ether ,,	37	,,
46·6	,,	of Oil of Turpentine ,,	68	,,

The expansive force of the different vapours obviously depends upon the bulk of vapour produced from an equal bulk of each liquid; and although the latent heat of other vapours is much less than that of steam, yet no economy would be experienced, even did they cost no more than water, by substituting these liquids for water, as the materials for generating vapour in the steam engine.

Experiments already quoted have shown that equal volumes of alcoholic and of aqueous vapour contain equal amounts of latent heat at their respective boiling points; and, as will be seen from the table, an approach to this equality may be observed in the case of vapours from other liquids. The cost in fuel would be proportionate to the amount of latent heat in equal volumes of the vapours.

When steam of high elasticity is allowed suddenly to escape into the air from a small aperture, the temperature is so much reduced that the hand may be held in it with impunity, although, as is familiarly known, steam of the ordinary elasticity of the air scalds severely. The chief cause of this reduction of temperature in the case of high pressure steam is the sudden and forcible admixture of the steam with air at the first rush. Dr. Young proved, experimentally, that a stream of air or vapour (fig. 106, 1) slowly escaping into the air passes further in an unbroken column than a stream issuing with violence (fig. 106, 2), the reaction of the steam and air one against the other, causing their immediate intermixture. So great is the rarefaction of air in the axis of the jet from its sudden expansion, that a solid body of some weight may be suspended in the issuing steam, not only when it is escaping vertically into the air, but even when it is inclined at an angle of several degrees from the perpendicular. If a tube several inches in length be drawn out at one extremity to a fine aperture, and this contracted aperture be placed in the axis of the cone of issuing vapour, whilst the other end dips into a vessel containing a liquid, the latter may be raised seven or eight inches, and may even be projected in a stream from the upper orifice of the tube. The amount of air thus carried forward is so considerable, that a jet of steam is employed with good effect as a moving power in ventilation. In this case the jet-pipe is placed in the axis

FIG. 106.

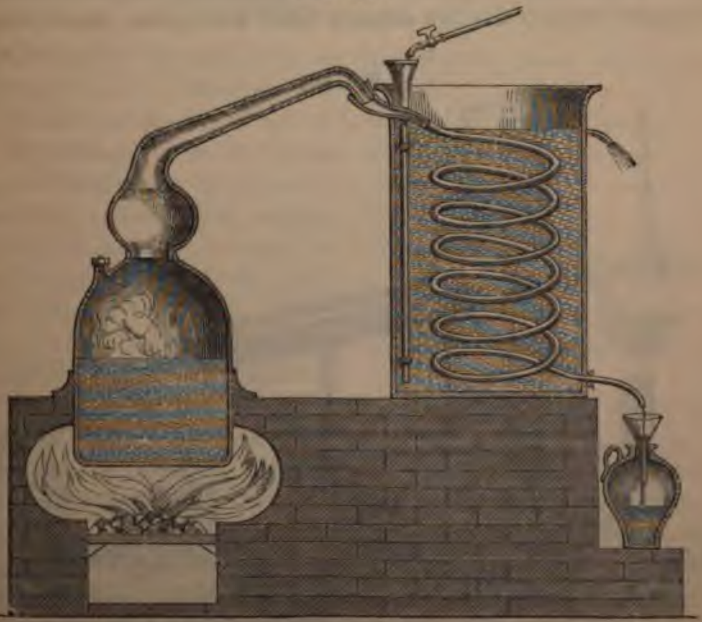
FIG. 107.

of a tube communicating with the apartment to be ventilated; the orifice of this outer tube is regulated so that the cone of issuing steam shall exactly fill it (fig. 107, 1); if the outer tube be of larger dimensions, a loss of power is experienced in consequence of part of the force being expended in producing a downward current of the external air (3); if too small, a loss is experienced by friction against the sides of the tube (2).

The working of a steam-engine depends upon the generation of elastic force in steam by the agency of heat, and its instantaneous destruction, by the application of cold, in order to condense the vapour; alternate motion in opposite directions is thus readily obtained, which may be applied by various mechanical contrivances to the production of any required movement. The theory of latent heat is all-important in the working of the steam-engine; but the practical application to this purpose of the principles above developed is beyond the object of this work.

(175) *Distillation.*—The rapid formation of vapour during ebullition is often made use of by the chemist for the purpose of separating fluids from solids, as in the ordinary case of distilling water to free it from the impurities dissolved in it, or for the separa-

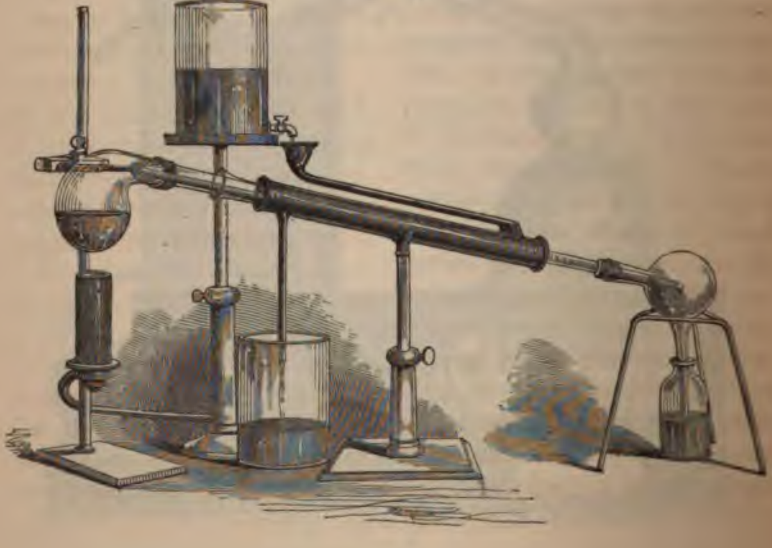
FIG. 108.



tion of two liquids which differ in volatility, as in separating spirit of wine from a fermented liquor. In such operations the arrangements for condensation acquire considerable importance: they are of various kinds, but the *worm tub*, the apparatus most usually employed, consists of a spiral pipe called a *worm*, which is shown in fig. 108, surrounded by a considerable volume of cold water; the vapour passes from the boiler into the worm, is condensed, and runs off at the lower aperture into suitable receivers. Fresh additions of cold water are continually required in the *refrigeratory*, as the worm and tub are called. The heat is greatest in the upper coils where the hot vapour enters, and as the heated water, from its diminished specific gravity, remains at the top, it is necessary, in supplying the fresh water for cooling, to allow it to enter at the bottom of the vessel, while the heated portions flow off at the upper part. The object of giving to the steam-pipe an ascending direction as it passes to the condenser, is to insure the return to the boiler of any particles of liquid which may have been mechanically carried up by the breaking of the bubbles in the act of ebullition.

In the laboratory various modifications of condenser are employed. The most convenient form of apparatus is that known as Liebig's. It consists of an outer metallic tube, through the axis of which a glass tube is passed, and is supported by perforated corks: the space between the two tubes is filled with water, which is con-

FIG. 109.



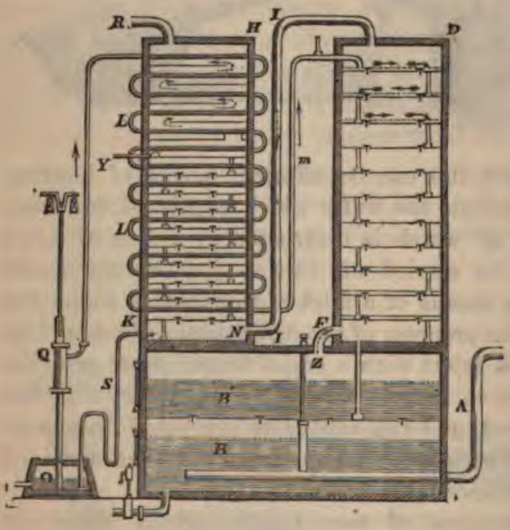
tinually renewed by cold water which enters by a funnel near the lower extremity, while the hot water escapes at the other end. The method of using it is sufficiently indicated in fig. 109.

Where the products of distillation are not very volatile it is often found convenient to make use of the evaporation of water from the neck of the retort as a means of condensation. Fig. 110 shows a method by which this can be effected; pieces of blotting paper are used to distribute the water which trickles slowly from the funnel, the throat of which is obstructed by a plug of tow; the superfluous water is carried off into a jug or other vessel placed to receive it, by means of a fillet of tow twisted round the neck of the retort. The progress of the distillation is hastened by covering the arch of the retort with a cap of brown paper or of tin plate; a chamber of hot air is thus maintained in contact with the upper part of the retort, and the vapour is prevented from condensing where it would necessarily return again into the mass of liquid undergoing distillation.

FIG. 110.

The complete separation of two liquids which differ in volatility, cannot however be effected by mere distillation, as a certain proportion of the less volatile one always passes over with that which is the more volatile. The separation of alcohol and water, for example, is never completely effected by distillation; because at 173° F. (the boiling point of alcohol) the tension of aqueous vapour is still considerable; indeed it is sufficient to balance a column of mercury nearly 13 inches in height. In the first distillation of a fermented liquor, a considerable proportion of water, therefore, comes over with the spirit. The less the amount of spirit originally contained in the liquid, the larger is the proportion of water in the distilled liquor. By a second distillation, the proportion of water in the distillate is reduced, and the process may be repeated with like effect until the reduction of the proportion of water in each successive product of distillation no longer compensates for the waste and expense of the operation. An ingenious method of dispensing with the necessity for these frequent and costly rectifications was devised by a Frenchman of the name of Adam. By its means he succeeded at a single operation in carrying the concentration to the highest point attainable by mere distillation. The principle of this invention consists in connecting together a number of rectifying chambers, in such a manner that the vapour driven off from the chamber nearest the fire shall condense in the second, and by the heat given out in its condensation shall cause the more volatile portions of the liquid of the second to distil into the third chamber, and those of the third into a fourth, and so on till a sufficient degree of concentration is effected. The most effective method of attaining this object is exhibited in the form of still, called, from its inventor, *Coffey's still.* Fig. 111 represents a section of one of these stills. B B′ is the body of the still, which is made of copper, and enclosed in a case of wood, to prevent loss of heat: upon the body two columns, D F, H K, are supported; O is the vessel from which the liquor for distillation is raised by the pump, Q; the liquor enters the column H K, by the long spiral pipe L L, by which it is ultimately conveyed, through the pipe *m*, to the top of the column

FIG. 111.



D F. The heat employed in the distillation is not the direct heat of a fire, but is procured by injecting steam obtained from a boiler not shown in the figure. The steam enters the body of the still through the pipe A; the amount of steam admitted being regulated by a valve, the handle of which is shown at F. B B′ is divided into two chambers, by means of a copper shelf, pierced with numerous small holes, which allow the passage of steam upwards, but which are sufficiently small to prevent the descent of any considerable quantity of liquid which may be resting upon the shelf. The steam at first condenses in the cold liquid of the lower chamber, but quickly raises this liquid to the boiling point, driving off the alcoholic portions first, as they are the most volatile. This vapour traverses the liquid which rests in B′, on the perforated shelf, and gradually raises it to the boiling point, driving off from it the alcohol in vapour; this vapour passes off by a pipe, Z, to the bottom of the column D F. This column is divided into a series of compartments, by perforated shelves of copper; each of these shelves is provided with a pipe for carrying off the liquid to the shelf below. This pipe projects about an inch above the upper surface of each shelf; a stratum of liquid, about an inch in depth, is thus retained upon each shelf, and is traversed by the vapours which ascend from the shelf next below it. The *wash*, or liquid for distillation, having become heated during its passage through the spiral pipe in the column H K, thus falls upon the uppermost perforated shelf in D F, flows off at the farthest end of that shelf, and then falls upon the next shelf; thence it passes to the third, and so on in succession to each shelf: as it descends, it encounters the ascending vapours, which at each successive step of the ascent become more and more alcoholic—the wash as it descends becoming weaker and weaker, until when it reaches the vessel B B′, it is wholly deprived of spirit. If the quantity of the ascending vapour should become at any time too great to pass through the perforations in the shelves, the pressure opens the valves T T, which are provided for security in each shelf. The vapour having reached the top of the column D F, is conveyed by the steam pipe I I N, to the bottom of the finishing column, or rectifier, H K. The lower part of this column, as high as the pipe Y, is constructed exactly upon the same plan as the column D F, but in each compartment between the shelves the spiral pipe L L makes three or four convolutions, and thus becomes warmed by the ascending heated vapours. In this second column the spirituous fluid distilled over from the first column thus undergoes a successive rectification upon each of the lower shelves, and becomes more and more concentrated by the ascent of the alcoholic vapours, which, by their condensation at each successive stage, emit sufficient of the heat previously held latent to effect the distillation of the more volatile portions of the liquid by which they are condensed. The five upper shelves of this column merely act as a condenser for the alcoholic vapours; the shelves are not perforated, and are attached to the alternate sides of the column, having a narrow passage at one end of each shelf, so as to oblige the vapours to describe a zig-zag direction; the pipe Y carries off the finished spirit into proper receivers; the pipe R carries off any uncondensed spirituous vapour to a refrigeratory, whilst the weak spirit which reaches the lower part of the column is returned to the vessel O. The spent wash, as it accumulates in B B′, is drawn off at intervals, and the still can thus continue its operations without intermission.

(176) *Evaporation.*—All liquids, at temperatures far below their points of ebullition, emit vapour by the tranquil process of evaporation. The amount of vapour given off at a constant temperature differs greatly in different liquids, and is dependent upon the temperature at which each liquid boils.

FIG. 112.

The great difference in the volatility of liquids at the same temperature is strikingly shown by filling a number of barometer tubes (fig. 112) with mercury, and inverting them in a bath of the same metal. One of these tubes (1) may be kept as a standard of reference: if into one of the others (2) a few drops of water be allowed to ascend, an immediate depression of the column of mercury is observed, due to the elasticity of the aqueous vapour furnished by the evaporation of the water. If into a third tube (3) alcohol be introduced, a greater depression will be perceptible; bisulphide of carbon in a fourth tube (4) will produce a still greater depression, and if ether be admitted to a fifth, the height of the mercurial column will be still less. Now let a second wider tube closed below by a cork be placed round the exterior of any one of these tubes, so as to inclose nearly its whole length, as in fig. 113; let the outer case thus formed be filled with water, the temperature of which is gradually raised, so as to communicate the heat uniformly to the tube within. A progressive depression of the mercurial column is thus produced; and by measuring the amount of this depression it is found that the elasticity of the vapour emitted from each liquid increases as the temperature rises, until at the boiling point of the liquid the elasticity becomes equal to that of the air. If the temperature increase according to the terms of an arithmetic ratio, the elasticity rises according to the terms of a geometric progression, the ratio of which differs for each liquid.

FIG. 113.

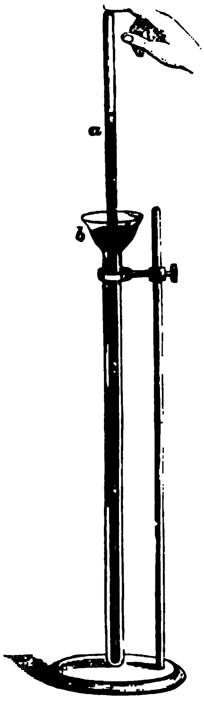
(177) *Dalton's Law of Tension of Vapours.*—It was assumed by Dalton that the tension or elasticity of all vapours was equal, if compared at temperatures which represented differences of an equal number of degrees above or below the boiling points of their respective liquids. This law is not strictly in accordance with the results of experiment. However, for short distances above and below the boiling point, it is very nearly true, excepting in the case of mercury, and may be employed for the purpose of correcting the observations of the boiling points of liquids made at atmospheric pressures, which are but little above or below the standard of 30 inches.

The following table exhibits the elasticity of the vapours of five different liquids at corresponding distances above and below their boiling points. The ether used in these experiments could not have been perfectly pure, as its boiling point is too high. The boiling point of mercury was estimated by a mercurial thermometer without correction for the increasing rate of expansion at high temperatures.

Tension of Vapours at equal distances from the Boiling Points of the Liquids.

Number of degrees F. above or below boiling.	REGNAULT.		URE.		URE.		MARX.		AVOGADRO.	
	Water.		Alcohol. Sp. Gr. 0·813.		Ether.		Sulphide Carbon.		Mercury.	
	Temp. ° F.	Press. Inches.	Temp. ° F.	Press. Inches.	Temp. ° F.	Press. Inches.	Temp. ° F.	Press. Inches.	Temp. ° F.	Press. Inches.
+ 40	252	63·14								
+ 30	242	52·90			134	50·9				
+ 20	232	44·06			124	42·64	137	40·19		
+ 10	222	36·47	183	37·00	114	35·2	127	35·60		
Boiling Point.	212	30·00	173	30·00	104	30·00	117	29·87	680	30·00
— 10	202	24·50	163	24·20	94	24·70	107	24·91		
— 20	192	19·87	153	19·30	84	20·00	97	20·65		
— 30	182	16·00	143	15·05	74	16·10	87	17·00		
— 40	172	12·78	133	11·60	64	13·00	77	13·89		
— 50	162	10·12	123	8·75	54	10·30	67	11·27	630	19·85
— 60	152	7·94	113	6·70	44	8·10	57	9·07		
— 70	142	6·18	103	4·90	34	6·20	47	7·24		
— 80	132	4·67	93	3·67			37	5·73		
— 90	122	3·63	83	2·73			27	4·49	590	14·08

FIG. 114.



The increase of elasticity produced by heat in those vapours which are in contact with the liquids by which they are furnished, indicates also a corresponding increase in their density: the one may, in fact, be calculated from the other. When the temperature is reduced, the elasticity falls, and a portion of the vapour is condensed. There is, indeed, for every vapour a maximum density for each temperature which, when the liquid is in contact with the vapour, is speedily attained, but which cannot be surpassed, no matter how much the pressure to which the vapour is subjected may vary; an increase of pressure immediately condenses a part of the liquid that had evaporated, and a diminution of pressure is attended with immediate volatilization of a fresh portion of the liquid; consequently a cubic inch of vapour of any particular liquid at any given temperature, is always of the same elasticity, and possesses the same weight. If a small quantity of ether be thrown up into the vacuum of the barometer tube, represented in fig. 114, the length of the column of mercury, *a b*, above the level of that in the bath, will continue the same whether the tube be raised or lowered in the outer vessel; if it be raised, fresh ether will evaporate, if depressed part of the vapour will be condensed.

(178) *Limit of Evaporation.*—From what has just been stated it might be supposed that all fluids, at even the lowest temperatures, were constantly emitting vapour. That mercury does so at common atmospheric temperatures may be shown by a very simple experiment. Place at the bottom of a bottle a few drops of mercury, and suspend in the neck a bit of gold leaf; in a few weeks the lower portions of the gold will become white from the condensation of the vapour of mercury upon it. In the tube of a well-made barometer the same thing is shown by the formation of a dew of metallic globules in the space above the column of metal. Faraday has, however, proved that there is a temperature below which this volatilization ceases, a temperature which varies for different substances: for mercury the limit is about 20° F.; for sulphuric acid the limit is much higher, since the acid undergoes no sensible evaporation at ordinary atmospheric temperatures. The cohesive force of the liquid here appears to overcome the feeble tendency to evaporation.

It is not necessary for the evaporation of a body that it should be in the liquid form. Camphor rises in vapour from the solid, and condenses in a crystalline form on the sides and upper part of the vessel which contains it. Ice, if introduced into the vacuum of a barometer, immediately causes a depression of the mercurial column amounting at 32° to upwards of 18 hundredths of an inch, and even at zero the tension of the vapour of ice is found to amount to 4 hundredths of an inch. It is owing to this evaporation that patches of snow and tufts of ice are observed gradually to disappear even during the continuance of a severe frost.

It has been shown that if the temperature of one of the tubes, shown in fig. 112, which contains a volatile fluid, be uniformly raised throughout its entire length, the elasticity of the vapour rapidly increases till the liquid reaches its boiling point. The application of heat to one portion only of the tube, however, is attended with a very different result: the liquid may even be heated to ebullition, and it will distil and be condensed, but unless the whole of that portion of the tube which is filled with vapour be heated to the same degree, no corresponding increase of elasticity will be observed: the tension can never exceed that due to the elasticity of the vapour which would be emitted by the liquid which is at the same temperature as that of the coolest portion of the tube above the liquid; because the excess of vapour is at once condensed as soon as it reaches this colder part of the space. The ether, for example, in the barometer, may be made to boil by the heat of the hand, but the height of the column of mercury undergoes little change; the ether vapour being condensed in the colder portions of the space as rapidly as it is produced.*

(179) *Circumstances which Influence Evaporation.* — In the process of evaporation the vapour is supplied only from the surface or superficial layer of the liquid. It is, therefore, evident that the extent of surface exposed must greatly influence the amount and rapidity of evaporation, independently of the temperature. Now if the evaporating surface be in any way protected, as by allowing a small quantity of oil to become diffused over it, evaporation is entirely suspended. Advantage is sometimes taken of this fact in the laboratory in cases where it is necessary to maintain a gentle heat for many hours: the vessel to be heated is supported in a larger one containing water, upon the top of which a little oil has been poured; under these circumstances the temperature required is kept up by a smaller expenditure of fuel, as the escape of latent heat by evaporation is prevented, and the danger of the water bath becoming dry is obviated. When, on the contrary, a rapid evaporation is necessary, a large extent of surface is exposed. In the salt works of Cheshire, for instance, the brine is evaporated in shallow pans, four or five feet wide and forty or fifty feet in length, the fire being lighted at one end and the flue passing horizontally underneath to the other extremity. At Salzburg, in the Tyrol, the same object is effected by pumping the weak brine into reservoirs, whence it is allowed to trickle down through stacks of brushwood, by which means the surface exposed to evaporation in the air is almost indefinitely increased. In the southern parts of Europe the sea water is admitted into extensive shallow pans excavated on the sea coast, where by exposure to the sun's rays it becomes concentrated, and the salt crystallizes out.

Another circumstance which influences the rate of evaporation is the amount and nature of the pressure upon the surface of the fluid. Upon this subject a series of experiments was made by Professor Daniell. He placed a circular dish of water, 2·7 inches in diameter, under a receiver connected with the air-pump, and supported above a dish containing concentrated sulphuric acid,

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* In the Appendix will be found a table, giving the tension of aqueous vapour for each degree F. between 0° and 100°.

the object of using the acid being to absorb the aqueous vapour as fast as it was generated: the results of these experiments are given in the following table:—

Rate of Evaporation under Different Pressures.

Pressure in Inches of Mercury.	Grains Evaporated.	Pressure in Inches of Mercury.	Evaporation in Grains.
30·4	1·24	1.9	15·92
15·2	2·97	0·95	29·33
7·6	5·68	0·47	50·74
3·8	9·12	0·07	112·22

The time in each experiment was 30 minutes, the temperature 45° F. It is obvious that the rapidity of evaporation under these circumstances was inversely as the pressure, which was read off upon the gauge.

The resistance offered by the pressure of a gas or vapour upon the surface of a liquid is purely mechanical; and it follows as a necessary consequence of the law of the diffusion of gases, that the quantity of vapour which rises from a volatile body in a confined space, is the same whether that space be filled with air or not. The time that is occupied before the space shall have received its full complement of any given vapour varies inversely with the pressure; and with different vapours under similar pressures, the time varies with the diffusiveness of the vapour. The vapour, as it rises, adds its own elastic force to that of the air present. When a liquid evaporates into an empty space, the full elasticity due to the temperature and, consequently, the maximum density of the vapour is acquired at once; but when it evaporates into a gas, that degree of density is not acquired until after the lapse of a variable interval of time. The circumstance which in both cases finally limits the evaporation of the liquid, is the pressure of its own vapour of a definite degree of elasticity upon its surface. It is, therefore, clear that the larger the proportion of moisture that is contained in the air at any given time, the smaller will be the quantity of aqueous vapour that rises from an exposed surface in a given time; and that in proportion as the space is more nearly charged with vapour, the more slowly is each succeeding portion of vapour produced. Evaporation, in short, is more rapid in a dry than in a moist atmosphere. For the same reason evaporation proceeds more rapidly during a breeze than in a still air: the air resting on the surface of a liquid soon becomes charged to the maximum with vapour, and then all further evaporation would cease were it not for circulating movements, which even in the stillest air are occasioned by the change of density due to the accession of moisture; the currents produced by a breeze, assist these movements, and the vapour rises into portions of air which are being continually changed, so that the pressure of the aqueous vapour on the surface of the liquid is rapidly removed.

Evaporation in a confined space, in which the atmosphere is kept constantly in a state of dryness, is often resorted to in the laboratory. Crystallizations on a small scale are frequently effected in this way; the liquid evaporates, and is absorbed by a surface of sulphuric acid, as in the experiment of Leslie (172). An arrangement, such as is represented in fig. 115, may be employed for this purpose. In this figure, P is the plate of the air-pump; S a dish of oil of vitriol; and T a dish supported by the wire triangle, and containing the substance to be dried, or the solution to be crystallized. The evaporation may be rendered quicker or slower according to the extent to which the exhaustion of the receiver is carried. Many compounds which would be injured by exposure to air, or to a moderate temperature, may be dried effectually in this manner.

FIG. 115.

As a necessary consequence of the evaporation which is continually going on over the entire surface of the earth, the atmosphere is at all times charged with moisture, the amount of which is perpetually varying, but it is almost always below the proportion which experiment gives as the maximum density due to the observed temperature. It is owing to the circumstance that the air is rarely fully charged with vapour, that wet bodies become dry, and that the surface of the soil, although saturated with moisture, yet in a few hours or days becomes parched and dusty. By the process of evaporation from the surface of the land as well as of the ocean, a natural distillation is thus in continual operation, by which a perpetual circulation of water is maintained; the waters conveyed by the rivers into the sea, imperceptibly return into the atmosphere: the vapour thus raised either assumes an invisible form, or it floats about in masses of cloud: these are at length arrested, particularly by mountains and elevated ridges of land; and being condensed, descend as showers, and supply stores of water, which, sinking into the porous strata of the hills, burst out as springs in the valleys. These springs in their turn furnish constant supplies to the rivers, and the rivers after irrigating the countries through which they flow again empty themselves into the ocean. The frequency of rain, and various other meteorological phenomena of the highest interest and importance,—in fact, many of the great peculiarities of climate are mainly influenced by the variations in the quantity of moisture which is contained in the atmosphere. The knowledge of the quantity of aqueous vapour which exists at any given time in a certain bulk of air, becomes, therefore, a problem which is constantly requiring solution for meteorological purposes. Various methods have been proposed for attaining this end; the simplest and the most accurate of these consists in the determination of the *dew point*.

(180) *Dew Point.*—Since the tension of vapour in every liquid remains constant for each degree of temperature, and diminishes according to the terms of a *geometric* progression, as the temperature falls in *arithmetic* progression, the elasticity of vapour falls with a fall of temperature more rapidly in proportion than the temperature declines; and it is evident that a reduction of temperature in a space already charged to the maximum with vapour, must produce a deposit of moisture in the liquid form. Such a result, in fact, accords with daily observation: for example; when a glass of cold water is brought into a warm room, its surface becomes bedewed with moisture. Now this observation has been ingeniously turned to account for the purpose of determining the quantity of moisture present in the air at any given time. If the cold liquid be poured from one vessel to another, its temperature will be gradually raised; the quantity of dew which forms on the outside of the vessel into which it is poured will become less and less, until it ceases to form at all. By noting with a sensitive thermometer the exact temperature at which this formation of dew ceases, the tension of the aqueous vapour present in the air at that period can be easily ascertained from tables constructed for that purpose, and the corresponding proportion of moisture calculated. If the temperature of the air at the time be noted, it is easy to determine the additional proportion of moisture which the air at that time is capable of taking up. This comparison is generally made by calling the quantity of invisible vapour which it is possible for air to retain at the particular temperature at the time of observation 1000, and calculating from the observed dew point the proportion which the amount actually present bears to that which might

exist at that temperature. For example, when the air is at 60° F., the *dew point* may be as low as 50°; that is, the temperature at which dew begins to form is 50°. On reference to the table, it appears that the tension of vapour at 60° amounts to 0·519 inch of mercury, while at 50° it is equal to only 0·361. Now the quantity of vapour is directly proportioned to its tension, therefore by proportion:—

$$0{\cdot}519 \ : \ 0{\cdot}361 \ :: \ 1000 \ : \ x \ (= 695).$$

695 represents the degree of atmospheric saturation at the time of observation.

Practically, however, it is desirable also to know the actual rate of evaporation at the time, as it is this which in great measure determines the influence of the atmosphere upon the human body, and upon the substances exposed to its influence.

(181) *Daniell's Hygrometer; Wet Bulb Hygrometer.*—The method of observing the dew point above mentioned, although it affords very exact results, is tedious in practice. To facilitate this operation, a beautiful instrument was contrived by the late Professor Daniell and termed by him the *Dew-point Hygrometer*. It consists essentially of a small cryophorus (fig. 116), containing ether instead of water, one limb of which, *c*, is longer than the other, and terminates in a ball *b* which is made of black glass for the purpose of rendering the moment at which the deposition of dew occurs more readily observable. In the long limb of the instrument is placed a sensitive thermometer, *d*, the bulb of which is partially immersed in the ether. The second bulb, *a*, is covered with muslin. In constructing the apparatus, the ether is boiled to expel the air, and the instrument is hermetically sealed whilst the ether is still boiling. When the instrument is to be used, the ether is driven into *b* by warming the bulb *a* with the hand, and the instrument is then placed in the clip *h*, on the top of the stand *g*. On allowing a few drops of ether to fall on the muslin, the vapour within the ball *a* is condensed by the

Fig. 116.

reduction of temperature occasioned by the rapid evaporation thus produced on its outer surface; fresh vapour rises from the surface of the ether in the blackened ball, from the diminished elasticity of the vapour above it: the temperature of this ether and of the ball in contact with it is lowered, and deposition of dew commences on the surface of the black ball in the form of a ring, which coincides with the level of the ether. The moment that this occurs, the temperature marked by the included thermometer, *d*, is observed. It is, however, possible, if the reduction of temperature has been rapid, that the loss of heat may not be perfectly uniform throughout the ether in the black bulb, in consequence of which the temperature indicated by the thermometer *d*, may be a little too high; it is therefore well to observe the temperature of *d*, a second time at the moment when the ring of dew disappears, during the return of the instrument towards the temperature of the surrounding air. This observation will now probably be slightly too low, but the mean of the two will accurately furnish the temperature of the dew point. The temperature of the atmosphere at the time is indicated by the thermometer *k*.

In making an observation the hygrometer should be placed at an open window, and a small cardboard screen should be interposed between the two bulbs, to prevent the vapour of the ether from extending to the atmosphere around the blackened bulb. With proper care, the instrument will yield results of great accuracy. A very good hygrometer, on a similar principle, but of less portable construction, has been used by M. Regnault.

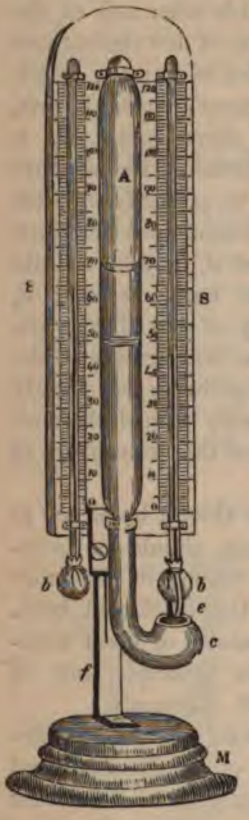
The following table has been calculated from a mean of seventeen years' daily observations at the gardens of the Horticultural Society, Chiswick, and it displays very strikingly the vast amount of evaporation which is continually occurring; and at the same time, the great fluctuations to which its average amount is liable at different seasons.

	Mean Temp. °F.	Mean Dew Point °F.	Mean Saturation.	Possible amount of Evaporation.		
				Gns. per square ft. in 1 min.	lb. per acre in 1 min.	Gallons per acre in 24 hours.
Annual . .	49·88	44·31	837	8·00	49·87	7166
Summer .	62·21	54·56	776	16·80	104·50	15048
Winter .	38·95	35·64	913	3·84	23·89	3450

The full amount of this evaporation only takes place from the surface of water, and then only during a breeze.

Other methods have been proposed for determining the quantity of moisture present in the atmosphere. Of these *hygrometers,* as such instruments are called, one only need be noticed here; it goes by the name of the *wet bulb hygrometer,* and is shown at fig. 117. In simplicity of action it leaves nothing to be desired, as it consists merely of two similar thermometers, S S, placed side by side on the same stand M f; the bulbs b b, of both are covered with muslin, and one of them is kept constantly moist by means of the capillary action of a few fibres of cotton, e, which connect it with a small vessel, A c, containing water. The rate of evaporation, and consequently the depression of temperature of the moistened bulb, will be greater in proportion as the atmosphere is further from its point of saturation; and tables have been given for determining the degree of saturation for all differences of temperature within the ordinary atmospheric range. The elaborate researches of Regnault (*Ann. de Chimie,* III. xv. 129) have shown that the indications of this hygrometer require a variety of corrections which cannot be correctly estimated. The formula which on the whole corresponds best with observation is that of Dr. Apjohn: $f' = f - \frac{d}{88} \times \frac{p}{30}$. In this formula f' is the tension of steam at the dew point, f is the tension of steam at the observed temperature of the air, d is the difference in temperature of the two thermometers, 88 is a constant coefficient for the specific heats of air and steam, p is the observed height of the barometer, 30 is the mean height of the barometer.

FIG. 117.



Mr. Glaisher, from an extensive series of comparisons made at the Greenwich Observatory, between the wet bulb hygrometer and Daniell's instrument, concludes that the dew point may be ascertained by multiplying the difference between the temperature of the dry and the wet bulb, by a number depending upon the temperature of the air at the time of observation.

The numbers which he gives are contained in the following table :—*

Dry bulb. Temperature ° F.	Multiplier.	Dry bulb. Temperature ° F.	Multiplier.
below 24	8·5	35 to 40	2·5
24 to 25	7·3	40 to 45	2·2
25 to 26	6·4	45 to 50	2·1
26 to 27	6·1	50 to 55	2·0
27 to 28	5·9	55 to 60	1·7
28 to 29	5·7	60 to 65	1·7
29 to 30	5·0	65 to 70	1·6
30 to 31	4·6	70 to 75	1·5
31 to 32	3·6	75 to 80	1·5
32 to 33	3·1	80 to 85	1·0
33 to 35	2·8		

(182) *Liquefaction and Solidification of Gases.*—Vapours were formerly considered to be essentially different in their nature from gases; but comparatively recent experiments, particularly those by Faraday, have shown that the difference between gases and vapours is merely one of degree. Under his skilful manipulation, numerous gases have been reduced to the liquid state, and not a few have even been obtained in the form of solids. Some few of the gases have still resisted the best devised attempts to liquefy them ; but it can hardly be doubted that all gases may be regarded as the vapours of liquids of an extremely high degree of volatility; the liquids resulting from the condensation of gases boiling at temperatures far below the ordinary atmospheric range : vapours, on the contrary, may be considered as the gases of liquids of comparatively low volatility.

Some of the gases are liquefiable with much greater facility than others ; for instance, a mere reduction of the temperature to 0° F., suffices to reduce sulphurous acid gas to the liquid form. Many gases, if generated in strong tubes, under a pressure of their own particles, lose their elastic form. In this way carbonic acid, cyanogen, and many others, have been liquefied. But in other cases, a combination of the pressure obtained by means of a condensing syringe, with the application of an intense degree of cold, has been requisite.

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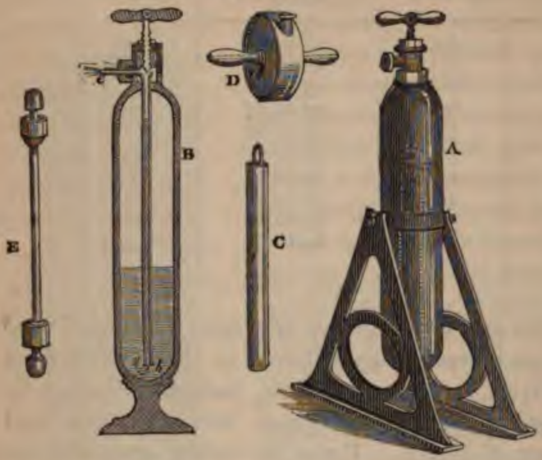
* When the dew point was calculated by Dr. Apjohn's formula from the indications of the wet bulb thermometer, the extreme differences from the true dew point, furnished by Daniell's instrument, were found in two years at Greenwich, to be —3°·9 between 65° and 70°, and + 3°·6 between 75° and 80° ; whilst the extreme differences by Glaisher's factors are —3°·7 between 75° and 80°, and + 5°·6 between 75° and 80°.—(*Daniell's Meteorology*, vol. ii. p. 100.)

Fig. 118.



Carbonic acid is manufactured in large quantities, and stored up in the liquid form, in strong wrought-iron vessels. The apparatus used for this purpose was devised by Thilorier. A modification of it is represented in fig. 118. It consists of two very strong hollow cylinders of wrought iron, one of which, A, is employed as a retort for generating the gas; the other, B, as a receiver, in which it is accumulated. The generator, A, is charged with a mixture of 2¾lb. of bicarbonate of soda and 6¼lb. of warm water: a brass tube, C, containing 1½lb. of oil of vitriol, is cautiously introduced, and the head of the apparatus, furnished with a stop-cock of peculiar construction, is screwed down and rendered tight by a leaden washer. The generator is then reversed, so as to mix the materials, which, by their reaction, liberate carbonic acid; this gas accumulates in the upper part of the vessel, where, by its own pressure it is liquefied: a strong tube, E, is screwed on laterally to both vessels A and B, and connects them together. The receiver, B, is kept cool by being immersed in melting ice. As soon as the stop-cocks are opened, the liquefied gas distils over; the stop-cocks are then closed, the vessels A and B are separated, and a fresh charge is introduced into the generator. The same operations are then repeated, until a sufficient quantity of the liquefied gas has been obtained. Communicating with the stop-cock of the receiver, is a tube, *b*, which passes down nearly to the bottom of the vessel, and terminates in an open extremity, so that as soon as the stop-cock is opened, a jet of the liquid acid is, by the pressure of its own vapour, forced up the vertical tube, *b*, and it escapes from the vessel through a fine nozzle, *e*, which is screwed to the stop-cock. The issuing liquid immediately begins to evaporate with great rapidity; by this means so large a quantity of latent heat is carried off in the escaping gas, that a portion of the liquid is converted into the solid form. If the jet of liquid be made to play into a cylindrical box, D, furnished with lateral apertures for the free passage of the gas, the solidified acid may be collected in the form of a flocculent deposit, of snowy whiteness, which gradually evaporates in the air, without undergoing previous liquefaction. This may be seen by placing a few flakes of the acid in a retort, the mouth of which is immersed in water: the gas, as it rises in bubbles, can thus be collected.

If means be taken to cut off the supply of heat from external objects, by placing the solidified acid in a glass vessel, covered externally with flannel, enclosing this in a second glass, and covering the whole with a card, and thus making, in fact, an extemporaneous ice-pail, the solidified acid may be kept in open air for some hours. As will readily be supposed, the temperature of this solid is extremely low. According to the experiments of Faraday, it is as much as 106° below 0° F. It may, notwithstanding, be handled with impunity, and may be put into water, without causing the water to freeze. These paradoxical effects are, however, easily explained. The cold acid never really touches either the water or the hand, as from the rapidity with which it evaporates it is constantly surrounded by a badly conducting atmosphere of its own vapour; but if it be really brought into contact with any solid or liquid, which may be done by moistening the solid acid with ether, which has a strong adhesion to carbonic acid, its low temperature is at once manifested, and this low temperature is maintained by its continual evaporation, which constantly carries off a large quantity of heat in the latent state. By placing some mercury in a basin, pouring on it a small quantity of ether, and adding a little solidified carbonic acid, the mercury will in a few seconds be converted into a malleable solid, although before the metal will freeze it is necessary that the temperature be reduced as low as —39° F. If the frozen mercury be transferred to a vessel containing a small quantity of water, the metal will be quickly thawed, but spiculæ of ice will be formed, showing that the process of liquefaction in the case of mercury, as in all other instances, is attended with a disappearance of heat.

By accelerating the evaporation of the bath of carbonic acid and ether, Faraday was enabled to command a still greater reduction of temperature, and in the vacuum of the air-pump he obtained by this means a degree of cold which he estimated at —166° F. In such a cold bath, many of the liquefied gases were frozen, and were obtained in the shape of solids, clear and transparent as ice. Among the number which assumed this form was carbonic acid itself. (*Phil. Trans.*, 1845, p. 155.) Even without the aid of pressure, but simply by employing a bath of carbonic acid and ether in the air, the following gases—viz., chlorine, cyanogen, ammonia, sulphuretted hydrogen, arseniuretted hydrogen, hydriodic acid, hydrobromic acid, and carbonic acid, were obtained in the liquid form, and were sealed up in tubes. The tubes used were of green bottle glass, bent, as represented in fig. 119; to these tubes brass caps and stop-cocks were, when necessary, securely attached, by means of a resinous cement. The cold bath was applied at the curvature. When pressure was requisite, it was obtained by the employment of two condensing syringes; the first had a piston of an inch in diameter, the second one of only half an inch; these syringes were connected by a pipe, so that the first syringe forced the gas through the valves of the second; and the second syringe was then used to compress still more highly the gas which had already been condensed by the action of the first, with a power varying from ten to twenty atmospheres.*

FIG. 119.

M. Natterer obtained a still more intense degree of cold than that produced by carbonic acid and ether *in vacuo*, by mixing liquid protoxide of nitrogen with bisulphide of carbon, and placing the bath *in vacuo*; the lowest temperature which he has recorded is —220° F. Fluoride of silicon, at this point, became a transparent solid, but liquid chlorine and bisulphide of carbon preserved their fluidity. (*Ann. der Chem. und Pharm.* liv. 254.)

FIG. 120.

In order to estimate the degree of pressure which the condensed gas exerted upon the interior of the vessel in which it was contained, and to determine the force requisite to overcome the repulsive energy of its own particles, Faraday made use

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* The temperatures recorded in these experiments are in all probability somewhat too high. They were estimated by means of a spirit thermometer, subdivided into degrees below 32° F., "equal in capacity to those between 32° and 212°;" but the contraction of alcohol is more rapid at low than at high temperatures: at the lowest temperatures attained the alcohol became somewhat viscid.

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of small air-gauges, which he enclosed in the tubes employed for the condensation (fig. 120). These gauges consisted of a somewhat conical capillary tube of glass, which was divided into parts of equal capacity, by introducing into the tube a globule of mercury, shown at *a*, which was made to occupy each part of the tube in succession; the length of the little cylinder into which the mercury was reduced in each portion of the tube was marked upon the glass with black varnish. The mercury was then transferred towards the widest extremity, and the tube was sealed at its narrow end. A known volume of air was thus included, and by the compression which this air experienced in the course of the experiment (the bulk being inversely as the pressure) the elastic force of the gas under examination was easily calculated. It is remarkable that many of these condensed liquids expand upon the application of heat more rapidly than the gases themselves. It has been also found that Marriotte's law, according to which the elasticity of a gas increases directly as the pressure, although correct for pressures at some distance above the point of condensation, does not hold good as this term is approached; probably, as suggested by Berzelius, because the distance to which the particles are separated is not sufficient entirely to overcome the cohesive force, which increases in power the more nearly the point of condensation is reached.*

Although indications of this departure from Marriotte's law have been observed at common temperatures, with some of the more condensible gases, such as sulphurous acid, sulphuretted hydrogen, cyanogen, and ammonia, it was most distinctly exhibited in the experiments of Cagniard de Latour (*Ann. de Chimie*, II. xxi. and xxii). M. de Latour partially filled some strong glass tubes with water, with alcohol, with ether, and with some other liquids, furnished them with gauges, and hermetically sealed them. He then cautiously raised the temperature. The alcohol (Sp. gr. 0·844), which occupied $\frac{2}{5}$ the capacity of the tube, gradually expanded to double its volume, and then suddenly disappeared in vapour, at a temperature of 404½° F.; it then exerted a pressure of about 119 atmospheres. Ether became gaseous at 328° F., in a space equal to double its original bulk, exerting a pressure of 37½ atmospheres; whereas, if Marriotte's law held good in these cases, calculating from the volume of vapour which a certain bulk of each liquid yields under the atmospheric pressure, ether should have exerted a force equal to about 209 atmospheres, and alcohol of at

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* See also Note, page 36 and at page 170.

least 242. Water was found to become gaseous in a space equal to about four times its original bulk, at a temperature of about 773° (that of melting zinc). So great was the solvent power of water on glass, at this high temperature, that the addition of a little carbonate of soda was necessary to diminish the action on the glass, which frequently gave way until this expedient was adopted. As the vapours cooled, a point was observed at which a sort of cloud filled the tube, and, in a few moments after, the liquid suddenly reappeared.

It will be seen from the subjoined table, that even after the liquid has wholly disappeared, the increase in the elastic force of the vapour, as the temperature rises, is as rapid as before it had all volatilized, and indeed it continues to increase in a proportion far greater than that which would be produced in air by an equal elevation of temperature. Atmospheric air, under a pressure of 37·5 atmospheres at 302° F., would, at 392°, exert a force of 65, and at 500° of 73 atmospheres, whereas the corresponding pressures with ether were 86·3 and 130·9 atmospheres.

Cagniard de Latour's Experiments.

Temperature ° F.	Ether.		Bisulphide of Carbon.
	Volume, as liquid 7 parts, as vapour 20 parts.	Volume, as liquid 3½ parts, as vapour 20 parts.	Volume, as liquid 8 parts, as vapour 20 parts.
	Pressure in atmospheres.	Pressure in atmospheres.	Pressure in atmospheres.
176	5·6		4·2
194	7·9		5·5
212	10·6	14·0	7·9
230	12·9	17·5	10·0
248	18·0	22·5	13·0
266	22·2	28·5	16·5
284	28·3	35·0	20·2
302	37·5*	42·0*	24·2
320	48·5	50·5	28·8
338	59·7	58·0	33·6
356	68·8	63·5	40·2
374	78·0	66·0	47·5
392	86·3	70·5	57·2
410	92·3	74	66·5*
428	104·1	78	77·8
446	112·7	81	89·2
464	119·4	85	98·9
482	123·7	89	114·3
500	130·9	94	129·6
518			135·5

*** At this point the liquid had entirely disappeared as vapour.**

From these experiments it is obvious that there exists for every liquid a temperature at which no amount of pressure is sufficient to retain it in the liquid form. Space must always be allowed for the full expansion of the liquid, otherwise, as frequently happened in the experiments of M. Cagniard de Latour, the strongest vessels will give way. It is not surprising, therefore, that mere pressure, however intense, should fail to liquefy many of the bodies which usually exist in the form of gases.

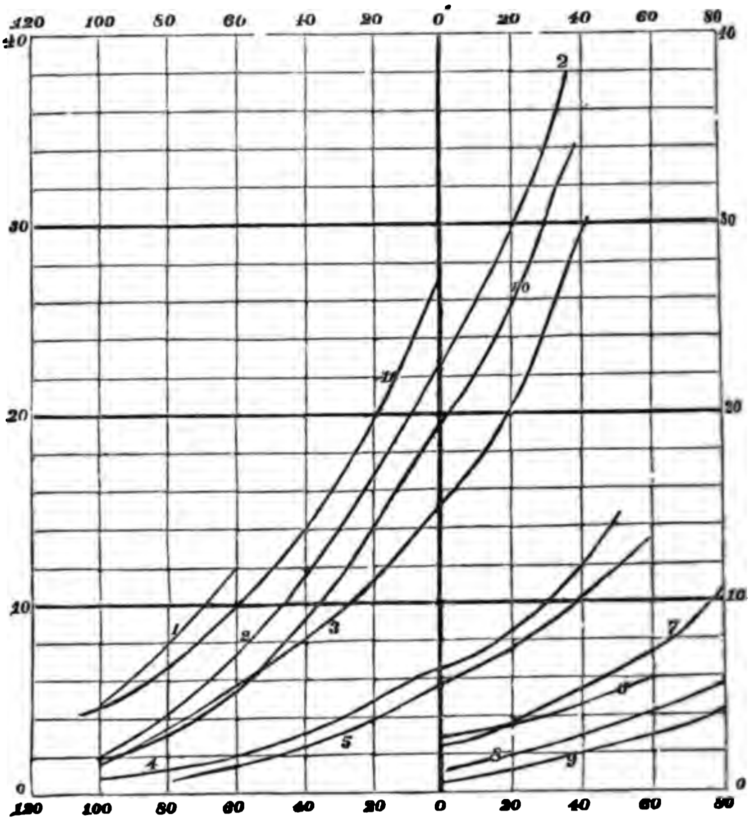
The following table embodies the results obtained by Faraday on the condensation and solidification of the gases. The solids usually were heavier than the liquid portions from which they separated.

