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OPINIONS OF DISTINGUISHED CHEMISTS AND EDUCATORS.

THE following expressions of opinion concerning the plan of illustrating Chemistry adopted in the present volume, are from the most eminent teachers and scientific men in the country. It will be seen that the testimonials refer to the Author's "Chemical Chart;" but as the "Atlas" is a reproduction and improvement of that mode of exhibiting chemical facts and phenomena, the commendations apply to this work with much greater force.

OF THE PLAN OF ILLUSTRATION.

From BENJAMIN SILLIMAN, LL. D., *Professor of Chemistry in Yale College.*

I have hastily examined Mr. Youmans' new Chemical Diagrams, or Chart of chemical combinations by the union of the elements in atomic proportions. The design appears to be an excellent one. It conveys to learners the idea of chemical combinations by connecting the elements by right lines with the compounds which they produce. Colored squares, differently colored in the different cases, are employed to represent the elements, and proportion in area indicates their relative combining weight. * * * * *

From W. F. HOPKINS, *Professor of Natural and Experimental Philosophy in the U. S. Naval Academy, Annapolis, Md.*

Having given to the Chemical Chart of Mr. E. L. Youmans such an examination as my small leisure permitted, I cheerfully state my conviction that its plan is admirably adapted to assist the teacher in communicating, and the learner in receiving, correct notions of the laws of chemical combination.

I commend it to the patronage of schools and academies where chemistry is taught, and shall immediately introduce it into the institution with which I am connected.

From DR. JOHN W. DRAPER, *Professor of Chemistry in the University of New York.*

Mr. Youmans' Chart seems to me well adapted to communicate to beginners a knowledge of the definite combinations of chemical substances, and as preliminary to the use of symbols, to aid them very much in recollecting the examples it contains. It deserves to be introduced into the schools.

From JAMES B. ROGERS, *Professor of Chemistry in the University of Pennsylvania.*

We cordially subscribe to the opinion of Professor Draper concerning the value to beginners of Mr. Youmans' Chemical Chart.

JOHN TORREY,

Professor of Chemistry in the College of Physicians and Surgeons, New York.

WILLIAM H. ELLET,

Late Professor of Chemistry in Columbia College, S. C.

From JAMES R. CHILTON, M. D., *Chemist.*

I have examined the Chemical Chart of Mr. E. L. Youmans, and am much pleased to say that it is a valuable means of readily imparting a correct knowledge of the nature of chemical combinations. A variety of compounds are dissected so as to show at a glance their ultimate atomic constitution, in such a way as to impress it more forcibly upon the mind than could be effected by any other method with which I am acquainted. To those who are studying to obtain a knowledge of elementary and agricultural chemistry, as well as to all learners of chemical science, Mr. Youmans' Chart will render easily understood what might otherwise appear very difficult.

From DR. THOMAS ANTISELL, *Professor of Chemistry in the Vermont Medical College.*

Experience in teaching theoretical and practical chemistry for many years, has convinced me of the great benefit derivable from exhibiting the chemical elements in a material form to the eye, and I therefore take great pleasure in bearing testimony to the utility and value of Mr. Youmans' Chart. It represents the principal elements, binary compounds and salts, those minerals

which interest chiefly the geologist and agriculturist, together with the most important organic bodies. It is got up in a style which renders it a neat appendage to the lecture-room, and wherever chemistry is taught in schools and public institutions, it will be found an invaluable assistant to both teacher and pupil. * * * * *

From PROF. GRAY, *Author of Text-Books on Natural Philosophy and Chemistry.*

Mr. Youmans' Chart presents to the eye a clearer view of the manner in which the atoms of chemical compounds are united, than could be gained by the most labored description. * * *

It would be especially useful to institutions not furnished with chemical apparatus.

From ROBERT HARE, M. D., *Emeritus Prof. of Chemistry in the University of Penn., and Associate of the Smithsonian Institute.*

I concur in thinking favorably of Mr. Youmans' Chemical Chart. The design is excellent, and as far as I have had time to examine the execution, I entertain the impression that it is well done.