Condensation and Solidification of Gases.

Names of the Gases.	Melting Pt. °F.	Pressure in Atmospheres.		
		at 32° F.	at 60° F.	° F.
Sulphurous Acid . . .	— 105	1·53	2·54	5·16 at 100°
Cyanogen	— 30	2·37		4·00 at 63°
Hydriodic Acid . . .	— 60	3·97	5·86	
Ammonia	— 103	4·4	6·90	10·00 at 83°
Sulphuretted Hydrogen	— 122	10·		14·60 at 52°
Protoxide of Nitrogen .	— 150	32·		33·40 at 35°
Carbonic Acid	— 70	38·5		
Euchlorine	— 75			
Hydrobromic Acid . .	— 124			
Fluoride of Silicon . .	— 220			
Chlorine		8·95	13·19	
Arseniuretted Hydrogen				
Phosphuretted Hydrogen				
Olefiant Gas				26·90 at 0
Fluoride of Boron . . .				11·54 at —62°
Hydrochloric Acid . .		26·20		40· at 50°

The diagram which follows (fig. 121) shows the curves indicating the increase of pressure with the temperature, from Faraday's tables. In this diagram, the vertical lines represent the degrees of temperature on Fahrenheit's scale; the horizontal lines show the pressure in atmospheres exerted by the condensed gas.

FIG. 121.



1. Fluoride of Boron.
2. Carbonic Acid.
3. Hydrochloric Acid.
4. Sulphuretted Hydrogen.
5. Arseniuretted Hydrogen.
6. Hydriodic Acid.
7. Ammonia.
8. Cyanogen.
9. Sulphurous Acid.
10. Protoxide of Nitrogen.
11. Olefiant Gas.

Mr. Faraday remarks, that as far as his observations go, "it would appear that the more volatile a body is, the more rapidly does the force of its vapour increase by further addition of heat, commencing at a given point of pressure; for all these, for an increase of pressure from two to six atmospheres, the following number of degrees require to be added for the different bodies named:—Water, 69° F.; sulphurous acid, 63°; cyanogen, 64°·5; ammonia, 60°; arseniuretted hydrogen, 54°; sulphuretted hydrogen, 56°·5; muriatic acid, 43°; carbonic acid, 32°·5; nitrous oxide, 30°."

The pressures, indicated by the curves in fig. 121, after all, are probably only approximations. The experiments of Cagniard de Latour show that under these enormous pressures, the bulk which the liquid bears to the space in which it is confined has a material influence upon the pressure which its vapour exerts when the results of different experiments with the same liquid are compared at the same temperatures, and before the liquid has wholly assumed the state of vapour; this will be seen by comparing the two columns showing the elasticity of ether at temperatures below 302° F. in two different experiments (page 256). It is not unlikely that the extraordinary discrepancies in the estimates of the elasticity of liquefied carbonic acid given by Faraday, Thilorier, and Addams, are due to this cause. Similar differences, to a less extent, have been observed in the case of sulphurous acid and cyanogen, and some other gases.

Faraday states, as the results of his experiments, that ammonia and sulphuretted hydrogen, when solidified, each furnished a white translucent mass, like fused nitrate of ammonia: euchlorine gave a transparent orange-coloured crystalline solid. The other liquefied gases which were susceptible of solidification furnished colourless transparent crystalline masses like ice. Phosphuretted hydrogen, nitrous oxide, and olefiant gas, appeared each to consist of a mixture of two gases, one considerably more condensible than the other.

Oxygen remained gaseous under a pressure of 27 atmospheres, at a temperature of —166° F.; and a pressure of 58·5 atmospheres at —140° was equally ineffectual in producing its liquefaction. Nitrogen and binoxide of nitrogen resisted a pressure of 50 atmospheres; with carbonic oxide, a pressure equivalent to that of 40 atmospheres, with coal gas, one of 32, and with hydrogen, one of 27 atmospheres, was applied without effecting the liquefaction. In all these experiments, the temperature was maintained at —166°. Owing to the superior diffusiveness of the lighter gases, such as hydrogen, the apparatus began to leak at comparatively low pressures; and thus a limit was placed to the amount of pressure that could be applied to them.

(183) *Spheroidal state produced by Heat.*—Much attention has of late years been excited by a phenomenon first described by Leidenfrost, and which has been made the subject of careful investigation by M. Boutigny. The following experiments will illustrate its character. If a good conductor, such as a sheet of metal, be heated to between 300° and 400° F., and water be allowed to fall

upon its surface, the liquid does not enter into ebullition; but instead of wetting the surface as usual, it rolls about in spheroidal masses in the manner shown at fig. 122; the temperature of such a spheroid never rises to the boiling point of the liquid. If the source of heat be removed, the temperature will fall until a point is at length reached, when the liquid suddenly begins to boil vehemently, and is dispersed in all directions with a loud hissing noise.

FIG. 122.

This phenomenon is a complicated result of at least four distinct causes. Of these the most influential is the repulsive force which heat exerts between objects which are closely approximated to each other. A low manifestation of this action has been already noticed when speaking of the effect of a rise of temperature in producing a decrease of capillary attraction (50). When the temperature reaches a certain point actual repulsion between the particles ensues: this fact is curiously exemplified when pure silica, in an extreme state of division is highly heated; the slightest motion then causes the particles of the powder to slide over each other, and the surface of the powder is thrown into undulations almost like those of a fluid. Besides this repulsive action occasioned by heat, the other causes which may be mentioned as tending to produce the assumption of the spheroidal condition by the liquid, are these:—1. The temperature of the plate is so high that it immediately converts any liquid that touches it into vapour, upon which the spheroid rests as on a cushion. 2. This vapour is a bad conductor of heat, and prevents the rapid conduction of heat from the metal to the globule. 3. The evaporation from the entire surface of the fluid carries off the heat as it arrives, and assists in keeping the temperature below the point of ebullition. The spheroidal form assumed by the drop, is a necessary consequence of the action of cohesion among the particles of the fluid, and the simultaneous action of gravity on the mass.

M. Boutigny finds that even if the liquid be boiling, its temperature sinks from 5° to 7° below the boiling point, as it assumes the spheroidal form at the moment that it falls on the heated surface.

All liquids are capable of assuming this condition; but the temperature to which it is necessary to heat the conducting surface varies with each liquid; the lower the boiling point of the fluid, the lower also is the required temperature. The exact heat is dependent partly upon the conducting power of the plate, and partly upon the latent heat of the vapour; the temperature of the plate approaches the boiling point of the liquid more closely as the latent heat is less. In the case of the undermentioned liquids the lowest temperature required in the plate was found to be for water, 340° F.; for alcohol, 273° F.; for ether, 142° F.

M. Boutigny considered the temperature of each liquid, when in the spheroidal state, to be as definite as that of its boiling point; and he gives 205°·7 as the temperature of the spheroid of water; 167°·9 for that of alcohol; 93°·6 for that of ether; and 13°·1 for that of sulphurous acid. M. Boutan has, however, shown that these temperatures are liable to slight variations.

Even *in vacuo* the spheroidal state is observed to occur when the liquid is allowed to fall upon a plate sufficiently heated. Solids in liquefying in hot capsules, pass into this same state, as is well exemplified by throwing a few crystals of iodine upon the heated surface. Provided that the hot surface be a sufficiently good conductor of heat, the nature of the material is unimportant. Silver, platinum, copper, and iron may all be successfully used. Mr. Tomlinson has shown that even one liquid may be thrown into the spheroidal form on the surface of another, as water, alcohol, or ether, on the surface of hot oil; but this experiment requires care, otherwise the water sinks in the oil, evaporation from the surface of the drop is prevented, steam is generated with explosive violence, and the hot oil is scattered about in all directions.

If the hot metal be sufficiently massive, a large body of water may be converted into this spheroidal state. M. Boutigny has suggested that in certain cases the explosion of steam-boilers may have been due to this cause. It is indeed quite possible, although such an occurrence must be rare, that the water may be all expended in a boiler beneath which a brisk fire is maintained, so that the mass of metal may become intensely heated. On the admission of cold water under such circumstances, it would at first assume the spheroidal state, and as the boiler gradually cooled down, by the introduction of more water, a sudden and uncontrollable burst of vapour would ensue. The safety-valve in such a case would be inadequate to allow the needful escape for the immense volume of steam which would be instantaneously generated, and an explosion would probably occur.

By tracing the effects above detailed to their extreme consequences, some singular and paradoxical effects have been produced. For example, liquid sulphurous acid becomes spheroidal in a red-hot capsule at a temperature of about 14° F., that is 18° below the freezing point of water. If a little water be dropped into this spheroid, the temperature of the water is instantly reduced below its freezing point, and a mass of ice is formed within the glowing crucible. If a bath of solid carbonic acid and ether be substituted for the sulphurous acid in the red-hot capsule, mercury placed within it in the bowl of a small spoon may be frozen with equal certainty. But perhaps the most marvellous result is the impunity with which the moistened hand may be plunged for an instant into molten lead, or even into cast iron as it issues from the furnace. In these cases the adhering moisture is converted into vapour, which forms an envelope to the skin, sufficiently non-conducting to prevent the passage of any injurious quantity of heat during the brief immersion. An ingenious application of this principle has long been employed in the glass-house. In first rudely shaping the large masses of glass which are to be blown into shades, and into cylinders which are afterwards flattened into the heavy sheets technically termed British plate, open hemispherical wooden moulds are used to give the globular form; in order to prevent the wood from being burned, the workman pours a little water into the mould; it protects the wood, but assumes the spheroidal form, and neither touches nor injuriously cools the molten glass.

CHAPTER VI.

MAGNETISM AND ELECTRICITY.

I. *Magnetism.*—II. *Static Electricity.*—III. *Dynamic or Voltaic Electricity.*—IV. *Electro-Magnetism.*—V. *Magneto-Electricity.*—VI. *Thermo-Electricity.*—VII. *Animal Electricity.* VIII. *Diamagnetism.*

(184) The forces of magnetism and electricity are now found to be so intimately related, that it is hardly possible to study the operations of either separately.

The power of the loadstone to attract small pieces of iron was recognised as a remarkable natural phenomenon for centuries before the Christian era; and the 'pointing' of the magnetic needle north and south, was early applied to the purposes of navigation by the Chinese; but it was not employed for that purpose by European nations till the latter end of the fifteenth century. The property of temporarily attracting light objects which amber acquires when rubbed, was also familiar to the Grecian philosophers; but it was not till about 250 years ago that Gilbert laid the foundation of electrical science, and that Otto Guericke and Hauksbee contrived the first electrical machines. Nautical men, likewise, had often observed that after a ship had experienced a stroke of lightning, the compass was deranged or its poles were reversed; but it was not until the year 1819 that the true connexion between electricity and magnetism was pointed out by Oersted, when he published his memorable discovery, that a magnetic needle if suspended freely at its centre, would place itself at right angles to a wire which was transmitting an electric current. After the publication of Oersted's discovery, the means of obtaining powerful temporary magnets by transmitting electrical currents through wires coiled around masses of soft iron, or in other words, the methods of preparing electro-magnets, were speedily devised; and thus the dependence of magnetism on electricity in motion was shown: whilst in 1831 the completion of this chain of discovery was effected by Faraday, who announced that a current of electricity might be obtained in a closed conducting wire from the magnet, by moving it across the line of the conductor.

In its chemical bearings, particular importance attaches to the discovery of the voltaic pile or battery, by Volta, which, in the hands of Davy, led to the discovery of the metallic bases of the alkalies and of the earths, and effected a complete change in the aspect of chemical science. In later years, the applications of the voltaic battery to the chemical arts of gilding, silvering, zincing, &c., have rendered it an instrument of great importance in the industrial arts.

§ I. MAGNETISM.

(185) It will not be necessary to enter fully into the subject of magnetism, but a few remarks upon its more important peculiarities will materially aid in fixing upon the mind clear ideas of polarity and polar action.

Electricity is, like magnetism, a polar force, and the phenomena of chemical affinity fall into the class of polar actions.

The most obvious character of magnetism is seen in the power of attracting masses of iron, which is displayed to a greater or less extent by magnetized bodies. This power of attracting iron was first observed in an iron ore obtained from Magnesia in Asia Minor; hence the property was termed *magnetism*, and the mineral itself was named the *lead-stone* or loadstone. A steel bar if rubbed in one direction with the loadstone acquires similar properties; when poised horizontally, as may be done by supporting it upon a point, such a bar will take up a fixed position with regard to the poles of the earth; in this country it will point nearly north and south. The end of a magnetic bar which points towards the north is distinguished by a mark, and is hence often termed the *marked end* of the magnet. This peculiarity in the magnet of taking a fixed direction, renders it invaluable to the navigator. A magnetized needle attached to a card marked with the cardinal points, and properly suspended, constitutes the *mariner's compass*.

FIG. 123.

If a sheet of paper be laid over a magnetized steel bar, and iron filings be evenly sifted upon the paper, it will be found on gently tapping the paper, that the particles of iron accumulate in two groups, one around each extremity of the bar as a centre, and that from these points the filings arrange themselves in curved lines, somewhat resembling those shown in fig. 123, extending from one end of the bar to the other. This experiment shows that the attractive forces are concentrated at the two extremities of such a bar. A soft iron wire freely suspended at its centre in a horizontal direction, will be attracted indifferently at both ends by either end of the magnetic bar; but if a second magnetic bar be poised in the same way as the iron wire, it will be found that one end of this bar will be attracted when the magnet is brought near it in one direction, whilst the same end will be repelled if the opposite end of the magnet be presented to it. Further examination shows, that this repulsion takes place when the ends presented to each other are those which would naturally point in the same direction; two north ends repel each other, and similar repulsion ensues when two south ends are presented to each other; whereas, if the extremities presented naturally point in opposite directions, attraction ensues between them; the north end of one bar attracts the south end of the other. Thus it appears that there are two kinds of magnetism endowed with qualities analogous, but opposite to each other. The two magnetic forces are always developed simultaneously, are always equal in amount, but are opposite in their tendencies; and thus are capable of exactly neutralizing each other. They accumulate at opposite ends of the bar. These ends are termed the *poles* of the magnet. Forces which exhibit this combination of equal powers which act in opposite directions, are termed *polar forces.*

FIG. 124.

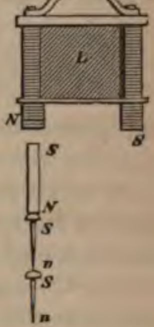
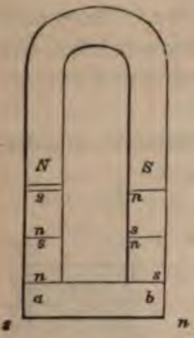


FIG. 125.

(186) *Magnetic Induction.*—Magnetism acts through considerable intervals of non-magnetic matter upon bodies such as iron, which are susceptible of magnetism, and it produces a temporary development of magnetism in such magnetizable substances. A piece of soft iron brought near to a magnet immediately assumes the magnetic state. This influence of the magnet operating at a distance is termed *magnetic induction,* and it is in consequence of this action that the iron is attracted. If the north end, N, of a magnet L (fig. 124), be presented to a piece of soft iron, the latter becomes a magnet with its poles similarly arranged; that is to say, the soft iron acquires in the extremity, s, presented to the permanent magnet, magnetism of the opposite kind to that of the end, N, of the magnet, L, which it approaches. The soft iron will now attract other pieces of iron, *s n, s n,* and they in turn will act upon others by a continuation of the inductive force. On gradually removing the permanent magnet, the effects diminish as the distance increases, and at length disappear altogether. This diminution in the effect takes place much more rapidly than in the ratio of the squares of the distance from the magnetic pole, but the exact law has not as yet been ascertained. The polar character of magnetic induction may be seen by suspending two pieces of soft iron wire over one of the poles of a magnet, s (fig. 125); the lower ends of the wires, *n n,* repel each other, but are both drawn towards the magnet, and the upper extremities, *s s,* also repel each other. It is this mutual repulsion of the corresponding ends of the pieces of iron which causes the iron filings (fig. 123) to distribute themselves in curves around the magnet; for in this experiment each particle of iron becomes for the time a magnet with opposite poles. It is likewise in consequence of this polarity that a number of pieces of

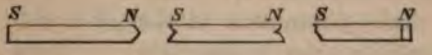
fine iron wire under induction form a continuous chain. A bar of soft iron placed on a magnet of equal dimensions neutralizes its action for the time; by connecting the two extremities of the magnet, it diverts the induction from surrounding bodies, and concentrates it upon itself. On the other hand the induction is much strengthened if the magnetic circle be completed (as in fig. 126) by uniting the pieces of iron suspended from either pole by the connecting piece, *a b*. This induction is maintained across the greater number of bodies, such as atmospheric air, glass, wood, and the metals. It is, however, modified by the interposition of iron, cobalt, and nickel, which are themselves powerfully susceptible of magnetism.

FIG. 126.



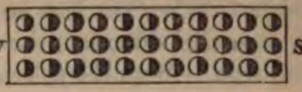
Magnetic induction differs essentially from electric induction (198) in this particular—viz., that it is not possible to insulate either kind of magnetism from the other. For instance, if one end of the two united pieces of iron, *s n*, *s n* (fig. 124), exhibit the properties of a north magnetic pole, the other end will exhibit those of a south magnetic pole; but if the two pieces of iron, whilst still under the influence of induction, be separated from each other, and then the magnet be withdrawn, both pieces of iron will have lost their magnetism. Again, if a magnet be broken in the middle, it will not be separated into one piece with a north and another with a south pole; each fragment will still possess two poles, turned in the same direction as those of the original bar (fig. 127); and each fragment may again be subdivided into an indefinite number of smaller fragments, each of which will still possess a north and a south pole.

FIG. 127.



These phenomena may be explained by supposing that a magnet consists of a collection of particles, each of which is magnetic and endued with both kinds of magnetism. In the unmagnetized condition of the bar, these forces are mutually combined, and exactly neutralize each other; but when the mass becomes magnetized, the two forces separate from each other, though without quitting the particle with which they were originally associated. The two halves of each particle assume an opposite magnetic condition. All the north poles are disposed in one direction, whilst all the south poles are disposed in the opposite direction. Each

FIG. 128.



particle thus acquires a polar condition, and adds its inductive force to that of all the others: as a necessary consequence of such an arrangement, the opposite powers accumulate at the opposite extremities of the bar. If in fig. 128 the small circles be taken to represent the ultimate magnetic particles, the portions in shadow would indicate the distribution of south magnetism, whilst the unshaded half of the particles would show the distribution of magnetism of the opposite kind. This hypothesis is supported by the fact that a magnet whilst producing induction loses none of its force, but on the contrary suffers temporary increase of power, owing to the reaction of the induced magnetism of the soft iron upon it.

(187) *Preparation of Magnets.*—Pure soft iron loses its magnetism as soon as it is withdrawn from the inductive influence; but the presence of certain foreign bodies in combination with the iron, particularly of oxygen, as in the natural loadstone, and of carbon, as in steel, enables the body permanently to retain the magnetic power. Hardened steel is always the material employed in the preparation of permanent magnets: it is not susceptible of so intense a degree of magnetization as soft iron, but when induction has once been produced within it, the effect is retained for an indefinite length of time. The development of this power in steel is much facilitated by friction; and the amount of force thus developed is greatly dependent upon the direction in which the friction is performed. A simple method of magnetizing a bar consists in placing the bar on its side and bringing down upon one of its extremities either of the ends of a bar magnet. If the north end be brought down on the steel bar, it must be drawn slowly along towards that extremity of the bar which it is intended shall possess south magnetic force: this operation must be repeated three or four times in the same direction. A more effectual plan is to bring down upon the centre of the bar the two ends of a powerful horse-shoe magnet, as represented in fig. 129; the south pole being directed towards the end of the bar that is intended to possess the northern polarity, and *vice versâ*. It is then moved along the surface from the centre, alternately towards either extremity, taking care not to carry the horse-shoe beyond the extremities of the bar,

FIG. 129.

and to withdraw the horse-shoe from the bar when at its centre, *c*. The bar is then turned over and the process repeated on the opposite side, but in the same direction, for an equal number of times. When two bars are to be magnetized, they may be disposed in a parallel direction, the extremities being connected by pieces of soft iron. Both the poles of the horse-shoe are brought down upon the centre of one of the steel bars, and it is carried round the parallelogram always in the same direction, taking care, as before, to withdraw it when over the centre of one of the bars. In the last arrangement, the induction of one bar acts upon and exalts the intensity of the magnetism excited in the other. For this reason, the opposite poles of magnets, when not in use, should be connected by soft iron armatures, or keepers, so that the continued induction shall maintain the force of each.

In the act of magnetization, the horse-shoe loses nothing of its power; but the north and south magnetism, which are supposed to exist in every particle of steel and iron, and which in the unmagnetized condition are so combined as exactly to neutralize each other, appear from the effect of the induction to which they have been subjected, to be permanently disturbed in their equilibrium in the newly-magnetized bars. The more intense the power of the horse-shoe, the greater is this disturbance, and the more powerful are the magnets which are produced.

By uniting together several bar magnets, taking care that the corresponding poles of each are in the same direction, magnetic batteries of great power may be obtained. The magnets should be all as nearly as possible of the same strength; because if one of the bars be weaker than the others, it materially diminishes the power of the whole, and acts in the same manner as a bar of soft iron would do, though to a more limited extent. As a matter of convenience, the bar magnet is often bent into the form of a horse-shoe, so that the inductive and attractive power of both poles may be simultaneously exerted on the same piece of iron; the effect is in this manner much increased, and the weight sustained by the two poles united is much greater than the sum of the two weights which would be supported by each pole separately. For this reason, the soft iron armatures N S, of a loadstone (fig. 124) add greatly to its power, and by facilitating the application of the *keeper*, or piece of soft iron which connects the two poles when not in use, prevent the loss of the magnetic power.

(188) It has been mentioned that the friction of a steel bar, whilst under induction, facilitates its magnetization. The same

effect is occasioned by percussion of the bar, or by any other mode of producing vibration in it whilst it is under magnetic induction. On the other hand if a bar has been fully magnetized, its force is reduced by the application of a sudden blow; even the simple act of scratching the surface with sand-paper, or with a file, may seriously impair the power of a good magnet.

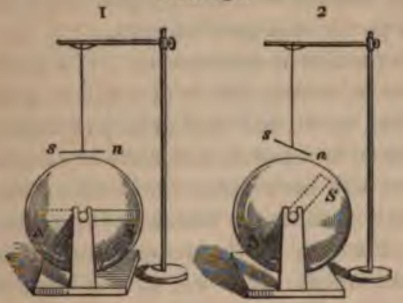
The influence of heat on magnetism is remarkable. If a steel bar be ignited and placed under induction, and whilst still in this condition it be suddenly quenched, it will be found to be powerfully magnetic. Again, if a steel magnet be ignited, and allowed slowly to cool, all its acquired magnetism will have disappeared. Elevation of temperature, therefore, evidently favours the transfer of magnetic polarity within the particles. Further, if the temperature of a piece of iron be raised to redness (about 1000° F.), it will become indifferent to the presence of a magnetic needle, though on again cooling it will be as active as before. A similar effect is produced upon cobalt. Nickel, at a still lower temperature, loses its action upon the magnet, as at 600° F. it exerts scarcely any attractive effect on the needle. So great is the influence of temperature upon a magnetic bar, that at a heat of boiling water, the diminution of its power is perceptible by the rudest tests. If the temperature do not exceed 212° the magnet regains its force on cooling. On the other hand, by artificially cooling a magnet, its power for the time is exalted.

(189) The simplest method of ascertaining the intensity of the power of a magnet, consists in attaching to its armature a scale pan, and ascertaining the amount of weight which it will support; but it is obvious that this plan is not susceptible of any high degree of accuracy; it is, moreover, in many cases, quite inapplicable. A still easier, and more generally useful, because far more accurate, method, consists in suspending the magnet delicately by a few fibres of silk, and allowing it to take a fixed direction under the influence of a standard magnet: it is then displaced from its position of equilibrium, and the number of oscillations which it describes in a given time is counted. The relative intensity of the power of two or more bars, which may thus be compared, is proportionate to the square of the number of vibrations performed in equal intervals of time. For estimating low degrees of power, the torsion of a glass thread (as employed in Coulomb's electrometer, 196) may be used. The mutual action of two magnets is inversely as the square of the distance between them.

(190) *Magnetism of the Earth—The Dip.*—The remarkable fact of the pointing of the needle towards the north pole of the earth

has been explained upon the hypothesis that the globe of the earth itself is a magnet, the poles of which are situated nearly in the line of the axis of rotation; the magnetism of the earth's north pole being of the same kind as that of the unmarked end of the magnet. If a small magnetized needle, *s n*, be freely suspended horizontally by a thread over the equator of a sphere (fig. 130) nine or ten inches in diameter, in the axis of which a small steel magnet, N S, is placed, the needle will, when the axis is horizontal, as in No. 1, point north and south, and will preserve its horizontal position; for it is equally attracted by the north and south polarities of the bar; but if one of the poles of the sphere be made gradually to approach the needle, as at 2, that end which previously pointed towards this pole will begin to incline downwards, or to *dip*, until, when situated exactly over the pole, its direction will become vertical. On bringing the opposite pole towards the needle, similar phenomena are repeated with the other end of the needle. Similar phenomena are also exhibited when a magnetic needle, poised horizontally at the equator of the earth, is carried towards either of its poles. A needle, therefore, which when unmagnetized is so poised as to assume a horizontal position, in the latitude of London, appears to become heavier at its marked end by the process of magnetization. An instrument by means of which the angular amount of this *inclination* can be accurately observed, is called a *dipping needle*.

FIG. 130.



(191) *Declination or Variation.*—The axis of magnetic power in the earth does not exactly correspond with its axis of rotation, and in consequence the needle does not point due north excepting at those places which lie on the meridian passing through the magnetic pole: in all other places it points either west or east of the true north. At the present time, the magnetic pole lies to the west of the meridian of Greenwich, and the needle in London points nearly 24° west of north. This deviation from the true north is called the *variation* or *declination* of the needle. The principal north magnetic pole, or point at which the dipping needle stands vertically, is situated about 96° 40′ W. lon. and 70° 14′ N. lat.; the

south pole being nearly in 73° S. lat. and 130° E. lon. The magnetic equator, or line of *no dip*, is inclined to the earth's equator at about 12°, and forms an irregular curve crossing it in four places.

It is remarkable that the declination of the magnetic needle is not constant. In the year 1657, the needle pointed due north at London, as it would do if the magnetic pole were contained in the meridian of Greenwich. It then passed westward until the year 1816, at which time the variation to the west in London was nearly 25°; since this time it has been gradually returning towards the east. The rate of its motion differs in different parts of its progress, becoming slower as it approaches the point of retrogression. Independent of these gradual and progressive changes, the variation is subject to diurnal movements of very small amount: north of the magnetic equator the north end of the needle moves slowly eastward in the forenoon, and returns to its mean position about ten in the evening. These movements are dependent upon the diurnal variations of temperature. Connected with these alterations are corresponding variations in the dip, which during the last fifty years has been observed in London to diminish annually more than 3′. It is now (1854) something less than 68°30′.

(192) The intensity of the earth's magnetism is also found to vary at different points of the surface: it is weakest near the equator, and increases in strength on approaching the poles. The points of greatest intensity, however, do not coincide with the poles at which the dipping needle is vertical. The intensity does not follow a regular law of increase. If the highest degree of intensity be 2·052, and the mean be 1, the lowest will be 0·706. Both the maximum and minimum here mentioned are in the southern hemisphere (Harris' *Rudimentary Magnetism*, part iii. p. 99). If it be supposed that the globe be divided by a plane passing through the meridians of 100° and 280°, the western hemisphere, comprising America and the Pacific Ocean, presents a higher intensity than the eastern; but the charge of the northern and of the southern hemisphere is equal.

The intensity of the earth's magnetism, like the variation and the dip, is found to suffer periodical changes. Besides these regular variations of the magnetism of the earth, other irregular variations have been observed. These have been termed *magnetic storms*: they are indicated by sudden and considerable disturbances of the magnetic instruments, of short duration, which are produced by some widely acting causes, as these disturbances have been noticed simultaneously at very distant parts of the earth's surface. Colonel Sabine considers that these magnetic storms are connected with changes in the solar atmosphere, which are indicated by variations in the number and form of the spots upon the sun's disk.

Since, then, the earth may be looked upon as an immense magnet of small intensity, it is natural to expect that, under favourable circumstances, magnetic induction should arise from its influence. Such effects are indeed continually observed. If a soft iron bar be placed in the line of the dip, it acquires temporary magnetic properties, the lower extremity acting as the marked pole of a magnet upon a magnetized needle, while the upper extremity acts as the unmarked pole. By reversing the position of the bar, the end which is now the lower will still possess the magnetism of the marked pole. A bar of steel, such as the poker or tongs, which is kept in a vertical position (a line in this latitude not far removed from that of the dip), is from this cause frequently found permanently, though weakly, magnetic. It is to the same cause operating upon the loadstone through the lapse of ages, in the same direction, that its polarity is to be ascribed.

If a steel bar be made to vibrate while placed in the line of the dip, as by giving it a smart blow, it is magnetized still more powerfully, and this effect may be still further increased by the inductive influence of other masses of iron placed in contact with it. Thus by allowing a steel bar, supported in the line of the dip, to rest upon an anvil, and striking it strongly with a hammer, it becomes decidedly magnetized. All permanent magnetism may, however, again be removed from it by placing it *across* the line of dip, and striking it two or three blows as before.

Iron, nickel, and cobalt are the only substances which are powerfully magnetizable; but a susceptibility to magnetism in a much feebler degree has, by the researches of Faraday and others, been proved to exist in a variety of other bodies. Before describing the method in which these experiments were conducted, it will be necessary to examine the leading phenomena of electricity, and these will now be considered.

§ II. STATIC ELECTRICITY.

(193.) The force of electricity is one of those subtle and all-pervading influences which are intimately connected with the operations of chemical affinity. Indeed some of our most eminent philosophers have been disposed to regard electricity and chemical affinity in the light of different manifestations of the same agent.

For upwards of 2000 years it has been known that when amber is rubbed upon such bodies as fur, or wool, or silk, it acquires for a short time the property first of attracting light objects, such as fragments of paper or particles of bran, and afterwards of repelling them. Until about 250 years ago, amber was the only known substance by which such effects were produced. Dr. Gilbert about that time discovered that a number of other bodies, such as glass, sealing-wax, and sulphur might be made to excite similar motions. The power thus called into action has been called *electricity*, from electrum (amber), the body in which it was first observed. Independently of its origin in friction, it has been found that electricity is liberated by chemical action, by certain vital operations, by heat, by magnetism, by compression, and in fact by almost every motion that occurs upon the face of the globe. Electricity neither increases nor diminishes the weight of bodies under its influence; and neither enlarges nor reduces their bulk. It may be excited in all substances; may be communicated from one electrified or *excited* body to another previously in a *neutral* or unelectrified condition, and it may be stored up for the purposes of experiment.

(194) *Two Kinds of Electricity.*—A very simple contrivance will suffice for examining the fundamental phenomena of electricity as developed by friction:—

Soften a little sealing-wax in the flame of a candle, and draw it out into a thread eight or ten inches long, and of the thickness of a stout knitting pin. Attach to one end of it a disk of paper about an inch square, as represented in fig. 131; suspend this rod and disk by means of a paper stirrup and a few fibres of unspun silk from a glass rod fixed horizontally to some convenient support. Now rub a stick of sealing-wax with a bit of dry flannel, and bring it near the paper disk: the disk will at first be strongly attracted, and will then be as strongly driven away. Whilst it is in this condition of repulsion by the wax, bring towards it a warm glass tube that has been rubbed with a dry silk handkerchief; the disk will be immediately attracted, and in an instant afterwards it will again be repelled, but it will now be found to be attracted by

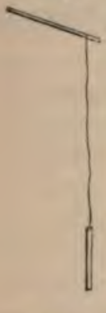
FIG. 131.

the wax. It is therefore evident, that by the friction of the glass and of the wax, two similar but opposite powers are developed. A body which has been electrified or *charged* with electricity from the wax is repelled by the wax; but it is attracted by the excited glass, and *vice versâ.* In order to distinguish these two opposite powers from each other that power which is obtained from the glass has been termed *vitreous* or *positive* electricity; that from the wax *resinous* or *negative* electricity.

Let us suppose that the paper disk has been charged by means of the glass tube, so that it is repelled on attempting to bring the glass near it; this state will be retained by the disk for many minutes. This contrivance forms, in fact, an *electroscope,* for it furnishes a means of ascertaining whether a body be electrified or not, and even of indicating the kind of electricity. Suppose that a body suspected to be electrified is brought near the disk, which is in a state repulsive of the glass tube; if repulsion occur between the disk and the body which is being tested for electricity, it is at once obvious that the substance is electrified; and moreover, that it is vitreously electrified, since it produces an effect similar to that which would be exhibited by an excited glass tube.

The phenomena of attraction and repulsion may be further exemplified by the following experiments:—Suspend two straws, separately, by a fibre of silk, each to a glass rod (fig. 132); bring an excited stick of sealing-wax towards each; each will be first attracted and then repelled: whilst thus repulsive to the wax, bring the one near to the other; they will recede from each other as they did from the wax. If both straws be excited by glass, they will in like manner repel each other; but if one be excited by the glass and the other by the wax they will attract each other. Hence we learn, that bodies similarly electrified repel, those differently electrified attract each other.

FIG. 132.



Proceeding a step further, it will be found that whenever two bodies are rubbed together, both kinds of electricity are liberated, but so long as the two bodies remain in contact no sign of the presence of either electricity appears; on separating them, both are found to be electrified—one vitreously, the other resinously: for example, stretch a piece of dry silk over a brass plate, and rub it upon a glass plate; so long as the two bodies are in contact, the quantities of each kind of electricity set free are precisely sufficient to neutralize each other, but as soon as the plates are separated the glass will repel the disk (fig. 131), while the silk will attract it.

(195) *Insulators and Conductors.*—Bodies that have been thus electrically excited, return to their neutral condition when touched by other substances, but with degrees of rapidity depending on the kind of body which touches them. A rod of sealing-wax or of shell lac may, for example, be held in contact with any electrified body without sensibly lessening the charge; but the momentary touch of a metallic wire, or of the hand, is sufficient to remove all indications of electric excitement: it is therefore clear that there are some bodies which readily allow the passage of electricity, and these are termed *conductors;* whilst there are others which do not easily allow its passage, and these are called *insulators.* There is, however, no absolute line of distinction between these two classes of bodies; there is no such thing as perfect insulation, or perfect conduction, for the two classes of bodies pass gradually one into the other.

In the following table each substance enumerated is superior in insulating power to all those which follow it. The nearer the substance is to the bottom of the table, the better, on the contrary, is its conducting power:—

Insulators.

Dry Gases and Dry Steam.
Shell Lac.
Sulphur.
Amber.
Resins.
Gutta Percha.
Diamond.
Silk.
Dry Fur.
Glass.
Ice.
Spermaceti.
Turpentine and Volatile Oils.
Fixed Oils.
String and Vegetable Fibres.
Moist Animal Substances.
Water.
Flame.
Melted Salts.
Plumbago.
Charcoal.
All the Metals.

Conductors.

Any object is spoken of as being electrically *insulated* when it is supported by means of some badly-conducting substance which prevents the free escape of the electricity. The presence of moisture deposited from the air upon the surface even of the best insulator, converts it for the time into a conductor, and is one of the most annoying impediments to the success of electrical experiments, as the power is carried off as fast as it is accumulated. Glass is especially liable to this inconvenience, but by varnishing it when practicable, and keeping it thoroughly warm, the difficulty is diminished. By due precautions instruments may be constructed which, in dry air, will preserve a charge for several hours.

The most perfect insulators still allow electric power to traverse them, although by a process different from conduction, and hence they are termed *Dielectrics*. Thus, if one side of a plate of glass be electrified by rubbing it with a piece of silk, the opposite face also acquires the power of attracting particles of bran or other light objects.

(196) *Electroscopes.*—Various instruments have been devised for detecting feeble charges of electricity. One of the most convenient of these is the *gold leaf electroscope* (fig. 133), which is sensible to extremely small charges. It consists of a pair of gold leaves suspended from the lower extremity of a metallic wire which terminates above in a brass plate. The wire is insulated by passing through a varnished glass tube, packed with silk, and the whole is surrounded and supported by a glass case. The approach of an excited body instantly causes the divergence of the leaves. If a glass tube be rubbed with a dry handkerchief and touched with a small disk of paper insulated by attaching it to a rod of sealing wax, as directed in preparing the electroscope (fig. 131), a small vitreous charge will be received by the paper, and if carried by it to the cap of the electroscope, the leaves will diverge permanently with vitreous electricity. The approach of the glass rod would cause the leaves to diverge further, whilst that of a stick of excited wax would cause them to collapse.

Fig. 133.

Fig. 134.

An instrument (fig. 134,) called a *torsion electrometer* was devised by Coulomb for accurately measuring minute differences in the amount of electrical force. The force which he opposed to that of electricity was the resistance to twisting which is offered by an elastic thread. A fibre of silk, a fine silver wire, or a thread of glass, have been used for the purpose of measuring the angle of torsion, this angle in perfectly elastic bodies being exactly proportioned to the force applied.

By means of a long glass thread, fastened above to a pin, P (carrying an index which traverses the graduated plate B), a needle of shell lac is suspended freely in the glass case A. This needle is terminated at one end by a gilt ball, *b*, at the other by a paper disk which serves to check its oscillations. In the glass cover of the instrument is a small aperture through which another gilt ball, *a* (the *carrier*), also suspended by shell lac, can be introduced and withdrawn. In order to equalize the induction, two narrow strips of tinfoil, *c* and *d*, connected with the earth, and having a narrow interval between them, are pasted upon the inside of the glass cylinder, one a little above and the other a little below the level of the balls; a graduated circle is pasted on the glass for reading off the angular deviation of the needle. When the instrument is to be used, the carrier ball is adjusted so that after it has been removed it can with certainty be replaced in the same position as at first; the ball upon the needle is adjusted by turning the pin until, without any twist upon the thread, it shall just touch the carrier, its centre being at the zero of the scale, and the position of the index on the upper graduated plate, B, is noted. The carrier ball, *a*, is next made to touch the object the electricity of which is to be measured: it takes off a quantity proportioned to the amount accumulated on the spot. The ball *a* is immediately replaced in the instrument; it divides its charge with the ball *b* on the needle, and repulsion ensues. The thread which supports the needle is then twisted until the centre of the ball *b* is, by the force of torsion, brought back towards the carrier, *a*, to some determinate angle (say 30°) marked on the graduation of the glass case; suppose the number of degrees through which it has been necessary to twist the thread to be 160°; $160° + 30°$, or 190° will represent the repulsive force. To compare this amount with any other quantity, the balls must be discharged, and the experiment repeated under the new conditions, noting the number of degrees of torsion required to make the needle stand at 30° as before: the amount of the force is directly proportionate to the torsion angle in the two cases. Suppose in a second experiment that the thread sustain a twist of 180° before the ball *b* is brought back to the angle of 30°; the force will now be $180° + 30°$ or 210°, and the relative electrical repulsions in the two experiments will be as 190 : 210.

It was long imagined that non-conductors only were capable of excitement by friction, and hence they were termed *electrics*; all bodies, however, if proper care be taken to insulate them, exhibit this phenomenon. If, for example, a piece of brass tube insulated by a glass handle be rubbed upon fur, it receives a charge, as may be shown by bringing it near the disk of the electroscope (fig. 131). Even two dissimilar metals, after being brought into contact with each other may, with proper precautions, be made to show signs of electric excitement on being separated (225). The friction of glass against metal spread over silk is attended by a more powerful development of electricity than when silk alone is used; and an *amalgam* consisting of 1 part of tin, 2 of zinc, and 6 of mercury, rubbed to fine powder and mixed with a little lard, is found to be highly effectual in exalting the force which is developed. The same substance, however, does not always manifest the same electrical condition when rubbed: glass when rubbed upon silk becomes vitreously excited; but if rubbed on the fur of a cat it exhibits resinous electricity. The amount of friction necessary to produce electric excitement is exceedingly small; the mere drawing of a handkerchief across the top of the electroscope (fig. 133), or even across the clothes of a person insulated by standing on a cake of resin, or on a stool with glass legs, provided he touch the cap of the instrument, is sufficient to cause divergence of the leaves. The simple act of drawing off silk stockings, or a flannel waistcoat, or the combing of the hair in frosty weather, frequently occasions the snapping and crackling noise due to the electric spark; and the stroking of the fur of a cat at such a season is known to produce similar effects.

(197) *Electrical Hypotheses.*—These various phenomena have been accounted for by two principal hypotheses.

One of these, commonly known as the 'theory of one fluid,' is due to Franklin. Electricity, upon this view, is supposed to be a subtle imponderable fluid, of which all bodies possess a definite share in their natural or unexcited state. By friction, or otherwise, this normal state is disturbed. If the body rubbed receive more than its due share, it acquires vitreous electricity, or, in the terms of Franklin, becomes electrified positively, or +; whilst at the same time the quantity of electricity in the rubber which becomes resinously charged is supposed to be diminished, and thus the rubber acquires a negative or — state. Franklin supposed the particles of the electric fluid to be highly self-repulsive, and to be powerfully attractive of the particles of matter.

The other hypothesis, the 'theory of two fluids,' was originally proposed by Dufay. According to this view there are two electric fluids, the vitreous and the resinous, equal in amount but opposite in tendency; when associated together in equal quantity they neutralize each other perfectly: a portion of this compound fluid pervades all substances in their unexcited state. By friction the compound fluid is decomposed; the rubber acquires an excess of one fluid, say the resinous, and thus becomes resinously excited; the body rubbed takes up the corresponding excess of vitreous electricity, and becomes excited vitreously to an equal extent. Upon this view the particles of each fluid are self-repulsive, but powerfully attract those of the opposite kind.

The language of either theory may be employed in order to distinguish the two kinds of electricity: the term vitreous or positive may be used indifferently for one kind, and resinous or negative for the other kind, provided it be borne in mind that positive and negative are mere distinguishing terms: negative electricity being as real a force as the positive.

It is manifest that one or other of these hypotheses must be false, yet either will serve to connect the facts together. The supposition of an electric fluid is, notwithstanding, gradually being abandoned. The supposition of a gravitative fluid might, with nearly as much propriety, be insisted on to explain the phenomena of gravitation, or a cohesive fluid to account for those of cohesion.

Electricity is now regarded a compound force, remarkable for the peculiar form of action and reaction which it exhibits. This kind of action and reaction follows the same law of equality and opposition in its manifestations as that which is exhibited more obviously in the phenomena of mechanics. Whenever vitreous electricity is manifested at one point, a corresponding amount of resinous electricity is invariably developed in its vicinity, reacting against it, and thus enabling its presence to be recognised, although this reacting force may not be immediately perceptible.

The phenomena of vitreous and resinous electricity may be rudely but not inaptly illustrated by those of elasticity exhibited by an ordinary spring, as shown at S, fig. 135. The spring in its unstretched state may represent the body in its unelectrified condition; it then displays nothing of the peculiar power that it possesses. The spring cannot be stretched from one extremity only; but if fixed at one end, as by hooking it to the pin, P, a weight, W, may be applied to the other end, and it will seem to be stretched by one force only. In reality, however, it is not so; for by substituting at V a weight equal in amount to that at W, instead of the fixed point P, the strain upon the spring remains unaltered, but a reaction, equal in amount to the original action of the weight W, is instantly rendered evident.

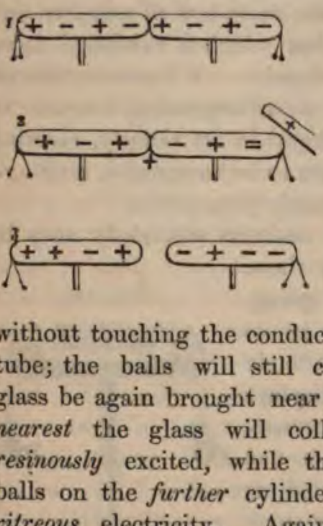
FIG. 135.

So it is with electricity; cases not unfrequently occur where only one kind of electricity seems to be present, but a careful examination will always detect an equal amount of the opposite kind. This essential character of action and reaction in the electrical force will be more clearly manifested in the following remarks and experiments.

(198) *Electrical Induction.*—In the preceding cases the electricity has been excited by friction and communicated to other bodies by contact. An insulated charged body, however, exerts a remarkable action upon other bodies in its neighbourhood. Long before contact occurs, the mere approach of an excited glass tube towards the electroscope causes divergence of the leaves, and on removing the glass, if it have not been allowed to touch the cap of the instrument, all signs of disturbance cease.

The following mode of performing the experiment will afford a means of examining this action of an electrified substance upon objects at a distance:—

FIG. 136.

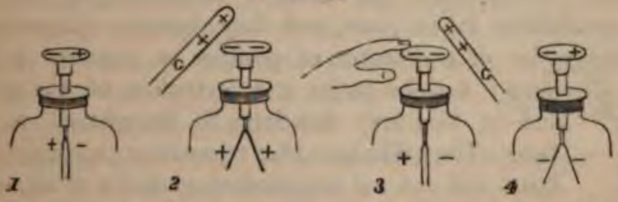


Place two cylinders of wood, or of metal, each supported on a varnished stem of glass, so as to touch each other end to end (fig. 136, 1); from the outer extremity of each suspend a couple of pith balls by a cotton thread, and bring the excited glass tube near one end of the arrangement as shown at 2. Electric disturbance will be shown by the repulsion of both pairs of balls. Separate the two cylinders without touching the conducting portion, and then remove the glass tube; the balls will still continue to diverge (3). But let the glass be again brought near; the balls on the cylinder originally *nearest* the glass will collapse, showing this cylinder to be *resinously* excited, while the same excited glass will cause the balls on the *further* cylinder to diverge from the presence of *vitreous* electricity. Again, remove the glass altogether, and bring the two cylinders into contact; a spark may sometimes be seen to pass between them, and both pairs of balls will immediately collapse and continue at rest. The entire amount of force existing upon the two cylinders taken together remains the same throughout the whole period of the experiment, but its distribution is altered, as is shown by the position of the signs + and —. The experiment may be explained in the following manner:—Suppose the two cylinders to be in the neutral state (No. 1); on bringing the excited glass tube near to them, the resinous, or negative electricity, appears to be drawn towards the end of the cylinder nearest to the glass, as in No. 2, whilst the disengaged positive electricity causes the balls on both cylinders to diverge: the moment the glass is removed, the negative electricity redistributes itself as in No. 1, and the balls collapse; but if the two cylinders be separated before the glass is removed, and if the excited glass be then withdrawn, the results will be such as are represented in No. 3, in which the negative electricity on one of the cylinders is more than sufficient to neutralize the positive, and hence the balls diverge negatively; while on the other it is less than sufficient for the positive, consequently the balls diverge with positive electricity. On causing the two cylinders to approach each other when in this state, the two forces will neutralize each other, and if of sufficient power, the reunion will be attended with a slight spark.

This action at a distance of one electrified body upon others in its neighbourhood is termed *electrical induction*. It is a principle of very extensive application, and indeed it furnishes a key to the explanation of the greater number of electrical phenomena.

An instance of electrical induction is afforded in the action of the gold leaf electroscope. Let 1 (fig. 137) represent the instrument in a neutral state. As soon as an excited glass tube, G, is caused to approach the cap of the electroscope, the leaves will diverge, as at 2. Whilst the glass tube is still near the instrument, let the cap of the electroscope be touched with the hand, so as to uninsulate it for a moment, as at 3, by placing it in communication with the earth through the body, which acts the part of a conductor; the leaves will collapse, and the instrument will seem to be quiescent: now remove the finger from the cap, and then take away the glass tube G; instantly the leaves diverge, and the electroscope is permanently charged, in consequence of a change in the distribution of the electricity, as represented at 4. But its charge is not positive like that of the glass, but negative;

Fig. 137.

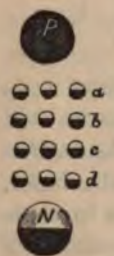


for, if the glass be again brought near, the leaves will collapse, while a stick of excited wax will make them open out further. These effects arise from electrical induction, and the process which takes place is believed to be the following. The approach of the tube in the first instance causes the negative electricity to accumulate in the cap, as at 2, where it is retained by a species of attraction. The leaves therefore diverge with a corresponding quantity of positive electricity thus set free; things being in this state, a touch is sufficient to neutralize the excess of positive electricity, as seen in 3, and the instrument appears quiescent. Remove the glass tube, however, and the negative electricity that had been accumulated on the surface of the cap spreads over the whole instrument, and the leaves diverge with negative electricity (4).

In all these cases the excited body itself, neither loses nor gains electricity by the process just described. The mode in which this transfer of force from a distance is effected still remains to be considered.

(199) *Faraday's Theory of Induction.*—We owe to Faraday a theory of these effects which has been thus concisely summed up by Sir W. S. Harris (*Rudimentary Electricity*, first edition, pp. 33 and 34). Mr. Faraday 'conceives electrical induction to depend on a physical action between contiguous particles, which never takes place at a distance without operating through the molecules of intervening non-conducting matter. In these intermediate particles, a separation of the opposite electricities takes place, and they become disposed in an alternate series or succession of positive or negative points or poles: this he terms a *polarization* of the particles, and in this way the force is transferred to a distance. Thus, if in fig. 138, P represent a positively charged body, and *a b c d* intermediate particles of air, or other non-conducting matter, then the action of P is transferred to a distant body, N, by the separation and electrical polarization of these particles, indicated by the series of black and white hemispheres. Now, if the particles can maintain this state, then insulation obtains; but if the forces communicate or discharge one into the other, then we have an equalization or combination of the respective and opposite electricities throughout the whole series, including P and N.' . . . . 'He assumes that *all particles* of matter are more or less conductors; that in their quiescent state they are not arranged in a polarized form, but become so by the influence of contiguous and charged particles. They then assume

FIG. 138.



a forced state, and tend to return, by a powerful tension, to their original normal position; that being *more* or *less* conductors the particles charge either *bodily* or by *polarity;* that contiguous particles can communicate their forces more or less readily one to the other. When less readily, the polarized state rises higher, and *insulation* is the result; when more readily *conduction* is the consequence.' . . . . . 'Induction of the ordinary kind is the action of a charged body upon insulating matter, or matter the particles of which communicate the electrical forces to each other in an extremely minute degree; the charged body producing in it an equal amount of the opposite force, and this it does by polarizing the particles' (fig. 138).

(200) *Distribution of Electric Charge.*—Bodies susceptible of this polarization are termed *dielectrics;* and whether they be solid, liquid, or aeriform, the electric force is transmitted through them freely. A pane of glass interposed between the excited tube and the cap of the electroscope will in no sensible manner affect the divergence of the leaves, which will occur as usual; but the interposition of an uninsulated sheet of tin plate, or even of a screen of wire gauze, will effectually stop all signs of electric excitement on the leaves.

Owing, however, to the molecular action by which induction is propagated, it may, under certain circumstances, be traced round the edges of such a screen, and it may be continued either in *curved* or in straight lines. Let S (fig. 139) represent a mass of shell lac which has been excited by friction at its upper part; B, a brass plate resting on the shell lac, but also in communication with the ground. At *a*, a strong inductive action is perceived, which is weaker at *b*, weaker still at *c*, and very trifling at *d;* at *e* it increases, and at *f* is nearly as strong as at *b*, whilst at *g* it again decreases, from the effect of increasing distance.

FIG. 139.

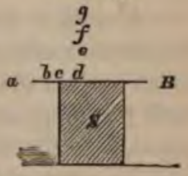


FIG. 140.

In consequence of these inductive actions, electricity when at rest is always distributed over the surface of a charged object; and therefore, for the purpose of collecting electricity, a hollow shell of conducting matter is quite as effectual as a solid mass of the same size. Many striking experiments may be given in proof of this important fact. For instance, place a metallic can, C (fig. 140, 1), upon a small insulating stand, S; communicate a charge to a brass ball, insulated by a slender glass rod, and introduce the charged ball into the interior of the can, allowing it to touch the bottom; withdraw the ball, it will be found when tested with the electroscope to have given up all its electricity. Touch the inside of the can with a *proof plane* (or small disk of paper insulated by a stout filament of shell lac), and hold it towards the charged disk of the electroscope (fig. 131), no action will be perceived: bring the proof plane, however, into contact with any part of the outer surface of the metallic can, and an abundant charge will be obtained. No charge can be sustained towards the interior, because there is no object within towards which induction can take place; but the polarization of the air on the outside produces induction towards all surrounding objects.* But now, whilst the exterior still remains charged, hold an unexcited brass ball, attached to a metallic wire, in the inside of the cup (fig. 140, 2), without, however, allowing it to touch it; if the insulated paper disk, under these circumstances, be made to touch any part of the inside of the can, it will receive a charge: the particles of the air can, under these circumstances, become polarized, because the brass ball is in a condition to become oppositely charged to the can. If the can be positive, the ball becomes negative, its positive electricity passing off to the earth by the wire.

A similar disturbance of electric equilibrium will be found whenever a charged body is brought near other uninsulated ones. If an excited glass tube be brought towards the wall of the room, and just opposite to the tube the wall be touched with the proof-plane, a small charge of resinous electricity will be carried off, and will be perceptible by the electroscope.

By increasing the surface of the conductor whilst the amount of electricity continues the same, it is obvious that the quantity upon each portion of exposed surface is diminished, and the *intensity* of the charge is said to be lowered. Thus, if a metallic ribbon, coiled up by the action of a spring, be attached to the cap of an electroscope, and a small charge be given to it, a certain divergence of the leaves will be produced; on uncoiling the ribbon, by means of a silk thread attached to it for the purpose, the leaves will partially collapse, because the same amount of induction towards the ceiling and floor of the room is now distributed over a larger sur-

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* Indeed, a delicate electrometer may be enclosed in a shell of conducting matter, which may be so highly charged as to emit sparks in all directions, and the electrometer will remain wholly unaffected.

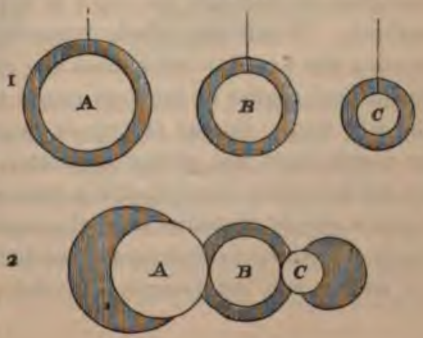
face; but on allowing the spring to exert its elasticity, and coil up the ribbon, the leaves will again resume their original divergence.

In all cases of electric excitement the charge is diffused over the surface of the conductor, but the form of that surface materially influences the mode in which the electricity is distributed. If a charged sphere be suspended in the centre of a room, the superficial distribution of the force will be uniform on all parts of its surface. But if two similar and equally excited spheres be suspended side by side, the electric accumulation will be greatest at those points of their respective surfaces which lie at the opposite extremities of a line passing through the centre of each; and in a cylinder the force is highest at the two ends.

This change in the distribution of electricity over the surface, which depends upon the change of form, was carefully investigated by Coulomb. For this purpose he employed his torsion balance, shown at fig. 134. The carrier ball, *a*, of the instrument was brought into contact with that point of the conductor which was to be examined; the ball thus acquired a charge proportional to the intensity of the electricity at that spot, and the intensity was measured in the manner already described (196), by the angular repulsion of the needle; different points of the conductor were thus examined in succession, and the intensity at each point was compared with the others.

In this way it was found that if two spheres of unequal diameters were each originally electrified to the same degree of intensity (that is, if each sphere were so charged that the quantity of electricity upon a square inch of the surface of each was exactly equal, when the two were separate) on bringing the two into contact, the greatest accumulation still occurred at the extremities of a line joining the centres of the spheres, but the accumulation was greater on the small ball than on the large one. The experiment may be carried still further; for if a series of spheres gradually diminishing in size be employed, till at last they virtually end in a point, the accumulation at length becomes so great that the point is unable to retain the charge, and dispersion ensues.

FIG. 141.



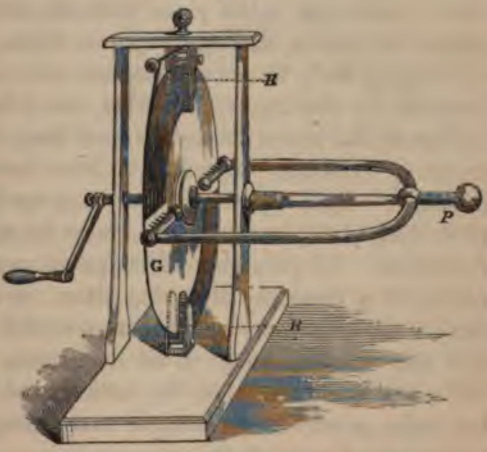
A rough idea of this effect may be conveyed by fig. 141, in which A, B, and C represent three independent spheres diminishing in size, and which in No. 1 are supposed to be charged with electricity of equal intensity, as represented by a shaded layer of equal thickness around each, while No. 2 represents the same three balls in contact. The intensity of the charge, as shown by the lines of shadow, is proportionately much greater on the smallest ball than on the largest. Points must therefore be carefully avoided in the construction of apparatus for retaining electricity. For similar reasons sharp or rough edges are equally objectionable.

(201) *Electrical Machines.*—In order to obtain large supplies of electricity, the electrical machine is employed. Two principal forms of this instrument—viz., the *cylinder* and the *plate* machine, are in general use.

FIG. 142.

In the cylinder machine (fig. 142) a hollow cylinder of glass, C, is mounted on a horizontal axis turning by a winch in two strong wooden supports. On one side is placed a leather cushion R, stuffed with hair and faced with silk; from its upper edge proceeds a silk flap, S, which reaches round the upper half of the cylinder. N is a brass conductor for collecting electricity from the rubber. The cushion is insulated by a strong glass pillar, G. To collect the electricity from the glass a metallic conductor, P, is mounted on an insulating stem of glass, H; this conductor on the side next the glass is furnished with a row of points, which from the high degree of induction produced upon them act as powerfully in receiving as in dispersing a charge. Before using the machine, a little of the amalgam of zinc and tin (196) is spread over the surface of the cushion. When the whole is made properly dry and warm, on turning the handle a brisk crackling snapping noise is heard, whilst flashes and sparks of fire dart round the cylinder from the edge of the silk flap. Sparks of two or three inches in length may now be drawn from the *prime conductor*, P, if the hand be applied to the rubber when the cylinder is turned. In order to obtain a continuous supply of sparks from the conductor P, it is, however, absolutely necessary to maintain a conducting communication between the rubber and the ground. If the prime conductor be made to communicate with the ground while the rubber continues insulated, on working the machine, sparks may be freely obtained from the rubber. The electricity from the cylinder and conductor P, however, is vitreous, like that from glass generally, whilst that from the rubber is resinous. If the rubber and the conductor, while both are insulated, be connected by a metallic wire, no sparks can be obtained from either, however vigorously the machine be worked, the resinous electricity of the rubber being exactly neutralized by an equal amount of vitreous electricity from the cylinder and conductor. The reason why it becomes necessary in working the machine effectively, to connect either the rubber or the conductor P with the earth, is thus rendered obvious, as otherwise induction takes place between the liberated resinous electricity on the rubber and the positive electricity which accumulates on the prime conductor, and thus prevents its free discharge. No sooner, however, is the negative electricity in the rubber supplied from the unlimited stores of the earth with an equivalent amount of positive electricity, through a chain suspended to it, or through the body, by placing the hand on the rubber, than the accumulated positive electricity on the conductor P is free to pass off in sparks to such objects as are sufficiently near.

Fig. 143.



In the *Plate Machine* (fig. 143), a flat plate of glass, G, is substituted for the cylinder C in fig. 142. The axis of rotation passes through the centre of this plate, and the rubbers, R R, are placed on each side of the glass along a portion of its circumference. It is not easy in this form, however, to insulate the rubbers and to obtain negative electricity separately, though it supplies positive electricity in abundance. P is the prime conductor, insulated by a glass stem.

(202) *Extensive operation of Induction.*—The principle of induction already explained being one which pervades the whole phenomena of electricity, we proceed to point out a few more examples.

Every case of attraction is preceded by induction; the opposed surfaces become oppositely electrified by polar action, after which attraction ensues. The following elegant experiment by Sir W. Harris shows the steps of the process clearly: Attach to a circular disk of gilt card A, fig. 144, about three inches in diameter, one end of a slip of gold leaf, and by a rod of shell lac fasten the disk to a light strip of wood, balanced at the other end by a weight. Suspend this freely by a thread as represented in fig. 144; on bringing another similarly insulated charged gilt disk, B, near A, the gold leaf upon A will diverge, and then attraction of the disk will follow.

FIG. 144.

Even the phenomena of electrical repulsion may be traced to induction. If a pair of slips of gilt paper be insulated and suspended side by side as in the electroscope, they will diverge when charged; whilst in this condition a proof plane will detect no electricity on their inner surfaces, but abundance on the outer ones; induction takes place towards surrounding objects, which attract the leaves, and they separate from each other; but if any conducting body in communication with the earth be introduced between the two leaves, induction now takes place from the inner surface of the leaves towards it, and they instantly collapse. Many amusing electrical experiments have been contrived upon this principle,—light figures, placed on a conducting surface under an electrified plate, are made to dance by alternate attractions and repulsions. If a number of strips of paper be supported in the centre of a room, by attaching them to a wire which is in connexion with the conductor of a powerful machine in action, they will rise up and diverge in all directions, towards the ceiling, the walls, and the floor, under the influence of induction; if a conducting point or surface be brought near them, they will all bend over and converge towards it.

(203) *Electrophorus.*—The electrophorus of Volta is an inexpensive and portable kind of electrical machine: it owes its activity to the operation of induction, which indeed it is well calculated to exemplify. The instrument (fig. 145) consists of a resinous plate, B, twelve or fifteen inches in diameter, which may be composed of equal parts of shell lac, resin, and Venice turpentine, melted together and cast into a circular cake of about an

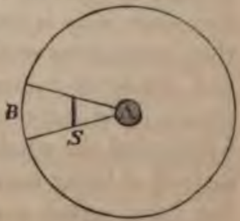
FIG. 145.

inch in thickness. This cake rests on a sheet of tinfoil or tin-plate, T; it is furnished with a moveable cover consisting of a somewhat smaller circular metallic plate, M, to which is attached an insulating handle. The resinous cake is rubbed with warm and dry fur or flannel, and then placed on an insulating stand; on putting down the metallic cover by its insulating handle, a spark of resinous electricity may be drawn from it; and on again raising it, a spark still brighter, of vitreous electricity, may be obtained. On replacing the cover another resinous spark may be drawn, and on raising it, another vitreous one, and this may be repeated for an indefinite number of times.

The action of the electrophorus may be thus explained. When the cake is rubbed, it becomes negatively electrified on its upper surface; the under surface, which is in communication with the earth through the tinfoil, becomes, by induction, positive to a similar extent, the particles of the cake being thrown into a polar condition; the plate is then placed on an insulating support. If the metallic cover be now brought down upon the upper surface of the cake, it only touches the resin on a few points, and from the inferior conducting power of the resin receives but little direct negative charge from the contact; instead of this, the under surface of the metal becomes positive by induction from the resin, whilst upon its upper surface a corresponding amount of negative electricity is set free; this escapes in the form of a spark, if a conductor be presented. On now raising the cover, the positive electricity, which before was attracted to the lower surface and held there by induction, is in excess, and it is ready to escape as a spark when a conductor is presented near enough to it. As the resin has lost none of its charge, the process may be repeated for an indefinite number of times. Care must, however, be taken not to make a conducting communication between the cover and the inferior metallic plate while the former is resting on the resin, otherwise the whole charge will pass off in the spark, as in discharging the Leyden jar (205).

(204) *Spread of Induction.* — A remarkable peculiarity in electrical induction has yet to be noticed. When a charged sphere, A, is suspended exactly in the centre of a hollow spherical cavity, B, fig. 146, induction diminishes in every direction as

FIG. 146.



the square of the distance; but it is quite otherwise if the charged ball be suspended within the hollow sphere in any other position. If we compare radiant heat with induced electricity it will be found that the approach of a cold body, S, towards a source of radiant heat does not affect the radiation to the objects around, excepting in the case of those which are immediately sheltered by its shadow, as at B, fig. 146: not so, however, if we bring an uninsulated conductor towards a body charged with electricity. The fewer are the intervening particles of the dielectric air to be polarized, the higher does the polarity rise in each particle, and the more completely is the induction called off from more distant objects; consequently the smaller the distance between the charged and the disturbing body, the more complete is the diversion. The polarity of the interposed air may at last rise so high that it can sustain the tension no longer, and a spark passes between the two surfaces. The particles of the dielectric are in a forced condition, and, like the coils of a spring, tend to return to their normal state.

Fig. 147.

This important fact may be illustrated in the following way. Let A, fig. 147, represent an insulated circular conducting plate, connected with an electroscope. Give to the plate A a small positive charge sufficient to cause divergence of the leaves of the electroscope; then cause a second conducting plate, B, which is uninsulated, to approach the plate A. The leaves of the electroscope will gradually collapse, but will open out again, when B is withdrawn. In this experiment a portion of the positive electricity of plate B, equivalent in quantity to that of the charged body A, passes off to the earth. Owing to this lateral action, if the plate B be retained very near to A, the plate A may receive a considerable amount of charge, by repeated applications of a body feebly charged, provided that such body is freshly charged between each contact with A: by these repetitions small quantities of electricity may be accumulated, and rendered evident by suddenly withdrawing the uninsulated plate B; the leaves of the electroscope diverge, because by such withdrawal the whole induction is directed to surrounding objects instead of being concentrated upon B. An apparatus of this kind has been called a *condenser*, from its power of collecting and rendering visible, by repeated contacts, quantities of electricity too minute to be otherwise perceptible.

(205) *The Leyden Jar.*—By substituting a solid dielectric, such as glass, for the sheet of air between the plates A and B in the preceding experiment, a much higher degree of induction may be obtained, since the fixed position of the particles of the glass prevents them from moving off when highly charged. In fact, a plate of glass between two metallic surfaces constitutes an apparatus for storing up electricity; and is, in its simplest form, the important instrument celebrated from the place of its discovery as the *Leyden jar*. Excepting as a matter of convenience it does not signify whether the glass be flat or curved, only it is found more advantageous to use jars instead of flat plates. The ordinary form of Leyden jar is represented at O, fig. 148. It consists of a thin glass bottle, with a wide neck. A coating of tinfoil is pasted upon both the internal surface, I, and the outer surface, O, to within three or four inches of the neck. The upper portion of the glass is left free from conducting matter in order to preserve the insulation of the two coatings. A wire, surmounted by a brass knob, and supported by a smooth plug of dry wood, serves to convey the charge to the inner coating, with which it is in contact. Such a jar will receive and sustain a charge of much higher intensity than a simple conducting surface of tinfoil of the same extent.

Fig. 148.

A simple experiment will suffice to show the correctness of this statement. A single turn of the machine will be sufficient to cause a straw, E, fig. 148, suspended from the centre of the graduated arc, and attached to the prime conductor of the machine, P, to assume its utmost angular repulsion; but if the knob of a Leyden jar be held to the conductor, it will take eight or ten turns of the machine to produce the same amount of repulsion; bright sparks will pass in rapid succession between the knob and the conductor, and on connecting the two coatings of the jar by the discharging rod, D (which is merely a jointed wire terminating in brass balls, and which for safety is insulated on a glass handle), the equilibrium is restored suddenly and completely with a loud snap and a brilliant spark. If the discharge were allowed to take place through the arms, or any part of the body, a sudden painful sensation, termed the *electric shock*, would be experienced. The power of the Leyden jar may be increased by increasing its size; and when it would be inconvenient to use jars of large size, a similar increase in power may be obtained by placing a number of small jars side by side upon a sheet of tinfoil, or other conductor, which connects together all their outer coatings, whilst by means of wires all their inner coatings are similarly connected with each other. Such an arrangement of jars is called an *electrical battery*, and is shown at fig. 159, p. 302. If the jars be of uniform thickness, the power of the battery will be in proportion to the extent of the coated surface, but the intensity of the charge will be inversely as the thickness of the glass.

That the charge of the Leyden jar results from an action of contiguous particles, polarization taking place across the dielectric, may be shown by taking three or four laminæ of glass, and placing them one above another between two metal plates, thus forming them into one compound plate, and then charging the whole. Each plate becomes charged separately, and thus each one adds its inductive effect to the whole.

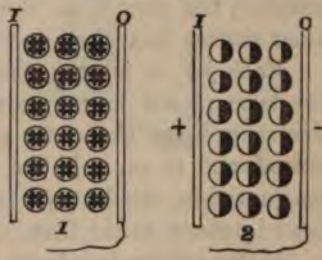
As might be anticipated from this experiment, it is found that the charge of the jar does not reside in the coatings, which merely act as dischargers.

FIG. 149.

The following experiments will elucidate the action of the Leyden jar when in the process of receiving a charge. Let a jar, A, fig. 149, be placed upon an insulating stand, and let its knob be brought near to the prime conductor, P, of an electrical machine in action; under these circumstances it will be found to receive little or no charge. Now place an uninsulated conductor, C, near its outer coating; sparks will pass from P to the knob of the jar A; and for every spark that passes to the knob of the jar, a spark will pass from the outer coating to the uninsulated conductor C. If the jar be receiving positive electricity from the machine upon its interior, it will be found that an equal quantity of positive electricity is disengaged from the exterior. A second uninsulated jar may be placed so as to receive upon its knob the sparks from the exterior of the first, it will thus become charged to an extent equal to the charge of the first jar. Again, if three insulated jars be placed as in fig. 150, where P indicates the prime conductor, whilst the coating of the last jar is brought near to a wire, N, proceeding from the insulated rubber of the machine, for each spark that passes from the conductor, P, a similar spark will be seen to pass between each of the jars, and between the last jar and the wire, N. In this way each jar will become equally and powerfully charged, although both the machine and the jars are completely insulated. From these experiments it is plain that a jar when charged contains no more of either electricity than it does in its neutral condition, but the distribution of the two forces is different. This statement may be illustrated by the diagram fig. 151. Let No. 1 represent a section of the jar with its particles in the neutral state; let No. 2 be the same jar when a charge of positive electricity has been thrown upon one of its surfaces I, whilst the other surface O is uninsulated; the two electricities are represented as being accumulated on opposite sides of each particle, the white half indicating the positive electricity, the black half the negative. Polarization of each particle of the dielectric glass intervening between the two coatings is produced, and a quantity of positive electricity is therefore disengaged from the second surface, which is exactly equal to that distributed by the coating upon the first; but unless an escape be afforded for this excess of positive electricity from the second surface, no charge is received by the jar, for polarization becomes impossible, and no appreciable amount of electricity can enter the jar from the machine.

FIG. 150.

FIG. 151.



It thus appears that the charging of a jar with electricity is totally different from the operation of filling a bottle with a liquid;

the electricity is distributed not in the cavity of the bottle, but in the substance of the glass itself. Indeed it has been already stated that a flat plate will answer equally well with the jar, but the jar, from its form, is for the sake of convenience preferred. In the experiment with the three insulated jars, an explanation similar to the foregoing may be given. A quantity of positive electricity passes from the conductor of the machine to the inner surface of the first jar. A corresponding quantity of the same kind of electricity simultaneously passes off from the opposite coating into the next jar, which in its turn becomes similarly polarized; and so on in succession, until, from the last jar, a quantity of positive electricity passes to the rubber, exactly sufficient to neutralize the negative electricity liberated by the machine, which is necessarily equivalent to the positive electricity accumulated on the internal surface of the first jar. It is not necessary that the last jar be connected with the rubber directly, the same object will be attained by allowing the discharge to take place into the earth. Although it is usual in the charging of a jar to connect the internal coating with the prime conductor, yet the jar may be charged equally well if its insulated *external* coating be connected with the conductor whilst the inner coating is made to communicate with the earth; in this case, however, the charge on the outer surface is positive, whilst the inner surface becomes negative.

Each jar, it is seen, thus receives a charge, though only one has been placed in connexion with the machine; the superfluous electricity upon the outer coating of the first having charged the second, and so on. If the insulations be good, and the glass of the jars thin, the last jar will be charged with very nearly the same intensity as the first.

When all the jars have been thus charged, all will be simultaneously discharged if the inner coating of the first jar be connected with the outer coating of the last; but although no greater amount of electricity passes between the two extreme jars than would have passed between the inner and outer coating of a single one, M. Dove has pointed out the remarkable fact that the distance through which the spark passes is very much greater, and for equal charges it is found to increase as the square of the number of jars thus discharged: if a spark of one inch in length be obtained with one jar, with two jars the spark would be four inches, with three, nine inches, with four, sixteen inches, and so on. In practice the distance is something less, as, owing to imperfect insulation and to the resistance of the glass to receive a charge, each succeeding jar receives a somewhat weaker charge than the one which precedes it. Supposing these views to be correct, the charge of a Leyden jar should be entirely independent of its coatings, which should act merely as conductors to favour the distribution and escape of the electricity. This view is completely confirmed by experiment. If a jar be fitted with moveable coatings, and then charged, each of the coatings may be removed; the coatings may be handled after such removal; the jar may then be replaced in them, and it will give a powerful spark when discharged in the usual manner.

(206) *Measures of Electricity.*—It is upon the principles just explained that Sir W. Snow Harris has constructed his *Unit jar*, for measuring out definite quantities of electricity. The unit jar is a miniature Leyden jar mounted on a slender insulating rod of glass. Attached to the outside of the jar is a wire terminating in a ball, *a*, fig. 152, parallel to the usual wire and ball which passes to the interior; on the wire connected with the inside, is a third sliding ball, *b*, which can at pleasure be brought to any required distance from the ball, *a*, which is connected with the outside: whilst the unit jar is becoming charged from the machine (say that its outer surface is rendered positive, as represented in the figure), an equal quantity of positive electricity is passing off from the interior along the wire, *w*, attached to the inside of the jar, B, which is to be loaded with a definite quantity: as soon as the charge in the unit measure rises sufficiently high, it discharges itself between the adjusted balls, *a b*, without affecting the charge in the jar, B. A second charge is now given to the unit jar, which discharges itself when it rises to the same amount as before: during each successive charge of the unit jar, a corresponding quantity of positive electricity passes from its exterior into B, so that by counting the number of sparks that pass between *a* and *b*, the number of equal quantities or arbitrary units which have been given to the jar, B, is ascertained. Supposing the adjustment of the balls, *a* and *b*, to remain the same, the jar B may be made to receive, for any number of times successively, equal amounts of electrical charge, by causing an equal number of discharges of the unit jar to take place in each case.

FIG. 152.

Fig. 153.

Other means have been proposed for ensuring an equal accumulation of electricity in a jar. *Lane's discharging electrometer* is the simplest of these. One form of the apparatus is shown in fig. 153: its principle of action will be at once apparent. L is an ordinary Leyden jar, in the ball, A, of which a hole is drilled to receive the brass pin of the electrometer; a bent glass arm, *b*, carries upon its lower extremity a brass socket, *c*, through which slides an insulated rod carrying a brass knob on either extremity: one of these balls, *f*, can be placed at any required distance from the knob of the Leyden jar. A chain or wire, *w*, effects a communication between the sliding rod and the outside of the jar. If the interval, A *f*, be maintained uniform, the jar will always require the same amount of charge before the discharge takes place between these two balls, A and *f*. The quantity of electricity in the charge is proportioned to the distance between the balls: with an interval of half an inch the force would be double that required when the distance was only a quarter of an inch.

The force of attraction between two charged surfaces has been measured by an ingenious modification of the common balance devised by Sir W. Harris. A light disk of gilt wood is substituted, as shown in fig. 154, for one of the pans of the balance; beneath it is a second similar insulated disk: the suspended disk and the balance beam, through its support, are connected with the exterior of a Leyden jar; the lower insulated disk with the interior of

Fig. 154.

the jar. By charging the Leyden jar with definite quantities of electricity by means of the unit jar, the laws which regulate the attractive force were experimentally determined. One or two of the more important results may be given as an illustration of the mode of proceeding.

If a Leyden jar charged with a certain quantity of electricity produce between the disks an attractive force sufficient to raise 4 grains, it will when charged with double the quantity raise four times the amount, or 16 grains; with three times the quantity it will raise nine times the amount, or 36 grains; consequently, if the extent of charged surface continue constant, the attraction increases as the square of the quantity.

When two equal and similar jars are used instead of one jar, and the same quantity, say ten units, is distributed over them, the attractive force will be diminished to ¼, and with three jars to ⅑ of what it was when a single jar was employed. Thus a quantity which on one jar would raise 18 grains, would, if diffused over two similar jars, raise only 4½ grains; and if diffused over three, it would raise only 2 grains. If, therefore, the quantity remain constant, the attractive force is inversely as the squares of the charged surfaces of the jars.

(207) *Specific Induction.*—It has been shown that the induction between two conducting plates, one of which is insulated while the other communicates with the earth, is facilitated by diminishing the thickness of the dielectric which separates them, and that the insulated plate is enabled to receive a higher amount of charge by reducing the number of particles of the dielectric which undergo polarization. It is evident from this circumstance that the polarization is attended with a certain amount of resistance. Faraday discovered that this resistance varies in amount with the material of the dielectric employed; some substances becoming polarized more readily than others. The relative facility of induction through the different bodies as compared with a common standard constitutes their *specific inductive capacity.* A plate of shell lac, for example, an inch in thickness, allows induction to take place across it twice as readily as does an equal thickness of atmospheric air, and sulphur with a facility equal to that of shell lac.

The following table represents, according to Sir W. Harris (*Phil. Trans.* 1842, 170), the specific inductive power of various bodies.

Air	1·00
Resin	1·77
Pitch	1·80
Bee's-wax	1·86
Glass	1·90
Sulphur	1·93
Shell lac	1·95

FIG. 155.

The fundamental fact may be shown by the following simple experiment (fig. 155). About 1½ inch above the cap of a gold leaf electroscope suspend an insulated disk of metal, and communicate a small charge to the insulated disk; the gold leaves immediately diverge by induction. Between the disk and the electroscope substitute for the dielectric air, a body the specific induction of which is greater than that of air, such, for example, as a plate of shell lac, s, an inch in thickness, and mounted on an insulating handle; the leaves will immediately diverge more widely, because induction towards the instrument takes place more freely; on removing the shell lac the leaves of the electroscope return to their original divergence. The effect is precisely similar to that which would be produced by bringing the charged plate nearer to the electroscope in air. Similar phenomena occur if a mass of sulphur or resin be substituted for the shell lac.

In good conductors no such polarization can be traced, and in imperfect conductors, such as spermaceti, the results become indistinct.

With gaseous bodies no difference in specific inductive power is found to exist: it is remarkable that the chemical nature of the gas has no influence; all gases having the same inductive capacity as common air. No variation in temperature, in density, in dryness, or in moisture, produces any change in this respect. The apparatus with which Dr. Faraday investigated these curious phenomena was a kind of Leyden phial (fig. 156), consisting of two concentric metallic spheres, A A, insulated from each other by a stem of shell lac, B. Any dielectric could in succession be placed between the spheres, whether the subject of experiment were solid, liquid, or aeriform, as by connecting it with the air-pump by means of the stop-cock s, it could be exhausted, and the interval filled with any gaseous medium with the same facility as with a liquid (*Phil. Trans.* 1838, p. 9). Two of these jars having been prepared, a charge was given to one of them, after it had been filled with the body the inductive capacity of which was to be determined, and the charge was then divided with the second similar apparatus, in which the interval between the spheres was only filled with air. The intensity of the charge in each case was measured by means of a carrier ball and Coulomb's electrometer.


Fig. 156.

(208) *Various Modes of Discharge.*—We pass on now to consider the different modes in which the electric equilibrium is restored after it has been disturbed; this restoration may be effected in one of three ways, for the excited body may be discharged either by *conduction*, by *disruption*, or by *convection*.

(209) *Conduction.*—When a charged Leyden jar is discharged in the usual way through a discharging rod, the electricity passes quietly through the wire of the discharger by conduction, but traverses the interposed air by disruption, in the form of a spark attended with noise.

All bodies, shell lac and glass not excepted, possess a certain amount of conducting power, which gives rise to the phenomenon termed the *residual charge* of a jar, or battery. If a jar be charged strongly, and allowed to remain undisturbed for a few minutes, and then be discharged, a slight apparent renewal of the charge will take place, and a second smaller spark may be obtained from it. This Faraday considers to be due to the penetration by conduction of a portion of the charge into the substance of the dielectric. Each surface of the glass acquires a weak charge, one of positive, the other of negative electricity; but as soon as the constraining power which caused this penetration of the electricity is removed, it returns towards the nearest surface and produces the slight recharge, or residual charge.

As no bodies are perfect insulators, so none are perfect conductors, for even the metals offer a certain measurable resistance to the transmission of electricity. The following experiment will serve to illustrate this point. Charge a large Leyden jar (fig. 157), and arrange a metallic wire, W, 50 or 100 feet in length, so as to act the part of a discharger, as represented in fig. 157, at the same time open a short path for the discharge to the outer coating, by bringing the balls *a* and *b* within a short distance of each other. Under this arrangement, a portion of the electricity takes the shorter course from *a* to *b*, and overcomes the high resistance of the stratum of air interposed between the balls, owing to the resistance experienced by the discharge to its passage along the continuous conducting wire, W.

FIG. 157.

This resistance, even in good conductors, often occasions the spark to pass between two contiguous conductors, and produces what has been called the *lateral spark*, which can be elicited, even if the conductors subsequently unite below. Thus, in fig. 158, at the moment a spark passes from P to the ball *a*, a minute spark will be seen to pass between the wire and the loop *b*, if they be sufficiently near each other. This lateral spark may acquire sufficient power to ignite gunpowder or other combustible matter. In fact, momentary as is the duration of the discharge, induction takes place towards all surrounding objects whilst electricity is in motion, as well as when it is at rest.

FIG. 158.

If in a darkened room a thin insulated wire be made to terminate at each extremity in a metallic ball, and on one ball large sparks be thrown, whilst from the other ball the sparks are allowed to pass off to some contiguous conductor, the air will be seen to become feebly luminous from induction along the whole course of the wire.

(209 *bis*) *Development of Heat.*—The passage of electricity through conductors is attended with evolution of heat, the amount

of which is inversely as the conducting power. Sir W. Harris, by means of an air thermometer with a large bulb, across which were passed in succession wires of equal length and thickness, found that when equal quantities of electricity were discharged through these wires, the heating effects were as follows (*Phil. Trans.* 1827, p. 21).

The metals which stand first on the list are the best conductors, and they emit the least heat:—

Copper	6
Silver	6
Gold	9
Zinc	18
Platinum	30
Iron	30
Tin	36
Lead	72

Alloys.	
Brass	= 18
Gold 3, Copper 1	= 25
Gold 1, Copper 3	= 15
Gold 3, Silver 1	= 25
Tin 1, Lead 1	= 54
Tin 1, Copper 8	= 18

It will be seen that by alloying the metals with each other, the conducting power is often greatly reduced. Great care should therefore be taken to ensure the purity of the metals in experiments of this nature.

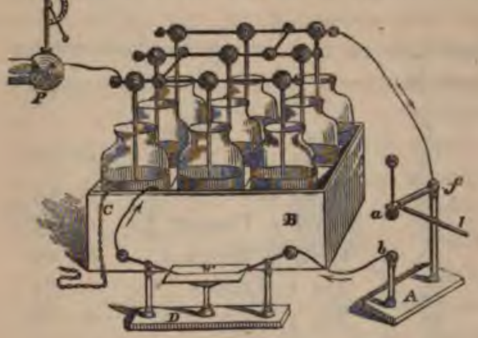
If different quantities of electricity be transmitted through the same wire, it is found that the temperature rises as the square of the quantity that passes: thus, if the thermometer, with a given charge, rise 10°, it will require a charge of four times the power to raise it twice as much, or 20°.

By sufficiently reducing the thickness of the conductor at one part of the circuit, the heat may be raised so far as to fuse the wire, or even to convert it into vapour.

The amount of electricity required to produce this effect, when measured by a unit jar, is found to be equally powerful whether it be diffused over a large or a small surface; the *intensity* (*i. e.* quantity which passes through a given space in a given time) is the same in the wire in both cases, though the intensity of the charge on equal surfaces of the jar is very different. Where large quantities of electricity are needed, a corresponding extent of coated surface is requisite; this may be obtained either by employing a single jar of large dimensions, or several smaller ones, the inner surfaces of which are connected by wires, and the outer surfaces likewise united by placing them upon a sheet of tinfoil, or on a metallic tray. By discharging such a battery through thin metallic wires of silver, steel, platinum, or copper, for instance, they will be fused and dispersed.

The arrangement represented in fig. 159, shows one method of employing such a battery for the deflagration of metallic wires: nine jars are in this case represented; they are enclosed in a wooden case B, and rest on tin-foil, which communicates with the earth through the chain C. The battery is charged from the prime conductor P. The internal coatings of all the jars are connected by cross wires. In order to direct the discharge of the battery, a wire passes from its inner coating to the insulated upper arm, *f*, of the discharger A, a second wire passes from the ball *b*, to one of the insulated wires on the stand of the *universal discharger* D. The wire for deflagration *w*, is fastened to a card which is also supported on a little stand insulated by glass; and the communication with the external coating of the battery is continued by a wire connected with the other insulated support of the universal discharger D; thus the conducting communication is complete with the exception of the interval between *a* and *b*. When the battery is adequately charged, the lever *l* is withdrawn, the ball *a* and its attached wire are thus released, and fall through a hole in the metallic arm *f*, which is connected with the inner coating, and the circuit is completed when the balls *a* and *b* come into contact.

Fig. 159.



It must be observed that in these cases of conduction the charge passes through the whole thickness of the rod or wire, and is not confined to its surface: it therefore makes no difference whether the metal is in the form of wire, or is extended over a large surface as leaf.

The dispersion of the conductor by the passage of high charges of electricity leads us to consider next what Faraday terms the *disruptive* discharge.

(210) *Disruptive Discharge.*—This mode of discharge is attended by sudden and forcible separation of the particles of the medium through which it occurs; and it is attended with extrication of light and heat. It is best seen between two conductors separated by a dielectric, such as two metallic balls in air. In these cases when a sudden bright spark passes, the discharge is as

complete as if it had been effected by direct metallic communication. The particles of the intervening dielectric are brought up to a highly polarized state, until at length the tension on one particle rising higher than the rest, and exceeding that which it can sustain, it breaks down; the balance of induction is thus destroyed, and the discharge is completed in the line of least resistance.

In all these cases, portions of the solid conductors are detached, and by their ignition increase the brilliancy of the spark. This transfer of material particles by the spark is easily proved, for if sparks be caused to pass between a gold and a silver ball, the surface of the gold becomes studded with particles of silver, and *vice versâ* If an iron chain be laid on a sheet of white paper, and a powerful discharge be sent through it, each link will leave upon the paper a stain, arising from the portions of the metal which have been detached; and if the discharge be effected over a plate of glass, particles of the metal are frequently forced into it. The experiment may be varied by suspending the chain in a dark room, and passing the discharge through it; brilliant deflagration of the iron will be seen at each link.

Sparks attended with disruption may also take place in the midst of liquid dielectrics. More rarely disruption from the force of the discharge occurs in solids; occasionally this is exemplified in the Leyden jar itself: the tension upon the glass now and then rising so high that the glass is perforated. Across this fracture discharge always afterwards occurs; so that no effective charge in a battery can be maintained till the cracked jar is removed. This disruption of glass may be produced at pleasure by bending a wire so that its point may press against the side of a tube or other vessel filled with some liquid dielectric, such as olive oil. On charging the wire from the prime conductor, and applying a ball to the outside of the tube opposite the end of the wire, a spark passes, and a minute perforation is produced.

Great expansion of the air occurs from the heat developed at the moment of the discharge, as is shown in the following experiments. Paste a strip of tinfoil on glass, cutting it through in two or three places with a knife; place a few wafers or other light bodies over the interrupted points, then discharge a jar through the tinfoil, and the wafers will be immediately scattered in all directions. If a card or half quire of paper be placed in the direction of its thickness in the track of the discharge, the card or the paper will be burst outwards on both sides.

Many pleasing experiments may be made by causing a succession of discharges to occur through such interrupted conductors: a beautiful display of the electric light may thus be exhibited in a darkened room.

(211) *Velocity of Discharge.*—Of the velocity of the spark discharge some notion may be formed from the brief duration of its light, which cannot illuminate any moving object in two successive positions, however rapid its motion. If a wheel be thrown into rapid rotation on its axis, none of its spokes will be visible in daylight, but if the revolving wheel be illuminated in a darkened room by the discharge of a Leyden jar, every part of it will be rendered as distinctly visible as though it were at rest. In a similar manner, the trees even when agitated by the wind in a violent storm, if illuminated at night by a flash of lightning, appear to be absolutely motionless.

By a very ingenious application of this principle Professor Wheatstone has shown that the duration of the spark is less than the one millionth part of a second. The apparatus is the same in principle as the revolving wheel.

By a modification of the apparatus, Professor Wheatstone was also enabled to measure the velocity with which the discharge of a Leyden jar was transmitted through an insulated copper wire. He estimated the rate of its passage at 288,000 miles in a second (*Phil. Trans.* 1834, p. 589). For this purpose he employed an insulated copper wire about half a mile long, through which a Leyden jar was discharged. This insulated circuit was interrupted at three points; one of these interruptions was within a few feet of the inner coating of the Leyden jar; the second was in the middle of the wire, and the third within a few feet of the outer coating of the jar. The parts of the wire at which these three breaks in the circuit occurred were all arranged side by side on an insulated disk, so that the three sparks could be seen simultaneously. In fig. 160 a wire is represented as proceeding from the knob of the jar to an insulated rod; when the charge attains

FIG. 160.

a certain intensity, a spark passes between this rod and a small knob attached to the axis of the revolving mirror, *m*: to one extremity of this axis, the wire which passes to the outer coating is fastened; but the discharge is made to traverse the whole length of the two intervening long contorted portions of wire, before it reaches the outside of the jar. The three sparks, if viewed by the naked eye, appear to be simultaneous. If viewed through the glass plate, *c*, in a small steel mirror, *m*, to which is given a regulated but extremely rapid revolving motion on an axis *parallel to its surface*, the sparks appear no longer as dots of light in the same horizontal line, but present the appearance of three bright lines of equal length. The two outer ones commence and terminate in the same horizontal line, but the middle one occurs later than the other two, and the angular position of the mirror has had time slightly to advance before the middle spark appears, which consequently exhibits an image slightly displaced. As the velocity of rotation of the mirror is recorded by the register, *b*, and the amount of this angular deviation of the image of the central spark is easily ascertained, the retardation of the discharge by the copper wire, or, in other words, the velocity with which it travels along it, can be estimated.

This experiment has another important signification, to which due weight appears hardly to have been given; for it affords a convincing proof of simultaneous action and reaction in the operations of electricity, and of its existence as a duplicate force: at the same moment that a positive influence leaves the inner coating, an equal amount of negative influence leaves the outer coating, and these two neutralize each other at the central point of the conductor, after the lapse of an extremely minute but still appreciable interval of time. It appears from this experiment that Franklin's theory (197) though in many cases a simple and convenient mode of explaining facts, is not the true representation of the phenomena. The theory of two fluids, or rather of two forces acting in opposite directions seems by this experiment to be demonstrated.

The velocity of the electric discharge is, however, found to vary with the intensity of the charge, and with the nature of the conducting medium.* The duration of the discharge may be prolonged by causing it to take place through bodies of inferior conducting powers. A charge of a given amount, if transmitted

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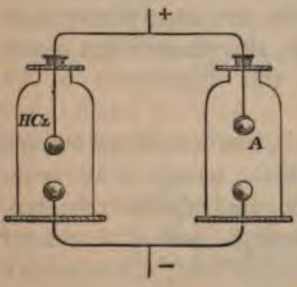
* For an interesting paper on this subject see a Lecture, by Faraday, in the *Philosophical Magazine* for March, 1854.

slowly, by the prolonged period through which its heating powers can be applied to a combustible, may be made to ignite bodies, which the same charge more quickly transmitted would only have dispersed :—thus, if two metallic wires be brought within an eighth of an inch of each other, and if a little loose gunpowder be placed over the interval, the powder will simply be dispersed if the charge of a Leyden jar be sent through the wires; but if a few inches of wet string be interposed in any part of the circuit, the discharge will be prolonged sufficiently to fire the powder.

(212) *Striking Distance.*—In air, whatever be its density, the same amount of charge produces, *cæteris paribus*, induction to the same extent. But the distance through which the discharge of equal quantities of electricity takes place in the same gaseous medium, varies inversely as the pressure. This might be anticipated, since under a double pressure double the number of particles of air would exist in the same space, and the polarity would therefore be transmitted through double the quantity of insulating matter:—thus, if a given charge in air of ordinary density pass as a spark at two inches, at double the usual pressure the striking distance would be reduced to one inch; at a pressure of one half it would be increased to four inches; at one quarter, to eight inches, and so on, until *in vacuo* it would pass through an unlimited distance. If the density of the air continue constant, it is found that the striking distance varies directly as the intensity of the charge. For example: if with a certain charge the striking distance be one inch, a double charge will discharge itself through two inches, a threefold charge through three inches (Harris). For equal charges the striking distance, however, varies in different gases, independently of their relative density, so that each gas has a specific insulating power. Hydrochloric acid has twice the insulating power of common air, and three times that of hydrogen of equal elasticity. This is in striking contrast to the equality of inductive capacity in all gases.

FIG. 161.



This inequality of insulating power was proved by Faraday by opening to the same charge two separate paths, one of them through air, the other through a receiver filled with the gas which was to form the subject of the experiment as shown in fig. 161. The distances between the balls were varied until the discharge took place with equal facility in both; the same charge was thus found to traverse double the distance in air that it did in hydrochloric acid.

Rarefaction of air, whether effected by heat or by mechanical means, equally favours the electric discharge. A jar may consequently be discharged through several inches of a common flame, in which the air is rarefied by heat to nearly six times its ordinary bulk, the temperature of flame according to Becquerel's experiments being nearly 2200° F. A flame also acts by its pointed form in dissipating a charge with great rapidity, and its proximity should be avoided in exact experiments.

The form and size of the spark depend upon the shape of the discharging surfaces almost as much as upon the intensity of the charge. Between the rounded parts of the prime conductor and a large uninsulated metallic ball dense brilliant sparks pass; whilst if the same ball be presented to a wire which projects three or four inches from the conductor, and which terminates in a ball an inch in diameter, a long forked, and often branching spark, resembling a miniature flash of lightning, will be obtained.

When disruptive discharge occurs between a good conductor of limited surface and a bad one which exposes a larger surface, an intermitting and dilute spark or *brush* passes, which when it occurs in air consists of a rapid succession of discharges to the particles of air around; such a brush has a bright root with pale ramifications, attended with a quivering motion and a subdued roaring noise. Such brushes are well seen when, the machine being in powerful action, the conductor is made to discharge itself into the air by means of a blunt rod which projects from it.

The colour, light, and sound of the electric brush vary in different gases, the brush being larger and more beautiful in nitrogen than in any other gas. The brush is largest from a vitreously charged surface, such as the prime conductor of the machine. From a resinously charged surface this discharge occurs at a lower tension, and more resembles a bright point or star of light. The formation of brushes is facilitated by rarefying the air around the charged points.

(213) *Convection.*—With a feebler charge the sonorous brush is replaced by a quiet glow, attended in this case with a continuous dispersion of the charge. The process of disruptive discharge thus gradually passes into the third method—viz., that by *convection.* When the glow is produced, a current of air, the particles of which are individually charged, passes from the charging

surface. The course of this current may be exhibited by its action on the flame of a taper, which will often be extinguished if brought near an electrified point which is connected with the machine in action; and light models may be set in motion by it. If the production of the current from the point be prevented, as by sheltering the pointed wire in a varnished glass tube, the brush or glow may be converted into a series of small sparks. These currents may take place in liquid dielectrics as well as in gaseous ones. Let a piece of sealing-wax be fixed on the end of a wire and attached to the conductor of a machine in action; if it be softened by the application of the flame of a spirit lamp, it will be thrown off in filaments towards a sheet of paper held near it. Solid insulated particles may also be the medium of convective discharge, as is seen when pith balls or other light substances are attracted and repelled by electrified objects; and in delicate experiments even the particles of dust floating in the atmosphere are not without effect in charging or discharging the apparatus employed.

The process of convection assumes considerable importance in the phenomena of voltaic electricity, where it is intimately connected with chemical decomposition. (246 *et seq.*)

(214) *Other Sources of Electricity.*—Hitherto we have limited our attention to cases in which electricity is excited by the friction of dissimilar substances. The development of electricity by friction is, however, but a special case of a much more general law, for it has been found that, whenever molecular equilibrium is disturbed, a concomitant development of electricity takes place. The following instances will exhibit the variety of circumstances under which this observation has been made. The mere compression of many crystallized bodies is attended by electric action. A rhombohedron of Iceland spar, if compressed by the fingers, exhibits this peculiarity. It is also found that all bodies that have been pressed together, if properly insulated, offer signs of electricity on being separated; although the effect is most easily observed between a good conductor and a bad one. The two bodies are always in opposite states. Even where two disks of the same substance are pressed together, if one be a little warmer than the other, distinct excitement is produced, the warmer disk becoming resinously electrified; the intensity of the charge, *cæteris paribus*, increases in all cases directly as the pressure to which they are subjected.

In some instances simple elevation or depression of temperature causes electric excitement. These effects are most distinctly seen in crystallized non-conductors, which are not symmetrical in form. Tourmaline, boracite, and the crystals of tartaric acid offer the best examples of this description. If a crystal of tourmaline be gently heated it becomes powerfully electrical whilst the temperature is rising, one extremity being positive, the other negative. When the temperature becomes stationary, the electric excitement ceases: as the crystal cools the effect returns, but the electric polarity is reversed; the end of the crystal that before was positive now becomes negative. The particles of the mineral are electrically polarized throughout the whole mass; for, if the crystal be broken while thus electrified, each fragment retains its polarity, being negative at one end and positive at the other. In fig. 162, No. 1 represents a tourmaline in which the temperature is rising uniformly; No 2 the same tourmaline in which the temperature is falling uniformly; and No. 3 shows the effect upon a cooling tourmaline which has been broken across. If the tourmaline be delicately poised upon its centre whilst cooling, these electric states may be rendered apparent by bringing an excited glass tube near to the mineral: one extremity will be attracted by the excited glass tube, while the other extremity will be repelled.

Fig. 162.

Fracture is likewise attended with electric disturbance; the freshly broken surfaces of roll sulphur often exhibit this effect to an extent sufficient to produce divergence of the leaves of the electroscope when the fragments are placed upon the cap of the instrument. The sudden rending asunder of the laminæ of a film of mica in a dark room, is usually attended with a pale electrical light, and the separated portions in this case exhibit opposite electrical states. A melted substance in the act of solidifying, sometimes exhibits electric excitement. If sulphur be allowed to solidify in a glass vessel it becomes resinously excited, whilst the glass is rendered vitreously electrical; ice also is frequently electric; and the same thing has been observed of chocolate as it becomes solid. These results are probably due to friction occasioned by the contraction or expansion of the solid mass in the mould, from which it detaches itself by this change of bulk.

(215) *Electricity of Vapour.*—The act of evaporation has also been asserted to be one of the sources of electricity, but the truth of this statement is doubtful. It is true that if a few drops of water fall upon a live coal insulated on the cap of the gold leaf electroscope the leaves of the instrument diverge. This, however, is due to the chemical action between the coke and the water, and not to mere evaporation; for by allowing pure water to evaporate in a clean hot

platinum dish connected with the electroscope, no signs of electric disturbance occur. If the dish, however, be heated to redness, and water be dropped in, as long as it evaporates quietly in the spheroidal form (183) no electricity is developed; but the moment that it cools down sufficiently to boil violently with friction against the metallic capsule the leaves diverge powerfully.

In accordance with this observation, Faraday has explained the development of electricity by high-pressure steam, which occurs to so remarkable an extent under certain circumstances. This he has traced to the friction of water accompanying the steam against the orifice of the jet through which it escapes into the air. An insulated boiler from which steam is allowed to blow off at high-pressure through long tubes, in which a partial condensation of the steam occurs, furnishes, as in the *hydro-electric machine* of Armstrong, exhibited at the Polytechnic Institution, an admirable source of high electric power. In this experiment, the boiler becomes negative, the escaping steam being positive. It is remarkable that the presence of the smallest quantity of oil or of turpentine in the exit-pipe reverses these electrical states. Wood was found to be the material best adapted for use in forming the orifice of the jet, as it produced the highest amount of charge by friction; some bodies, such as ivory, produced scarcely any electric effect when used as jets to the pipe.

Perfectly dry steam is in fact as complete an insulator of electricity as atmospheric air; but from the facility of its condensation it easily produces upon cold surfaces a film of conducting matter which destroys the insulation.

(216) *Atmospheric Electricity.*—Another source of electricity, the origin of which is at present shrouded in mystery, is the atmosphere itself, which affords displays of electric phenomena on the most magnificent scale. The identity of lightning and electricity had long been suspected by electricians; but it was first proved by Franklin, who, by the simple expedient of raising a boy's kite during a thunder-storm, succeeded in obtaining from the clouds, sparks of electricity, with which he charged Leyden jars, and performed some of the usual electrical experiments. Such kite-flying, however, forms a dangerous experiment; and experiments on atmospheric electricity proved fatal to Professor Richman of St. Petersburgh, who, a few years after Franklin's discovery, was killed by a flash from his apparatus.

No sooner had Franklin proved the identity of lightning with electricity, than he proposed his plan of averting the destructive influence of lightning from buildings, by means of metallic conducting rods. To render these efficient, they must project into the air for some distance beyond the highest point of the building to be protected. They must also be sufficiently thick to carry off the discharge without fusion. This is ensured by the use of a copper rod half an inch in diameter. The pieces composing these rods should be in metallic contact with each other throughout their length, and the conductor should terminate in a bed of moist earth, or better still, in a well or body of water, so as to ensure free communication with the soil. If any considerable metallic mass, such as a leaden roof, form part of the building, it should be connected with the conductor by branch rods, and should also be furnished with branch conductors into the earth. The conductors are best placed exterior to the walls of the building.

The amount of damage done by lightning to elevated objects unprotected by conductors is much greater than is commonly supposed. Between the years 1822 and 1844, in this country alone, not fewer than twenty-two churches were struck, and all of them were more or less seriously injured; whilst in the navy the amount of damage is enormous. The annual damage to the Royal Navy has been estimated by Sir W. Snow Harris at between 7000*l.* and 10,000*l.* during the late war, and from 2000*l.* to 5000*l.*, since its termination. The same observer has collected and recorded upwards of 220 cases in which ships of the Royal Navy alone have been seriously damaged; several of these ships have been injured more than once; in six cases the same ship has on three separate occasions been disabled by lightning. Of late years, owing to the persevering exertions of Sir W. Snow Harris, efficient conductors have been introduced into the Royal Navy; and at the present time every Queen's ship is furnished with them. Of seventeen cases in which details are preserved of ships thus protected having been struck, the efficiency of the conductor in carrying off the severest discharges has been amply proved.

The explosive power of lightning is so great that its effects may well excite our awe and amazement. A single instance may be cited in illustration of this point. In November, 1790, the mainmast of H.M. ship *Elephant*, 74 guns, was struck by a powerful flash of lightning. This mast weighed 18 tons, it was 3 feet in diameter, and 110 feet long, and was strongly bound together by iron hoops, some of which were half an inch thick and 5 inches wide; yet it was shivered into pieces, and the hoops were burst open and scattered around, amidst the shattered fragments of the mast (Harris). One of the most instructive instances recorded is that of the *Dido*, which, when off Java Head, in May, 1847, was struck soon after daylight, during a storm attended with heavy rain and little wind, by a tremendous bifurcated flash of lightning, which fell upon the main royal mast. One of the branches struck the extreme point of the royal yard-arm, and in its course to the conductor on the mast, demolished the yard, and tore in pieces or scorched up the greater part of the sail; the other part fell on the vane-spindle (the point of which showed marks of fusion) and truck, which last was split open on the instant of the discharge seizing the conductor. From this point, however, the explosive action ceased, and the discharge freely traversed the whole line of the conductor, from the masthead downward, without doing further damage. One of the chief points of interest connected with this case is the entire destruction of the yard-arm, which was not supplied with a conductor, and the complete protection of the mast, which was furnished with one. It is also important as proving the incorrectness of the law of protection laid down by some French writers—viz., that a conducting-rod will protect a circular area having a radius double the height of the conductor above the highest point of the building. In all cases, the lightning will take the path of least resistance, and, from the recorded results of experience, it appears that that path of least resistance will, in about seven times out of ten, be such that the lightning will strike the highest point, if it be furnished with a good conducting line to the earth or sea; but it is quite possible that instances may occur, as in the case of the *Dido*, in which the line of least resistance may be in a different direction, or that there may be two such lines where the resistances are equal.

If a break occur in any part of the conductor, explosion will take place at this spot when a discharge of lightning is directed upon the rod, producing, in many cases, fearful destruction. One of the most awful catastrophes of this kind occurred on the 18th August, 1769, when the tower of St. Nazaire of Brescia was struck by lightning. Beneath this tower were vaults containing upwards of 90 tons of gunpowder, belonging to the republic of Venice. The whole of this enormous quantity of powder exploded, destroying one-sixth part of the city of Brescia, and burying 3000 persons beneath its ruins. On a small scale, the track followed by the electricity may be illustrated by sending a discharge through a series of interrupted conductors, such as gold leaf pasted upon paper. The portions of gold leaf in the line of the discharge will be burned up, whilst the contiguous portions not included in the track of the electricity remain untouched.

The peal of thunder which accompanies the lightning flash, is like the snap which accompanies the discharge of a Leyden jar, to the sudden displacement of air, which, in the case of lightning, sometimes extends through a distance of a mile or more. The reverberation of the peal arises chiefly from the echoes produced by objects upon the earth, and by the clouds themselves. The flash from the thunder cloud is exactly analogous to the discharge of the Leyden jar: the cloud and the surface of the earth form the two coatings to the intervening layer of air, which, as in the case of the condenser, supplies the place of the glass, whilst a church steeple, or any projecting object, acts the part of a discharging rod.*

But it is not only during a storm that the atmosphere exhibits signs of electricity. In fine weather, if a flame, or a pointed rod, be connected with an electroscope, the instrument usually diverges vitreously. Before rain, the instrument often assumes a resinous state; in general, the rain that first falls after a depression of the barometer is charged resinously. It frequently happens that the rain is resinously charged, although the atmosphere, both before and after its fall, exhibits signs of vitreous charge. Fogs, snow, and hail, if unattended with rain, are nearly always vitreously charged in a high degree.

In winter, the atmospheric charge is usually higher than in summer. According to Quetelet, whose conclusions are based upon a series of five years' uninterrupted observations, the atmospheric electricity attains an average maximum in January, and steadily decreases till June, when it is at its minimum: from this period it again progressively increases till January: the electricity in January has an intensity thirteen times as high as that in June. The electricity of the air may be stated generally to be higher in a cloudless than in a cloudy sky. Only once during the months of October, November, December, and January, has he obtained proof of negative electricity in the air.

The intensity of the charge varies likewise during each twenty-four hours; it has two maxima and two minima. The first maximum is before eight o'clock A.M. in summer, and before ten A.M. in winter; the second after nine P.M. in summer, and before six P.M. in winter. The first minimum is uniformly about four A.M., and the second about three P.M. in summer, and one P.M. in winter.

An ingenious experiment of Becquerel's shows that the

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* No satisfactory explanation has been offered to account for the extraordinary rapidity with which these electrical accumulations are renewed. On the 6th of July, 1845, about 10 P.M., after a clear hot day, in the masses of vapour forming a bank of cumuli, I counted in two minutes 83 flashes unattended by thunder; and several times during the same evening, I observed between 30 and 40 discharges from one cloud to another, per minute.

intensity of the charge increases with the elevation above the earth's surface, and according to Quetelet's observations, the increase in intensity is proportional to the height. This law of Quetelet has only, however, been verified for heights not exceeding sixteen feet. Becquerel's experiment was the following:—Having ascended Mount St. Bernard, he attached one end of an insulated gilt thread to the shaft of an arrow, and connected the other extremity with the cap of an electroscope by a running knot. The arrow was then discharged in a vertical direction by means of a bow; as it ascended, the leaves expanded gradually till they struck the sides of the glass. When the full length of the thread was attained, the upward motion of the arrow detached it altogether from the electroscope, leaving the instrument charged vitreously. On repeating the experiment, shooting the arrow horizontally, no charge at all was obtained. Similar results may be obtained on a clear day by ascending a lofty eminence or building, to avoid the induction of near objects, and taking a gold leaf electroscope, terminating above in a ball. The electroscope being now in a neutral state, it will, if elevated only for a foot or two, diverge with vitreous electricity. On bringing it back to its original position, the leaves collapse, and on depressing it below this point, the leaves again separate with the opposite electricity.

Electricity developes itself in the atmosphere in other forms; thus luminous brushes, stars, and glows, have been frequently observed in stormy weather on the extremities of the masts and yard-arms of ships, on the points of weapons, and even occasionally on the tips of the fingers. These phenomena are, in fact, cases of brush discharge upon a large scale, and are in many instances attended with a roaring noise like that of a burning portfire. Appearances of this description formerly went by the name of *St. Elmo's fire*; our own sailors term them *comazants*.

(217) *Aurora Borealis.*—Another very beautiful meteor which is occasionally seen in this country in clear frosty nights, but which is observed very frequently in higher latitudes, has probably an electrical origin. This is the *aurora borealis*. It has been supposed to be occasioned by the passage of electricity through the rarefied portions of the upper regions of the atmosphere from the poles towards the equator, but the explanation is unsatisfactory, and not adequate to account for the effects observed. The varieties of coloured light exhibited by the aurora may, however, be imperfectly imitated on a small scale by discharging a continued, or an intermittent supply of electricity through a vessel partially exhausted of air.

The forms which the aurora assumes are very varied, and of extraordinary beauty; there is, however, usually some general similarity in its aspect at the same locality. Commonly, streams of light are seen shooting upwards from the northern horizon. These streams are frequently observed to meet together in the zenith, and produce an appearance as if a vast tent were expanded in the heavens, glittering with gold, rubies, and sapphires.

A remarkable connexion has been observed between the aurora and the magnetism of the earth; the magnetic needle being very generally disturbed during a display of the aurora. The arches of the aurora most commonly traverse the sky at right angles to the magnetic meridian, though deviations from this direction are not rare. Sir J. Franklin says that the disturbance of the needle was not always proportionate to the agitation of the aurora, but was always greater when the quick motion and vivid light were observed to take place in a hazy atmosphere. The aurora is most frequent and vivid in high latitudes towards either pole, but the meteor is not confined to these parts, as Dr. Hooker states that one of the most brilliant displays he ever witnessed, was under the tropical sky of India; and other observers have recorded instances of its appearance in the equatorial districts of the globe.

The altitude of the aurora varies considerably; there is no doubt, however, that it frequently occurs at small elevations. Both Capt. Franklin and Capt. Parry record examples of its appearing below the level of the clouds, which they describe as concealed behind the masses of its light, and as reappearing when the meteor vanished.

§ III. GALVANIC OR VOLTAIC ELECTRICITY.

(218) *Galvani's Discovery.*—About the year 1790 Galvani made the observation that convulsive movements were produced in the limbs of a frog recently killed if brought into contact with two dissimilar metals, such as zinc and copper, which were themselves in contact. The experiment may be readily repeated in the following manner:—Expose the crural nerve (N, fig. 163) of a recently killed frog, touch it with a strip of zinc, z, and at the same time touch the surface of the thigh, *m*, with one end of a bit of copper wire, C; the moment that

FIG. 163.

the other end of the copper wire is made to touch the zinc, the limb is convulsed: the convulsions cease when the two metals are separated from each other, though they are still in contact with the animal. Each time that the zinc and copper are made to touch the convulsion is renewed. A live flounder laid upon a pewter plate shows no particular sign of uneasiness; a silver spoon may also be laid upon its back without any apparent effect: but if the spoon be made to touch the pewter while it rests on the fish, the animal becomes strongly convulsed. If a piece of zinc and a shilling be placed one above and the other under the tongue, no particular sensation is perceived so long as the two metals are kept separate, but if the silver and the zinc be allowed to touch each other, a peculiar tingling sensation or taste is experienced; and if the silver be placed between the upper lip and the teeth instead of under the tongue, each time that the two metals are brought into contact, not only will a taste be perceived, but a momentary flash of light will appear to pass before the eye.

These phenomena are all analogous to each other, and have an electrical origin; and by tracing them to this source, a branch of electrical science has gradually been developed, which in honour of its first discoverer has been termed *galvanism*. The term galvanism, or *voltaic electricity*, as it is also called, in remembrance of the researches of Volta in this field, is applied to electricity, which is set in motion by chemical action. It is usually developed by the contact of two dissimilar metals with a fluid.

(219) These effects may be traced by very simple means. When a plate of zinc is immersed in dilute sulphuric acid, the metal becomes rapidly dissolved, and an extrication of hydrogen gas takes place, water is decomposed, the oxygen of the water unites with the zinc, oxide of zinc is formed, and becomes dissolved in the sulphuric acid. But if the surface of the zinc, after it has been cleansed by immersion in the acid, be rubbed over with mercury, a brilliant amalgam is speedily formed over the whole face of the zinc. Such a plate may then be plunged into the acid, and it will remain without undergoing any chemical change for hours. The cause of this inactivity of the zinc is not satisfactorily accounted for, but the fact is continually made use of in voltaic experiments. The addition of a second amalgamated zinc plate, whether it be in contact with the first, or be separated from it, produces no change. But if the second plate be of platinum, of copper, or of some metal which is less rapidly acted on by the acid than zinc is, although no action will occur whilst the two plates remain

separate (as shown in fig. 164, 1), yet the moment that they are allowed to touch, either above (2) or beneath (3) the surface of the liquid, an escape of bubbles of gas will take place from the surface of the platinum. The platinum, however, in this case is not acted upon; if the two metals be weighed before the experiment is commenced, and again after it is concluded, the weight of the platinum will be found to be unaltered; but the zinc will have been acted on, and will weigh less than it did before. The gas may easily be collected by filling a tube with acid, and after introducing the platinum plate, inverting the tube in the glass, so that the lower edge of the platinum may touch the strip of zinc (No. 3). On examining the gas which rises in the tube it will be found to be pure hydrogen. It is not necessary that the two plates should directly touch each other. They may be connected by means of a metallic wire (as at 4, fig. 164), by a piece of graphite, or by any good conductor of electricity; gas will continue under these circumstances to rise from the platinum plate; but if a glass rod, a stick of shell lac, a bit of gutta percha, or any electric insulator, be made the medium of intercommunication, all signs of action will cease. The length of the metallic wire employed is comparatively unimportant; it may vary from a few inches to many miles, and in either case it will enable the action across the fluid to take place. A pair of plates of dissimilar metals immersed in a fluid, and in effectual communication either by direct contact, or through the medium of a wire, is called a *voltaic circuit*.

Fig. 164.

(220) The wire or other medium of communication, during the time that it forms the connexion between the two metals, exhibits signs of activity which it did not before possess; it exerts a variety of influences upon surrounding bodies, and it loses these powers immediately that the contact with the metal plates is broken. For instance, the temperature of the wire is for the time elevated. This may be proved by causing the wire to traverse the bulb of a delicate air thermometer, or by making a compound metallic

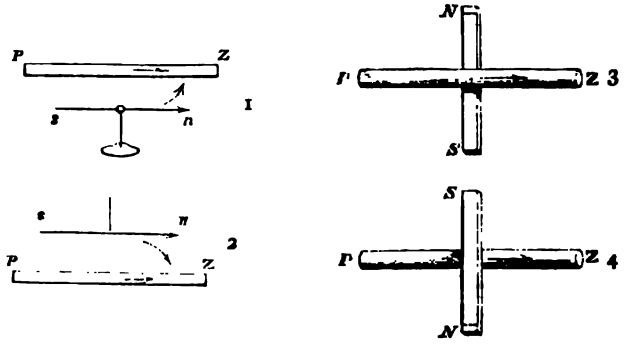
ribbon, such as is used in Breguet's thermometer (134), part of the chain of communication between the plates. If a portion of the wire be sufficiently reduced in thickness, visible ignition of such portion may even be produced. Indeed the quantity of heat given out by the connecting wire may be employed as a measure of the amount of force which it is transmitting.

(221) *Action of the Conducting Wire on the Magnetic Needle.*—Another remarkable proof of the activity of the wire which connects the two metallic plates, is exhibited in the peculiar influence which it exerts over a magnetic needle freely suspended in a direction parallel to the wire. Such a needle tends to place itself at right angles to the wire. If the wire and the needle be previously arranged in the magnetic meridian, the amount of deviation in the needle affords a comparative measure of the force which is conveyed by the wire, as the needle ultimately assumes a position of equilibrium between the directive power of the earth's magnetism and that of the wire (252).

The movements of such a magnetic needle afford one of the most delicate tests of the development of galvanic electricity, or of electricity in motion. It will therefore be necessary to examine the direction and nature of these movements.

The direction of the needle under any circumstances may easily be calculated by recollecting the following rule:—When the wire is placed in the magnetic meridian, with the end connected with the zinc plate towards the north, and the needle is placed below the wire, the marked end will deviate westward. When the wire is below the needle, the marked end will move towards the east. The first effect is shown in fig. 165, 1; the second in 2. On reversing the attachment of the wire to the

FIG. 165.



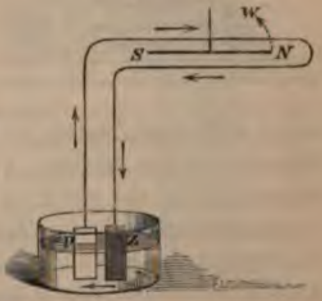
plates, the phenomena will in each case be inverted. By means of a simple model, the direction of the needle under any conditions may be readily indicated. Across a square strip of wood nail a cylindrical piece at right angles; let the square rod represent the magnetic needle, the round rod the connecting wire (fig. 165, 3 and 4); then mark upon the square rod the letters N, and S, and on the round rod, P and Z, in conformity with the rule just given; by placing the model in any given position, the relative effect of the wire upon the needle under these circumstances will be shown.

Even the liquid part of a voltaic circuit acts thus upon the magnetic needle. This may be shown by suspending a needle, *n s*, by means of a fibre of silk, over a dish of diluted sulphuric acid. On one side of this dish a zinc plate, Z, is inserted, on the other a plate of platinum, P. The needle must be placed so that one of its ends may point towards one plate, and the other end towards the other plate. If the two plates be now connected by a wire, as shown in the figure, the needle will be deflected, and will place itself nearly parallel to the metal plates.

FIG. 166.

(222) *The Galvanometer.*—Since every part of the circuit acts equally upon the needle, and since it is possible to make several parts act simultaneously upon it, actions may be rendered perceptible which would otherwise be too weak to influence its motion. Fig. 167 will convey an idea of the principle upon which this is effected. Suppose the wire connecting the plates P and Z to be bent into a loop with parallel sides. If a magnetic needle be suspended between the wires, and parallel to them, the loop and the needle being both in the magnetic meridian, with the end N pointing to the north, the marked end of the needle would be impelled westward under the influence of the force in the upper branch; and as the current returns in the reverse direction through the lower wire, this tendency of the north end westward would be doubled. By

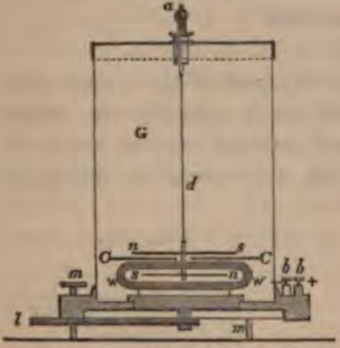
FIG. 167.



increasing the number of coils which are placed around the needle parallel to each other, very feeble actions may be rendered evident. An instrument constructed on this principle is termed a *galvanometer.*

The sensibility of the galvanometer may, however, be still further increased by placing outside the coil a second magnetic needle with its poles reversed; the directive force of the earth may be thus almost exactly neutralized; its attractive power upon the north end of one needle being almost exactly counterbalanced by its repulsive action upon the south end of the needle which is parallel to it. A pair of needles thus arranged constitutes what is termed an *astatic* combination. A very feeble force will be sufficient to drive one particular extremity of such a pair of needles to the east or to the west; but the second needle being outside the coil will be acted upon by the upper wires only, the lower ones being at too great a distance to produce any sensible effect. The action of the upper wires upon the needle above them coincides with their action upon the lower needle, with its reversed poles: and the effect of a feeble current is thus materially increased by these combined actions.

Fig. 168.

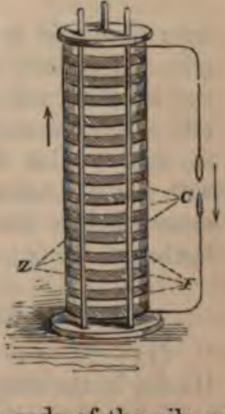


The astatic galvanometer is represented in section in fig. 168. The needles, *n s*, *s n*, are suspended one within, and the other above the coil of wire, *w w*, by means of a fibre of silk, *d*, the whole being enclosed within the glass-case, G. By means of a screw at *a*, the point of suspension of the silk can be raised or lowered without twisting it, so that when the needles are not in use their weight need not be supported by the silk fibre. C C, is a sheet of copper provided with a graduation on its margin for estimating the angular deviation of the needles; *b b*, are binding screws for connecting the extremities of the coil with the wires which transmit the current; the apparatus can be levelled by means of the screws, *m m*, and at *l*, a lever is shown by which the coil of wire, *w*, can be placed accurately parallel with the magnetic needles, so as to make them coincide with the zero of the graduated circle. Such an instrument may be made not only to indicate the existence of voltaic action, but also to measure its amount. When the deviations of the needle mall, not exceeding 15° or 20°, the number of degrees of tion gives nearly accurately the relative force; but for angles eater magnitude, this is not the case, because the more the e deviates from parallelism to the wire, the more obliquely herefore the less powerfully does the force act which occasions otion; and it becomes necessary to determine the value of the es by direct experiment. It would require a greater amount wer to move the needle from 20° to 25°, than from 10° to and a still greater to produce a deviation from 30° to 35°; he deviation in each case is definite, and consequently may be ated and measured.

223) Allusion has already been made to the physiological n of the current, in consequence of which, if a living animal, part of one recently killed, such as the limb of a frog, be in- d between a pair of plates, muscular contractions are pro- d; similar effects occur if a portion of the human body, such e tip of the tongue, be included between two interrupted ts of the conducting wire. But in addition to the heating, etic, and physiological effects, another remarkable series of omena, those of chemical decomposition, may be exhibited at nterrupted points of the conducting wire. These, however, are distinctly shown when a number of pairs of plates is employed.

224) *The Voltaic Pile.*—In prosecuting the experiments of Gal- , Volta discovered that by using a number of similar metallic moistened by a saline or by an acid liquid, many of the effects dy described were greatly increased, and e year 1800 he published a description e apparatus which he had contrived, and h has perpetuated the name of its in- or under the designation of the *voltaic* This important instrument is repre- ed in fig. 169. It consists of a succession airs of plates of two dissimilar metals, as zinc, z, and copper, c, or zinc and silver, pair being separated on either side from adjacent pairs by pieces of card or of el, F, moistened with salt and water, or very weak acid: these plates may be sup- ed by a frame of dry wood. The effects luced by such an apparatus were soon to be of an electrical character. If the ends of the pile or wires connected with them were touched, one with each hand

Fig. 169.



previously moistened, a sensation similar to that of the electric shock was experienced. Sparks could be obtained between two pieces of charcoal attached to the ends of the wires, divergence of the gold leaves of the electroscope was produced when one wire touched the cap of the instrument, and other electrical effects were obtained. In arranging the plates of metal it is necessary strictly to observe a certain order in their succession: thus, if a plate of zinc with a wire attached to it form the bottom of the pile, a piece of wet flannel must be placed upon it, then a piece of copper, then a piece of zinc, then flannel, then copper, then zinc, then flannel, and so on, till the pile terminates at the top with a plate of copper to which a wire is attached. By soldering together the zinc and copper in pairs, a considerable improvement is effected, complete contact of the two metals is insured, and the apparatus can be mounted with more rapidity. Many practical inconveniences, however, are experienced when the instrument is mounted in the form of a pile: the liquid in the flannel soon loses the power of chemically acting on the zinc, and the activity of the combination rapidly declines.

Another more effectual arrangement adopted by Volta is shown in fig. 170; he termed it the *Crown of Cups*. In this form the liquid in the cell corresponds to the moist flannel of the pile, and the zinc of one cell being connected with the copper of the *adjacent* cell corresponds exactly to the arrangement of the pile, where the zinc is on one side of the flannel, whilst the copper in contact with the other surface of the flannel communicates with the zinc touching the flannel next above it, and so on. Other more efficient forms of the voltaic battery will be described further on. (231.)

FIG. 170.

The Conditions required to produce Voltaic Action.

(225) *Electric Disturbance by Contact of Dissimilar Metals.*—Having in the foregoing remarks traced the voltaic phenomena to a modification of electricity, we may now proceed to examine more particularly the conditions under which they occur.

It was early observed by Volta that when two different metals, properly insulated, are brought into contact, and then separated by means of insulating handles, each plate exhibits signs of electricity. The more oxidizable metal is found to be positive, while the metal which is least oxidizable is negative. If zinc filings be sifted through a piece of insulated copper wire gauze upon the cap of a gold leaf electroscope, the leaves of the instrument will diverge. On approaching the electroscope with an excited stick of sealing-wax the leaves will collapse, thus proving that the zinc filings have acquired vitreous or positive electricity. If copper filings be sifted through zinc gauze, the filings will be found to be negative. The various metals may, with reference to these electric actions, be arranged in a series in which those first in order become positive by contact with all those that follow, and negative with all those that precede: for example, potassium, zinc, iron, lead, tin, copper, mercury, silver, gold, platinum.

Volta regarded the interposed liquid of his pile in the light merely of an imperfect conductor which allowed induction to take place through it, the electrical equilibrium being perpetually disturbed by the contact of the two metals; and he overlooked the chemical changes which the liquid is continually undergoing.

(226) *Chemical Action Essential to the Production of Voltaic Action.*—It is now known that chemical changes are essential to the production of the force. Contact of dissimilar substances is also necessary to the voltaic action. Such contact produces disturbance of the electric equilibrium in the bodies which are brought together, and thus occasions a state of tension or polarity which always precedes the discharge. Chemical action, by renewing these contacts and by furnishing appropriate conductors to the electricity thus accumulated, maintains the action and accurately measures its force. Until chemical action occurs no current is produced. The following experiment may be cited in illustration of this point. Let an iron wire be connected with one extremity of a galvanometer, and a platinum wire with the other extremity; immerse the ends of the wires in highly concentrated nitric acid (sp. gr. about 1·45), no chemical action will occur upon the iron, and no movement of the magnetic needle will be produced; but the addition of a little water will determine a rapid solution of the iron in the acid, and the needle, at the same moment that the chemical action commences, will receive a powerful impulse.

(227) *Polarization and Transfer of the Elements of the Liquid.*—The simple occurrence of powerful chemical action is not alone

sufficient to produce a powerful voltaic effect. The metals are all excellent conductors of electricity, and in combining with each other to form alloys, they often give evidence of intense chemical action, but they do not produce any adequate voltaic effect. For example, if a small quantity of tin be placed in a tube bent into the form of the letter U, and be melted by the heat of a spirit lamp, and it be connected on one side with the wire of a galvanometer, which is introduced into the melted metal in one limb of the tube, whilst into the second limb of the tube a platinum wire, connected with the other extremity of the galvanometer, is plunged, the platinum will unite with the tin with incandescence, but after the first moment of contact no permanent deviation of the magnetic needle will be observed, although a brisk chemical action is continued for several seconds. A solution of the elementary bodies, chlorine or bromine, when used as the liquid between the plates, although it acts powerfully on the zinc, produces by no means a proportionate power in the circuit.

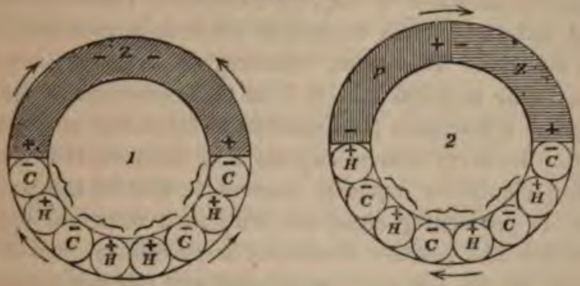
In order that the liquid shall possess any marked power of exciting voltaic action, it must be a compound fluid susceptible of decomposition by one of the metals, such, for instance, as dilute sulphuric, hydrochloric, or hydriodic acid, or a saline substance, such as chloride of sodium or iodide of potassium. This necessity for the employment of a compound liquid for exciting the force, appears to arise from the necessity of a peculiar polarization in the liquid in order to enable it to transmit the voltaic action.

Indeed in all Voltaic actions the transfer of power is effected by a polar influence, propagated through both the solid and the liquid particles of the circuit, and the chain of conducting material must be continuous throughout, so that the force shall *circulate*.

This process of polarization may be conceived to occur in the following manner, which offers an explanation of the mode in which the platinum (or the plate of metal which corresponds to platinum) may be supposed to act.

When a plate of zinc is immersed in a compound liquid, which, like a solution of the hydrochloric acid (H Cl), is capable of chemically attacking it, the metal at the points of contact becomes positively electrified, whilst the distant portion becomes negative. The layer of liquid in contact with the zinc undergoes polarization, which affects each molecule of its chemical constituents; the particles of chlorine become negative, and the particles of hydrogen positive; but in this form of the experiment there is no communication between the negative part of the zinc and the positively electrified particles of hydrogen, consequently beyond the production of this state of electric tension, no change ensues. This condition is represented in fig. 171 (1). But the case

FIG. 171.



is entirely altered if a plate of platinum, or of some other metal which is not easily acted upon by the acid, be introduced, and made to touch the zinc. By contact with the zinc the platinum itself becomes polarized; it imparts a certain amount of positive electricity to the zinc, and receives a portion of negative in return, and transmits the polar action to the liquid. A chain of polarized particles is thus produced, as represented in fig. 171 (2); the chlorine of the particle of H Cl nearest the zinc becomes negative under the influence of the chemical affinity which exists between it and the zinc, and the hydrogen becomes positive; the second and third particles of H Cl become similarly electrified by induction, but the platinum, under the influence of the induction of the zinc, being negative, is in a condition to take up the positive electricity of the contiguous hydrogen. The action now rises high enough to enable the zinc and the chlorine to combine chemically with each other; the chloride of zinc thus produced dissolves in the liquid, and is removed from further immediate action; but the particle of hydrogen nearest the zinc now seizes the oppositely electrified chlorine which lies next to it, and a new portion of hydrochloric acid is reproduced, whilst the hydrogen in the second particle of the acid is transferred to the chlorine of the adjacent particle, and the particle of hydrogen which terminates the row is electrically neutralized by its action upon the platinum, to which it imparts its excess of positive electricity, and immediately escapes in the form of gas. Fresh particles of hydrochloric acid continually supply the place of those which have undergone decomposition, and thus a continuous action is maintained. Thus the transfer of electricity from particle to particle of the liquid is attended at the same instant by a transfer of the constituents of the liquid in opposite directions.

These changes are not successive, but are simultaneous in each vertical section of the liquid, and are also attended with corresponding changes at all points of the entire circuit. These changes when continued uninterruptedly constitute what is conveniently termed a *voltaic current.* This term, 'current,' is in general use, but it should be borne in mind that it is in this sense employed merely to signify the continuous transmission of force, not of any material substance. In every voltaic current it is assumed that a quantity of negative electricity, equal in amount to that of the positive set in motion, is proceeding along the wire in a direction opposed to that in which the positive electricity is travelling; and it is conceived that by the perpetual separation and recombination of the two electricities in the wire, its heating and other effects are produced. In order to avoid confusion, however, whenever the *direction* of the voltaic current is referred to, the direction of the positive current alone is indicated.

The polarization of the metallic and liquid particles composing a circuit, or in other words, the occurrence of electric tension where zinc is placed in an acid, previous to the completion of the voltaic current, may be shown by the following experiment, due to Mr. Gassiot. A plate of platinum, P, fig. 172, and another of amalgamated zinc, Z, are immersed in dilute sulphuric acid, and the wire which proceeds from each is insulated and connected with the two gilt disks, *a b*, of the electroscope, E; these disks are insulated from each other and from the ground, by the glass of the apparatus; they slide easily to and fro in the sockets, and can be brought within a quarter of an inch or less of each other; a single gold leaf, mounted as in the ordinary electroscope, is suspended midway between them: now if the positive end of a *Deluc's* pile (249), D, be brought near the cap of the instrument, the gold leaf will approach the disk *a*, which is connected with the zinc plate; the

FIG. 172.

leaf becomes positive by induction from the positive end of the pile, and is therefore attracted by the negatively electrified disk *a*; but if the opposite end of the pile D, which is charged with negative electricity be presented, the gold leaf becomes negative, and is attracted by the positively electrified disk *b*, which is in connexion with the platinum plate.

(228) *Energy of the Current Proportionate to the Chemical Activity.*—In order to produce a current, the two metals which are employed must be acted upon by the exciting liquid with different degrees of rapidity:—thus, when two similar slips of zinc, or of any other metal, are opposed to each other, no current is excited. The galvanic action is strongest between two metals upon which the chemical action of the components of the exciting liquid differs most widely; for, from what has been already stated, it is evident that two strips of zinc would tend to produce polarization, and subsequently currents of equal intensity, in opposite directions, and the two would necessarily neutralize each other. When zinc is opposed to tin, a current is produced, setting out through the liquid from the zinc to the tin; zinc and copper give rise to a stronger current in the same direction; whilst between zinc and platinum the current is still more powerful; and between potassium and platinum the action attains its maximum. By forming an amalgam of potassium, this last mentioned experiment admits of easy performance; for it has been found that the voltaic relations of all amalgams are the same as those of the more oxidizable metal which they contain. A good deal of potassium is oxidized by what is termed *local* action, without contributing in any way to the production of the current. The distinction between local action and action which contributes to the voltaic effect is important, and may be illustrated by the difference in action of dilute sulphuric acid upon a slip of ordinary zinc and of a slip of zinc from the same sheet which has been amalgamated: in the first case rapid solution of the metal will occur although the connexion with the platinum plate may remain incomplete; in the second, the zinc will be attacked only when the circuit is completed; but the unamalgamated zinc will produce no greater voltaic effect than an equal slip of the metal which has been properly amalgamated. In no instance is the force in circulation increased by the local action on the plates, whatever be the nature of the metal.

Professor Wheatstone has devised a method (240) of m
the amount of the *electro-motive force*, or energy of th

power, produced by any combination; and he has by this means proved conclusively that this energy depends upon the intensity of the chemical action between the elements of the liquid, and the metals which compose the circuit. He has shown that if any three of these dissimilar metals be taken in their electrical order and be formed in pairs into separate circuits, the force generated by a combination of the two extreme metals of the series is equal to the sum of the forces developed when the intermediate metal is separately combined with each of the other two in succession. For example, the voltaic energy, or electro-motive force, excited between platinum and an amalgam of potassium may be represented by the number 69: the electro-motive force between platinum and zinc, expressed in terms of a similar standard, is equal to 40; and in a similar experiment between zinc and potassium, where zinc acted the part of a negative metal towards the potassium, the number obtained was 29. Now

the amount of force between platinum and zinc = 40
the amount of force between zinc and potassium = 29

the two taken together = 69

and this number, 69, is identical with that obtained by opposing platinum to the amalgam of potassium.

(229) *Direction of the Current Dependent on the Direction of the Chemical Action.*—In all these cases the positive electricity sets out from the more oxidizable metal, which may be termed the positive, or generating plate, and traverses the liquid towards the less oxidizable metal which forms the negative or conducting plate: from the conducting plate the force is transferred to the wire, and thence in turn to the generating plate; thus the circuit is completed. Unless this circulation can take place, all the phenomena of voltaic action are suspended. Since the chemical action of any combination is thus always in one uniform direction, the motion of a magnetic needle under its influence is equally uniform: the amount of force which is thrown into circulation, whether it be measured by its magnetic or by its heating effects, is proportioned to the quantity of the positive metal which is dissolved in a given time.

Every liquid which thus acts in exciting a voltaic current may be regarded as consisting of two groups of substances, one of which attacks the generating or positive plate, and may be termed the electro-negative constituent of the liquid, whilst the other is sferred to the conducting or negative plate, and constitutes the tro-positive constituent.

The elementary bodies have indeed been classified upon this ciple into electro-positive and electro-negative substances; rogen and most of the metals being the electro-positive; gen, chlorine, and other substances of this nature being electro-ative. In the following table the more important of the nents are arranged in the electro-chemical order on the au-ity of Berzelius. It has been remarked that the more strongly tro-positive metals crystallize in forms belonging to the ular system, whilst generally the non-metallic elements, and those als which are most electro-negative, crystallize in other forms.

Electro-chemical Order of the Principal Elements.

Electro-negative.

Oxygen
Sulphur
Selenium
Nitrogen
Fluorine
Chlorine
Bromine
Iodine
Phosphorus
Arsenic
Chromium
Vanadium
Molybdenum
Tungsten
Boron
Carbon
Antimony
Tellurium
Titanium
Silicon
Hydrogen.

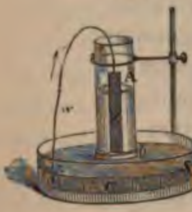
Gold
Platinum
Palladium
Mercury
Silver
Copper
Bismuth
Tin
Lead
Cadmium
Cobalt
Nickel
Iron
Zinc
Manganese
Uranium
Aluminum
Magnesium
Calcium
Strontium
Barium
Lithium
Sodium
Potassium.

Electro-positive.

It is probable that the order here followed is not exactly cor-. Fluorine, and chlorine perhaps, ought to stand at the head of the list; and there is no doubt that hydrogen should stand much nearer to potassium; it is also certain that the elements do not under all circumstances maintain the same relative order, but that in particular cases the order is altered; for example, in strong nitric acid, iron is nearly as electro-negative as platinum; a metal may be electro-positive when it forms the base of a salt, but electro-negative when associated with the elements of the acid constituent: still the general arrangement is useful, though the distinction of bodies into electro-positive and electro-negative is not absolute, but merely relative, the classification in the table being regarded as indicating that those bodies which stand first on the list are electro-negative when associated in combination with those that follow them.

The relative size of the generating and conducting plates has no influence upon the direction of the current, which sets in as certainly through the liquid from a square inch of zinc to a square foot of copper as from a square foot of zinc to a square inch of copper. The spread of this force may be traced in an interesting manner by substituting a solution of sulphate of copper for sulphuric acid as a part of the exciting liquid; copper will be thrown down instead of hydrogen, and by its colour and thickness will very accurately indicate the extent and direction of the action. The experiment is easily made by taking advantage of a property possessed by porous diaphragms, in consequence of which, a piece of any animal membrane, or of unglazed earthenware, which can be thoroughly wetted by the liquids, will allow the current to traverse it without opposing any material obstruction to its passage. Dilute sulphuric acid may thus be employed upon one side of the diaphragm, and a solution of sulphate of copper upon the other side: under these circumstances a current would be freely transmitted, whilst the two liquids would be prevented from intermingling. For example, let a piece of bladder, *b*, fig. 173, be tied firmly over the lower end of a wide tube open at both extremities; place some dilute sulphuric acid, A, in the tube, and suspend a rod of zinc, Z, in its axis; support the tube so that its lower end shall dip beneath the surface of a solution of sulphate of copper, S, contained in a shallow glass dish, upon the bottom of which rests a sheet of copper, C: on connecting the zinc and copper by the wire, *w*, voltaic action will ensue, and a deposit of metallic copper will be produced upon the plate C. It will, however, be observed that this deposit

Fig. 173.



does not take place uniformly over the surface of the sheet c, but that it assumes a circular form; the layer of copper is thickest at the point immediately beneath the extremity of the zinc rod, and it gradually becomes thinner towards the circumference of the circle, which, however, continues to increase in diameter as the experiment proceeds, until, if sufficient time be allowed, the plate is covered with reduced copper.

Whilst a metal is thus rendered electro-negative by voltaic action, it is no longer liable to the ordinary action of chemical agents. A beautiful application of this principle was made by Sir H. Davy to the prevention of the corrosion of the copper sheathing of ships by the action of sea water. Copper is the material best adapted to preserve the timbers of the ship from the attacks of marine insects and boring animals; but this metal, when subjected, under ordinary circumstances, to the combined influence of the salts dissolved in sea water and of the atmospheric air which it also holds in solution, experiences corrosion, which in the course of a few years renders it necessary to renew the copper. It was, however, discovered by Davy, that by placing pieces of zinc, or of cast-iron, in contact with the copper under water, this corrosion could be prevented, and that a surface of zinc, not exceeding $\frac{1}{150}$ of that exposed by the copper was adequate to the entire protection of the copper, the whole of the chemical action being transferred to the zinc; and that even when the surface of zinc was reduced until it was only equal to $\frac{1}{1000}$ of that of the copper, a considerable preservative effect was experienced. But the very success of the experiment in the direction anticipated, created difficulties of another kind; earthy matters, consisting of compounds of lime and magnesia, were deposited from the sea water by the slow voltaic action, and they attached themselves to the surface of the copper; weeds and shell-fish found in this deposit a congenial pabulum, the bottom of the ship became foul, the sailing qualities of the vessel were necessarily impaired, and the system of voltaic protectors was abandoned. For some years past a kind of brass, introduced by Mr. Muntz, which admits of being rolled whilst hot, has, in the merchant service, been largely and advantageously substituted for copper as a material for ships' sheathing. In this case the zinc and the copper are combined in the sheet itself, which is less rapidly corroded than if composed of either metal separately. The protective influence of zinc both on copper and on iron is readily shown by exposing bright bars of these metals in separate vessels, either in sea water or in a solution of common salt containing an ounce of salt in each pint of water. If a fragment of zinc be attached to one of the bars of copper and to one of the bars of iron these bars will remain bright, whilst the zinc is corroded; but the unprotected bars will, in a few hours, give evidence of the commencement of chemical action.

Another remarkable proof of the dependence of the current, for its direction and its force, upon chemical action, is afforded by the manner in which a voltaic circuit may be produced between two surfaces, one of which has a stronger affinity for *hydrogen* than the other possesses. For example, when two clean plates of platinum are immersed in dilute acid, and connected with a galvanometer, no voltaic action is excited; but the case is different if one of these plates be first coated with a film of some metallic peroxide, such as peroxide of manganese (MnO_2), peroxide of lead (PbO_2), or peroxide of silver (AgO_2). The platinum plate may be thus coated by immersing it in a solution of sulphate of manganese, of nitrate of lead, or of nitrate of silver, and connecting it with the platinum side of a weak voltaic arrangement for a few minutes, whilst the liquid is connected by a second plate with the zinc end of the battery: the plate thus prepared, after it has been well washed with distilled water, when opposed to a plate of clean platinum, and immersed in any dilute acid, will originate a current which depends upon the affinity of the hydrogen of the dilute acid for the second equivalent of oxygen in the peroxide. In a combination of this description the clean platinum becomes positive, and corresponds to the zinc plate, whilst the coated platinum becomes negative. The coated plate, although negative, thus becomes the generating or active surface, and transmits the current at once to the conducting wire.

Faraday has shown that the direct contact of dissimilar metals is not necessary to the production of the voltaic current, provided that they are connected by some liquid of sufficient conducting power. This is a point of considerable importance, as it shows that Volta's theory of the origin of the force, which is still maintained by many philosophers who have not made the chemical phenomena of the pile their especial study, is deficient in accuracy. The following is the simple experiment, which proves the point now under discussion: Z, fig. 174, is a plate of zinc, bent at a right angle; P, a platinum plate, to which a platinum wire is

FIG. 174.

attached. At *a*, a small piece of blotting paper, moistened with a solution of starch and iodide of potassium, is interposed between the plate of zinc by which it is supported and the platinum wire which rests upon it; no change occurs in the solution of the iodide until the two plates are immersed in dilute nitric acid; but in a few minutes after such immersion, evidence of a current in the direction of the arrows is afforded, by the appearance of a blue spot against the platinum wire, due to the liberation of iodine, from the decomposition of the iodide of potassium by the voltaic action.

(230) *Circuits with one Metal and two Liquids.*—For the establishment of a voltaic current, it is further necessary that the body which decomposes the liquid be a conductor of electricity, in order to carry off the force generated; but it is not necessary to use two dissimilar metals, provided that one extremity of the metal be plunged into a liquid capable of acting on it whilst the other extremity dips into a different liquid, which has little or no action on the metal, but which communicates freely with the first liquid.

Take, for example, a tube bent into the form represented in fig. 175, 1. Place a plug of tow in the bend; into one limb, *a*, pour

FIG. 175.

a solution of chloride of copper (Cu Cl), in the other limb, *b*, place a solution of common salt (Na Cl) (chloride of sodium). Connect the open ends of the tube by bending a strip of copper so that one end of it shall dip into the solution of copper and the other end into the solution of salt. Crystals of copper will form gradually upon the end of the strip which is immersed in the metallic solution, whilst the end of the strip which is immersed in the salt and water will slowly be corroded, and chloride of copper will be formed. The following diagram may assist in explaining this change:—

Let the symbol Cu Cl represent the combination of chloride of copper, Na Cl that of chloride of sodium, the line at A being used to show the position of the plug of tow. If No. 1 indicate the state of things before any change has occurred, No. 2 will represent the change after the circuit is complete.

$$(1.)\ \text{Cu}\ \underline{\Big|\ \overbrace{\text{Cu Cl}},\ \overbrace{\text{Cu Cl}}\ \overset{\text{A}}{\Big|}\ \overbrace{\text{Na Cl}},\ \overbrace{\text{Na Cl}}\ \Big|}\ \text{Cu}$$

$$(2.)\ \text{Cu}\ \underline{\Big|\ \text{Cu},\ \overbrace{\text{Cl Cu}},\ \overbrace{\text{Cl}\ \Big|\ \text{Na}},\ \overbrace{\text{Cl Na}},\ \overbrace{\text{Cl Cu}}\ \Big|}$$

If the strip of copper be divided in the middle, and the two ends be connected with a galvanometer, as shown in fig. 175, 2, a current is found to be circulating through the apparatus. A still simpler arrangement may be adopted; if a long straight tube be filled half full with dilute sulphuric acid, and the remainder with a solution of sulphate of copper, a strip of copper plunged into it will be dissolved below, while an equal amount of copper will be deposited on the upper extremity; from the extreme slowness and regularity of the action, the metal will assume the form of crystals. M. Becquerel, by using various liquids in the two limbs of the tube, has obtained many of the metals crystallized in forms of great beauty.

By employing two dissimilar metals in the metallic arc, as P Z, (fig. 175, 3) a more powerful but equally regular action may be excited. If a solution of common salt be placed in one limb, *b*, and a solution of protochloride of iron in the other, *a*, whilst the zinc end of a compound arc of zinc and platinum is plunged into the first, and the strip of platinum is immersed in the second liquid, tetrahedral crystals of iron will in a few days be deposited upon the platinum. If a little chloride of iron be mixed with chloride of zirconium, and substituted for the chloride of iron in the limb *a*, plates of zirconium will be obtained of a steel gray colour, and which, by exposure to the air, oxidize and fall to a white powder.

M. Becquerel has shown, that within the strata of the earth similar actions are going on; and Mr. Fox and others, by connecting, by wires attached to a galvanometer, the surfaces of two contiguous lodes of metallic ore, have succeeded in demonstrating to the eye the existence of these feeble but continuous currents which are probably the cause of the accumulation of the different metals in regular beds, and of their beautiful crystalline arrangement.

Other combinations may be produced, in which the mutual action of the two liquids originates the current, the metal merely acting as a conductor. M. Becquerel was the first to point out the means of obtaining circuits of this description, of which the following is a good example:—If a small porous vessel be filled with nitric acid, and be immersed in a second vessel containing a solution of potash, on plunging two platinum plates connected with the wires of a galvanometer, one into the acid, the other into the alkaline liquid, a steady current of considerable intensity will be produced, and will be maintained for many days, in a direction passing from the potash to the nitric acid, and thence returning through the galvanometer to the alkaline liquid. Mr. Arrott (*Phil. Mag.* xxii. 427), has described a variety of other cases of this kind. These actions, however, will be more conveniently studied in connexion with the chemical effects of the voltaic battery at a future point.

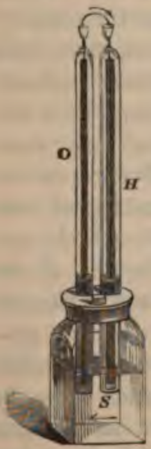
(230 *bis*) The conditions necessary to the production of a voltaic current may be shortly recapitulated as follows:—Though the contact of dissimilar metals produces electric disturbance, chemical action is necessary to propagate the voltaic current. This chemical action must be produced by means of a compound liquid, which is decomposed in the process, one of the constituents of the liquid entering into combination with one of the metals. In the transmission of the voltaic power, a polarization of the liquid as well as of the solid portions of the circuit, is produced, and this polarization of the liquid is attended with the separation of its constituents into two groups, one of which unites with the positive metal, the other makes its appearance at the same moment upon the negative plate. The activity of the combination, or its electro-motive force is greater, the greater the difference between the chemical affinity of the electro-negative constituent of the exciting liquid for the two metals which are opposed to each other in the particular case. The relative size of the plates employed has no influence on the direction of the current which is produced. Contact of two metals is not necessary to the production of voltaic action: circuits may be formed between one metal and two liquids, if the liquids be in liquid communication with each other, and if they be unequal in their chemical affinities for the metal. It is even possible to obtain a current from the mutual action of two dissimilar liquids, if these liquids exert a chemical action upon each other, by connecting the liquids through the intervention of a metal upon which they exert no chemical influence, and which therefore simply performs the part of a conductor.

Different Forms of the Voltaic Battery.

(231) *Counteracting Currents: Gas Battery.*—We shall now resume the consideration of those forms of voltaic combination which are the most important in practice, and in which, generally, two dissimilar metals are employed.

It has been already stated that the amount of force set in motion in a voltaic arrangement, depends upon the difference between the affinity of the two metals for the active principle or *radicle* of the acid. Under circumstances favourable to the production of a current, decomposition of the liquid which excites the action always occurs; the elements of the liquid are separated from each other, and they either combine with the metallic plate, or else they accumulate upon its surface. These adhering substances oppose the voltaic action and enfeeble it, owing to the tendency of the separated components of the fluid to re-unite. Thus, when dilute sulphuric acid is used, it becomes a desideratum to get rid of the hydrogen which adheres to the platinum, and produces a current in the opposite direction. The existence of this counter-current may be rendered evident by connecting with one end of the wire of a galvanometer a platinum plate, which has been thus opposed to a plate of zinc: on attaching to the other end of the galvanometer wire a second, but clean platinum plate, and plunging both into dilute acid, a powerful deflection of the needle will be observed.

Fig. 176.



Mr. Grove has ingeniously applied this observation, and by opposing a plate covered with oxygen to the plate coated with hydrogen, whilst at the same time he increased the surfaces of contact between the platinum and the oxygen and hydrogen, he has constructed what he terms a *gas battery*. Fig. 176 represents a cell of this battery. It consists of two tubes, O and H; through the upper extremities of each is soldered a platinum wire, to which is attached a platinum plate sufficiently long to reach to the bottom of the tube. The surfaces of these plates are coated by means of voltaic action with finely divided platinum, for the purpose of increasing the surfaces of contact between the metal and the gas. The tube H has double the capacity of the tube O. These tubes are supported in the vessel S, by the plug through which they pass. In order to use the apparatus, the vessel S is lled with dilute sulphuric acid, and by inverting the cell, the ubes are likewise filled with the liquid. The tubes O and H are hen connected by the mercury cups at top with the wires of a oltaic battery in action, so that by the decomposition of the dilute cid the tube O shall become filled with oxygen, and the tube H with ydrogen. The tubes having been thus filled, the battery wires re withdrawn. If the mercury cups at the top of the tubes O and be now connected with the wires of a galvanometer, powerful eflection of the needle will be produced, and a current will be naintained through the apparatus in the direction of the arrows. he two gases will gradually diminish in bulk, and will in a few ays entirely disappear, but the current will be maintained so long s any portions of the gases remain uncombined. By connecting ight or ten cells in succession, so that the oxygen tube of one ell shall be connected with the hydrogen tube of the adjacent ell, sparks may be obtained between charcoal points, and various hemical decompositions may be effected. The polar chain by hich these changes are produced, may thus be represented by ymbols: H, SO_4 indicating a molecule of dilute acid, O and H epresenting the disturbing molecules of oxygen and hydrogen.

$$\underbrace{\mathrm{O}\ \mathrlap{\overbrace{\mathrm{H},\ \mathrm{SO}_4}}\mathrm{H}}\underbrace{\mathrm{SO}_4\ \mathrlap{\overbrace{\mathrm{H},\ \mathrm{SO}_4}}\mathrm{H}}\underbrace{\mathrm{SO}_4\ \mathrlap{\overbrace{\mathrm{H},\ \mathrm{SO}_4}}\mathrm{H}}\underbrace{\mathrm{SO}_4\ \mathrm{H}}$$

The brackets above the row of symbols are intended to show he molecular arrangement before the circuit is completed; those eneath the symbols show the action during the passage of the urrent.

Since no action occurs in the gas battery until metallic comunication between the plates is effected, it appears that the use f the platinum plates consists in favouring the action, by conensing the gases upon their porous surfaces, and in acting as onductors of the current.

It may indeed be stated generally, that the accumulation of ither of the elements of the exciting liquid upon the metallic lates of a voltaic combination, always tends to produce a counter urrent, and therefore reduces the efficiency of the combination to proportionate extent. Hydrogen is the element which, in the sual mode of experiment, principally accumulates upon the negaive plate, so that any contrivance by which the adhering hydrogen s removed, exalts the energy of the circulating force. This removal f the hydrogen may be effected by means which act either on hemical or on mechanical principles. The chemical principle is the most perfect. It consists in adding to the liquid a compound which has a tendency to unite with the hydrogen; hence the energy of the current is much increased by mixing a little nitric acid HO, NO_5 with the exciting liquid, comparatively little hydrogen being set free.* The same end is attained by adding to the sulphuric acid, a solution of some of the metallic salts, such, for instance, as sulphate of copper. Scarcely any hydrogen is in either of these cases given off from the surface of the conducting plate. When sulphate of copper is employed, metallic copper is deposited, whilst the oxygen and sulphuric acid with which it was previously united, combine with the zinc. A disadvantage, however, is experienced when the liquid which absorbs the hydrogen is in contact with the zinc, and this is particularly evidenced when sulphate of copper is used. The zinc acts at once on the solution of copper, and becomes coated with reduced copper; hence innumerable small circuits are produced between the particles of zinc and those of the reduced copper, which occasion a violent discharge of hydrogen from the entire surface of the generating metal, or rather from the copper deposited upon it; but the zinc thus dissolved contributes nothing to the general effect; it becomes merely a case of local action (228).

This experiment with the sulphate of copper throws light upon the cause of the effervescence which takes place when common zinc is treated with dilute sulphuric acid. Commercial zinc always contains iron and other foreign metals mixed with it in very appreciable quantity; these act as dischargers to the hydrogen, and give rise to numerous local circuits at all points of the surface of the zinc. Perfectly pure zinc dissolves very slowly in acid for want of these discharging points, but the acid is not absolutely without action upon the metal. Any inequality in susceptibility to chemical action gives rise to a current between two substances suitably disposed; hence any difference in density between two pieces of the same metal may suffice to cause a current; and a piece of hammered zinc will generally act as a conducting plate to a piece of zinc well annealed. The adherence of a film of oxide or of fatty matter to the surface of one piece will also cause a difference, and hence two pieces of metal which may even have been cut from the same strip, may, under certain circumstances, produce a feeble current.

The inconvenience which is occasioned by local action, when

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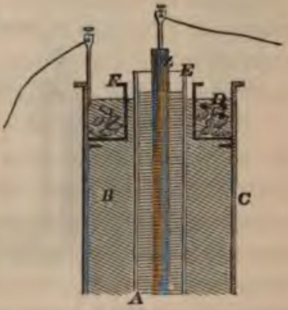
* By the action of hydrogen on nitric acid, peroxide of nitrogen (NO_4) and water are formed, thus: $NO_5 + H = NO_4 + HO$.

nitric acid or sulphate of copper is mixed with the liquid which is in contact with the zinc may be avoided by the employment of porous diaphragms, and if the zinc or generating plate be plunged into dilute sulphuric acid, whilst the platinum or conducting plate is made to dip into the nitric acid or into the solution of sulphate of copper, which is separated from the generating plate by a tube of porous earthenware, combinations of great efficiency are obtained.

(232) *Daniell's Battery.*—These important facts were first clearly enunciated by Professor Daniell. Their application to the voltaic battery enabled him to detect the cause of the rapid decline in the activity observed in all the forms of batteries which up to that period had been devised, and they led him to the invention of an arrangement which not only obviated these defects, and enabled him to keep up a current of uniform strength for many hours, but also furnished electrical science with a battery of far greater activity for its size than any which had previously been used. Fig. 177 exhibits a section of one of the cells of Professor Daniell's combination. The outer case, C, consists of a cell, or cylinder of copper, which is constructed so as to retain liquids, and is filled with a solution of sulphate of copper, B, acidulated with $\frac{1}{8}$ of its bulk of sulphuric acid. The solution is kept saturated with the salt by means of crystals of sulphate of copper, D, which rest upon the perforated shelf, F. In the axis of the cell is placed a tube of porous earthenware, E, filled with an acid solution, A, which consists of 1 part of oil of vitriol diluted with 7 parts of water. A rod of zinc, Z, is placed in this tube. On making a metallic communication between the zinc rod and the copper cell, a voltaic current is established; and by employing twenty or thirty cells of this description, always connecting the zinc of one cell with the copper of the next, a combination of great power is obtained.

FIG. 177.



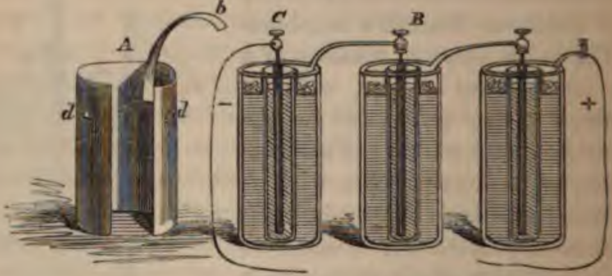
The following diagram may serve to explain the manner in which the force is transmitted through the cells:—the dilute sulphuric acid may be regarded as a compound of hydrogen with sulphur and oxygen, and is represented as H, SO_4; whilst sulphate of copper may be looked upon as a compound of copper with the same compound of sulphur and oxygen, and is indicated by the symbol

$\mathrm{Cu}, \mathrm{SO_4}$. Let the brackets above the row of symbols represent the connexion of the particles which compose the liquid before contact is made between the plates Cu and Zn at the ends. After the connexion is made between the copper and the zinc, the altered molecular arrangement in the liquid may be represented by the altered position of the brackets beneath: the line A, which divides the symbols of the sulphate of copper from those of the sulphuric acid, in this case represents the porous diaphragm.

$$\rlap{$\underbrace{\phantom{\mathrm{Cu},\ \mathrm{Cu}}}\underbrace{\phantom{\mathrm{SO_4},\ \mathrm{Cu}}}\underbrace{\phantom{\mathrm{SO_4}\ \overset{\mathrm{A}}{\big|}\ \mathrm{H}}}\underbrace{\phantom{\mathrm{SO_4}\ \mathrm{H}}}\underbrace{\phantom{\mathrm{SO_4}\ \mathrm{Zn}}}$}\mathrm{Cu},\ \overbrace{\mathrm{Cu},\ \mathrm{SO_4}},\ \overbrace{\mathrm{Cu},\ \mathrm{SO_4}}\ \overset{\mathrm{A}}{\big|}\ \overbrace{\mathrm{H},\ \mathrm{SO_4}}\ \overbrace{\mathrm{H}\ \mathrm{SO_4}}\ \mathrm{Zn}$$

The result of the action is, that so long as the contact between the plates is maintained, sulphate of zinc is formed uninterruptedly in the porous tube, whilst a continual deposit of a corresponding quantity of metallic copper takes place upon the internal surface of the copper cylinder. Fig. 178 shows a convenient and inexpensive form of Daniell's battery. The solution of sulphate of copper is contained in glass or earthenware jars seven inches deep, and three and a half inches in diameter. The copper plates consist merely of rectangular sheets of copper, one of which is represented at A; they are bent into a cylindrical shape and placed in the jars. By means of the strip *b*, each plate is easily connected with the zinc rod of the adjacent cell, and made fast to it by the binding screw C. The colander for the support of the crystals of sulphate of copper, rests upon three or four little pieces of copper, which are made to project inwards upon the sheet, at a suitable height as shown at *d*. At B, several cells of the battery are represented as arranged in a consecutive series. Twenty such cells compose a battery adequate to the performance of almost any experiments on the chemical decomposition of bodies in solution.

FIG. 178.



It is essential in mounting a voltaic arrangement of any kind, that the surfaces of contact between the metals be perfectly clean:

a film of oxide will materially impede the transmission of the current, and if the force in circulation be feeble, it may even arrest it altogether. As a precaution, it is better before connecting the different parts of the apparatus, to pass a file or a piece of emery paper over all the surfaces of the copper, the zinc, or the other oxidizable metals which are to be placed in contact with each other. Surfaces of platinum, if well washed and dried, do not need friction with emery paper.

(233) *Grove's Nitric Acid Battery.*—The nitric acid battery contrived by Mr. Grove, is a still more powerful combination on the same principle as Daniell's. It consists of a slip of platinum, P, fig. 179, which is plunged into the porous tube, N, and this is filled up with undiluted nitric acid. The outer cell, S, is filled with dilute sulphuric acid, and in this acid is placed a flat sheet of amalgamated zinc, Z; bent so as to infold the porous tube. The acid liquid in S may be conveniently made of 1 measure of oil of vitriol, diluted with 4 measures of water. This combination presents in a small compass the principal desiderata for attaining intense voltaic action. Platinum is the least liable of the metals to chemical action, whilst amongst the metals that admit of being easily wrought, zinc is the one which is most readily attacked by acids; consequently the opposition of platinum to zinc furnishes a most effective voltaic combination; whilst nitric acid absorbs with ease the hydrogen liberated on the platinum, and thus forms water and peroxide of nitrogen, which remain in solution in the undecomposed acid; the resulting liquid constitutes one of the most perfect of liquid conductors. If NO_4 O in the following diagram represent nitric acid, and H, SO_4 dilute sulphuric acid, Pt the platinum plate, and Zn the zinc one, the molecular arrangement will be indicated before the action by the position of the brackets above, and after the action by the position of those below.

FIG. 179.

$$\rlap{$\phantom{\mathrm{Pt}\ \mathrm{NO_4},\ }\underbrace{\phantom{\mathrm{O},\ |\ \mathrm{H},}}\ \underbrace{\phantom{\mathrm{SO_4}\ \mathrm{H},}}\ \underbrace{\phantom{\mathrm{SO_4}\ \mathrm{Zn}}}$}\mathrm{Pt}\ \overbrace{\mathrm{NO_4},\ \mathrm{O},}\ |\ \overbrace{\mathrm{H},\ \mathrm{SO_4}}\ \overbrace{\mathrm{H},\ \mathrm{SO_4}}\ \mathrm{Zn}$$

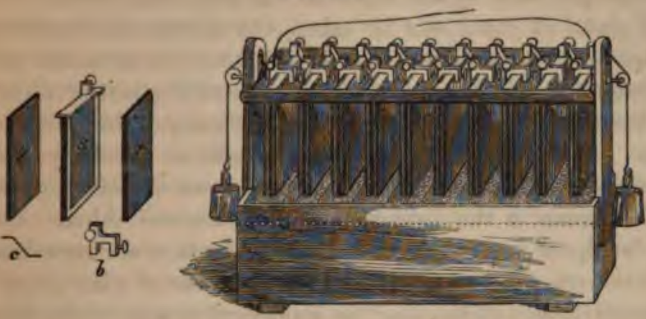
With a battery of ten such cells, five inches high, and two and a half inches wide, a large number of brilliant experiments may be performed, but four or five cells are generally sufficient for most purposes of electro-chemical decomposition. Mr. Callan mixes oil of vitriol with the nitric acid in the porous cells, and thus obtains a current, the strength of which is more uniform than when nitric acid only is used.

With a view to economy, Bunsen substitutes for the platinum plates in Grove's battery, cylinders of carbon, prepared by heating together a mixture of powdered coke and caking coal, or powdered coke moistened with a strong solution of sugar. A firm coherent coke is thus obtained. Cylinders made of this material answer well while new; but being porous, the carbon absorbs the nitric acid, which corrodes and impairs the surface of contact with the zinc. Poggendorff (*Liebig's Annal.* xxxviii. 308) has employed plates either of sheet iron or cast iron instead of either platinum or carbon; in strong nitric acid the iron is totally unacted on; but if the acid become diluted till it has a specific gravity of 1·35, or less, it is liable to act upon the metal with uncontrollable violence. No combination possesses the intense energy, in union with convenience of working and comparative durability, in the same degree as that proposed by Mr. Grove. It is necessary, however, to place the nitric acid battery so that the fumes of nitrous acid (which are copiously evolved during its action, especially after the battery has been in use for some time) shall pass at once into the open air; as they would otherwise seriously incommode the operator.

(234) The other mode of obviating the counteracting agency of hydrogen upon the negative plate of the battery is less perfect, and is of a mechanical nature. It was first practically applied in the construction of the voltaic battery by Mr. Smee. Hydrogen adheres to smooth surfaces of platinum and other metals with considerable force, but it passes off with ease from their asperities and edges: by multiplying their points and irregularities, as, for example, by the deposition of metal on the surface in a pulverulent form, the escape of the gas is much facilitated. Mr. Smee employs as the negative or conducting plate in his battery, a plate of silver, the face of which has been roughened by the deposition of finely divided platinum upon its surface; each side of the silver plate being exposed to a plate of zinc well amalgamated, and of equal extent, which acts as the positive plate. This pair of plates is excited by means of dilute sulphuric acid. Fig. 180 represents a battery constructed upon Smee's principle; a thin platinized silver plate is supported in a light frame of wood, as shown

detached at S; to the upper part of this frame a binding-screw, in metallic connexion with the silver, is fastened, for the purpose

FIG. 180.



of connecting the plate with the zinc plates of the adjoining cell, by means of a strip of sheet copper bent as at *c;* on either side of the silver plate a sheet of amalgamated zinc, Z Z, is supported by the clamp shown at *b*; the zinc plates are prevented from contact with the silver plate by means of the wooden frame, and they are connected with the silver of the adjacent cell by a second binding-screw in the clamp shown at *b;* the separate plates are attached to a wooden frame, and being counterpoised by weights, as indicated in the figure, can be lowered into the trough of acid when wanted for use, or can be withdrawn from it when the experiment is over.

(235) *Resistances to the Voltaic Current.*—The amount of force which circulates in any given circuit is not dependent solely upon the energy of the chemical action which is exerted between the generating metal and the exciting liquid. The current experiences a retardation or a resistance from the very conductors by which its influence is transmitted; just as in the transmission of mechanical force, the intervention of the pivots and levers which are required for its conveyance introduces additional friction and additional weight, which require to be overcome or moved, and which thus diminish the efficient power of the machine.

The resistance to the voltaic current may be considered as of two kinds—first, that resistance which arises from the exciting liquid employed in the voltaic cell itself; and secondly, that which arises from the conducting wire and apparatus exterior to the voltaic cell. In a large number of cases the resistance offered by the exciting liquid is by much the most considerable, and it is inseparable from the combination; whilst the second source of resistance, or that which is exterior to the cell, can be increased or diminished at pleasure, and by the employment of very short and thick wires for connecting the plates, can be virtually removed altogether or annihilated. It will be advisable to consider first the resistance produced by the liquid in the active cell itself.

If plates of equal size be taken, the resistance occasioned by the liquid increases directly as the distance between the plates; the longer the column of imperfectly conducting matter which the force has to traverse the greater is the difficulty which it will experience. If two plates be immersed in acid at the distance of an inch asunder, they will produce twelve times the effect that they would occasion at the distance of a foot from each other. On the other hand, the larger the area of the plates that are immersed the less is the resistance. For example, if a pair of plates, one inch broad and twelve inches long, be immersed in acid to the depth of one inch only, the current produced will only be equal to one-twelfth of that which would be obtained by immersing each plate for its whole depth of twelve inches in the liquid. The resistance of the liquid is therefore directly as the distance between the plates, and inversely as the surface of the plates exposed to its action. A pair of plates exposing each a square inch of surface, immersed in acid at a distance of one inch apart, will consequently produce an effect equal to that which would be obtained from a pair of plates which each exposed a surface of twelve square inches to the action of the liquid, if they were twelve inches apart.

A case somewhat analogous is offered when water is transmitted through pipes. The greater the length of the pipe, the more considerable will be the friction and the consequent resistance to the passage of the liquid; whilst the larger the area of the pipe the more readily will the water escape. A pipe which exposes a circular sectional area of two square inches will allow twice as much water to escape from it in a given time as a pipe of which the area on section is but a single square inch.

If the two plates are of unequal size, but are immersed parallel to each other, they may, for most practical purposes, be calculated as each exposing a surface equal to the mean surface of the two. Other circumstances independent of the extent of surface exposed by the plates, and the distance between them, materially influence the resistance of different liquids to the current. Any cause that favours chemical action between the active metal and the liquid, or which diminishes the force by which the elements of the liquid are united, such as elevation of temperature, diminishes the resistance of the liquid. In most cases an increase in the concentration of the solution, provided its strength be not so great as to render deposition of crystals liable to occur, diminishes the resistance (243). The current likewise experiences a specific resistance in each liquid which depends upon the force with which its particles are united together.

Similar, but distinct resistance, though to a less extent, is offered by the metallic part of the circuit. However good its conducting power may be, it always offers some obstruction to the current. The longer the wire employed, the greater is the difficulty experienced by the force in traversing it. The resistance of each metal, like that of each fluid, is specific. Copper and silver, for instance, when wires of equal thickness and length are compared, offer far less resistance to a given amount of force than less perfect conductors, such as iron and lead. Experiment has demonstrated that with metallic conductors the same law holds good as with liquids—viz., that the conducting power is inversely as the length of the wire, and directly as the area of its section. In cylindrical wires this sectional area will of course vary as the square of the diameter of the wire. A wire $\frac{1}{10}$th of an inch in thickness will for equal lengths offer four times the resistance of a wire $\frac{2}{10}$ths or $\frac{1}{5}$th of an inch thick. If wires of the same metal, and of equal lengths, be compared, the resistance will vary directly as the weights of the wires.

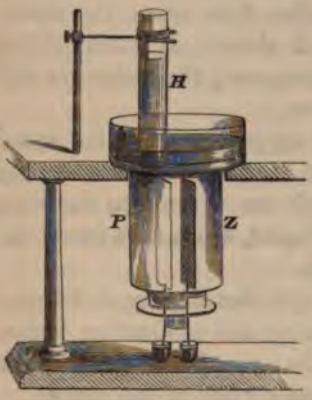
In the experiment with sulphate of copper (fig. 173), the metal is deposited in greatest quantity where the force is most readily transmitted—viz., in those points which are nearest to the zinc, and where the resistance offered by the liquid, which here forms the thinnest layer, is consequently the least.

A rod of zinc supported within a cylinder of copper forms a convenient arrangement of the generating and conducting plates, because, when such a rod is placed in the axis of the cylinder, the force is evenly distributed over the whole surface of the copper.

(236) *Difference between a Simple and a Compound Circuit.*—The observations hitherto made have referred to cases in which only a single pair of metals is employed. It will be necessary now to consider in what way the results are modified by the employment of several pairs of plates. It has already been stated, when speaking of the electricity developed by friction, that when a large supply of electricity is needed, it may be obtained with equal effect either from a single Leyden jar which exposes a large extent of coated surface, or from a number of smaller jars which together expose the same amount of coated surface, all

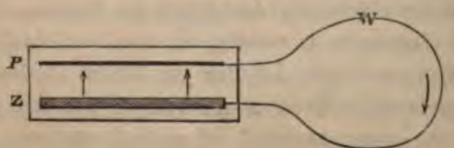
the inner surfaces of the small jars being in metallic communication with each other, but insulated from the outer coatings, all of which likewise are connected by some good conducting material (205). A similar result is also obtained in voltaic arrangements. Provided that the plates expose the same extent of surface and be kept at an equal distance apart, it matters not whether they be immersed in a single vessel of liquid, or whether they be cut up into strips and be immersed in pairs in separate vessels of the same liquid. The only requisite is that all the zinc plates shall be connected together by stout metallic wires, and that all the platinum plates shall be similarly connected by other wires. No action will occur until metallic communication between one of the platinum and one of the zinc plates is effected by means of a conducting wire; and then the whole force of the united plates will traverse the connecting wire.

FIG. 181.



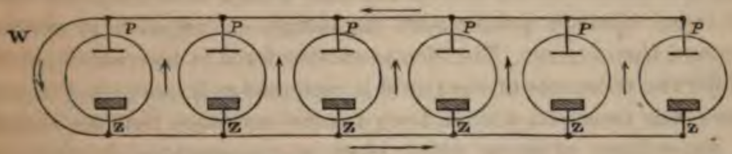
These results may be exhibited to the eye in a form of battery in which the hydrogen evolved from each platinum plate admits of being collected—a contrivance proposed by Professor Daniell, and which he called a *dissected battery.* fig. 181 shows the manner of mounting one of these cells. In order to use the dissected battery, the cells are charged with dilute sulphuric acid, and a small graduated jar, H, filled with dilute acid, is inverted in each of the cells over the platinum plate, P, in such a manner as to receive the hydrogen which is disengaged during the operation. The plates of such a battery can easily be connected so that all the plates of zinc, Z, shall be united by conducting wires, and all the platinum plates in a similar way by other wires; or they can with equal readiness be united so that the zinc of one cell shall be connected in the platinum of the following cell. Suppose, for instance, two plates (Z and P, fig. 182), one of zinc, the other of platinum, each six inches square, be im-

FIG. 182.



mersed in a vessel of sulphuric acid, at a distance of an inch apart. A current of a certain amount of power will be obtained on connecting the two plates by means of a wire, W, and in five minutes a certain quantity of zinc will be dissolved, and a corresponding quantity of hydrogen gas will escape from the platinum. Now if the zinc and the platinum be each cut into strips of an inch broad and six inches long, and the several pairs of zinc and platinum strips be immersed in separate vessels of dilute sulphuric acid at the distance of one inch from each other, and if, as in fig. 183, all the zinc strips Z Z be connected by wires, and all the platinum strips P P be similarly united, on connecting them together by a wire, as shown at W, the same amount of power will traverse the wire as in the first combination, and the quantity of zinc dissolved in the six plates taken together will in five minutes be the same as that which was dissolved from the single zinc surface in the first arrangement; whilst the quantity of hydrogen gas which will rise from all the six plates of platinum together will be equal to that obtained from the single plate in the former experiment (fig. 182). Such a combination, in whichever of the forms just described it be employed, may be regarded as a single pair of plates, and it constitutes a *simple voltaic circuit*.

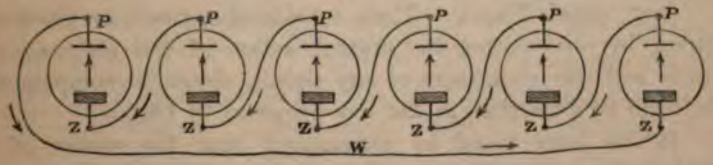
FIG. 183.



By acting upon extensive surfaces arranged in simple circuits, the *quantity* of electricity which can be thrown into circulation is very large, though its *intensity*, that is to say, its power of overcoming resistances, is comparatively small.

The results would, however, be altered if, instead of connecting the divided plates together in the manner represented in fig. 183, they were connected as in fig. 184, in which the zinc in each

FIG. 184.



cell is supposed to be connected with the platinum plate of the adjacent cell, in regular order through the series. When the extreme plates are connected by a thick wire, w, the amount of force which traverses this wire in a given time is equal only to one-sixth of the force which was thrown into circulation in the former instances; but the quantity of zinc dissolved in the six cells taken together is the same as before: and if the hydrogen be collected from the six platinum plates, the quantity will still be equal to that disengaged in the experiments shown in figs. 182 and 183. The current has now to traverse each cell of the liquid in succession, and thus has to encounter a great additional resistance. Yet now the power starts from six separate points of origin, and each of these separate points adds its energy or impulse in driving forward the current. The electro-motive force is increased sixfold, whilst the resistance of the liquid is increased still more; in the first place it is increased sixfold, from the circumstance that the length of the column of liquid which must be traversed,. is six times as great, and it is next further increased sixfold by a proportionate diminution in the breadth of the column. In the arrangement of fig. 182 there was a column of liquid six inches wide and one inch thick to be traversed; whilst in the arrangement of fig. 184 there is a liquid column six inches thick and only one inch wide to be traversed. When the plates are arranged in separate compartments, and are connected together alternately, as in fig. 184, they constitute a *compound voltaic circuit.* Volta's pile and his crown of cups are therefore compound circuits, and it is this form of combination which enabled him to obtain results so much superior to those of any previous experimenter. The electricity in this case is not greater in quantity than that obtainable from a simple circuit; nay, it is often much less; but it has a much higher intensity, and its power of overcoming resistances is very much greater, as a further examination will show. If, for example, 50 or 100 miles of wire, such as is used for telegraphic purposes, be introduced in a combination arranged, as in fig. 183, as a simple circuit, the effect obtained would be very materially less than if the same plates were arranged in the form of a compound circuit, as shown in fig. 184.

(237) *Ohm's Theory.*—These considerations may be much simplified, by representing the mutual action of the electro-motive forces and the resistances of any circuit, simple or compound, in the form of a fraction, in the way proposed by Ohm.

It has been found by experiment that the power of any combination is directly proportioned to the electro-motive force, or chemical energy between the active metal, and one of the elements of the liquid upon which it acts; and inversely proportioned to the resistances to be overcome. The numerator of the fraction will therefore be represented by E, the electro-motive force, and the denominator by $R+r$; here R represents the resistance in the cell or the battery, (due chiefly to the affinity between the elements of the liquid for each other,) and r all resistances exterior to the cell or the battery, such as the connecting wire: thus the expression $\frac{E}{R+r} = A$, would represent the effect of any combination where A indicates the amount of force actually in circulation, whether measured by its heating or by its magnetic effects. If the connecting wire be very thick, so as to offer little or no resistance to the current, r becomes evanescent, and the fraction assumes the form of $\frac{E}{R} = A$.

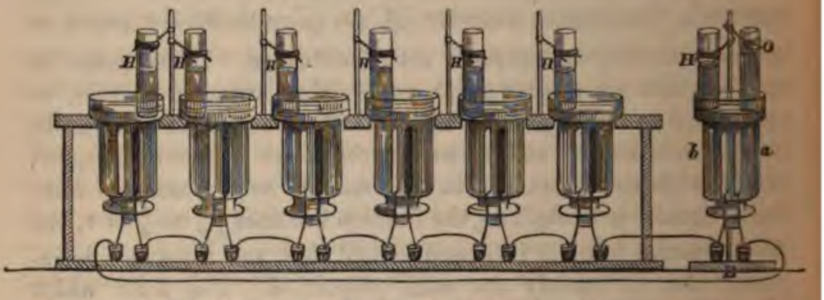
Now let it be assumed that $E = 1$, and that $R = 1$, when a pair of zinc and platinum plates an inch broad and six inches long, is immersed in dilute acid at the distance of one inch asunder, so that under these circumstances, $\frac{E}{R} = \frac{1}{1} = 1$. If a pair of plates, six inches broad and six inches long, be immersed in the same acid, since the resistance is inversely as the surface of the plates immersed, the fraction becomes $\frac{E}{\frac{R}{6}}$ or $\frac{1}{\frac{1}{6}} = 6$, or the power is increased sixfold, as compared with the former. If the plates be each cut into six similar strips, and be then arranged in pairs, as represented in fig. 183, the same fraction still represents the result, since the relative size and distance of the plates remain unchanged: but if the plates be arranged in succession so as to produce a compound circuit, as in fig. 184, the fraction becomes $\frac{6E}{6R} = \frac{6}{6} = 1$, the electro-motive force is increased sixfold, but the resistance is increased also in exactly the same proportion. The force which under these circumstances circulates through the connecting wire is not greater than if a single cell only containing a piece of plate one inch broad and six inches long were employed.

But suppose now that several miles of wire, such as are employed in telegraphic communication, be introduced into the two combinations severally represented in figs. 183, and 184; r now acquires importance; let the resistance be twentyfold greater than that of the liquid in each cell. In the first case (with the simple circuit), the fraction becomes $\frac{E}{R+r} = \frac{1}{1+20} = 0·047$; in the second (the compound circuit), the fraction is $\frac{6E}{6R+r} = \frac{6}{6+20} = 0·23$: so that although in both cases the resistance introduced most materially diminishes the amount of force which enters into circulation, the power in the compound circuit is now five times as great as that which emanates under these circumstances from the simple circuit. Indeed, in all cases where great resistances external to the battery have to be overcome, a compound battery has a great advantage over the simple circuit.*

(238) *Chemical Decomposition:—Voltameter.*—It is important to remember that the force which circulates through each cell in a compound circuit is not increased by the arrangement, if the connexion between its extremities be made by means of a good conductor: if, for example, 50 similar and equal cells be connected in succession, and be united by a stout short wire, the quantity of zinc which would be dissolved in a given time in each of these cells would not be greater than that which would be consumed in a single cell of the same size in the same time, if the plates which compose it were connected by a short thick wire.

The power of a compound circuit is shown in a striking manner, when some liquid such as dilute sulphuric acid is interposed in the course of the conducting wire. The experiments which elucidate this point may be instructively performed by means of the dissected battery. If a pair of platinum plates, *a b*, fig. 185, be immersed in the acid conducting liquid at B, and connected with the wires proceeding from the compound circuit in the manner

FIG. 185.



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* Let n = the number of the plates in a compound circuit.
,, E = the electro-motive force.
,, D = the distance between the plates.
,, S = the area of the plates.
,, l = the length of the conducting wire.
,, s = the area of a section of the wire.

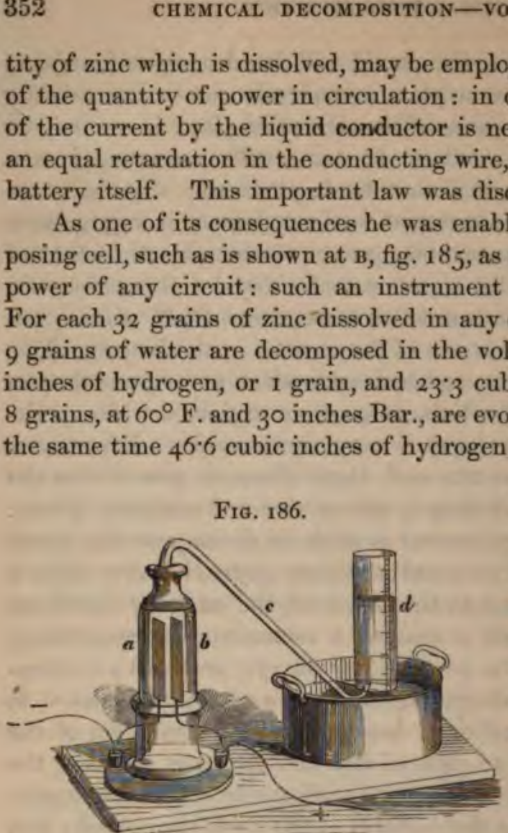
The fraction which represents the action of a compound battery when its extremities are connected by means of a thick metallic wire is the following: $\frac{nE}{\frac{nD}{S}+\frac{l}{s}} = A$. In this expression $\frac{D}{S}$ is substituted for R, (the resistance in each cell of the battery) to which it is equivalent; since R is directly as the distance between the plates, and inversely as their area, or surface.

represented in the figure, the liquid will be decomposed, oxygen will be given off from one plate, *a*, and will rise in the tube O; whilst hydrogen will be given off from the other plate, *b*, and may be collected in the tube H: but if the same cells be arranged as a simple circuit, fig. 183, no such effect is produced. By the introduction of the liquid conductor at B, the resistance is very greatly increased, such a resistance being more considerable than that of many miles of wire. But this is not all: besides this resistance, a new counteracting electro-motive force shows itself, which operates in a direction the reverse of the current in the battery. This force is due to the oxygen and hydrogen which are separated upon the platinum plates, and which, as has been explained when speaking of the gas battery (231) is very considerable. Experiment shows that it is between two and three times as powerful as the electro-motive force excited by a pair of zinc and platinum plates. When, therefore, the endeavour is made to decompose the dilute acid by a single pair of zinc and platinum plates, however large a surface they may present to the action of the exciting liquid, no visible action in the cell B ensues; a momentary decomposition, too small in amount to be perceived by the eye, produces a development of oxygen and hydrogen upon the two platinum plates *a*, *b*, sufficient to oppose an effectual barrier to the transmission of the current. Even when two pairs of zinc and platinum are used, the energy of the current is insufficient to effect any visible decomposition: with three pairs, a few bubbles of gas show themselves; and with a more numerous series, the effects increase rapidly; till at length a point is gained, beyond which no advantage is obtained by increasing the number of cells in the battery.

It is particularly worthy of remark that, in every vertical section of any voltaic circuit at a given instant, the quantity of force which traverses it is uniform: consequently, the same quantity of hydrogen makes its appearance upon the plate *b* of the cell B, which contains the liquid for decomposition, as is disengaged and collected during the same interval from each plate in the battery itself. If each zinc plate of the battery be weighed before the experiment is begun and after it is concluded, it will be found that each plate has lost weight to an equal extent. The interposition of the liquid at B, may occasion a great reduction in the amount of power which is thrown into circulation; but at every transverse section of the battery, the power that does circulate is uniform in quantity; and the measurement of the chemical action, whether it be estimated by the quantity of gas which is evolved at any one point, or by the quantity of zinc which is dissolved, may be employed as a sure indication of the quantity of power in circulation: in other words, retardation of the current by the liquid conductor is necessarily attended with an equal retardation in the conducting wire, and in each cell of the battery itself. This important law was discovered by Faraday.

As one of its consequences he was enabled to emplŏy a decomposing cell, such as is shown at B, fig. 185, as a measure of the voltaic power of any circuit: such an instrument is called a *Voltameter.* For each 32 grains of zinc dissolved in any one cell of the battery, 9 grains of water are decomposed in the voltameter, and 46·6 cubic inches of hydrogen, or 1 grain, and 23·3 cubic inches of oxygen, or 8 grains, at 60° F. and 30 inches Bar., are evolved upon its plates; at the same time 46·6 cubic inches of hydrogen are evolved from every platinum plate in the cells of the battery. A more convenient form of voltameter is shown in fig. 186. It consists of an upright glass cell, to the neck of which a bent tube, *c*, for the conveyance of the disengaged gases, is fitted by grinding; the vessel is filled with dilute sulphuric acid; *a, b,* are the two platinum plates, each of which is connected by a wire which passes through the foot of the instrument, to a mercury cup, by means of which communication can be made with the wires which convey the current from the battery; the oxygen and the hydrogen which are liberated by the action of the current upon the acidulated water both rise to the surface of the liquid, and are conveyed by the bent tube, *c*, to the graduated jar, *d*, which stands in a small pneumatic trough.

Fig. 186.



It is to be observed that the action of a simple zinc and platinum battery is not steady; it gradually declines, and before the acid has become saturated with oxide of zinc, the current almost ceases. On breaking the contact of the conducting wire with the two ends of the battery, and allowing it to remain disconnected for a few minutes, the action is partially restored; but it again gradually declines after the circuit has been completed. These effects were traced by Professor Daniell to the action of the current upon the sulphate of zinc, which is formed during the operation, in each cell of the battery; the zinc salt is decomposed in the manner shown in the subjoined diagram, in which Zn, SO_4 represents the sulphate of zinc, and P and Zn the platinum and zinc plates of the cell. The brackets placed above the symbols indicate the arrangement of the particles before the current passes; those below show the change produced by the voltaic action.

$$\underbrace{\mathrm{P}\ \mathrlap{\overbrace{\phantom{\mathrm{Zn}\ \mathrm{SO_4}}}}\mathrm{Zn}}\ \underbrace{\mathrm{SO_4},\ \mathrlap{\overbrace{\phantom{\mathrm{Zn}\ \mathrm{SO_4}}}}\mathrm{Zn}}\ \underbrace{\mathrm{SO_4}\ \mathrm{Zn}}.$$

In this manner metallic zinc becomes reduced or deposited upon the platinum plates, and the power of the battery is arrested when the two surfaces which are opposed become virtually zinc and zinc instead of platinum and zinc. This evil may be obviated by interposing a porous diaphragm between the two plates, as in the batteries of Daniell and of Grove (232, 233). A communication by means of liquid is thus kept up between the zinc and the copper or the platinum plates, but the sulphate of zinc is prevented from mixing with the liquid which is in contact with the copper or the platinum.

(239) *Further Application of Ohm's Theory.*—All the phenomena of compound circuits admit of ready calculation by the application of Ohm's principle: for instance, if n represent the number of the plates, the expression for any compound series, the cells of which are similar in nature and equal in size, becomes $\frac{n E}{n R + r} = A$; since in each cell not only is a new electro-motive force introduced, but at the same time a new resistance. Provided that the exterior resistance is such as would be offered by a metallic wire which may even be many miles in length, by doubling the number of cells, if at the same time the size of the plates be doubled, it is possible exactly to double the amount of force in circulation, for $\frac{2 n E}{\frac{2 n R}{2} + r} = \frac{2 n E}{n R + r}$. But if, instead of introducing a wire as the exterior resistance, a voltameter be employed to measure the power in circulation when the number of cells is doubled, and the surface of the plates also is doubled, the force measured by the voltameter is not found to be doubled, as might naturally have been expected; the difference arises from the counter current which is produced in the voltameter itself, by the accumulation of the oxygen and hydrogen upon its plates. Call this counter current e, and the formula becomes $\frac{n E - e}{n R + r}$.

The values both of e, the counter current offered by the voltameter, and r, which, if short thick conducting wires be used, is virtually the resistance of the voltameter itself, may be very simply estimated in the way proposed by Professor Wheatstone. This method consists in comparing two experiments in which, the resistances remaining the same, the electro-motive forces alone vary. Upon the supposition that the voltameter merely offers an increased resistance without introducing any counteracting electro-motive force, five single cells should produce a result equal to half that obtained by the use of ten cells of double size; but by experiment, the effects as measured by the voltameter are as 6 : 20. Comparing these effects with the arrangements which produce them, we obtain the following proportion, from which the value of e is deduced in terms of E by equating:—

$$\frac{\frac{10\,E - e}{10\,R + r}}{2} : \frac{5\,E - e}{5\,R + r} \quad :: \quad 20 \quad : \quad 6\text{; therefore } e = 2{,}857\ E.$$

The resistance r of the voltameter may be calculated with equal ease; for taking two similar batteries, each composed of ten cells, but in one of which the plates are exactly double the size of those in the other, the electro-motive forces will continue the same while the resistances alone will vary. Under these circumstances the experimental results, furnished by the voltameter in equal times, were as 12·5 : 20, and $\frac{10\,E - e}{10\,R + r} : \frac{\frac{10\,E - e}{10\,R + r}}{2} :: 12{\cdot}5 : 20$; therefore $r = 3{\cdot}333\ R$. By substituting, in the formula, the values for e and r thus obtained by experiment, the results for any given number of cells may be calculated; and on comparing the values obtained by such a calculation with the numbers furnished by actual experiment, Mr. Daniell (*Phil. Trans.*, 1842, p. 146) obtained the following results:—

Number of cells .	3	4	5	10	15	20	
Gas calculated . .	$\frac{5}{8}$	$3\frac{3}{5}$	6	$12\frac{18}{25}$	$15\frac{21}{25}$	$17\frac{13}{25}$	Cubic In.
Gas observed . .	$1\frac{1}{8}$	$3\frac{7}{8}$	6	$12\frac{1}{2}$	$15\frac{3}{4}$	$17\frac{1}{2}$	Cubic In.

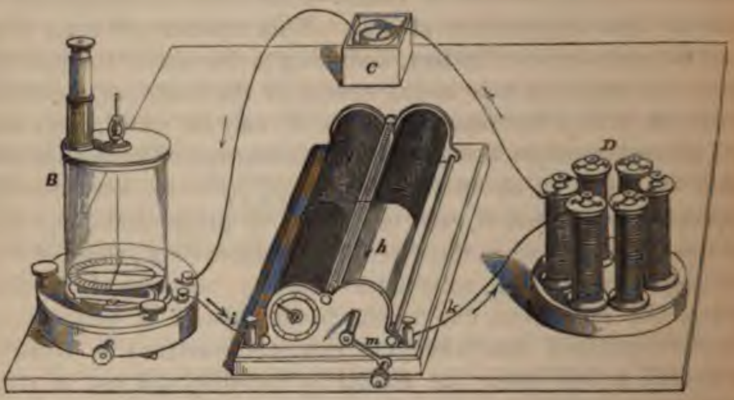
Any alteration in the size of the plates of the voltameter necessarily alters the amount of resistance which it offers to the current, and the influence of this change in the voltameter is most perceptible when a battery consisting of a few plates which expose a large surface is employed.

The preceding considerations will render it evident that no general answer can be given to the question, 'What number of cells should a battery contain to produce the greatest effect?' The electro-motive force, E, varies in amount with the kind of battery which is used; the values for R and r will also vary with the varying circumstances of the experiment. It is found that every different arrangement requires the employment of a distinct number of cells in order to obtain from it the maximum effect with the least expenditure of zinc. This number will even vary with the same form of battery, according to the size of the battery plates, the length of wire in the circuit, or the nature of the fluid conductor in the decomposing cell. It may be stated, however, as a general principle, that the most advantageous effect is obtained when the value of A, in the formula $\frac{n\,E - e}{n\,R + r} = A$, most nearly approaches 0·5, E and R, each being $= 1$: in other words, the advantage is greatest when the exterior resistances—viz., those of the conducting wire and voltameter together, are equal to the sum of the resistances due to the battery itself: it may therefore be concluded that when the exterior resistance is trifling, as usually occurs when the circuit is metallic, and not of very great length, little or nothing is gained by employing a large number of cells; two or three plates of large surface being the best under such circumstances; but that where a considerable chemical resistance is to be overcome, power is gained by employing a series, numerous in proportion to the resistance so introduced. In no case, however is it possible by the use of a series of plates of uniform dimensions, even if of unlimited number, to produce a chemical action greater in amount than that which would occur in a single cell of the arrangement in which the circuit was completed by a stout metallic wire.

(240) *Wheatstone's Rheostat and Resistance Coils.*—Guided by the principles which have just been explained, Professor Wheatstone has contrived an apparatus by which measured amounts of resistance may be introduced into the voltaic circuit: if the effect which such added resistance has upon the amount of the current in circulation be measured, the different values of E, R, and r in different arrangements, may be deduced by a simple calculation. To this instrument Mr. Wheatstone has given the name of the *Rheostat*. It is represented in fig. 187: g is a cylinder of well baked wood, $1\frac{1}{2}$ inch in diameter and 6 inches in length; it turns easily upon a horizontal axis; on this cylinder a spiral groove is cut, the thread of which contains 40 turns to the inch. This groove runs from one end of the cylinder to the other, and in it is coiled a brass wire $\frac{1}{100}$ inch in diameter: h is a brass cylinder, placed parallel to g, and equal to it in diameter; the thin wire

upon *g* is connected at the end *i* with a brass ring, and at the other extremity is attached to the cylinder, *h*: at *i* is a metal spring, one end of which is connected with a binding-screw, and the other end of which rests against the brass ring, and effects the communication with one wire of the battery: *m* is a moveable key, by which the wire can be wound upon the brass cylinder, or by transferring the key to the axis of *g*, it can be unwound from *h*, and returned to the wooden cylinder, *g*. In consequence of the non-conducting quality of dry wood, the coils of wire on the wooden cylinder are insulated from each other, so that the current traverses the whole length of the wire coiled upon this cylinder, but the coils not being insulated from each other on the brass cylinder, the current immediately passes from the point of contact to the brass spring at *k*, which is in communication with the other wire from the battery. A scale is placed between the two cylinders for the convenience of counting the number of coils unwound, and the fractions of a turn are read off upon a graduated circle, which is traversed by an index attached, as shown in the figure, to the axis of the cylinder, *g*.

FIG. 187.



Professor Wheatstone takes, as his standard of resistance, the resistance produced by a copper wire, 1 foot of which weighs exactly 100 grains; its diameter is 0·071 of an inch. It is sometimes necessary to be able to introduce an amount of resistance into a circuit much greater than can be effected by means of the rheostat. For this purpose Professor Wheatstone employs the *Resistance Coils*, shown at D, fig. 187. These coils are composed of fine copper wire, $\frac{1}{100}$ inch in diameter, carefully insulated by covering them with silk; two of the coils are 50 feet in length, the others, 100, 200, 400, and 800 feet long. The ends of each coil are attached to short thick wires, fixed to the upper faces of the cylinders, which serve to combine all the coils into one continued length of 1600 feet of wire. Two wires proceed from the extremities of the coils, by which they are united to the circuit. On the upper face of each cylinder is a double brass spring, moveable round a centre, so that its ends can be made to rest upon the thick brass wires, or can be removed from them at pleasure. When the spring rests upon the wires, the current passes through the spring instead of through the coil; but when the spring rests upon the wood, the current must pass through the coil. In the figure, all the springs are shown as resting upon the wires; in this case none of the coils are included in the circuit, but by turning the spring of any particular coil, 50, 100, 200, or 400 yards of wire can, in a moment, be introduced into the circuit.

The following is Professor Wheatstone's description of his method of ascertaining the sum of the electro-motive forces, in any voltaic circuit or circuits:—

'In two circuits producing equal electro-motive (or voltaic) effects, the sum of the electro-motive forces divided by the sum of the resistances is a constant quantity; *i. e.*, $\frac{E}{R} = \frac{n\,E}{n\,R}$: if E and R be proportionately increased or diminished A will obviously remain unchanged. Knowing, therefore, the proportion of resistances in two circuits producing the same effect, we are able immediately to infer that of the electro-motive forces. But, as it is difficult in many cases to determine the total resistance, consisting of the partial resistances of the *rheomotor* (or voltaic combination) itself, the galvanometer, the rheostat, &c., I have recourse to the following simple process. Increasing the resistance of the first circuit by a known quantity, r, the expression becomes $\frac{E}{R + r}$. In order that the effect in the second circuit shall be rendered equal to this, it is evident that the added resistance must be multiplied by the same factor as that by which the electro-motive forces and the original resistances are multiplied; for $\frac{E}{R + r} = \frac{n\,E}{n\,R + n\,r}$. The relations of the lengths of the added resistances r, and $n\,r$, which are known immediately, give therefore those of the electro-motive forces.' (*Phil. Trans.*, 1843, p. 313.)

Suppose, for example, it be desired to compare the electro-motive force obtained from a single pair of zinc and copper plates in one of Daniell's cells, with that of two pairs of the same combination, the following will be the mode of conducting the experiment:—Interpose the rheostat (fig. 187) and the galvanometer, B, in the circuit obtained from the single cell, C; then, by coiling or uncoiling the wire of the rheostat, bring the needle exactly to 45°. Next uncoil the wire of the rheostat, and count the number of turns required to bring the needle to 40°. Suppose thirty-five turns are required: this number of turns may be taken to represent the electro-motive force of the combination. Now introduce the two cells, arranged as a compound circuit, at C, instead of the single cell. Bring the needle as before to 45°, interposing one or more of the resistance coils at D, if needed, by turning the spring upon the wood of the reels, and complete the adjustment by coiling or uncoiling the wire of the rheostat. Again uncoil the wire of the rheostat until the galvanometer needle stands at 40°. Seventy turns, or twice the number previously required to produce this effect, will now be needed. The electro-motive forces in the two cases are therefore as thirty-five to seventy, or as two to one. If instead of arranging the two cells as a compound circuit the zinc plate be connected with the other zinc plate and the copper with the copper, so as to form a single circuit, it would have required the interposition of a greater resistance to reduce the needle to 45° to start with than when one coil only was used; but only thirty-five turns of the rheostat would be needed to bring the needle down to 40°. This experiment shows that the electro-motive force is not altered by increasing or diminishing the size of the plates.

The electro-motive power of any combination may by means of this arrangement be compared with any one selected as a standard; it was in this way that the results on the comparison of the electro-motive effects of platinum, zinc and potassium (228) were obtained.

Processes of Voltaic Discharge.

(241) Having now reviewed the principal circumstances which influence or exalt the activity of the voltaic battery, we may proceed to examine the phenomena which are manifested when a powerful combination is brought into action by connecting its opposite extremities. Voltaic action is exhibited only during the process of discharge, for the current is a continuous succession of discharges of the electricity developed and maintained by the contact and chemical action of the materials employed in the construction of the battery. The discharge of the voltaic battery may, like that of the ordinary machine, be considered under three heads—viz., the discharge by *conduction*, as when the circuit is completed by a wire or other good solid conductor; the discharge by *disruption*, in which case a luminous

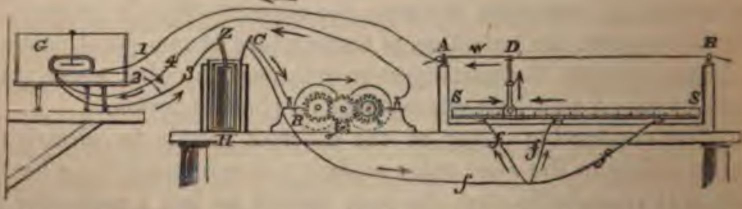
appearance is exhibited through a short interval of non-conducting matter; and the discharge by *convection*, which takes place in liquids, and is accompanied by chemical action and transference of the particles of the conductor.

(242) *Conduction.*—In all cases where electricity is in motion, whether it be excited by chemical action, as in the voltaic pile, or by friction, as in the common electrical machine, the force is conveyed by the entire thickness of the conductor; the charge is not confined to the surface, as occurs when the power is stationary and produces effects by induction only. In such a case the induction, as in electrical phenomena generally, occurs between one transverse section of the conductor and the adjacent sections immediately before and behind it; and but a small proportion of the induction, sufficient however to be distinctly manifest, is diverted to surrounding objects. By reducing the thickness or diameter of the conducting material, a larger quantity of the force is compelled to traverse a given number of conducting particles in the same time, and a great elevation of temperature is thus produced. The heat may rise sufficiently high to cause ignition of the wire, and this ignition may be produced at any point of the circuit, so as to produce the explosion of a charge of gunpowder sunk in the depths of the ocean, or buried within the recesses of a mine; the operations of blasting may thus be made to assume a degree of certainty and of safety hitherto unattained by other means, since the moment at which the discharge shall take place is absolutely under control.

Elevation of temperature diminishes the conducting power of the metals; a good experimental proof of this fact is afforded by transmitting through a platinum wire, a voltaic current of sufficient power to raise the wire to a dull red heat; and whilst the current is still passing, igniting a loop of the wire in the flame of a spirit lamp; the temperature of the other part immediately falls, owing to the diminished amount of electricity which traverses it, in consequence of the increased resistance offered to the passage of the current by the strongly ignited part of the wire. If a loop of the wire be cooled by immersion in water, the opposite effect is produced; for in this case the reduction of temperature at one point enables a larger quantity of electricity to pass through the wire, which may thus be raised to a heat approaching its point of fusion.

The conducting power of the different metals for electricity varies nearly in the same order as their power of conducting heat; but it is remarkable that charcoal, though so bad a conductor of heat transmits electricity with great facility. The measurement of the conducting power of solids and of liquids for electricity has occupied the attention of many of the most distinguished philosophers. An ingenious method was proposed many years ago by M. Becquerel who constructed a ***differential galvanometer***, in which the needles were surrounded by two insulated copper wires of equal length and diameter; they were coiled in the usual way, and formed two independent circuits, so that the galvanometer had four terminations instead of two. When two perfectly equal currents were transmitted, one through each wire in opposite directions, they exactly neutralized each other in their effect upon the needle, which therefore remained stationary; but if either current preponderated, a corresponding deviation of the needle was occasioned. To use the instrument, a small voltaic combination was connected with the galvanometer, two wires passing from each pole, so as to divide the current into two exactly equal portions, one being transmitted through one of the coils, the other through the second coil in the opposite direction. Wires of the different metals were then introduced into the two circuits. If into either circuit a conductor of inferior power were introduced, the current in that circuit was proportionately diminished, and the needle was disturbed; but the equilibrium could be restored by increasing or diminishing the length of one of the wires; then by comparing the lengths of the two wires thus introduced, their relative conducting power could be inferred. By means of this instrument, conjoined with the use of Mr. Wheatstone's rheostat, M. Becquerel, jun., was enabled to measure the conducting power of a number of wires of different metals, with precision (*Ann. de Chimie et de Phys.* III. xvii. 266). The relative conducting powers of the wires were obtained by ascertaining the lengths of the rheostat wire, which was required to restore the equilibrium, when wires of different metals were employed. In fig. 188 is exhibited the arrangement adopted

FIG. 188.



in these experiments. G is the differential galvanometer with four wires, 1 and 3 being the terminations of one coil, 2 and 4 ose of the other coil; H, a voltaic pair; R, the rheostat; and *w*, e metallic wire, the resistance of which is to be measured. This re is stretched and insulated between two binding clamps, A id B; S S, is a copper scale with linear subdivisions for measuring e length of the wire which is included in the circuit; D, is a iding clamp of copper, which can be made to move in either rection along the scale S, and can be connected with *w*, at any esired point, by the clamp at D. Suppose the resistance of a ertain length of *w* is to be measured. The current from H is ivided into two portions so as to send each in opposite directions hrough the galvanometer. One half of the battery current is made o pass along the wire, *f f f*, up the clamp, D, and through part of he wire, *w*; the other half is transmitted through the rheostat, in he direction shown by the arrows. By coiling or uncoiling the wire of the rheostat, the two circuits are rendered exactly equal, so that the needle of the galvanometer shall stand at 0°. Now, if D be unclamped, and it be caused to slide through a definite distance, say twelve inches towards B, the equilibrium of the galvanometer will be destroyed; since the resistance in *w* is increased, whilst that in the rheostat remains unaltered; but by uncoiling the wire of the rheostat, additional resistance can be introduced into the circuit of which it forms a part; the equilibrium may thus be again restored, and the resistance of twelve inches of *w* will be given, by counting the number of coils of the rheostat required. The comparative resistances of any number of different wires introduced at *w* may thus be readily ascertained.

The following table exhibits the conducting power of wires of equal length and diameter of various metals as determined by this process. The mercury was placed in a glass tube of uniform diameter.

Conducting Power of Metals for Electricity.

	At 32° F	At 212° F.	At 212° F.
		Silver at 32° F. = 100.	
Silver	100	71·316	100
Copper	91·517	64·919	91·030
Gold	64·960	48·489	67·992
Cadmium	24·579	17·506	24·547
Zinc	24·063	17·596	24·673
Tin	14·014	8·657	12·139
Iron	12·350	8·387	11·760
Lead	8·277	5·761	8·078
Platinum	7·933	6·688	9·378
Mercury.	1·738	1·575	2·208

These metals were carefully purified and well annealed. It was found that annealed metals conducted better than those which had not undergone this process. The effect even of a moderate elevation of temperature in reducing the conducting power is very considerable, as will be evident by inspecting the second column of figures in the table; though the amount of this reduction bears no uniform proportion to the conducting power at 32°, as will be seen by examining the third column; the maximum effect is produced in the case of tin; in this metal, if the conducting power at 32° be sixteen, it will be ten at 212°.*

If equal amounts of electricity be made to traverse wires of different metals of equal length and diameter in the same interval of time, the rise of temperature in the wire is inversely proportioned to its conducting power, and therefore the better the conductor the less heat does it emit. This has been proved by Snow Harris, for electricity from the common machine, by means of an air thermometer, across the bulb of which were placed wires of different metals of equal lengths and thickness (209 *bis*). The general truth of the fact may in the case of voltaic electricity be rudely but strikingly demonstrated by taking a wire of silver and one of platinum, each of exactly the same diameter, and forming them into a compound wire consisting of alternate links of the two metals. A current of electricity may be transmitted through this compound wire, of such a strength as to heat the platinum to visible redness, whilst the silver links will exhibit no such intense heat, though each link of the wire, from the form of the experiment, must transmit equal quantities of the force in equal times.

Alloys are generally far inferior in conducting power to the metals which compose them. Attention to the purity of the metals employed in such experiments, is therefore essentially necessary in order to obtain accurate comparative results.

A curious observation has been made by Mr. Grove (*Phil. Trans.* 1849, p. 50) upon the influence of the ambient gaseous medium on the heat emitted by a conducting wire. The following experiment illustrates the point very clearly. Take three pieces of stout copper wire, bend them into the form shown at w w w, fig. 189, and attach them to a weighted board, by which the lower part of the bends can be sunk beneath the surface of water con-

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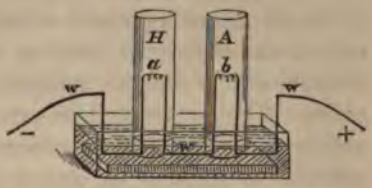
* Professor Wheatstone, in his paper already cited (*Phil. Trans.* 1843), describes a very simple plan of measuring metallic resistances, by the employment of an ordinary galvanometer. The whole paper is well worthy of attentive study.

tained in a shallow vessel. At *a* and *b*, where the wires project above the surface of the water, complete the connexion by means of spirals of fine platinum wire, both spirals being equal in length, and each cut from the same wire. Each spiral will thus oppose an equal resistance to the passage of the current. When a voltaic current of a certain intensity is transmitted through the wire, W W W, each spiral, consequently, becomes heated to the same degree of visible ignition. But if two similar jars, one, A, filled with air, the other, H, filled with hydrogen, be inverted over them, the wire in the jar H immediately ceases to be luminous, while that in A becomes more intensely ignited. This superior cooling action of the hydrogen is no doubt due to the superior mobility of the particles of the gas over those of air. Other gases, lighter than air, produce an effect similar in kind but smaller in degree (146, 154).

FIG. 189.



Mr. Grove varied the experiment by enclosing the wires *a* and *b* in separate glass tubes, and sealing them up, one in an atmosphere of air, the other in an atmosphere of hydrogen. He then included them both in the same circuit, so that they should transmit equal amounts of electricity. Before transmitting the current, however, each tube was immersed in a separate vessel which contained a weighed quantity of water, the temperature of which was accurately observed. After the current had been allowed to pass for a certain time, the temperature of the water which surrounded each wire was again observed, and it was found that the water which was around the tube which contained air was considerably hotter than that which surrounded the tube filled with hydrogen.

This result, paradoxical as it appears, and as it seems to have been regarded by Mr. Grove, must necessarily follow from the operation of two principles which have already been explained; the first of these is that the resistance offered by a metal to the passage of electricity is diminished by reducing the temperature; and the second is, that the heat evolved by a current in passing through a conductor is inversely as the resistance which it experiences. Now, in this experiment, the primary effect of the hydrogen is the cooling of the conducting wire; and the consequence is that this cooled wire, in transmitting the same current as a similar wire in air, offers less resistance, and less heat is therefore evolved by the wire surrounded by the hydrogen than by the wire which is surrounded by air.

(243) Liquids are very inferior to solids in conducting power; indeed, the difference between the two classes of bodies is so extreme that it is difficult to institute an accurate comparison between them. The attempt, however, has been made by M. Pouillet: assuming as the unit of comparison the conducting power of a solution of sulphate of copper saturated at 59°, he gives the following as the relative conducting power of the undermentioned solutions:—

Saturated solution of sulphate of copper . .	1
Ditto, diluted with an equal bulk of water .	0·64
Ditto, diluted with twice its bulk of water .	0·44
Ditto, diluted with four times its bulk . .	0·31
Distilled water.	0·0025
Ditto, with $\frac{1}{10,000}$ of nitric acid	0·015
Platinum wire	2,500,000·00

The conducting power of a platinum wire, of a diameter and length equal to that of the interposed columns of liquid is probably estimated too high.

Since these results of M. Pouillet's were published, the subject of the conducting power of liquids has been resumed by M. E. Becquerel, in the paper already cited. He states that saline solutions may be divided into two classes; in the first, the conducting power increases progressively in proportion to the strength of the solution, until it becomes saturated; sulphate of copper and chloride of sodium affording instances of this kind: whilst in the second class, of which nitrate of copper and sulphate of zinc may be taken as examples, the conducting power increases with the degree of concentration up to a certain point, beyond which it diminishes as the solution becomes more nearly saturated. The salts which exhibit this peculiarity are either deliquescent or extremely soluble. The following table contains a few of M. E. Becquerel's results. The saline liquids are to be considered as saturated unless otherwise specified.

Conducting Power of Liquids for Electricity.

Substances used.	Density.	Temp. ° F.	Conducting power.
re Silver		32	100,000,000·00
ution of Sulphate of Copper	1·1707	50	5·42
Do. half the strength . .		,,	3·47
Do. one fourth the strength		,,	2·08
ution of Chloride of Sodium		62	31·52
Do. half the strength . .		,,	23·08
Do. one fourth the strength		,,	17·48
lution of Nitrate of Copper .	1·6008	61	8·995
Do. half the strength . .		,,	17·703
Do. one fourth the strength		,,	13·442
lution of Sulphate of Zinc .	1·4410	58	5·77
Do. half the strength . .		,,	7·13
Do. one fourth the strength		,,	5·43
l of Vitriol 1 measure stilled Water 11 measures		66	88·68
tric Acid (Commercial) . .	1·31	56	93·77
atinum		32	7,933,000·00

is not surprising that differences so considerable should be ved between the conducting powers of liquids and those of ; the processes of conduction in the two cases are essentially ent. In liquids chemical decomposition and free movement component particles are indispensable, whilst nothing of the takes place in solids. The effects of heat are even inverted e two cases, for experiment shows that as the temperature the conducting power of the liquid rapidly increases; accord- E. Becquerel, the conducting power of many solutions at F. is three or four times as great as that of the same solution ° F. These phenomena, therefore, are the reverse of those nted by most solids. Exceptions, however, occur: Faraday hown that sulphide of silver, when cold, is an insulator, but arming it gently it begins to conduct, and when hot it affords rk like a metal; a little below redness it conducts sufficiently aintain its conducting power by the heat of the current which nsmits. Sulphide and fluoride of lead, as well as iodide of ury, also exhibit the same peculiarity. Glass, when cold, is an lent insulator of the electricity developed by friction, but when d it conducts, and when red hot it possesses scarcely any ting power. These cases have been traced to a partial ical decomposition of the compound (Beetz, *Phil. Mag.*, 1854, 1). When liquefied by heat, these compounds all undergo ical decomposition, and allow the current to pass freely.

(244) *Conducting Power of Gases.*—Gases are almost perfect insulators of the voltaic current; although some feeble indications of conducting power have been discovered by Hankel, by E. Becquerel and by Buff, in a highly rarefied atmosphere, between metallic surfaces strongly ignited and in close approximation.

Mr. Grove has shown, however, that in flame a current of electricity is not only transmitted, but that, there is evidence of its production by the chemical actions which occur within the flame. If two platinum wires be connected with the extremities of a galvanometer, the free ends of the platinum being twisted into a small coil, and one of the platinum wires being inserted into the root of the blowpipe flame whilst the other is introduced just in front of the apex of the blue cone, a current will be indicated passing from the root to the apex of the flame. By forming several jets of flame together into a compound circuit, Mr. Grove has succeeded in decomposing iodide of potassium by means of the currents obtained from flame: under certain circumstances, however, which we now proceed to notice, highly heated gaseous matter appears to transmit voltaic power of high intensity, and the phenomena thus displayed are of a most brilliant and remarkable kind.

(245) *Disruptive Discharge:—Electric Light.*—When the current is greater than the conductor is able to convey, the wire melts and is dispersed in vapour; disruptive discharge, in fact, occurs. From a powerful voltaic battery this disruptive discharge may be maintained continuously, owing to the enormous quantity of electricity in circulation.

If the air be rarefied between the interrupted conductors, the interval through which the discharge can be effected may be considerably increased. Thus the heat developed by the passage of the current between two pieces of charcoal, when they are in contact, will enable them to be separated for a considerable distance without interrupting the passage of the current; this distance ranges from ¾ inch to 1 inch when a series of seventy of Daniell's cells twenty inches in height are employed. Sir H. Davy, with the great battery of the Royal Institution, consisting of 2000 pairs of plates on Wollaston's construction, obtained an arc of flame, between charcoal points, four inches in length, and of dazzling brilliancy.

No doubt the transfer and ignition of the solid particles contributes materially to the production of the intense light which may thus be procured. A cavity is always produced in the piece charcoal attached to the wire which is connected with the last atinum or copper plate of the battery (the zincode, 247,3), and the same time a mamillated deposit, which continually increases length, is formed upon the charcoal in connexion with the zinc late (the platinode). Attempts have been made to apply this light to the purposes of illumination, and in particular cases it may be found advantageous. Its application is, however, at present attended with great practical difficulties, of which the transfer of conducting material from one wire to the other is one of the most serious. Indeed it seems doubtful if, even when the mechanical obstacles are removed, which they doubtless will be, such a light can be economically or advantageously used for the general purposes of illumination. The light is too intense for the unprotected eye to endure for any length of time in its immediate vicinity, and the expense is so great, that unless the electricity can be obtained in the process of preparing some chemical compound in the battery itself, which will defray the cost of production, its success as a mercantile speculation is very problematical.

This transfer of solid particles is not confined to cases in which a porous conductor like charcoal is used. The densest metals, such as platinum and iridium are transferred from the zincode towards the platinode. The light that attends the voltaic arc does not proceed from the combustion of the conducting material, for it occurs in a vessel from which air is exhausted, with a brilliancy not inferior to that exhibited by it in the air. It may even be produced between two charcoal points which are immersed under water. In every case, however, the transference of some material particles is essential to the production of the luminous arc. Mr. Gassiot found that even when a combination of 320 cells on Daniell's construction was employed, no spark could be obtained between two platinum surfaces, connected one with one wire, the other with the opposite wire of the battery, in a high state of efficiency, although the two platinum surfaces were brought within $\frac{1}{5000}$ of an inch of each other. If however the transfer of some material particles be effected between the two surfaces, either by a momentary contact, or even by the discharge of a Leyden jar across the interval, the current may be established and the luminous arc maintained with a small number of pairs of plates.

The heat produced in the voltaic arc is of the most intense kind. Metals which like platinum, iridium, and titanium resist the greatest heat that can be obtained by the direct chemical action attendant upon combustion in the furnace, readily melt and are transferred from the zincode to the platinode by a voltaic current of high intensity. The fusion is easily accomplished by excavating a circular piece of gas coke, about an inch in diameter and half an inch thick, into the form of a crucible, which is attached by stout copper bell wire to the wire which is in connexion with the platinum plate of the battery; a piece of boxwood charcoal or of gas coke about the thickness of a cedar pencil is attached to the wire connected with the zinc plate of the battery: the metal for trial is then placed in the little coke crucible, and the current from twenty or thirty pairs of Grove's battery is transmitted through it by means of the charcoal point with which the platinode of the battery is armed. Mr. Gassiot has pointed out the remarkable fact, of which no explanation has as yet been given, that the wire connected with the platinum plate or zincode becomes much the hotter of the two in this action.

The colour of the light emitted by the different metals when deflagrated between the wires of the battery, is peculiar for each: gold burns with a bluish white light, silver with a beautiful green light, copper with a reddish white, zinc with a powerful white light tinged with blue, and lead with a purple light; steel burns with brilliant yellow scintillations, mercury with a brilliant white light tinged with blue. If these lights be viewed separately through a glass prism, large dark intervals will be seen between a few brilliant streaks of light of different colours and of definite degrees of refrangibility.

Chemical Actions of the Voltaic Battery.

(246) *Discharge by Convection.*—To the chemist, however, the discharge of the voltaic current by the process of convection, is even more interesting than the brilliant phenomena exhibited by the disruptive discharge, since it is in the discharge by convection that the important chemical actions of electricity are displayed.

It has already been explained when describing the voltameter (238), that if the connecting wires of a voltaic battery terminate in platinum plates or wires which are made to dip into acidulated water, decomposition of the liquid takes place, and oxygen and hydrogen are evolved at the surfaces of the platinum plates. This important discovery was made in the year 1800, by Messrs. Nicholson and Carlisle, and the chemical action of the voltaic pile revealed, enabled Davy a few years later to decompose the lies and earths, which up to that time had been regarded as ents; and by showing their compound nature, he at once ified, in an important manner, the views of chemical philosophy h had prevailed up to that period.

In pursuing these experiments on the voltaic decomposition of er, it was soon observed that when copper wires, or the wires metals which are easily susceptible of oxidation are employed, escapes from one wire only; whilst if platinum or gold wires used, gas is evolved from both. In the first case, the oxygen bines with the copper or oxidizable metal, and forms an oxide ich is dissolved by the acid liquid, and therefore hydrogen alone apes; in the second case, both gases are evolved; since neither tinum nor gold has sufficient chemical affinity for oxygen to mbine with it at the moment of its liberation.

The process of resolving compounds into their constituents by ectricity, is termed *electrolysis*, and a body susceptible of such ecomposition, is called an *electrolyte;* the terminating wires or lates of the battery are called the *poles* of the battery. The word *lectrode* is also used as synonymous with the pole of the battery, nd it implies the door or path to the current by which it enters r leaves the compound through which it is transmitted.

(247) *Laws of Electrolysis.*—A great variety of bodies admit of being decomposed by electrolysis, but it is not applicable to all indiscriminately. It occurs under certain definite laws, which may be stated as follows:—

1. No elementary substance can be an electrolyte: for from the nature of the process, compounds alone are susceptible of electrolysis.

2. Electrolysis occurs only whilst the body is in the liquid state. The free mobility of the particles which form the body undergoing decomposition is a necessary condition of electrolysis, since the operation is always attended by a transfer of the component particles of the electrolyte in opposite directions. Electrolysis is necessarily a process of electrical conduction, but it is conduction of a peculiar kind; it is totally different from that of ordinary conduction in solids. If an electrolyte be solidified, it instantly arrests the passage of the force; for it cannot transmit the electric current like a wire or a solid conductor: the thinnest film of any solid between the two plates suspends all decomposition. Many saline bodies are good conductors when in a fused condition; for example, nitre, whilst in a fused state, conducts admirably; but if a cold electrode

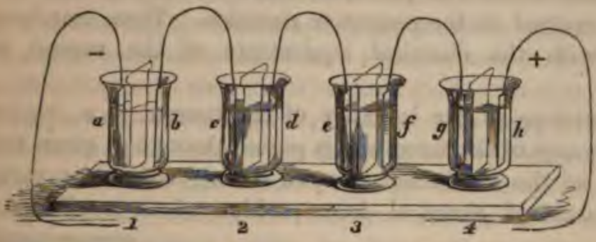
be plunged into the melted salt, it becomes covered with a film of solid nitre, and no current is transmitted until a continuous chain of liquid particles is restored between the plates by the melting of the film; these effects are readily exhibited by including a galvanometer in the circuit. A few partial exceptions to this rule have been observed, and have already been alluded to (243); but in such cases the decomposition is always extremely limited.

3. During electrolysis, the components of the electrolyte are resolved into two groups: one group takes a definite direction towards one of the electrodes; the other group takes a course towards the other electrode. This direction of the *ions* (as the two groups which compose the electrolyte have been termed) depends upon the direction in which the chemical actions are going on in the battery itself. The two platinum plates in the decomposing cell may be distinguished from each other in the manner proposed by Professor Daniell. These plates occupy respectively the position of a zinc and of a platinum plate in an ordinary cell of the battery: that is to say, if for this decomposing cell an ordinary battery cell were substituted, a rod of zinc would occupy the place of one of the platinum plates, and would be attacked by the oxygen and acid in the exciting liquid of the battery, whilst a plate of platinum or some other conducting metal would occupy the place of the second platinum plate, and would have the hydrogen of the exciting liquid directed towards it. To the plate of the decomposing cell which corresponds to the zinc rod, Professor Daniell gave the name of the *zincode,* which is synonymous with the *anode* of Faraday and the *positive pole* of other writers. To the plate which corresponds to the platinum or conducting metal, Professor Daniell gave the name of the *platinode,* which is synonymous with Faraday's term of *cathode,* and with the *negative pole* of other writers. Oxygen, chlorine, and the acids generally make their appearance at the zincode in the decomposing cell during electrolysis; whilst hydrogen, alkalies, and the metals are evolved upon the platinode.

This definite direction which the elements assume during electrolysis may be shown by collecting the gas which is evolved over two platinum plates, connected, one with the last platinum, the other with the last zinc plate, of a combination consisting of three or four pairs of Grove's battery. Hydrogen will be collected over the platinode, or the plate in connexion with the zinc end of the arrangement, and which would correspond to the platinum plate if another cell of the battery were here interposed; whilst from the ncode, or plate in connexion with the platinum of the battery, ygen is evolved.

The following experiment further illustrates the definite direc- on which the components of the electrolyte assume. Let four asses be placed side by side, as represented in fig. 190, each

FIG. 190.



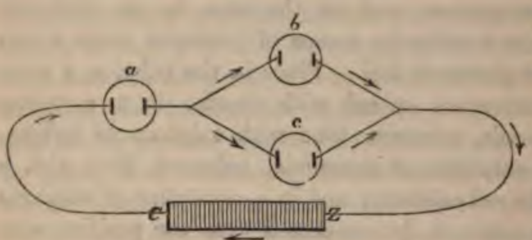
rided into two compartments by a partition of card, or three four folds of blotting-paper, and let the cups be in electrical mmunication with each other by means of platinum wires which rminate in strips of platinum foil. Place in the tube, 1, a solu- n of iodide of potassium mixed with starch; in 2, a strong ution of common salt, coloured blue with sulphate of indigo; 3, a solution of sulphate of ammonia, coloured blue with a utral infusion of the red cabbage; and in 4, a solution of sulphate copper. Let the plate, *h*, be connected with the positive wire zincode, and let *a* complete the circuit through the negative re or platinode. Under these circumstances iodine will speedily set free in *b*, and will form the blue iodide of starch; chlorine ll show itself in *d*, and will bleach the blue liquid; sulphuric id will be seen in *f*, and will redden the solution of cabbage; ilst a piece of turmeric paper will be turned brown in *a*, from erated potash; in *c* it will also be turned brown by the soda free; in *e* the blue infusion of cabbage will become green m the ammonia which is disengaged; and in *g* metallic copper ll be deposited on the platinum foil.

4. The amount as well as the direction of electrolysis is defi- e, and it is dependent upon the degree of action in the battery; ing directly proportionate to the quantity of electricity in circu- ion. It is clearly proved by experiment that for every 32 ins of zinc which is dissolved in any one cell of the battery, vided local action be prevented, 9 grains of water are decom- sed in the voltameter; or if, as in the preceding experiment,

several electrolytes be arranged in succession, each compound will experience a decomposition proportioned to its chemical equivalent. For instance, if the current be made to pass first through fused iodide of lead, and then through fused chloride of tin, for each 32 grains of zinc dissolved in any one cell of the battery, 104 grains of lead, and 59 grains of tin will be separated on the respective platinodes, whilst 126 grains of iodine, and 36 grains of chlorine will be evolved on the respective zincodes. These numbers correspond with the chemical equivalents of the several elements named.

Variations in the intensity of the current (*i. e.*, variations in the quantity of the force which passes through a given transverse section of the conductor in equal times) produce no variation in the amount of chemical decomposition which is effected by the arrangement. For example: if three similar voltameters, provided with plates of equal area, be arranged as at *a*, *b*, *c*, fig. 191, the first will transmit twice as much electricity in a given time as either of the others. The current will therefore have twice the intensity in *a*; but the total quantity of gas collected from *b* and *c* together will be exactly equal to the total amount yielded by *a* in the course of the experiment. Hence it follows that the quantity of electricity which is separated from a given weight of matter in the act of combination is able, irrespective of its intensity, when thrown into the current form, to produce the decomposition of an *equivalent quantity* of any compound body which is susceptible of electrolysis; and hence it has been concluded that the equivalent weights of bodies are those which are associated with equal quantities of electricity, and have naturally equal electric powers.

FIG. 191.



5. According to Dr. Faraday, if the same pair of elements forms more than one compound with each other, it is only the compound which contains one equivalent of each element that admits of electrolysis. For example, tin forms two compounds with chlorine; the protochloride (SnCl) is solid at ordinary temperatures, when heated it melts, and is then freely electrolysable;

ut the bichloride ($SnCl_2$) although liquid at ordinary temperatures, annot be decomposed so long as it is anhydrous, or free from ater. To these laws may be added a sixth—viz.:

6. Those bodies only are electrolytes which are composed of a onductor and a non-conductor. The conductors accumulate on he platinode, the non-conductors on the zincode. For example, odide of lead when melted conducts the current; metallic lead, hich is a conductor, accumulates at the platinode; whilst iodine, hich is a non-conductor even when melted, collects at the zincode. On the other hand, red chloride of sulphur (SCl), is not an electro-te, although composed of single equivalents of its components; and elted sulphur, and chlorine, when the latter is liquefied by pressure, re both insulators of electricity. A compound composed of two onductors is equally unfit for electrolysis. For instance, a metallic lloy, such as plumber's solder, composed of two parts, or one quivalent, of lead, and one part, or one equivalent, of tin, when elted, conducts the current perfectly, but no separation of its onstituents is effected.

(248) Every electrolyte, since it can transmit a current, is lso capable of generating a current if it be employed to excite ction in the battery itself. Comparatively few electrolytes, how-ver, are practically available for this purpose. It is necessary hat the deposited compounds be dissolved as fast as they are roduced; otherwise the crust of insoluble matter introduces a echanical obstacle by which the action is speedily checked.

Great differences occur in the facility with which different lectrolytes yield to the decomposing action of the voltaic current. Generally speaking, the greater the chemical opposition between he elements of a compound, the more readily it yields to elec-rolysis.

The following table exhibits the order in which, according to Faraday, the different compounds which are enumerated yield to lectrolysis; those which are most readily decomposed standing irst on the list:—

Solution of iodide of potassium
Fused chloride of silver
Fused chloride of zinc
Fused chloride of lead
Fused iodide of lead
Hydrochloric acid
Dilute sulphuric acid.

The consideration of the applications of the voltaic battery to the purposes of electrotyping, and to chemical decompositions generally, will be more advantageously considered after the properties of the metals have been described.

(249) *Resemblances between the Electricity of the Machine and that of the Voltaic Battery.*—Notwithstanding the extremely brief duration of the discharge from the electrical machine, it produces, whilst it lasts, phenomena similar to those of the voltaic current, which, indeed, may be regarded as a succession of discharges repeated so frequently as to become continuous. By repeating the discharge from the electrical machine many times through the same liquid conductor, Faraday was enabled to obtain true electrolytic decomposition. The following simple experiment may be adduced as an illustration of this fact:—Upon a plate of glass place a small piece of turmeric paper, moistened with a solution of iodide of potassium which has been mixed with a little starch; upon one end of this piece of paper allow the point of a fine platinum wire to rest, the other end of the wire being in communication with the prime conductor of the machine; on the other extremity of the paper place a similar wire in communication with the earth; it will be found on setting the machine in action that, after the lapse of one or two minutes, a small blue spot will appear round the point of the wire connected with the prime conductor, owing to the liberation of iodine; while round the wire which communicates with the earth a brown spot will be formed from the action of the alkali which is set free. If the wires, instead of being connected through the medium of iodide of potassium, be made to dip into a drop of the solution of sulphate of copper, metallic copper will be deposited on the wire connected with the earth, and oxygen and sulphuric acid will appear on the other wire. If a piece of litmus or turmeric paper, moistened with a solution of sulphate of soda, be supported on a thread of glass between two wires, one of which proceeds from the prime conductor, whilst the other is in communication with the earth, the saline solution in the paper will be decomposed by the electricity, even although it does not touch either of the wires: the litmus paper on the side towards the prime conductor will gradually be reddened, whilst the turmeric paper will be turned brown at the extremity which is furthest from the prime conductor.

The quantity of electricity which is required to produce chemical decomposition is very great. This fact is strikingly illustrated by a comparison which was made by Faraday between the amount of electricity which is developed from the machine by friction and that which is furnished by the chemical action of the battery. The experiment was performed in the following manner: —A wire of platinum and another wire of zinc, each $\frac{1}{18}$ of an inch in diameter, were immersed, $\frac{5}{16}$ of an inch apart, to a depth of $\frac{5}{8}$ of an inch in an extremely dilute acid liquid, prepared by adding a single drop of oil of vitriol to four ounces of water. The current obtained from this combination, at a temperature of 60° F., was transmitted through the coil of a galvanometer consisting of 18 feet of copper wire $\frac{1}{18}$ of an inch thick. It produced in about three seconds as great a deviation of the needle as was obtained by the electricity furnished by thirty turns of a powerful plate machine in excellent action. This quantity, if discharged in a single flash from a Leyden battery, exposing 3500 square inches of coated surface, would have been sufficient to kill a small animal, such as a cat or a rat; but the chemical action upon the zinc by which it was produced, was so trifling as to be quite inappreciable; and it is estimated by Faraday that not less than 800,000 discharges, equal in quantity to this, would be required for the decomposition of a single grain of water! Extraordinary as this estimate appears, it has been amply confirmed by later experiments of M. Becquerel upon this subject.

(250) *Deluc's Dry Pile.*—The relation between the electricity of the voltaic battery and that of the ordinary electrical machine admits of being traced in an interesting manner by intermediate steps. M. Deluc, soon after the discovery of the voltaic pile, contrived what he termed the dry pile. It may be constructed in the following manner:—Take a number of sheets of paper, one surface of which has been coated with gold or silver leaf, and paste upon the uncoated surface a sheet of zinc foil; when sufficiently dry, place several of these sheets of paper one over another, the zinc faces all being arranged in one direction; then cut out, with a punch, a number of circular disks, and arrange them in a glass tube, the diameter of which is rather greater than that of the circular disks of paper, to the number of 2000 or upwards, taking care that all the zinc surfaces are in one direction, and all the silvered or gilt surfaces in the opposite direction. A pile analogous to Volta's will thus be obtained; and if these disks are pressed together and connected at each end with a metallic wire, such a pile will cause divergence of the leaves of the gold leaf electroscope when one extremity of it is made to touch the cap of the instrument, whilst the other end is connected

with the earth, either through the human body or by means of any other conductor. If the pile be reversed, and then presented to the still diverging electroscope, the leaves will first collapse and will then immediately open with the opposite kind of electricity. Indeed, if the wires attached to the two extremities of the pile be bent round and made each to terminate in a small metallic disk, the two disks being placed at a distance of about an inch and a half from each other, care being taken to maintain their insulation, an insulated slip of gold leaf suspended midway between the two disks, will oscillate backwards and forwards between them, if an impulse be first given to it towards either side:—suppose it to approach the positive plate, it acquires a positive charge; it is then repelled from the positive plate, but is attracted by the negative plate, when it gives up its positive charge, and becomes negatively electrified, in which state it is again attracted by the positive plate; this alternate movement of the gold leaf will continue uninterruptedly for months or even years.* With a dry pile, which contained 20,000 pairs, or disks, of zinc and silver paper, sparks have been obtained, and a Leyden battery has been charged sufficiently to produce shocks. It is worthy of remark, that these actions are produced in Deluc's column, only when the paper contains that amount of moisture which is found in it under ordinary circumstances, and which is considerable, although it usually passes unnoticed. If the paper be artificially dried, the pile loses its activity, but again recovers its energy as the paper re-absorbs moisture from the air. Provided that the two extremities of the pile be insulated from each other, it will retain its activity unimpaired for years; but if the ends be permanently connected by means of a good conductor, the zinc becomes gradually oxidized, and the electrical effects disappear.

Zamboni obtains a more effective instrument by substituting finely powdered peroxide of manganese for the gold or silver leaf. One surface of the paper is coated with zinc or tinfoil, and the coating of peroxide may be given to the other surface either by rubbing it on in a dry state, or by applying it in admixture

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* Bohnenberger has contrived an extremely sensitive electroscope, which depends upon a modification of this experiment. Midway between the two insulated terminating disks of Deluc's pile, he suspends a single strip of gold leaf by a metallic wire from an insulated plate of metal; this gold-leaf, however, is not near enough to either disk to touch it. If a body with the feeblest electrical charge be made to touch the insulated plate, the gold-leaf becomes electric, and is attracted towards the oppositely electrified pole of the pile.

with water to which a little honey has been added. The paper disks are arranged in a column, and are terminated at either extremity by a metallic plate. These metal plates are made to compress the paper disks by means of ligatures of silk which pass from end to end of the pile and bind the disks firmly together; whilst effectual insulation is provided for by giving the pile a non-conducting coat of sulphur, which is easily applied by a momentary immersion of the whole instrument in a bath of melted sulphur.

(251) *Water Battery.* — It has been already stated (227) that even with a single pair of zinc and copper plates excited by dilute acid, polarization and electric tension may be proved to precede the voltaic current, though the experiment is one of considerable delicacy. These effects of tension are strikingly exhibited in the case of Deluc's pile; but they may be shown in a manner still more decided by employing a numerous series of alternations of zinc and copper, each of which need expose only a very small surface, and may be excited simply with distilled water. Such an arrangement or *water battery,* consisting of a thousand couples, produces, if insulated, and connected at each of its extremities with a gold leaf electroscope, considerable divergence of the leaves of each instrument. Such a battery will communicate a charge to a Leyden battery: this charge, though it rises only to a small extent, may be renewed and discharged for an indefinite number of times, in very rapid succession. The wire which is connected with the last zinc plate of this battery is negative, whilst that which is attached to the copper is positive.

Mr. Gassiot (*Phil. Trans.,* 1844, p. 39) has given an account of a very powerful and carefully constructed water battery, from which he obtained results of great interest. This battery was composed of 3520 pairs of copper and zinc plates, arranged in separate glass vessels, covered with a coating of lac varnish: the glass cells were supported on slips of glass thickly coated on both sides with shell lac, and these glass plates were insulated on varnished oaken boards, each board being further insulated by resting on thick plates of glass, similarly varnished. All these precautions were found by experience to be necessary in order to preserve the insulation. When the conducting wires of this battery were brought within $\frac{1}{50}$ of an inch of each other, sparks were obtained, and when the wires were made to terminate in brass disks which were brought very near each other, a rapid succession of sparks was maintained, which on one occasion continued without interruption for five weeks. A permanent deflection of the galvanometer was obtained when this instrument was included in the circuit whilst the sparks were passing; under similar circumstances, paper moistened with iodide of potassium and included in the circuit, speedily gave indications of the chemical decomposition of the iodide. The chemical effects produced by the water battery are, however, always feeble, but they are similar in kind and in direction to those which are obtained when acids are employed as the exciting liquid in the cells; and the principal effect that would be obtained if dilute acid were substituted for water in such a combination would be an increase in the quantity of electricity, by increasing the consumption of zinc and the chemical action in each cell in a given time. The intensity of the charge would not be materially affected by the change of the exciting liquid. Neither in the water battery, nor in any other form of battery is the intensity, as measured by its power of overcoming resistance to conduction, increased by increasing the size of the plates.

It thus appears, 1. That by voltaic arrangements electricity may be obtained, exactly similar to that developed by the common machine, in its effects of tension and in induction towards surrounding objects, in the polar character of its action, and in the opposite nature of the electricities accumulated at the extremities of the apparatus. 2. That the quantity of electricity obtained by voltaic action is almost immeasurably greater than that procured by friction; but that unless its intensity be exalted by using a very numerous series, it does not pass so readily through non-conductors in the form of sparks, as the electricity of the common machine. 3. That on the other hand, by allowing the electricity of the machine to discharge itself gradually through very small masses of imperfect liquid conductors which are susceptible of electrolysis, true electrolytic action may be produced.

The identity of the two forces under these different degrees of intensity no longer admits of question: in the voltaic action the quantity is great, but the intensity is feeble; whilst in the electricity of the machine the reverse is the case, the intensity is very high, whilst the quantity is extremely small.

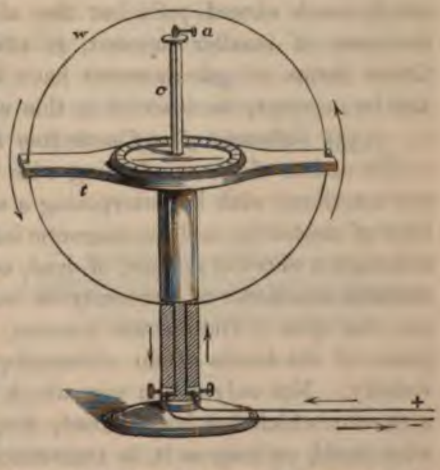
§ IV. Electro-Magnetism.

(252) *Law of Electro-Magnetic Action;—Tangent Galvanometer.* —The influence of an electric current upon a freely suspended magnetic needle has been already pointed out (221), but it will be

needful to examine the nature of the connexion between magnetism and electricity somewhat more closely. Mere electricity of tension, or electricity in a state of rest, has no influence upon a magnetized bar. It is only when the electricity is in motion that this magnetic action is excited. It has already been explained (221) that the direction in which a magnetic needle is deflected depends upon the direction of the current; and it has been stated that when the needle points north and south, and a wire is placed parallel to the needle, if the current flow from south to north above the needle, the north end of the needle will move westward. The power which the wire exerts upon the needle is inversely as the distance of the wire from such needle.

For measuring the force of the current, galvanometers of various forms have been employed. When the power is extremely feeble, the astatic galvanometer (fig. 168,) is well adapted, to the purpose, but in this form the value of the angular deviation requires to be experimentally determined for each instrument. When the current has a greater degree of power than can be conveniently estimated by the astatic combination, the ***tangent galvanometer*** is frequently employed. This instrument is simple, both in construction and in principle. The conductor, *w*, fig. 192, which is used for conveying the current round the needle, consists of a single coil of thick copper wire, bent into a circle of about one foot in diameter. It is supported vertically in a small table, *t*; the extremities of the wire, which are connected with the battery, are covered with silk, and pass vertically downwards, side by side, close to each other, for some inches; they are thus situated in the same plane as the coil, and in the direction of a prolongation of its radius. The object of this arrangement is to prevent this portion of the wires from exerting any influence on the needle. Within the circle *w*, a magnetic needle about an inch long is suspended by fibres of unspun silk, *c*, over a copper plate graduated to degrees. In order

FIG. 192.



to enable the movements of the needle to admit of more accurate measurement, its apparent length is increased by fastening a piece of fine copper wire to each end. This arrangement is protected from currents of air by means of a glass shade. The point of suspension of the needle is made to coincide accurately with the centre of the circle formed by the conducting wire: at *a* is a screw for raising or lowering the needle. When the instrument is placed exactly in the magnetic meridian, the needle, under the influence of the directive action of the earth's magnetism, assumes a position parallel to the diameter of the circle. On transmitting the current through the wire, the needle receives an impulse which, if it were free from the inductive action of the earth, would place it exactly at right angles to the coil: owing, however, to the influence of the earth, the needle is unable ever really to assume this position; but it takes one which represents the resultant of the two forces, and as the action of the earth may be assumed to be uniform, the measurement of the angle enables the force of the current which produces the deviation to be calculated. It may be demonstrated that the force of the current is proportioned to the tangent of the angle of deviation. The instrument cannot be relied on for angular deviations which much exceed 70°; but for all currents which produce a deviation of smaller amount, it affords a convenient measure. Other forms of galvanometer have been contrived, which it will not be necessary to describe in this work.

(253) *Influence of a Conducting Wire in Exciting Magnetism.*—The action of the conducting wire upon the magnetic needle is not interfered with by interposing a sheet of glass or other insulator of electricity, and the magnetic influence is equally transmitted, although a sheet of copper, of lead, or of any other non-magnetic metallic conductor of electricity be introduced between the needle and the wire. The electric current, however, produces no divergence of the leaves of an electroscope which is brought into its vicinity. Not only does a wire which is conveying electricity affect a needle which has been already magnetized, but the conducting wire itself, so long as it is transmitting the electric current, displays magnetic properties. If a thin wire of copper, or of any other non-magnetic metal, be employed to complete the voltaic circuit, such a wire will, for the time, attract iron filings, and the filings will be arranged in a layer of uniform thickness around the whole circumference of the wire, and along its whole length. The moment the connexion with the battery is broken, the magnetism ceases and the filings fall off; but the attractive power

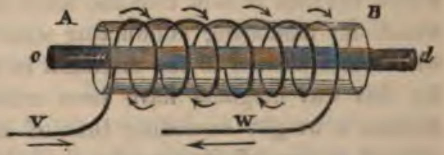
may be again instantly renewed on completing the circuit. The iron filings in this case become magnets, the poles of which are arranged alternately north and south around the wire. This arrangement may be better understood by referring to fig. 193, in which W is supposed to represent a section of the wire which is transmitting a current from + to −, the north end of each fragment of iron would be arranged as represented by the points, *n n*, of the arrows. If short wires of soft iron, be placed in the direction of the arrows around the wire, they become temporary magnets, the north and south poles of which are indicated by with the letters *n* and *s*.

Fig. 193.

If pieces of steel be substituted for soft iron they become permanently magnetic; all those which are above the wire, if the current be passing in the direction shown in the figure, will have their north ends to the left, whilst in all those below, the north ends will be to the right.

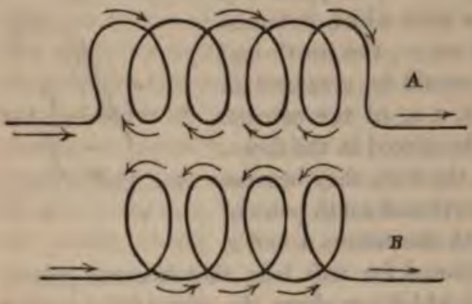
(254) *Formation of Electro-Magnets.*—We see, then, that every part of the wire along which a current is passing is magnetic. By coiling the conducting wire into a ring a larger number of particles are brought to act upon a piece of soft iron which is passed through the axis of the ring at right angles to the plane in which it lies; and by coiling up the wire into a spiral form, without allowing the spires to touch each other, and supporting them upon a glass tube, the action of a very considerable length of wire may be concentrated in a very effective manner upon the same piece of soft iron, placed as at *c d*, fig. 194. Very powerful temporary magnets may thus be obtained. If the wire be covered with cotton, or, still better, with silk, to insulate the coils from each other, the effects may be greatly augmented by winding a second series of coils upon the first, and a third upon the second, and so on till six or seven layers of wire are coiled around the bar which is to be magnetized. In preparing these coils it is quite necessary, however, that the wires be coiled in one direction; for instance, if the coils follow the direction of the thread of a right-handed screw in the first layer, as in A B, fig. 194, the wire must be carried back in a single line to A before

Fig. 194.



again beginning to wind on the second layer, and the same precaution must be observed with each successive layer of coils. A row of coils which follows the direction of a left-handed screw would neutralize the effect produced by the right-handed spiral, as a glance at fig. 195 will show, where A represents a right-handed spiral, B, a left-handed spiral: in the straight portions of the wire, the current, as indicated by the arrows, flows in the same direction in both; but it is reversed in the spirals. Such a spiral coil of wire is usually termed a *helix*.

Fig. 195.



A helix through which an electric current is passing is powerfully magnetic; the two magnetic forces accumulating at its opposite extremities. If the helix be supported with its axis in a vertical position, and a bar of soft iron be partially introduced within it, as soon as an electric current of sufficient power is transmitted through the coils, the bar will start up, and will raise itself in mid air nearly equidistant between the two extremities of the coil, the iron, by induction, becoming for the time a powerful magnet: the poles of the iron bar are of course exactly the reverse of those of the helix by which its magnetism is produced.

The most powerful electro-magnets, however, are those in which the iron is bent into the form of a horse-shoe, and around which an insulating conducting wire is coiled in several layers, with due attention to the direction in which the coils are arranged. In this way magnets have been constructed which are able to sustain a weight exceeding that of a ton. The magnetism developed in the soft iron, under the influence of the voltaic current, attains its maximum in a few moments. It ceases as quickly, when the contact of the wires with the battery is broken; and by reversing the direction of the current the magnetic polarity of the bar is instantly reversed.

(255) *Molecular Movements during the Magnetization of Bars.*—The production of magnetism in a bar of iron, and the cessation of magnetism, are both attended with molecular motion, which pervades the whole mass of iron. Mr. Joule has shown that the

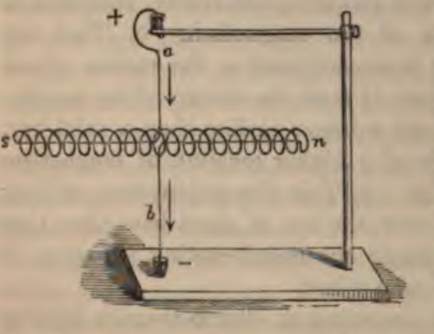
bar, on becoming magnetic, acquires a slight increase in length, and suddenly contracts to its former dimensions when the magnetism ceases. Each time that the bar either becomes magnetic or loses its magnetism, a distinct sound is emitted, the note being similar to that elicited by striking one end of the bar so as to produce vibrations in a longitudinal direction. The molecular movements, if repeated in quick succession by rapidly making and breaking contact between the ends of the helix and the wires of the battery, so as repeatedly and quickly to magnetize and demagnetize the bar, produce an elevation of temperature, which, as Mr. Grove has shown, is quite independent of the heat produced in the conducting wire by the current.

(256) *Laws of Electro-Magnetism.*—According to the researches of Lenz and Jacobi, it appears that if the battery current be maintained of a uniform strength—1. That the magnetism which is induced in any given bar is directly proportioned to the number of coils which act upon the bar: it is a matter of indifference whether the coils be uniformly distributed over the whole length of the bar, or whether they be accumulated towards its two extremities. 2. That the diameter of the coils which surround the bar does not influence the result, provided that the current be in all cases of uniform strength; for though the inductive influence decreases as the distance of the magnet from the wire, the induction produced by the increased length of the wire in the circumference of the coil is augmented in precisely the same proportion. 3. That the thickness of the wire composing the coil does not influence its effect upon the bar. 4. That the energy of the magnetism is, *cæteris paribus*, proportioned to the strength of the current, being directly as the electro-motive force and inversely as the resistances of the circuit. 5. That the *retentive* power of the magnet, like the attractive power in electricity, increases as the square of the intensity of the magnetism. 6. That the magnetic effect in a solid bar is proportioned to the surface which it exposes; or in cylindrical bars it is as the square of the weight. Bundles of isolated wires expose a larger surface than a solid bar, and hence they are susceptible of a higher amount of magnetism than a solid bar of equal weight. 7. That the employment of long bars has no other advantage over the use of short bars than that of removing to a greater distance the counteracting influence of the two magnetic poles upon each other.

The practical question in preparing an electro-magnet resolves itself into the determination of the thickness and length of the wires which are required to produce the *maximum* effect. It is obvious, that for a battery of a given power, the longer the wire which is employed, the greater is the resistance introduced, so that the number of convolutions practically has a limit beyond which nothing is gained by increasing them, and this limit is attained when the increased resistance introduced by the increasing length of the wire balances the gain produced by the influence of the additional coils upon the bar; the greater the diameter of the coil the longer, of course, will be the wire required to form it, and the greater will be the resistance of such a coil in proportion to its magnetizing power. Experience shows, that in order to attain the most economical combination in the battery in proportion to the quantity of materials consumed, when magnetic power is required, the same rule must be followed as when chemical resistance has to be overcome—viz., that that combination is the most effective in which the resistance of the wires and of the coils which are exterior to the battery is equal to the resistance of the liquids and other materials used in the construction of the battery itself, or when in Ohm's Formula ($\frac{nE}{nR+r}=A$) the value of A most nearly approaches 0·5; in which case $r = nR$.

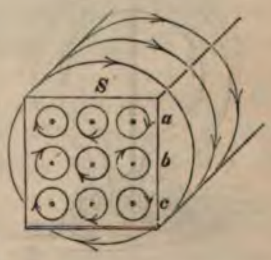
(257) *Ampère's Theory of Electro-Magnetism.*—It will be necessary to examine somewhat further the properties of a spiral wire which is conveying a current, in order that the reader may be enabled to understand the theory of Ampère, by which he accounts for the mutual action of magnets and electric currents. If a simple helix, which for lightness may be made of thin wire, be freely suspended, it will, whilst conveying the current, place itself in the magnetic meridian; that is to say, it will point north and south, and will be attracted and repelled by a magnet which is presented to it, just as an ordinary bar magnet would be. Fig. 196 shows a method of suspending the helix, or *electro-dynamic cylinder*, *n s*, so as to exhibit these effects; the wire, *a*, terminates in a small hook, which dips into a cup containing mercury, which is connected with one of the wires from a small voltaic battery; the other end, *b*, of the

FIG. 196.



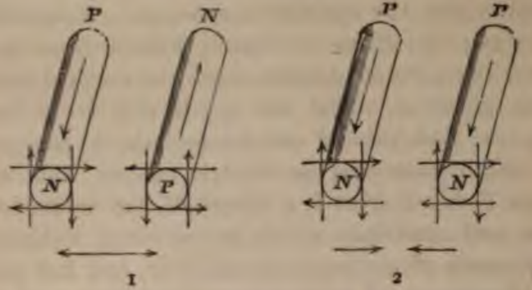
coil dips into a second mercury cup, which is in communication with the other wire of the battery: the magnetism corresponding with that of the north end of the needle accumulates at one extremity of the coil, whilst the opposite magnetism accumulates at the other extremity; this effect necessarily follows from the influence of each coil upon its neighbours, since the north side of every coil is in one direction, whilst the south side is in the opposite. Ampère, who first pointed out the remarkable analogy between the helix when conveying an electric current and an ordinary magnet, has deduced from it a theory of the connexion between magnetism and electricity which has satisfied, hitherto, the rigorous requirements of mathematical analysis, and has also explained all the phenomena of electro-magnetism that have as yet been discovered. Ampère assumes that all bodies which exhibit magnetic polarity, derive this polarity from currents of electricity which are perpetually circulating around the particles of which the magnetic bodies are composed. Around each particle an electric current is supposed continually to circulate; the direction of these currents is supposed to be uniform, each current circulating in a plane at right angles to the axis of the magnetic power. In fig. 197, the currents are shown as at *a*, *b*, *c*, circulating in a uniform direction around the particles of a bar magnet, of which the south pole, s, is nearest the observer. The resultant effect of these united and concordant small currents would be equivalent to that produced by a single current winding in a spiral direction uniformly around the bar which would occupy the axis of such a spiral. In an ordinary magnetic needle, which is pointing north and south, the currents would ascend on the western side and descend on the eastern. No definitive proof of the existence of these currents can be given, nor can a reason for the persistence of such currents in permanent magnets be assigned; but, granting that such currents do exist, all the mutual actions between wires which convey currents and permanent magnets follow as a matter of necessity.

Fig. 197.



(258) *Mutual Influence of Wires which are conveying Currents.*—We proceed to point out one or two of these consequences. When two wires are freely suspended near each other, and electrical currents are transmitted through them, the wires will be mutually repulsive if the currents pass in opposite directions, but

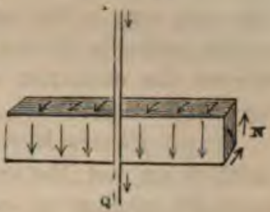
Fig. 198.



they will attract each other if the currents be in the same direction. Fig. 198 will explain the reason. When the currents are in opposite directions (No. 1), the magnetism on one side of the wires is exactly similar to that in the contiguous side of the second wire, as indicated by the arrows arranged round P and N. The two north poles and the two south poles consequently repel each other; whereas when the current is passing through the two wires in the same direction, as shown in No. 2, the effects are exactly reversed; attraction follows, and if the wires be freely suspended, as in Snow Harris's arrangement, represented in fig. 199, they will place themselves parallel to each other. Three concentric troughs containing mercury are arranged on a small stand; the current passes from one of the wires of the battery to the central trough, returns by the inner loop of wire to the second trough, and by the outer loop is transmitted to the exterior trough, which is in communication with the other wire from the battery. This attraction between currents which are passing in the same direction, may be rendered evident in the contiguous coils of a helix: from this cause, a helix formed of a slender harpsichord wire, shortens itself when the current is transmitted, but recovers its former dimensions when the current is intermitted. Now if it be granted that in every bar magnet electrical currents are perpetually circulating around the particles of which it is composed, in a direction at right angles to a line adjoining the magnetic poles, we have in the foregoing experiments an explanation of the tendency of a magnet to place itself across a wire which is conveying an electric current, since the currents in the magnet and in the wire, assume a direction parallel to each other by such a movement. Let

Fig. 199.

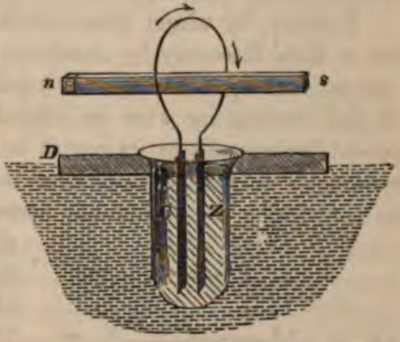
Fig. 200.



P Q, (fig. 200), represent a wire conveying an electric current in the direction of the arrow; N will indicate the north end of a magnet in which the currents supposed to circulate around its particles would be parallel to the current in the wire P Q.

If the magnet be stationary whilst the wire is moveable, the wire will place itself at right angles to the magnet. In fig. 201, a plate of zinc, Z, is represented as connected by a loop of wire with the copper plate, C; both are suspended in a tube containing dilute acid, and the little battery is made to float in a vessel of water by the aid of a piece of cork, D. If the north pole of a magnet, *n*, be presented towards the loop in the direction shown in the cut, the wire will be attracted, and place itself midway between the two extremities of the magnet; if the south pole be presented, the wire will be repelled; the little floating combination will turn half round so as to reverse its direction, and then will be attracted.

Fig. 201.

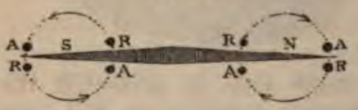


Motion is also produced in a wire which conveys a current, if it be suspended perpendicularly between the two poles of a horseshoe magnet placed upon its side, the lower extremity of the wire dipping into a trough of mercury which is connected with one wire of the battery, whilst it rests by a hook at its upper end upon a metallic arm which is in communication with the other wire of the battery; according to the direction in which the current is passing, the suspended wire will be either attracted or repelled, by the simultaneous action of the two poles of the magnet on the opposite magnetism of the two sides of the wire: the lower end will be thrown out of the trough of mercury; this movement will break the connexion with the battery, and the wire will then cease to be acted upon by the magnet until it falls back again into the mercury; the battery contact is by this means renewed, and the same series of motions is repeated. A spur wheel or star, if substituted for the wire, may in this manner be kept in continual revolution; for as one radius is thrown out, another enters the mercury, and thus renews the connexion with the battery, till it in its turn makes way for another.

(259) *Electro-Magnetic Rotations.* — The movements just described are not the only ones which the magnet and the wire mutually produce on each other. If the action of the electric current be limited to a single pole of the magnet, a continuous rotation of the pole round the conducting wire may be obtained; or if the magnet be fixed whilst the wire is moveable, the wire will revolve around the magnet.

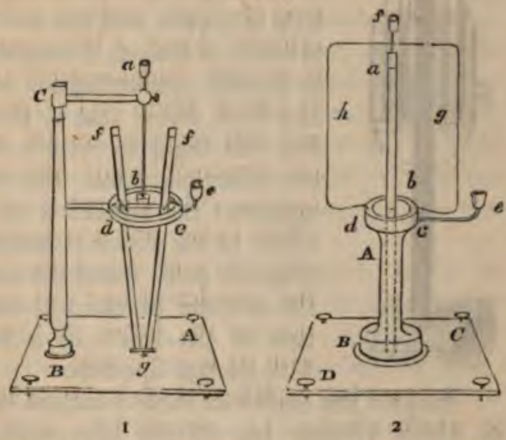
Faraday, by whom these rotations were first investigated, was led to their discovery by observing the manner in which a voltaic current acts upon a magnetic needle which is moved in its vicinity. If the conducting wire be placed perpendicularly, and a needle poised horizontally at its centre be made gradually to approach the wire on one side, each pole of the needle is first attracted, and on continuing the movement across the wire, is then repelled by the wire; on the other side of the wire the needle is repelled where it was previously attracted. The points indicated in fig. 202 by the letters A A, represent the positions of the wire when it produced attraction; R R, those in which it occasioned repulsion: at the points S and N midway between A and R, the needle is neither attracted nor repelled. From these results Faraday concluded that each pole had a tendency to revolve round the wire, and therefore that the wire had a similar tendency to revolve round the poles; the revolution of the north end of the needle, it was expected, would be in a direction the reverse of that assumed by the south end. Experiment completely verified these expectations. The facts admit of being shown in a variety of forms.

FIG. 202.



No. 1, fig. 203, shows an arrangement by which the magnet may be made to revolve around the fixed wire, *a b*; *f f* are the north ends of two bar magnets, which are united below, and terminate in a pivot, *g*, which works upon a hard steel plate in the board, A B; *c d* is a wooden ring which contains mercury, and which is in metallic communication with the cup, *e*. At the centre of each of the magnets is a small brass hook which dips into the mercury of the trough, *c d*, for conveying the current transmitted through the wire, *a b*, which is supported by the arm, C. As soon as the connexion of the cups *a* and *e* is made with the battery, the magnet begins to rotate around the wire, *a b*, and continues to do so as long as the current passes; if the direction of the current be reversed, the direction of the rotation is reversed likewise. No. 2 is a similar arrangement for showing the rotation of the wire, *h g*, around the north end of the magnet, *a b*; the current enters at the cup, *f*, divides itself, and passes down *h* and *g* into the ring, *d c*, which contains mercury, and is supported above the board, C D, by the stand, A B; the circuit is completed by means of the cup, *e*: reversal of the current reverses the direction of the rotation. If the current descend in the wire around the north end of the magnet, the direction of the rotation is the same as that of the hands of a watch lying with the face upwards. The current may be transmitted through the upper half of the magnet itself, and if delicately poised, the bar may thus be made to rotate rapidly upon its axis. These rotations may also be exhibited by liquid and by gaseous conductors; if the wires from a powerful voltaic battery be made to dip into mercury, the mercury over the points where the wires terminate will rotate rapidly if a magnet be held above or below the spot. The flame of the voltaic arc revolves with equal regularity and distinctness under magnetic influence; thus by making a powerful horseshoe magnet a part of the circuit, and transmitting the current through the magnet itself, the voltaic arc of flame which may be drawn from one of its poles will rotate in the opposite direction to the flame which may be drawn from the other pole.

Fig. 203.



A beautiful proof of the magnetic condition of the liquid part of the circuit so long as the current is passing, is exhibited by the rotation of the battery itself, in obedience to the action of a magnet;

the experiment may be made as follows:—Let a double cylinder of copper, shown in section at *c*, fig. 204, of about two inches in diameter and three inches high, be formed into a cell capable of containing liquid, and be supported by a point attached to a connecting strip of copper, over one end of a bar magnet; let a cylinder of zinc, z, be supported on a second point in metallic communication with the copper: as soon as a little dilute acid is poured into the cell, the zinc will begin to revolve around the magnet in one direction, while the copper rotates in the opposite; the current is ascending in the copper, whilst in the zinc it is descending around the same magnetic pole: round the north end of the magnet, the cylinder of zinc will move in the same direction as the hands of a watch which is lying with its face upwards.

FIG. 204.

Ampère has explained these rotations by means of the theory to which allusion has already been made; but it will not be needful to pursue this part of the subject further.

(260) *Electric Telegraph.*—The most important and remarkable of the uses which have been made of electricity, consists in its application to telegraphic purposes; an application which has not only brought distant towns upon the same island or continent within the means of instantaneous communication with each other, but which has spanned the seas, and placed an insular metropolis like London within momentary reach of the distant capitals of the continent.

It would be impossible in a work like the present, to give even a sketch of the numberless modifications and improvements in the apparatus which have been suggested or practised for carrying out telegraphic communications by means of electricity, since the year 1837, which is memorable as the period at which Messrs. Cooke and Wheatstone took out their first patent for electric telegraphing, and proved to the world the possibility of transmitting and receiving signals produced by electricity, with facility and with certainty through insulating wires of great length. On the present occasion, an outline of the essential parts of the telegraphic system which is generally adopted in this country is all that can be attempted.

The electric telegraph may be regarded as consisting of three parts—viz.: 1. The *battery*, or source of electric power. 2. The *line*, or the means of transmitting the signals. 3. The *telegraphic indicator*, or instrument for exhibiting the signals.

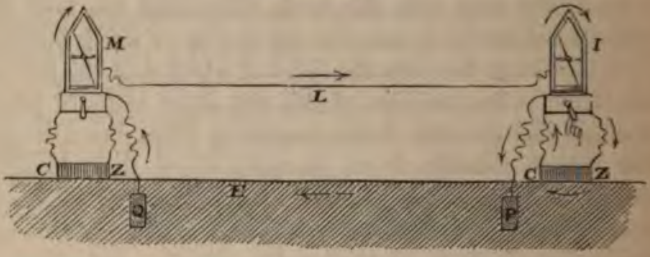
1. *The Battery.*—The apparatus for producing the signals is simply a voltaic battery, any form of which may be used; but the one commonly employed consists of a series of alternate pairs of copper and amalgamated zinc plates arranged in wooden troughs, sub-divided into compartments, similar to those used with Smee's battery (fig. 180). These compartments, after the plates have been introduced, are filled with sand, which is then moistened with dilute sulphuric acid. In this form of instrument the risk of leakage is diminished and the amount of evaporation is lessened: the charge requires renewing once in ten days or a fortnight, according to the frequency with which the telegraph is used.

2. *The Line.*—The conducting wire was formerly made of copper, but is now generally made of iron wire about one third of an inch thick, coated with zinc, to protect it from oxidation. For the purpose of insulation this wire is supported upon wooden posts, which are firmly sunk into the earth, and which are kept dry at the upper extremity by means of a cap or case of wood, fourteen or sixteen inches long, between the sides of which and the post is an interval of air. To the sides of this cap short tubes of porcelain are attached, and through these insulating tubes the wire passes. Suppose that a message is to be transmitted from London to Manchester; a continuous insulated conducting wire must extend between the instrument or battery in London and the instrument at Manchester which is to receive the signals, and there must also be a continuous conducting communication to complete the circuit between Manchester and London. This return conductor may consist of a second metallic wire which must be insulated from the earth and from the first wire, though it may be suspended upon the same posts side by side with the first. The earlier telegraphic wires were all made in this way.

It was, however, discovered by Steinheil that the second metallic wire may be dispensed with, and that the earth itself may be employed as the conductor for completing the return communication between the two distant stations. The possibility of doing this arises from the law of conduction in solids—viz., that the conducting power increases in proportion to the area of the section of the conductor. The earth as a conductor of electricity is many thousand times inferior in power to any of the metals, if columns of each metal and of the earth of equal diameter be compared. But it is possible to multiply indefinitely the area of the conducting portion of the earth between the two stations, and thus a line of communication may be obtained which actually offers a smaller amount of resistance than the metallic part of the circuit. In practice all that is found necessary, in order to take advantage of this conducting power of the earth, and to substitute it for the return wire of the telegraph, consists in leading a wire from the telegraphic apparatus at one end, into the earth, the wire being attached to a plate of copper which exposes several square feet of surface, and this copper plate is buried in the ground, as represented at P (figs. 205, 206, 207). By increasing the size of this plate, any extent of surface of contact with the earth may be obtained, and thus the intrinsic inferiority of the earth to the metals as regards its conducting power is more than compensated for.

The general plan of this arrangement will be understood from fig. 205, in which M and I represent two telegraphic instruments, one stationed, we will suppose, in Manchester, the other in London. L is the metallic line or wire of communication which connects the stations; E, is the earth; and P, Q, copper plates attached to wires, one of which proceeds from each instrument. Suppose, for example, a message to be in the act of transmission from I, the instrument in London, to M, the instrument in Manchester; if C Z represent the battery at the London station, the current will take the course indicated by the arrows; it will pass from C to a wire connected with the earth plate, P, thence it will pass through the 200 miles of earth between the two cities; at Q it will be taken up again, and be transmitted by the wire to the instrument, M, thence it will be conveyed along the metallic wire L, and back again to London, where it will pass through the instrument, I, and so return to the end, Z, of the battery.

FIG. 205.

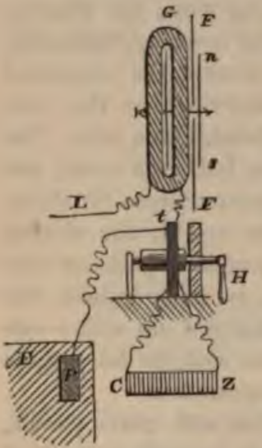


When it is impossible to insulate the conducting wire by supporting it in the air on posts, the whole length of the wire requires to be covered with an insulating material. Gutta percha is found to be admirably adapted to this purpose. In this case it is usual to substitute copper wires for the iron ones, as owing to the superior conducting power of copper, a wire of much smaller diameter can be employed without adding to the resistance, and a saving of space and of insulating material is thus effected. The wires, after having been covered with a coating of gutta percha about $\frac{1}{8}$ of an inch thick, may be inclosed either singly, or several of them side by side, in iron tubing, to protect them from mechanical injury; they are then placed under ground, in the same manner as pipes for the conveyance of gas or water. In the submarine telegraphs, copper wires coated with gutta percha are carefully twisted round a central rope of tarred hemp into a compound rope, which contains several strands of conducting wire; the whole is protected by enclosing it in a flexible metallic covering, formed by carefully twisting several thick iron wires around the compound conducting rope already described; the exterior has thus the appearance of a cable composed entirely of twisted iron wire. The cable having been previously coiled up in the hold of a vessel, and one of its extremities having been properly secured upon the shore, is carefully lowered into the sea; from its weight, the electric rope at once sinks to the bottom as it is gradually paid out over the ship's side. When the opposite shore is safely gained, the extremities of the conducting wire are connected on either side with other wires which are in communication with the telegraphic apparatus, and the signals can be at once transmitted.

In cases in which the wires are insulated with gutta percha, and are then encased in iron tubes, or sunk beneath a body of water, it has been observed that if the wire be connected with the battery, the signal is not instantaneously transmitted to the opposite extremity; and that if the battery contact be broken, there is not an instantaneous cessation of electric action at the distant point.

Faraday (*Phil. Mag.*, March, 1854) has shown that this retardation is produced by the action of the current upon the gutta percha insulator. The insulated wire, in fact, forms a Leyden jar; the gutta percha is the dielectric; the wire within forms the inner coating, and the iron tube, or water of the ocean which surrounds it, forms the exterior coating. The time lost at first is that which is expended in giving to the gutta percha its charge; and the current which is observed to continue for a short time after the wire has been disconnected with the battery, is produced by the gradual discharge of the electricity which had been communicated by lateral induction to the gutta percha: the gutta percha in this case becomes polarized, just in the same manner as the glass of an ordinary Leyden jar. When the wires are suspended in air, no retardation of this kind is observed; and no after current is perceived. The gutta percha in this case cannot assume the polarized condition, owing to the absence of any conducting communication with its external surface, by which the induced electricity could be carried off. Supposing that the line of communication has been established we have now to consider:

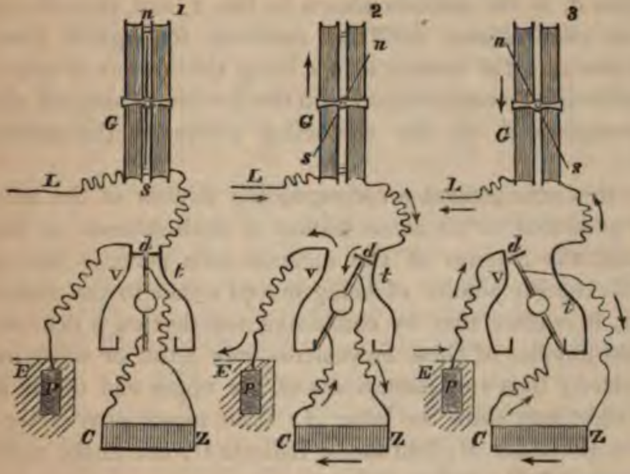
Fig. 206.



3. *The Instrument for Exhibiting the Signals.*—The indicator, or instrument by which the signals are exhibited, is essentially a galvanometer, in which the astatic needles are suspended vertically, instead of being placed in a horizontal direction. A side view of the coil is shown at G, fig. 206. One of the needles is shown vertically suspended within it; the other needle, *n s*, is represented in front of the dial-plate, F F, of the instrument. The needles are slightly heavier at their lower extremities than at their upper ones, in order that when disturbed from the vertical line, they may again resume it when the disturbing force ceases to act. The motions of the needle to the right or to the left are limited by a little ivory stud, which projects on either side from the face of the dial: loss of time, which would otherwise be occasioned by the unnecessary length of the oscillations of the needle, is thus prevented. L and P are the wires which communicate with the distant station; C Z is the battery; H is the handle by which the instrument is worked. Fig. 207 is intended to illustrate the principle upon which such an instrument is made to exhibit the signals; the details of its construction have been slightly modified in the diagrams, in order that the course of the electric current may be more clearly traced. No. 1 represents a back view of the essential parts of the instrument, when at rest and in a position to receive a message from the distant extremity. In this position, supposing the current to originate from the distant battery, and to enter the galvanometer G by the wire L, it will pass through the coil, will make its exit by the wire upon the

right hand, which is attached to the metallic spring *t*; thence it will pass along the brass crosspiece, *d*, into the metal spring V,

Fig. 207.



and complete the circuit through the wire attached to the plate P and the earth E, by which it is returned to the distant station. The battery shown at C Z is inactive during the whole of this stage. The wires which proceed from its two extremities are attached to insulated pieces of brass at either end of the vertical piece which is connected with *d*. No current therefore can in this position be transmitted from this battery; since the wire proceeding from C is completely insulated. But suppose it be desired to transmit a signal from this instrument to the distant station: by means of the handle H (fig. 206), the piece to which *d* is attached can be pressed against one of the springs at *t* (fig. 207, 2), whilst its lower extremity by the same movement is pressed against the other spring V; the current now passes from the battery in the direction shown by the arrows. From C it proceeds to V, thence, through the wire attached to P, into the earth; then through the distant station, where the instrument is arranged for receiving the signal, as in No. 1, and it then produces a deflection of its needle. Thence the current returns by L to the galvanometer coil G, and then deflects the needle, returns through the wire attached to the spring *t*, and by the metallic piece *d* completes the circuit through the wire attached to Z.

It is obvious that by reversing the movement given to the handle H, the direction of the current and the motion of the needles in the coil will be reversed both in the near and in the distant instrument, as shown at No. 3. As soon as the operator has finished making his signals, the springs, v and *t*, restore the crosspiece *d*, to the position shown in No. 1, and thus the instrument at once adjusts itself for receiving the signals from the distant station; the battery at C Z being thrown out of action and the conducting communication with the line being restored through the crosspiece *d*, by the self-acting power of the instrument itself.

By this arrangement a corresponding motion of the needle is always produced at the same instant at both stations, so that the giver and the receiver of the message each perceive the signal. Since the needle admits of being moved either to the right or to the left, it is clear that by combining together on a definite plan a certain number of these movements, any letter or word may be transmitted; thus two movements of the upper end of the needle to the right may show the letter *A*; three movements in the same direction the letter *B*; four might indicate *C*; one to the right and one to the left *D*; and so on.

By employing two or more needles in each instrument, a greater number and variety of signals can be transmitted in the same time, but each needle requires a separate conducting wire, though the number of batteries need not be increased.

§ V. MAGNETO-ELECTRICITY.

(261) *Volta-Electric Induction.*—The term *volta-electric induction* was given by Faraday, who first observed the phenomena, to the production of secondary currents, or currents obtained by inductive action, from wires conveying currents in their vicinity. The circumstances under which these currents are formed will be best understood by a description of an experiment. If a wire through which a voltaic current is passing be placed parallel to a second wire, the two extremities of which are connected with the ends of a delicate galvanometer, no perceptible effect is produced in the second wire, so long as the current passes without interruption through the first wire; but if the current through the first wire (or *primary current*, as it may for the sake of distinction be termed,) be suddenly stopped by interrupting the connexion with the battery, a *secondary current* of momentary duration is produced in the second wire, and this current is *direct*, that is to say, it is in the same direction as

that in the battery wire. On again completing the communication between the first wire and the battery, a momentary current or wave of electricity is again transmitted through the second wire, but it is now *inverse*, or in the opposite direction to the primary current.

These effects may be much increased, if instead of employing simple wires, the wires be coiled into the form of two concentric helices, the wire which is to convey the primary current, or primary coil, being placed in the axis of the coil for the secondary current, the ends of the secondary coil being connected as before with the extremities of the galvanometer. Under these circumstances the needle will receive a powerful impulse at the moment the primary coil is connected with the battery, but after a few oscillations the needle will return to its original position, notwithstanding that the current through the primary coil is maintained; the instant, however, that the primary coil is separated from its contact with the battery, a powerful momentary impulse upon the galvanometer needle, from a current through the secondary coil in a direction the reverse of the former, will be produced.

Similar effects are exhibited by causing the primary coil, whilst it is transmitting the battery current, suddenly to approach the secondary coil which is in connexion with the galvanometer. During the approach of the coil, the secondary current is in the opposite direction to the primary one, but during the withdrawal of the coil the secondary current is in the same direction as the primary current. If a small helix be substituted for the galvanometer in the secondary coil, a steel needle may be magnetized by the induction of these instantaneous currents, and the intensity of the magnetism thus induced is proportional to the intensity of the secondary current. By discharging a Leyden jar through a primary coil properly insulated, a secondary current may be obtained in the other helix, but in this case it is always in the same direction as the current produced on breaking contact with the battery.

(262) *Magneto-Electric Induction.*—Since electricity may be made to elicit magnetism, it seemed reasonable to expect that the converse operation of obtaining electricity by means of magnetism should likewise be practicable. After several fruitless attempts to solve this problem, Faraday succeeded in discovering the conditions necessary to ensure the result (*Phil. Trans.*, 1832, p. 125). The following experiment will serve to illustrate these conditions. Let the extremities of a helix of copper wire be connected by means of wires several feet in length with the two ends of a

galvanometer, so that the needles shall be beyond the direct influence of the magnetic bars to be employed. Motion of a permanent magnet across the coils of the helix instantly produces a current in the wire; if, for example, a bar magnet be introduced into the axis of the helix, an immediate deflection of the galvanometer needle is produced; but if the magnet be allowed to remain motionless within the helix, the needle after a few oscillations returns to its zero; the instant, however, that the magnet is withdrawn, the galvanometer needle is deflected to the same extent as before, but in the opposite direction. When the marked end of a magnetic bar is introduced into a right-handed helix, the current which is produced passes through the coils, so as to leave the helix at that extremity at which the magnet enters; so that the current moves in the opposite direction to that of the hands of a watch which is lying with its face upwards.

If a bar of soft iron be placed in the axis of the helix, so long as it remains unmagnetized no current is produced, but if the opposite poles of two bar magnets be presented one to each extremity of the soft iron, so as to render it temporarily magnetic by induction, a momentary current is produced whilst it is acquiring magnetism, and this current corresponds in direction with that which would be occasioned by introducing a bar magnet, the poles of which correspond in direction with those of the temporary magnet.

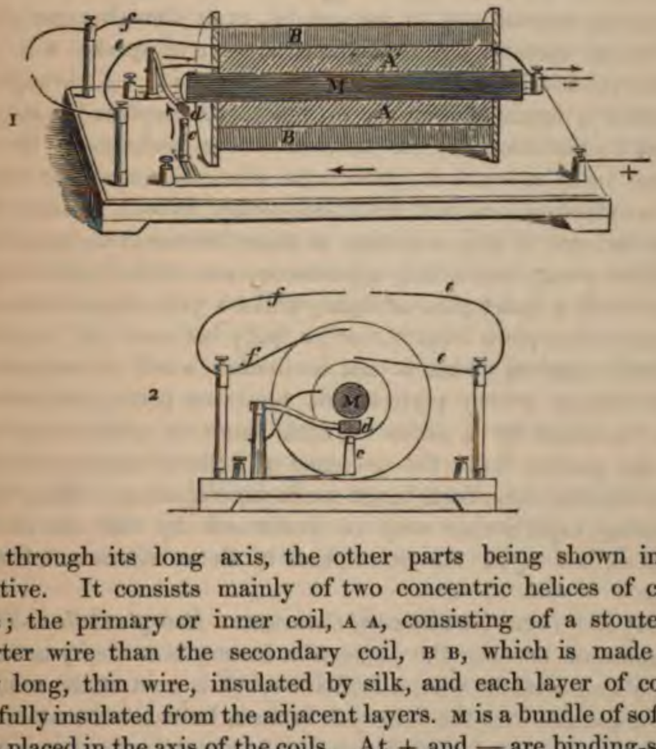
In like manner when two concentric helices are arranged, as in the experiment on volta-electric induction (259), and a bar of soft iron is placed in the axis of the primary coil, a much more powerful secondary current is obtained than when the two coils only are used; since the soft iron in acquiring and in losing magnetism produces a secondary current, which in each case occurs in the same direction as that induced by the primary coil alone. If a bar of copper be substituted for the iron bar or *core* in the primary coil, the current is not stronger than when the two coils alone are employed.

If, as Ampère supposes, a series of electric currents are perpetually circulating around the component particles of a bar magnet, in planes at right angles to the magnetic axis,—the motion of a magnet in the axis of a helix the opposite extremities of which are in metallic communication with each other, so as to form a closed circuit, must necessarily produce a current in such a helix; for the magnet corresponds to a helix through which an electric current is passing: experiment shows that the direction of the currents induced by the magnet is precisely such as would be required by Ampère's theory.

(263) The secondary currents which are obtained by magnetic induction possess a high degree of intensity; if the circuit be broken at the moment that the current is passing, a brilliant spark will be observed at the point at which the interruption is occasioned.

An effective apparatus for exhibiting these secondary currents has been in use for several years, and has recently been rendered still more efficient by M. Ruhmkorff. One of its forms is represented in fig. 208, in which No. 1 shows a vertical section of the coil through its long axis, the other parts being shown in perspective. It consists mainly of two concentric helices of copper wire; the primary or inner coil, A A, consisting of a stouter and shorter wire than the secondary coil, B B, which is made of a very long, thin wire, insulated by silk, and each layer of coils is carefully insulated from the adjacent layers. M is a bundle of soft iron wire placed in the axis of the coils. At + and — are binding-screws for connecting the primary coil with a voltaic battery of three or four elements. This primary coil is not continuous throughout its length, but admits of being broken at *c* and *d*; *d* is a small armature of soft iron, to the under surface of which a plate of platinum is riveted, and the upper surface of *c* is also faced with platinum. So long as *c*

FIG. 208.



and *d* touch, the current circulates uninterruptedly through A A; but as soon as the current passes through A A, the iron core M becomes magnetic, attracts *d*, and the contact between *c* and *d* is interrupted; the current immediately ceases to flow through A A, the magnetism in M disappears instantly, the hammer, *d*, falls, contact with *c* and with the battery is immediately renewed, *d* is attracted again, and M immediately falls back upon *c*. Thus the battery itself acts as a means of making and breaking the contact several hundred times in a minute. A powerful current is induced in the secondary coil, B B, by each of these momentary currents in A A. No. 2 shows an end view of the coil, and exhibits more distinctly the parts by which the contact is made and broken. The same letters apply in both cases. The shocks are of such intensity as to be painful, even though experienced only for an instant. A continuous stream of sparks will pass between the insulated ends of the secondary wire, *e f*, through an interval of a tenth of an inch or more. A Leyden jar may be charged by the secondary current; and if the discharge be allowed to occur in an exhausted receiver, the phenomenon of the aurora light is exhibited in a most beautiful manner through an interval of several inches. If this discharge be taken between two brass balls, it exhibits a very interesting appearance; one of the balls becomes covered with a quiet glow of light, whilst a pear-shaped luminous discharge takes place from the other ball; between the two balls is a small interval which is not luminous: when the exhaustion of the receiver is very perfect, this luminous portion is observed to be traversed by a series of dark bands or arches concentric with the positive ball; the presence of a little vapour of phosphorus renders these dark bands much more distinct. Many other interesting experiments may be performed by the aid of this apparatus, but upon the description of these we cannot further enlarge.

(263 *bis*) *Inductive Action of Currents:—Henry's Coils.*—When the connexion between the plates of a battery is made by means of a single long straight wire, a brilliant spark is seen at the moment that the contact with the battery is broken; but when the connexion is made by means of a short wire, and contact is broken, only a very small spark is produced. When a long wire is employed, the same length of wire, if coiled into a helix, gives a much brighter spark than when it is used merely as a straight conductor. The brilliant spark which is observed when the long wire is used, is produced by the inductive action of the battery upon

the electricity of the wire itself. The bright spark obtained from the battery wire on breaking contact arises from a current which is transmitted through the wire in the same direction as that from the battery itself. This inductive action may be entirely diverted if a second helix, the ends of which are in metallic communication with each other, be placed either within the primary coil or exterior to it.

If the conducting wire be coiled into a helix, within which an iron core is placed, the current on breaking contact acquires sufficient intensity to communicate a powerful shock, when the ends of the wire are grasped by the hand at the moment that the wire is disconnected with the battery, although the battery itself may be quite inadequate to produce any shock when its extremities are connected by a short wire. A striking experiment of this kind is related by Professor Henry (*Phil. Mag.*, 1840, vol. xvi. p. 205). A very small compound battery was formed of six pieces of copper bell-wire, each about 1½ inches long, and six pieces of zinc of the same size; the current which this arrangement produced was transmitted through a spool of copper wire covered with cotton: the wire was five miles in length and $\frac{1}{16}$ inch in diameter, and it was wound upon a small axis of iron. The shock, on breaking the connexion with the little battery, was distinctly felt simultaneously by twenty-six persons who had formed a circle by joined hands, and completed the circuit between the two ends of the wire. The shock which was felt on making contact with the battery was barely perceptible. A current is produced on making contact, but it is feeble, and in a direction the reverse of that emanating from the battery.

Dr. Henry, in the paper above referred to, has made some interesting observations upon the action of the battery current in inducing secondary currents. He employed for transmitting the primary current a flat coil or ribbon of sheet copper about ninety-three feet long and 1½ inch wide. This ribbon was sometimes coiled in the manner shown at *a*, fig. 209, sometimes in the form of a ring as shown at *b*. This coil was combined under various circumstances with other similar coils each about sixty feet long, or with helices of fine copper wire of various lengths. The form of ribbon is a very advantageous one, as it offers a large sectional area in the conductor, and thus diminishes the resistance, whilst the different layers of the coil are approximated to each other with the smallest possible intervals between them. When coiled as at *b*, and a helix was placed within the ring so formed, each time that the current from the battery through the ribbon was interrupted, a secondary current of considerable intensity was obtained in the helix: the helix could be supported upon a plate of glass which rested upon the flat coil, and still the inductive action was obtained; but if a metallic plate were interposed between the coil and the helix, no secondary current was obtained in the helix, as it was transferred to the interposed conducting plate.

By arranging a series of coils in the manner represented in fig. 209, Professor Henry succeeded in obtaining a succession of induced currents by their mutual action. If *a* represent the coil in connexion with the battery, *b* and *c* are arranged to form a continuous coil, through which, by induction, a momentary current is produced each time that the connexion of the coil *a* with the battery is broken; the current in *b c* then being direct, or in the same direction as in *a*. Now if two wire helices be connected together and placed as at *d* and *e*, the induced current in *c* will produce a second induced current, or *current of the third order*, in *d e*; but this current will be in the opposite direction to that in *b c*. If *f* be a ribbon coil placed above *e*, with its ends united by a small helix at *g*, a third current, or *current of the fourth order*, will be obtained, but it will be in the opposite direction to that in *d e*. Thus if the currents be compared together, they will be in the direction following:—

Fig. 209.

a	primary current	
b, c,	secondary current . . .	direct
d, e,	current of the third order .	inverse
f, g,	current of the fourth order .	direct.

By acting upon the principle just explained, and carefully insulating the coils, currents even of the seventh order have been obtained; the successive currents being alternately direct and inverse.

Professor Henry has shown that induced currents of several successive orders may also be obtained by the momentary passage of electricity occasioned by the discharge of the Leyden jar.

These induced currents not only give powerful shocks, but they magnetize steel bars and produce chemical decomposition. The latter may be shown by interposing acidulated water or solution of iodide of potassium between platinum wires which are in connexion with the ends of the coil. It is easy to obtain either currents of high intensity, such as those required to produce shocks, or currents of large quantity, such as would be required for magnetizing steel or for igniting platinum wire, by varying the diameter and length of the conductor. When a long thin wire was employed, as by uniting the two helices as at *d* and *e*, a current of great intensity, producing powerful shocks, was obtained; but this same current could be made to induce in the flat coil *f* a current of greater quantity, but of less intensity.

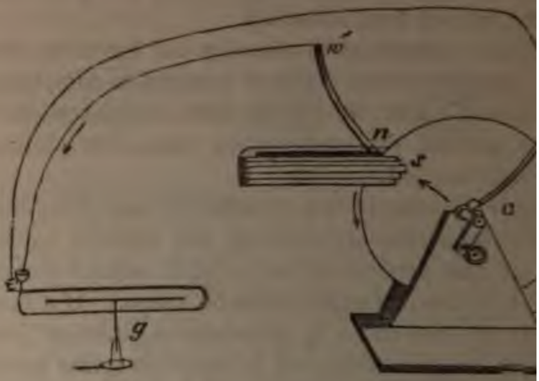
Owing to these variations in quantity and intensity, the investigation of the laws of these induced currents is complicated and difficult. M. Abria (*Ann. de Chimie,* III. i. 385, and iii. 1,) has published some careful researches upon them, but additional experiments are still needed.

(264) *Arago's Rotations.*—A remarkable exemplification of the facility with which secondary currents are induced by magnetic influence, and of the mutual action of such induced currents, are exhibited by the following experiments of Arago. If a magnet be suspended freely by its centre, in a horizontal direction parallel to a circular disk of copper which can be made to rotate horizontally beneath the magnet, it will be found, if the centre of suspension for the magnet be directly over the axis of the rotating disk, that when the disk is made to revolve with a certain degree of velocity the magnet begins to rotate also in the same direction as the disk; and the more closely the disk and the magnet are approximated, the more rapid is the rotation. This rotation occurs as freely when a sheet of paper or of glass is interposed between the magnet and the metallic disk. Disks of other metals by their rotation also produce this effect upon the magnet, but none of them show it so readily as copper; the facility with which the effect is produced being inversely as the power of the rotating disk to conduct electric currents. If a narrow strip be cut out of the metallic disk, extending from its circumference to the centre, no motion will be produced in the magnet when the disk is made to revolve; but if the cut edges of the divided disk be connected by soldering a piece of wire across the division, the rotation may be effected as readily as when the disk was entire. From causes similar to those which produce the foregoing results, it is found that if a magnetic needle or a bar magnet be set vibrating parallel to the surface of a

disk of copper, it will come to rest much more sp
vibrating over paper or glass.

These effects were first satisfactorily explained b
found that whenever a piece of conducting matter i
either before a single pole or between the oppo
magnet so as to cut the magnetic curves at right a
currents are produced across the metal, transverse t
of motion. For example, let the copper disk *c*, fig.
to revolve, in the direction of the arrows on the

FIG. 210.



between the poles, *n s*, of a horse-shoe magnet, and
which is connected with one end of the galvanometer,
against the centre of the disk, whilst the other wire *w'*
vanometer rests against the edge of the disk between
poles. Under these circumstances, a current will be
from the centre towards the circumference of the disk
through the wires, as shown by the arrows. If the
to revolve in the opposite direction, the current will
circumference towards the centre of the disk. Curr
be obtained from any of the f
ratus which exhibit the rotati
round a conducting wire, o
round the magnet, if a galv
substituted for the battery, an
net or the wire be made to rev

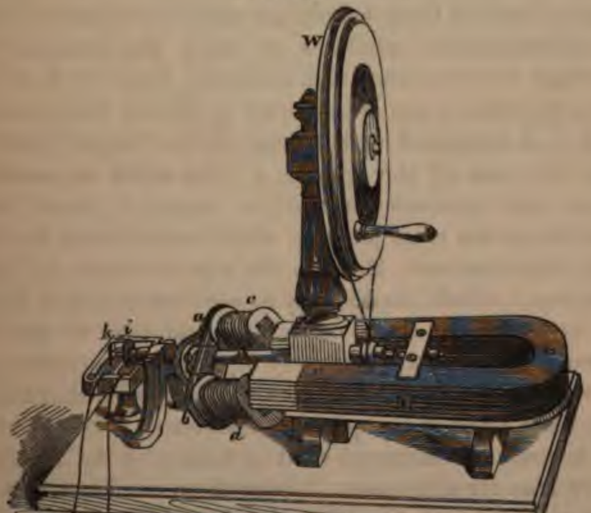
FIG. 211.

Now let us suppose that
experiment we are looking do
revolving disk *c*, fig. 211; wh

evolves beneath the magnet, it cuts the magnetic curves at right ngles; currents are produced underneath the north pole, from he centre of the plate towards the circumference, *a*, beyond the ole: these currents occur in the opposite direction—viz., from he circumference to the centre, underneath the south pole, and hus traverse the diameter of the plate parallel to the magnet, returning by the more distant parts of the plate, as shown by the dotted arrows. Such currents necessarily exert a repulsive action upon the magnet in a direction which coincides with that in which motion is observed, and no currents are obtained until either the magnet or the plate is set in motion.

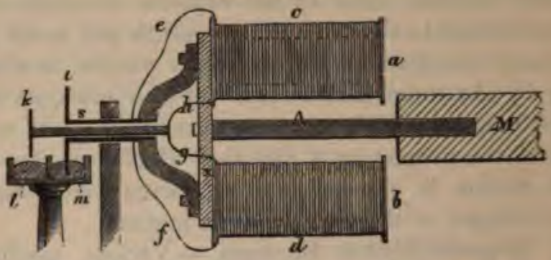
(265) *Magneto-Electric Machines.*—Various machines have been contrived for the production of magneto-electric currents. The most convenient of these is Saxton's Magneto-Electric Machine. It is represented in fig. 212, in perspective; fig. 213, shows a

FIG. 212.



section of the coils and armature. It consists of a powerful horse-shoe magnet, M, placed horizontally upon one of its sides: in front of its ends or poles, and as close to them as is possible, without producing actual contact, an armature of soft iron, *a b*, is made to revolve upon a horizontal axis, A, which admits of being turned by means of a strap, which passes over a multiplying wheel, W. This armature consists of two straight pieces of iron, about two inches in length, which, by means of a cross piece of iron, X, are connected together parallel to each other, at such a distance that they shall be opposite the middle of each pole of the horse-shoe magnet. Around each limb *c*, *d*, of the armature, a long fine copper wire, covered with silk to insulate the coils from each other, is wound in several successive layers. The corresponding ends of each of these helices are connected together; one pair, *e f*, is soldered to the spindle, *s*, on which the armature rotates, and through it is connected with a circular copper disk, *i*, the edge of which dips into a cup of mercury, *m*, whilst the other pair of wires, *g*, *h*, is connected with a stout piece of copper which passes through the axis of the spindle, *s*, from which it is electrically insulated, and terminates in a slip of copper, *k*, placed nearly at right angles to the cross piece, X, which connects the two limbs of the soft iron armature. Beneath the slip of copper, *k*, is a second mercury cup, *l*, which can be made to communicate with the cup, *m*, either by a wire, or by some other conductor of the current. The arms of the slip, *k*, alternately dip into the mercury, and rise above it, and the points of contact are so arranged that the circuit, (which, when *l* and *m* are properly connected, is complete so long as *k* is beneath the mercury) shall be broken at the time that the armature loses its magnetism. Under these circumstances a bright spark is obtained each time that the slip *k* quits the mercury. If the connexion between the mercury cups, *l* and *m*, is effected by grasping with the hands two copper cylinders, H H, each of which by means of a wire, is in connexion separately with one of the cups, a succession of powerful shocks will be experienced. Acidulated water and many saline solutions may be decomposed if these currents be transmitted through them; but in order to produce polar decomposition, it is necessary to suppress or turn up one of the points of the slip *k*, and thus to lose half the power of the

Fig. 213.



machine; otherwise the currents at each half revolution are in opposite directions.

In the construction of these magneto-electric machines, great care must be taken that the insulation of the coils is very perfect. Different effects are obtained from such a machine by varying the length and the diameter of the wire which is wound around the armature. When currents of high intensity are required, such as those needed for giving shocks, or for the decomposition of electrolytes, a great length of thin wire is preferable, but a much smaller length of thicker wire will give the largest sparks, and will ignite the greatest length of fine platinum wire.

Prof. Wheatstone and others have contrived electro-magnetic machines, by which a continuous electric current in a uniform direction may be kept up for any length of time. These batteries are, in fact, combinations of several simple machines, similar in principle to Saxton's; the coils are connected together so as to form a continuous circuit. The armatures are so arranged that each shall in turn become magnetic, just before the preceding armature has entirely lost its magnetism. By this contrivance, the current is made to commence in one coil before it has ceased in the coil which immediately precedes it. magn elect

Electro-magnetic machines are now used in Birmingham on a large scale, as a substitute for the voltaic battery in processes of electro-silvering and electro-gilding. A single Saxton's machine will, if kept in continuous revolution, precipitate from 90 to 120 ounces of silver per week from its solutions: and machines have been constructed by which 2½ ounces of silver per hour have been deposited upon articles properly prepared for this mode of plating. ditto

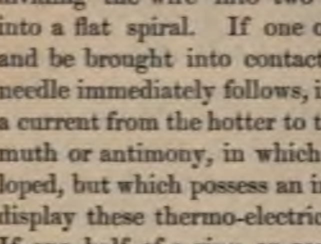
§ VI. THERMO-ELECTRICITY.

(266) The phenomena due to the development of electricity by heat are arranged under the head of *thermo-electricity*,—a term which serves to recal to mind the manner in which in these cases the force originates. The present section contains a summary of the more important facts which have been ascertained on this subject.

As any obstruction to the passage of the electric current in a conductor occasions the development of heat, so any obstruction to the equal propagation of heat in a conducting circuit produces a current of electricity. This important result was first obtained by Seebeck, in the year 1822.

If the extremities of the wire of a sensitive galvanometer be united by means of a straight piece of platinum wire, this wire may be heated at any point at a distance from its connexions with the galvanometer wire, without producing a current through the circuit; but if the platinum wire be twisted into a loop, and heat be applied to the wire close to the loop, and to the right of it, a current will flow through the apparatus from right to left, owing to the inequality of the conducting power, and the disturbance of regularity in the transmission of the force from the hotter to the colder portions. These effects are still more readily produced by dividing the wire into two portions, and coiling each extremity into a flat spiral. If one of these spirals be heated to redness, and be brought into contact with the cold spiral, deflection of the needle immediately follows, in a direction which indicates the flow of a current from the hotter to the colder portion. Metals such as bismuth or antimony, in which a crystalline structure is strongly developed, but which possess an inferior power of conducting electricity, display these thermo-electric phenomena in a more perfect degree. If one half of a ring or rectangular frame composed of either of these metals be heated, and the other half be kept cool, a current sufficient to deflect a magnetic needle suspended within the frame or ring, will be produced. Metals which are better conductors, such as copper and silver, although they also show the phenomena, exhibit it much less distinctly.

Fig. 214.



If the rectangle be composed of two dissimilar metals, as when a bar of antimony, A A, fig. 214, is soldered to a bar of bismuth, B B, the application of heat, such as the flame of a spirit lamp, to one of the junctions will cause deflection of the suspended needle, *n s*. A bar of bismuth when soldered to a copper wire, will readily deflect the needle of a galvanometer of moderate sensibility, if even the warmth of the hand only be applied to one of the junctions. Provided that the resistances in the circuit continue unchanged, it is found that the amount of force in circulation is exactly proportioned to the difference in temperature of the two junctions. M. Becquerel, relying upon the accuracy of this datum, has applied a thermo-electric pair of metals to the measurement of temperature. Amongst other experiments, he endeavoured to ascertain the temperature of flames; the metals which he employed were thin wires of platinum and of palladium; the junction of the wires was introduced into different parts of the flame which, as might be supposed, were found to vary considerably in temperature. The proportionality of the current to the temperature, however, only holds good with those non-crystalline metals which do not oxidize when powerfully heated.

With some combinations, the current increases in intensity up to a certain point, then declines, and is reversed; in the case of zinc and silver, the rise continues up to 248° F.; then the current declines, becomes null, and ultimately is reversed, as the temperature continues to rise. Most probably this is due to the peculiar effect which heat has upon the crystalline structure of zinc. Iron and antimony exhibit the same effect, but to a less marked extent; and Professor W. Thomson has extended the observation to a number of other metals. So important is the crystalline structure in these arrangements, that the thermo-electric power of bismuth is very materially reduced by the addition of a small per centage of tin, which impairs its tendency to crystallize.

It may indeed be stated that when two dissimilar metals are connected in any way so as to produce a closed circuit, an electric current is established each time that any difference in temperature is produced between the two points of contact; and the current is maintained so long as the difference of temperature continues.

The metals may be arranged in the following thermo-electric order:—

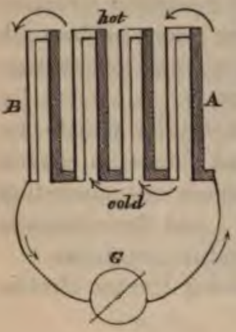
Bismuth
Platinum
Lead
Tin
Copper and Silver
Zinc
Iron
Antimony.

When heated together, the current proceeds from those which stand last on the list towards those which precede them. It is to be remarked that the thermo-electric order of the metals is very different from their voltaic order. According to the experiments of Wheatstone and Pouillet, who have arrived at the same result by very different methods, the electro-motive force of a pair of bismuth and copper, when one junction is maintained at 212° and the other at 32° F., is $\frac{1}{96}$th of that exerted between a pair of copper and zinc plates arranged in voltaic relation, as in Daniell's battery.

Thermo-electric circuits may also be formed with inferior conductors. Nobili brought the point of a heated cone of porcelain clay into contact with a cold cylinder of the same material, each connected with the galvanometer by cotton soaked in a conducting fluid: the current passed from the cone to the cylinder.

(267) *Thermo-Multiplier.*—By connecting together successive pairs of two different metals, and heating the alternate joints, whilst the other junctions are kept cool, a thermo-electric battery may be constructed. The size of the elements which are employed contributes nothing to the effect, except so far as by increasing the area of the conducting section, the conducting power of the circuit is increased. Such a battery will decompose a solution of iodide of potassium, and it is stated that, by a sufficiently numerous series, even dilute sulphuric acid has been decomposed. A thermo-electric current from a single pair is sufficient to convulse the limbs of a frog. The principle of the arrangement by which a *thermo-multiplier* or thermo-electric battery may be constructed is shown in fig. 215; to one series of junctions, a high temperature, to the other a low temperature may be applied; the shaded bars, A, represent bars of antimony, those in outline, B, indicate bars of bismuth. The intensity of such a current, however, is comparatively feeble, and the resistance which it experiences in traversing even metallic conductors of considerable diameter, such as the metallic bars themselves which are used in the construction of the battery, seriously reduces its power. MM. Nobili and Melloni applied a thermo-electric battery, consisting of 36 pairs of small bars of bismuth and antimony, to thermoscopic purposes. Such a battery was employed for thermometric purposes, by Melloni, in his investigations on radiant heat, to the exclusion of almost every other thermoscopic means. When the alternate junctions of the bars at each end of the pile were covered with lampblack, a coating was obtained which absorbed the radiations proceeding from a surface the temperature of which was much below that of the human body; even the amount of radiant heat emitted by insects could be estimated by connecting this battery with a galvanometer of extreme sensitiveness.

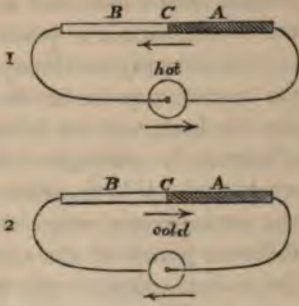
Fig. 215.



(268) In connexion with these thermo-electric effects, a curious observation was made by M. Peltier (*Ann. de Chimie*, II. lvi. 379); when a weak current of electricity was transmitted through a compound bar of bismuth and antimony, from the antimony to

the bismuth, as in No 1 fig. 216, a thermometer, placed at the point of junction, was observed in one experiment to rise 80° F., but when the current was reversed, as in No. 2, the temperature fell 6°·5 F. In some later experiments, M. Peltier succeeded even in freezing water placed in a cavity drilled at the point of junction of the two metals, when the bar was cooled to 32° by immersion in snow. When feeble currents of equal intensity are transmitted through a compound metallic bar, whatever metals be employed, there is a difference in the temperature at the points of junction, according to the direction in which the current is passing; the amount of the difference of temperature varying with the metals which are used, and almost uniformly the lower temperature is obtained when the current is transmitted from the better to the worse conductor of the two metals employed. In the case of bismuth, however, these effects are reversed; the depression of temperature being greatest when the current passes from the bismuth to the superior conductor.

Fig. 216.



§ VII. Animal Electricity.

(269) Some fish, particularly the torpedo, and the electrical eel, (*gymnotus electricus*) have the remarkable power of giving electrical shocks at pleasure, by means of an apparatus specially adapted to the purpose.

The torpedo, which is a species of ray, is a flat fish, tolerably abundant in the Mediterranean; it is provided with two electrical organs situated one on each side of the spine, near the head, occupying the whole thickness of the fish; these organs are supplied with large thick nerves; and it has been found that on cutting these nerves all voluntary electric power ceases; but according to Matteucci, the irritation of that end of the cut nerve which is attached to the organ in a lively torpedo, occasions the electric discharge, and even irritation of detached portions of the organ produces contraction in the limb of a frog recently killed, if the crural nerve of the frog be allowed to rest upon the organ of the torpedo. The structure of the electrical organs is gelatinous, and the material is divided by membranous septa into 400 or 500 columns, which have some resemblance to grains of rice in appearance; these columns run from the dorsal to the ventral surface of the fish, and are about the thickness of a goose-quill; the dorsal surface is positive, the ventral negative. The electricity is most strongly developed just at the points where the nerves enter the organ; a powerful shock is received on simultaneously touching the back and the belly of the fish at any part, but the shock obtained is stronger immediately over the two organs. A weaker shock is experienced on touching different parts even of the same surface, since the electric charge differs in intensity at different points of the same surface. Frequent discharges exhaust the animal quickly; the frequency of this discharge is under the control of the animal, but not its direction. The electric discharges of the torpedo are partly dissipated when the fish is immersed in water, by the conducting power of this liquid, and Matteucci estimated that in air the shock given by the animal is four times as powerful as when it is in water.

(270) In the gymnotus, which is a fresh water fish, tolerably abundant in the marshes of Surinam, and in the tributaries to the Orinoco, there are four electrical organs, a large and a small one on each side, running from the head to the tail of the animal. These organs, like those of the torpedo, are supplied with large nerves, and have a membranous structure, the septa running in a more or less longitudinal direction from the head towards the tail. The longer the column that produces the shock the greater is the force of the electric discharge: the anterior portions of this animal are positive to the posterior, so that the strongest shocks are obtained by touching the fish simultaneously near the head and near the tail; but shocks more or less intense may be obtained from any part of the body, if the hands be separated for a short distance in the direction of the head and tail of the animal; scarcely any shock is felt if the hands be placed one on each side of the fish at the same distances from the head or the tail. So great is the electric energy of the animal, that the specimen which was exhibited in the Adelaide Gallery, forty inches in length, was calculated by Dr. Faraday, at each medium discharge to emit as great a force as the highest charge of a Leyden battery of fifteen jars, exposing 3500 square inches of coated surface. Shocks differing in intensity with the position of the observer and his distance from the fish, were felt in all parts of the tub which contained it; this tub was forty-six inches in diameter. The shocks from the gymnotus have

power sufficient to kill or to stun fish: the same discharge produces a more powerful effect upon a large fish than it does upon a small one, since the larger animal exposes a larger conducting surface to the water through the mass of which the electricity is passing, and consequently it receives a more violent shock. On one occasion when a live fish was put into the tub, the animal was seen by Faraday to coil itself into the form of a semicircle, the fish lying across the diameter: this position was the one most favourable to the full effect of the electrical discharge; an instant afterwards the fish floated motionless upon its side, deprived of life by the shock which it had received, and was then speedily devoured by the gymnotus.

The shock of both the torpedo and the gymnotus gives rise to momentary currents sufficient to deflect the galvanometer, to magnetize a needle, and to decompose iodide of potassium: from both species sparks have also been obtained between two insulated gold leaves, properly connected with the fish.

(271) *The Muscular Current in Living Animals.*—The researches of Matteucci have shown that in the living animal an electrical current is perpetually circulating between the internal portion of a muscle, and its external surface; a current due probably to the chemical actions which are produced by the vital changes which are continually occurring in the organic tissue. This *muscular current*, as it has been termed, ceases to manifest itself in warm-blooded animals in a very few minutes after the life of the entire animal has terminated; but in cold-blooded animals, and especially in the frog, it continues for a much longer period. Vital contractility also continues in these animals for a longer period than in the higher orders of the vertebrata, and hence the frog has been extensively employed in researches of this description.

The following is one of the forms of experiment, devised by Matteucci, to show the existence of the muscular current. Five or six frogs are killed by dividing the spinal column just below the head; the lower limbs are removed and the integuments stripped off them; the thighs are then separated from the legs at the knee-joint, and are cut across transversely. The lower halves of these prepared thighs are then placed upon a varnished board, and so arranged that the knee-joint of one limb shall be in contact with the transverse section of the next, and thus a muscular pile is formed consisting of ten or twelve elements; the terminal pieces of this pile are each made to dip into a separate small cavity in the board, in which a little distilled water is placed. If the wires of a sensitive galvanometer be attached to a pair of platinum plates, and these plates be plunged simultaneously, one into each cavity in connexion with the muscular pile, a deviation of the galvanometer needle will be observed in a direction which indicates the existence of a current passing from the centre or cut transverse surface of the muscle towards its exterior.

M. Dubois Reymond, by the use of still more sensitive instruments, has shown that even the smallest shreds of muscular tissue exhibit proof of the existence of such a current, and the conclusion which he draws from his experiments is the following. Any point of the natural or artificial *longitudinal* section of a muscle is positive in relation to any point of the natural or artificial *transverse* section.

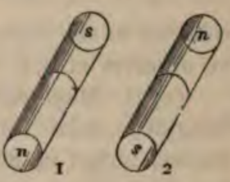
Interesting as this subject is in a chemical point of view, in connexion with the changes which take place in the circulating fluids, it would be irrelevant to our present purpose to pursue it further. The question belongs more properly to the physiologist than to the chemist; and the reader who desires fuller information upon this branch of inquiry is referred to the various papers of Matteucci, in the *Annales de Chimie*, and the *Philosophical Transactions*, and to the work of M. Dubois Reymond, or to the more recent systematic treatises on physiology.

§ VIII. ACTION OF MAGNETISM ON LIGHT—DIAMAGNETISM.

(272) *Influence of Magnetism on Polarized Light transmitted through Uncrystallized Transparent Bodies.* — Allusion has been already made (121) to a peculiar kind of polarization to which light is subject, when it is transmitted through certain transparent media, which are under the influence of magnets of high power. Some transparent bodies are better fitted than others to exhibit this phenomenon. Some years ago Dr. Faraday prepared a peculiar kind of glass for optical purposes; it consisted of a mixture of silicate and borate of lead and was much denser than ordinary flint glass: this glass is particularly well adapted to display the effects of magnetic polarization. Let a piece of this glass which has been properly annealed be cut into the form of a rectangular bar or prism, terminated by flat parallel faces; and let it be placed between the poles of a powerful electro-magnet not in action, the axis of the prism being parallel to a line which joins the two poles,—in fact in the direction of the keeper of a horse-shoe magnet. A ray of polarized light may be transmitted along the

axis of the glass bar, and if examined by an analysing plate in the usual manner (114) the light will disappear when the plane of reflection from the analysing plate is at right angles to the plane of polarization. If, now, whilst the polarized ray is at the point of maximum obscuration, the soft iron be magnetized by the action of the battery, the light will instantly reappear, and if white light be used the reflected ray will be coloured. The moment that the connexion with the battery is broken, the light will disappear, and will again become visible each time that the iron is rendered magnetic. If the north end of the magnet be towards the observer, the rotation of the plane of polarization is to the right, as represented in fig. 217, No. 1, but if the direction of the magnetism be reversed so that the south end is nearest the observer, the rotation is to the left as in No. 2.

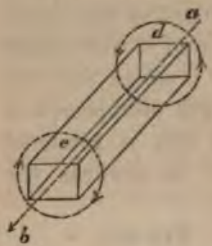
FIG. 217.



Different bodies, when placed between the poles of an electro-magnet, possess this property of rotating the ray in different degrees, but all singly refracting solids and liquids manifest it: in magnetized gases, and *in vacuo*, no such effects have been discovered. The extent of the rotation is, *cæteris paribus*, directly as the intensity of the magnetism, and as the length of the medium traversed by the ray. By placing the transparent bodies in the axis of a coil of wire conveying an electric current, the same effects are produced, but in a lower degree: the more numerous the coils of the helix, and the longer the column of the transparent body which is traversed by the ray, the greater is the extent of the rotation. When an electric current passes round a ray of polarized light in a plane perpendicular to the direction of the ray, it causes rotation of the ray in the same direction as that in which the current is passing. The interposition of bodies which are not susceptible of magnetism, between the coils of the helix and the transparent body placed in its axis, does not sensibly affect the polarizing action, but the interposition of a hollow iron core between the helix and the transparent body in its axis, greatly heightens the effect.

Bodies, such as oil of turpentine, which naturally produce coloured circular polarization (120) have the power exalted, annihilated, or reversed, according to the direction and intensity of the electric current which is transmitted through the coil. The polarization produced by magnetism differs from the ordinary coloured circular polarization shown by oil of turpentine, in this remarkable particular—viz., that the magnetic rotation is always in the same direction as that of the current which circulates around the coil.

FIG. 218.

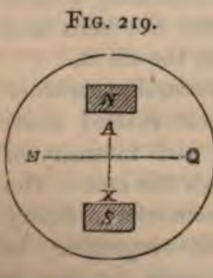


Let *c d*, fig. 218, represent a vessel filled with oil of turpentine endowed with right handed rotation, and let *a b* be a polarized ray. If the ray proceed from *a* to the observer at *b*, the rotation will of course appear right handed to him, as shown by the circle *c*; and if from *b* to *a*, the rotation will still appear right handed to the observer, as shown by the circle *d*. If now a current be passed round *c d*, in the direction of the circular arrow at *c*, the rotation to the observer at *b* will appear to be increased; while to an observer at *a*, it will appear to be neutralized or reversed.

(273) *Magnetism of Bodies in general.*—It was formerly imagined since iron was susceptible of magnetism in a high degree, nickel in an inferior degree, and cobalt in a degree still less, that all other substances might also be magnetic, although to an extent so minute as to elude the ordinary means of observation. Moreover, as experiment had proved that a reduction of temperature exalts the magnetic power of iron and of nickel, it seemed not unreasonable to anticipate that by extreme depression of temperature a point might be attained at which every species of matter would show itself obedient to the magnet. Experiments made upon this subject at very low temperatures have not, however, justified these expectations. The employment of magnets of unusual power has, on the other hand, revealed the existence of a susceptibility to this force in cases where under ordinary circumstances it had not been observed. (Faraday, *Phil. Trans.*, 1846.)

Before adverting to these experiments, it will be advisable to define clearly the different parts of the space between the two poles where the magnetic action is manifested. Let us suppose that we are looking down upon the poles N S (fig. 219), of a powerful horse-shoe magnet; the space between them has been termed by Faraday *the magnetic field*; the line A X, will give the direction of its axis; the line E Q, which is in the same horizontal plane, but at right angles to A X, will form the *equator* of the

FIG. 219.



magnetic field. A bar of iron suspended by its centre above such a magnet, will take a horizontal direction parallel to the axis A X, and is said to point *axially*. By using electro-magnets of enormous power (254) many bodies not usually reputed to be magnetic will take the axial position, like a bar of iron. For example, if an elongated fragment of hæmatite, or red oxide of iron, which is indifferent to a common magnet, be suspended horizontally at its centre by a few fibres of silk between the poles of such an electro-magnet, it will point axially; even a sheet of writing paper rolled up so as to form a short cylinder will, usually, owing to the small quantity of iron or cobalt that it contains, assume a similar direction.

Faraday has found as a general rule that the salts of the magnetic metals are themselves magnetic, provided that these metals enter into the *base* of the salts. For instance, crystals of protosulphate of iron placed in a thin glass tube, which is not magnetic, will cause the tube to point axially. Such salts preserve their magnetic properties even when dissolved in water: if the solution be placed in a glass tube of the form shown in fig. 220, the tube when suspended by a loop of copper wire and a few fibres of raw silk, will take an axial position between the poles of the magnet. Solutions of sulphate of nickel and of sulphate of cobalt act in a manner similar to the solutions of the salts of iron. The pure salts of chromium and of manganese have in like manner proved to be magnetic, and hence these metals themselves are inferred to be so, although, from the high temperature required to reduce them to the metallic condition, it is almost impossible to obtain them in such a state of chemical purity as would enable the fact to be verified by experiments upon the metals themselves in an uncombined state.

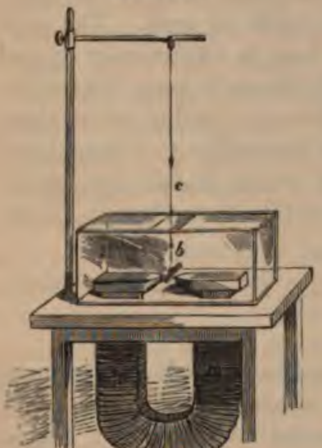
FIG. 220.

(274) *Diamagnetism.*—All the magnetic bodies mentioned above are attracted indifferently by either magnetic pole; and, if of elongated form, they place themselves with their longest diameter in the axial direction when suspended by their centre between two contrary magnetic poles. It is, however, far from being true that all substances are magnetic. Bodies exist, which when brought near to a magnetic pole are repelled instead of being

attracted: such substances have been termed *diamagnetics*. If a straw (s, fig. 221) be suspended horizontally by a silk fibre, and from one extremity of the straw a small piece of phosphorus, P, be supported in a ring of fine copper wire, repulsion of the phosphorus will be produced indifferently by either pole. In such an experiment it will be found convenient to place a soft iron armature, bevelled off to a blunt point, upon the pole of the magnet, in order to concentrate the power, as the repulsive force is very feeble when compared with the attractive power developed in iron. If a stick of phosphorus be suspended between the two poles of the electro-magnet, it takes the *equatorial* position, assuming a direction at right angles to that of a bar of iron, the phosphorus being repelled by each pole to the greatest distance possible. Phosphorus, it will be observed, is a non-conductor of electricity; but some of the metals, of which bismuth and antimony are the most remarkable, exhibit this repulsive action in an equal degree. Substances of an organic nature, such as slices of wood, apple, potato, or flesh, likewise show this diamagnetic power, though not strongly. In fact, all bodies which are not magnetic, exhibit diamagnetic properties. Owing to the feeble amount of these repulsive actions, it is necessary to screen the objects under experiment from the influence of currents of air, by surrounding them with a glass-case, as represented in fig. 222, in which *b* represents a bar of bismuth, or other diamagnetic body, delicately suspended by a few fibres of unspun silk, *c*. The bismuth bar is shown in the equatorial position between the two poles of the electro-magnet, which project through apertures made for their reception in the table.

FIG. 221.

FIG. 222.



(275) *Diamagnetism of Gases.*—The earlier experiments upon the gases, owing to the very small amount of ponderable matter to be acted upon, gave results which seemed to prove that they

were indifferent to the influence of the magnet; but subsequent researches have shown that even the different gases and vapours are susceptible of the diamagnetic influence in a degree which varies with the nature of the gas. (Faraday *Phil. Mag.*, 1847, xxxi. p. 401).

The gases upon which experiments were made by Faraday appear to stand in the following order, beginning with those which are least diamagnetic:—atmospheric air, deutoxide of nitrogen, carbonic acid, protoxide of nitrogen, carbonic oxide, hydrogen, coal gas, olefiant gas, hydrochloric acid, ammonia, and chlorine.

Elevation of temperature exalts the diamagnetic condition, a stream of hot oxygen appearing to be diamagnetic in an atmosphere of cold oxygen. A similar result was obtained with all such gases as were compared with each other at high and at low temperatures. On the other hand, depression of temperature lowers the diamagnetic force, so that a current of cooled gas when allowed to flow into a warmer atmosphere of the same kind, takes an axial position in the magnetic field. If a stream of one gas be allowed to escape into an atmosphere of a second gas more diamagnetic than itself, the less diamagnetic gas takes the axial position; when atmospheric air, for instance, is made to flow into coal gas, the air takes the axial or magnetic position between the poles; though air itself would take the equatorial position in oxygen gas. The diamagnetism of gases was first indicated in an experiment by Bancalari: he found that the flame of burning bodies was influenced by the action of a powerful electro-magnet. This effect is beautifully exhibited by simply placing the flame of a taper, or of any combustible substance, between the poles of the magnet, when in action; the flame appears to be repelled towards either side by the poles, and if the magnet be sufficiently powerful, the flame divides into two streams, which pass off horizontally, one on either side, in the magnetic equator. If the taper be extinguished, whilst the wick still continues to glow, the ascending column of smoke when placed between the poles of the magnet exhibits these motions equally well.

The following simple contrivance was employed by Faraday to show the position assumed by the different gases. A bent tube conveyed the gas for experiment in a very slow but continuous stream into the centre of the magnetic field; generally a piece of paper, moistened with a solution of ammonia, was placed in the bent tube. Supposing the gas to be lighter than air, three wide glass tubes, open at each end, and three or four inches long, were suspended with their lower apertures in the equatorial line, as represented in fig. 223, with the middle tube just above the bent tube for the delivery of the gas. In each tube a piece of paper moistened with hydrochloric acid was suspended. The whole was screened from currents of air by plates of glass. So long as the iron was not magnetized, the gas flowed readily up the axis of the middle tube; but on bringing the electro-magnet into action, the gas, instead of passing directly up the central tube, was, when more diamagnetic than air, diverted into each of the side tubes; and the currents were rendered visible by the white fumes produced when the ammonia carried by the gas came into contact with the vapours of the acid contained in the tube. If the gas under experiment were heavier than atmospheric air, the position of all the tubes was inverted, and, in place of ascending currents, descending currents were obtained.

Fig. 223.

By suspending a feebly magnetic glass tube, attached to the thread of a delicate torsion balance, between the magnetic poles successively in oxygen and *in vacuo*, M. E. Becquerel (*Ann. de Chimie*, III. xxviii. 324) found that the tube was less strongly attracted in oxygen than in the exhausted receiver, and by varying the experiment in different ways he succeeded in proving that oxygen is a highly magnetic body; and he has calculated that a cubic metre of oxygen, which at 32° F. and 29·92 inches Bar. weighs 22015 grains, condensed till it had a specific gravity equal to that of iron, would act upon a magnetic needle with a force equal to that of a little cube of iron weighing $8\frac{1}{3}$ grains; or that the magnetism of oxygen is to that of metallic iron as 1 : 2647. He computes that the magnetic effect of the oxygen in the air is equal to that of a shell of metallic iron $\frac{1}{250}$ of an inch in thickness surrounding the globe of the earth.

The fact of the magnetism of oxygen was first suggested by Dr. Faraday (*Phil. Mag.*, 1847), and was amply proved by him (*Phil. Trans.*, 1851, p. 23), independently of M. Becquerel. He has further ascertained that, like iron, it loses its magnetism when strongly heated, but recovers it when the temperature falls. In this diminution in magnetic intensity as the temperature rises, he considers, probably lies the explanation of the diurnal variations of the needle, the cause of which has so much perplexed magnetic observers.

(276) The following table contains a list of various substances arranged in the order of their magnetic and diamagnetic powers, as approximatively determined by Faraday:—

Magnetic	*Diamagnetic*
Iron	Bismuth
Nickel	Phosphorus
Cobalt	Antimony
Manganese	Zinc
Chromium	Silico-borate of lead
Cerium	Tin
Titanium	Cadmium
Palladium	Sodium
Crown glass	Flint glass
Platinum	Mercury
Osmium	Lead
Oxygen	Silver
	Copper
	Water
	Gold
	Alcohol
	Ether
	Arsenic
	Uranium
	Rhodium
	Iridium
	Tungsten

Nitrogen.

It is worthy of particular remark that the same substance may appear to be either magnetic or diamagnetic according to the nature of the medium in which it is placed. If a glass rod be suspended horizontally in a vessel of water, which is a strongly diamagnetic body, it will point axially, like a rod of iron; whereas the same rod, suspended in a solution of sulphate of iron, which is magnetic, will point in the equatorial direction. In like manner a tube containing a solution of sulphate of iron will in pure water seem to be magnetic, while in a still stronger solution of the sulphate it will act as a diamagnetic substance; just as a soap bubble filled with carbonic acid, which is heavier than air, will fall to the ground, while if filled with hydrogen, which is much lighter than the atmosphere, it will ascend.

Air, in consequence of its containing oxygen in an uncombined condition, is a magnetic substance.

(277) *The same Bodies in combination may be Magnetic or Diamagnetic according to the nature of the Compound.*—One of the most interesting peculiarities of diamagnetism is exhibited in the circumstance that the same body may assume the magnetic or the diamagnetic state according to the nature of the compound which it forms. A metal may, for example, occur as the base or electro-positive constituent of a compound, or it may enter into the composition of those substances which form the acid or electro-negative constituent of the compound. A good illustration of the difference thus produced occurs in the case of iron. Iron acts as a base in the crystals of green vitriol ($FeO, SO_3 + 7\ aq$), of which the metal forms about $\frac{1}{5}$ by weight, and gives to them a decidedly magnetic power; but in the yellow prussiate of potash ($K_2, Fe\,Cy_3 + 3\ aq$), which also contains iron to the extent of more than $\frac{1}{8}$ of its weight, the crystals are diamagnetic. The iron in this case occurs in the electro-negative constituent of the salt, and not as a base. In the same way, bichromate of potash ($KO, 2CrO_3$), where the chromium forms part of the acid, is diamagnetic, while the sulphate of chromium ($Cr_2\,O_3, 3SO_3$), where the metal acts as a base, is decidedly magnetic. Some of the compounds of cobalt exhibit analogous differences.

(278) In prosecuting this subject, MM. Knoblauch and Tyndall (*Phil. Mag.*, 1850, vol. xxxvi. p. 178 and xxxvii. p. 1) have been led to the conclusion that a substance may appear to be either magnetic or diamagnetic according to the arrangement of its component particles. It must not, however, be supposed that there is not a real distinction between the two classes of substances; but that, under certain circumstances, a truly magnetic body may appear to be diamagnetic, and a body truly diamagnetic may appear to be magnetic. The following experiments may be cited in order to explain this point. A small flat circular disk was prepared with a paste of wheaten flour; and in this disk a number of short pieces of iron wire were placed, all parallel to each other, and all passing from one surface of the disk to the other, perpendicularly to its two faces. This disk was suspended from a fibre of silk, by its edge, in a vertical direction, between the poles of an electro-magnet; but though it was undoubtedly magnetic, the plate placed itself with its faces parallel to the equator of the magnetic field. Each of the short pieces of wire, however, had assumed the axial position, although the disk as a whole arranged itself in a diamagnetic position.

When a similar disk was prepared in which threads of bismuth were substituted for the iron wire, the disk placed itself in the magnetic direction, with its faces parallel to the axis of the magnetic field. The bismuth, however, is unquestionably diamagnetic, and each of the pieces of this metal which the plate contains assumes the diamagnetic direction.

The conclusion which MM. Knoblauch and Tyndall draw from these experiments is, that if, in a magnetic or in a diamagnetic mass, there be one particular direction in which the particles which compose it are more closely approximated to each other than in any other direction, the line which corresponds to this direction of greatest density will be the one in which the magnetic or diamagnetic action is most strongly marked. One of the experiments made in support of this view is the following:—Powdered bismuth was formed by means of gum-water into a mass sufficiently coherent to be worked into a small cylindrical bar about an inch long and a quarter of an inch thick. When this cylinder was suspended by its centre in a horizontal direction between the poles of the electro-magnet, it pointed equatorially as an ordinary bar of bismuth would have done; but when this same cylinder was compressed laterally, so as to form a flat plate, it assumed the axial position, though its length in some cases was ten times as great as its thickness.

Again, carbonate of iron is a magnetic body: if reduced to fine powder, and formed into a cylinder similar to that made with the bismuth, it will point axially, or like a magnet, between the poles; but if compressed into a plate, this plate will set equatorially. Here, in each case, those parts in which the particles of the bismuth, or the salt of iron, are by compression brought the nearest to each other, are those in which the diamagnetic or the magnetic action predominates. It is by an application of this principle that MM. Knoblauch and Tyndall account for the fact discovered by Plücker, that in all crystalline bodies which belong to those systems which exercise a doubly refractive influence on light, the optic axis assumes a definite direction under the influence of the electro-magnet. Assuming that the optic axis of a crystal is the direction in which the particles of the crystal have experienced the greatest degree of condensation, the effects obtained by experiment admit of explanation. The position assumed by the optic axis is not uniformly the same in different specimens of the same substance, though in the same specimen it is always the same. For example: Iceland spar, when pure, is a diamagnetic substance, but, if it contain carbonate of iron, it exhibits magnetic properties. In the course of their researches, MM. Knoblauch and Tyndall took pieces from several specimens of Iceland spar, some of which were magnetic, others diamagnetic. These different samples were cut into the form of disks, or flat circular plates, the surfaces of which were parallel to the optic axis of the crystals. When the disks were suspended horizontally at their centres between the poles of an electro-magnet, so that the optic axis of the crystal was in a horizontal plane, each disk always assumed a determinate direction. When the disk was taken from a magnetic crystal, the optic axis placed itself axially between the poles; when from a diamagnetic crystal, the optic axis assumed the equatorial direction. Thus it appears, that whether the crystal be magnetic or diamagnetic, the action is exhibited in each case most powerfully in the direction of the optic axis, which is assumed to be the line in which the particles are most closely approximated to each other.

(279) It has been ascertained by E. Becquerel and by Tyndall, that the diamagnetic repulsion, as measured by means of the torsion balance is as the square of the intensity of the current. The phenomena of diamagnetism may be accounted for, as was remarked by Faraday, on the supposition that electric currents are circulating around the particles of the diamagnetic body in a direction the reverse of those which are supposed to exist in magnetic bodies, and the experiments of Reich, Weber, and quite recently of Tyndall, appear to have rendered it highly probable, that bodies which are under diamagnetic influence, exhibit polar characters. The question, however, is still under investigation, and may be expected ere long to be definitely settled.

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(280) *Definite Quantity of Force; Indestructibility of Force; Mutual Relations of Different Kinds of Force.*—The progress of philosophical inquiries for many years past has been of such a nature as to produce a growing conviction in the minds of the active cultivators of science, that force is equally indestructible with matter; and that, consequently, the amount of force which is in operation in the earth (perhaps in the solar system), is as definite as that of the material elements through which its existence is made known to us.

That the quantity of force associated with matter is definite, may be illustrated in various ways; one or two examples must suffice. The first which we will select will show the fixity in the proportion of heat which is associated with a given quantity of matter. A pound of charcoal, when burned with a free supply of air, combines with 2⅔ lb. of oxygen, and produces 3⅔ lb. of carbonic acid. The chemical action produced by this combustion is attended with the extrication of a definite quantity of heat: and this amount of heat, if it be applied without loss, is sufficient to convert 12½lb. of water at 60°, into steam at 212° F.: associated with each pound of charcoal there must therefore be a definite amount of power which is brought into action when that charcoal is burned. A different but equally definite amount of heat is emitted when a pound of phosphorus, of sulphur, of hydrogen, or of any other combustible is burned with free access of air. The quantity of electricity associated with a given quantity of matter is equally definite. When a piece of amalgamated zinc is placed in voltaic relation with a plate of platinum in dilute sulphuric acid, for each pound of zinc which is dissolved, a quantity of electricity is liberated, by means of which a pound of metallic copper may be separated from the solution of a sufficient quantity of the sulphate of copper, or 3⅖ lb. of silver may be reduced from a solution of nitrate of silver.

But it appears further, that there is no such thing as a destruction of force. The cases in which a superficial examination would lead to the conclusion that force is annihilated, show on closer investigation that such a supposition is erroneous. The only mode in which we can judge of the existence of a force is from the effects which it produces, and of these effects that which is most universal is the power either of producing motion, of arresting it, or of altering its direction: whatever possesses this power has been looked upon as a form of force. Motion is consequently looked upon as the signal of force. There is no difficulty in showing that gravity, elasticity, cohesion and adhesion, are all forces in the sense of the above definition. But even the more subtle and complex agents light, heat, electricity, magnetism and chemical affinity, are all capable of originating motion, and may thus fairly be admitted under the definition of force above given.

If we except the case of light, for which at present, when it has disappeared by absorption, no satisfactory account has yet been given, it will be found that in all cases in which force disappears, it has expended itself either in eliciting or setting into action an equivalent amount of some other force, or else it has temporarily disappeared in producing a definite amount of motion. In this case it is especially to be remarked that the amount of motion which it has thus brought into action, when that motion is destroyed, will again give rise to an equal amount of the force which originally produced it.

For example, the chemical action between charcoal and oxygen terminates as soon as the charcoal is wholly converted into carbonic acid; and a quantity of heat, which is equivalent to that amount of chemical action, remains as the representative of the force thus expended. The heat which has thus been developed, is ready to do other work; it may be employed in converting a certain quantity of water into steam, and the steam so obtained can be applied to the production of motion, the amount of which may be measured by determining the number of pounds weight which can be lifted through a given distance by the steam thus produced. Motion may again be made to produce heat, and, as Mr. Joule's experiments appear to show, the quantity of heat thus developed is strictly determined by the amount of motion which is applied to its development.

It appears, however, not only that force is definite in its amount, and indestructible in its essence, but that many of the more important varieties of force are intimately related, and are capable of mutually eliciting each other. The forces amongst which such mutual relations have been experimentally proved to exist in the closest manner, are those of light, heat, electricity, magnetism, and chemical affinity. The transfer of any one of these forces from one point to another, or in other words, the motion of any one of these forces, is always attended with a collateral manifestation of one or more of the other forms of force; probably, if our knowledge of the necessary conditions were more perfect, it would be found possible to produce all the five forces simultaneously. Something of this kind is indeed manifested in the action of a simple voltaic circuit, consisting of a single pair of plates of zinc and platinum. In this case the solution of a certain quantity of zinc, or the *chemical action* between the zinc and the acid sets free several forces—viz.: 1. *Electricity*, the quantity of which is dependent strictly upon the quantity of zinc which is dissolved in each cell. 2. *Chemical action:* if a voltameter, charged with solution of sulphate of copper, be interposed in the circuit between two electrodes of copper, a certain quantity of copper, corresponding to the zinc which is being dissolved in the battery, will be deposited on one electrode, whilst a corresponding amount of copper will be dissolved from the other electrode. Here is a chemical action, which corresponds in amount to that which is taking place in the cells of the battery. 3. *Magnetism:* if the connecting wire be coiled round a piece of soft iron, the iron will become powerfully magnetic for the time during which the current is traversing the conducting wire. That the amount of this magnetism is definite may be shown by causing the current to traverse the wire of a tangent galvanometer, which is introduced into the circuit; a deviation of the needle, to an extent depending on the amount of chemical action which is occurring in the battery at the time, will be produced. 4. *Heat:* if, whilst the voltameter, the electro-magnet, and the galvanometer are still included in the circuit, part of the circuit be composed of a thin wire which traverses the bulb of Harris's air thermometer, an elevation of temperature in the wire proportioned to the amount of electricity in circulation will be obtained; and 5. *Light:* on interrupting the connexion of any part of the circuit a bright spark is obtained. The chemical action, the electricity, the magnetism and the heat, are strictly proportional to each other. The amount of light at present has not been measured with sufficient accuracy to enable us to state that such is also the case with regard to it. With a compound circuit very intense development of light and heat may be obtained between two charcoal points, simultaneously with the electrical, chemical, and magnetic effects, but in this case the relations to the total quantity of zinc dissolved are different (236). Chemical affinity, then, whilst in operation, can throw a current of electricity into circulation, and a current of electricity will develop an equivalent amount of magnetism in a direction at right angles to such current. It also produces heat in conductors proportioned to the resistance which it experiences, and if the heat be sufficiently intense it produces light.

Faraday has shown that the electricity developed by friction in the ordinary electrical machine produces a corresponding amount of magnetic action on the needle of the galvanometer and an equivalent amount of chemical decomposition in electrolytes through which it is transmitted; whilst in the fusion of metallic wires we have evidence of its heating power, and in the electric spark we see its agency in producing light.

The experiments of Faraday, followed by those of other philosophers, have proved that the motion of a magnet of a given strength under certain conditions, produces, in a closed metallic conductor, a definite current of electricity, and through the electricity thus set in motion, light, heat, and chemical action may be developed.

On the other hand, heat may be made to develop electricity; and the thermo-multiplier (267) of Nobili and Melloni shows that the current of electricity which is produced is exactly proportioned, *cæteris paribus*, to the amount of heat by which it is excited. The ignition of solid matter shows that heat may elicit light under favourable circumstances. It further appears that heat may excite chemical action, and as it may also give rise to a current of electricity, through that current of electricity it may produce the development of magnetism.

Light may produce important chemical actions, but these actions only in a few cases develop electricity, magnetism, or heat. The definite connexion of light with the other forces and the quantitative valuation of that relation still remains to be brought out. Indeed, the subject appears to offer a field for research, difficult, because as yet untrodden, though full of interest and promise.

The reader who desires to pursue the subject of the mutual relations of different kinds of force, is referred to an interesting essay on the subject by Mr. Grove, entitled *On the Correlation of the Physical Forces*. For further information on the other subjects which have been treated of in this chapter, in addition to the papers already quoted, the student is referred to the important series of memoirs by Dr. Faraday, published during the last twenty-five years in the *Philosophical Transactions*, part of which have been reprinted in a separate form; or to the *Treatises* of Becquerel and De la Rive on *Electricity and Magnetism*.

END OF PART I.

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