From ALONZO POTTER, LL. D., *Philadelphia.*

The conception embodied in Mr. Youmans' Chemical Chart strikes me as a very happy and useful one, and the execution is evidently the fruit of much care and skill. I should think its introduction into schools, in connection with the study of the first principles of chemistry, was much to be desired.

From the HON. HORACE MANN, *President of Antioch College.*

I have been highly delighted by inspecting a Chart, shown to me by Mr. E. L. Youmans, of New York, the object of which is to represent the ratios in which chemical atoms are combined to form compound bodies. The different atoms are represented by square diagrams of different colors; and then the compounds exhibit the exact number, or numbers, of the respective atoms that unite to form them, each atom retaining its original color. Thus the eye of the learner aids his memory; and as the eye, in regard to all objects having form and color, can learn a hundred things by inspection, while the ear is learning one by description; so, when material objects, too minute to be seen, or too intimately combined to be distinguished, can be represented by form and color, the same great advantage is obtained. The power of the learner is multiplied, simply by an exhibition of the object, or its representative, to a superior sense.

I think Mr. Youmans is entitled to great credit for the preparation of his Chart, because its use will not only facilitate acquisition, but, what is of far greater importance, will increase the exactness and precision of the student's elementary ideas.

From GEORGE B. EMERSON, Esq., *of Boston.*

I have had the satisfaction of examining the Chemical Chart prepared by Mr. Youmans, and very gladly give my testimony to its value. The author avails himself of color to represent properties, and of magnitude to indicate quantities; and by a judicious selection and skilful use of these representatives, he makes remarkably clear to the eye, and very easily remembered, the most important principles and laws of the science, and renders intelligible many of the changes in chemical substances which are of most frequent occurrence and of the greatest interest. I would strongly recommend the use of the Chart to all teachers of chemistry.

From SAM'L S. RANDALL, *Superintendent of Schools of the City of New York, and Editor of District School Journal of Education.*

I have examined Youmans' new Chart of Chemistry, designed to present to the eye of the student of this science the fundamental principles of chemistry, and the ratios in which the various chemical atoms are combined in the formation of compound bodies; and cheerfully recommend it to the attention and patronage of teachers, trustees, and directors of public schools, as well adapted to promote a knowledge of the beautiful science for the illustration of which it is designed.

From JOSEPH MCKEEN, *Deputy Superintendent of Common Schools in New York City.*

I have been greatly pleased with an examination of a Chart of elementary chemistry, by Mr. Youmans. It seems to me that it so simplifies the subject, that pupils in the best classes in our common schools may acquire from a few lessons, with its aid, more knowledge of the laws and principles of this science than

from months of study without such means of illustration, I know of no other chart like this; and as by its means chemistry may now be taught with the same facility as geography or astronomy, I would earnestly commend it to the attention of school committees, teachers, and learners.

In the above view of the utility of Mr. Youmans' Chemical Chart, I fully coincide.

S. L. HOLMES,
Superintendent of Schools, Brooklyn, L. I.

From the *Boston Common School Journal.*

We consider this Chart a great simplification of a somewhat confused subject; and we welcome it as another successful attempt, not only to simplify truth, but to fix it in the mind by the assistance of the eye. If we were called to teach the elements of chemistry in a school-room, we should be very unwilling to lose the valuable assistance of this ingenious chart.

OF THE CLASS-BOOK OF CHEMISTRY.

From PROF. WM. H. BIGELOW, *Principal of Clinton st. Academy.*

I have introduced Mr. Youmans' Chart and Class-Book into the institution under my charge, and am very happy to say, after subjecting them to a practical test, that they are better calculated to excite the interest and fix the attention of pupils, than any other works upon the subject which I have seen.

The eminently practical character of the Class-Book, treating of the familiar applications of the science, is in my opinion its chief excellence, and gives it a value far superior to any other work now before the public.

From PROF. SYME

MR. YOUMANS: DEAR SIR,—I have carefully examined your Class-Book on Chemistry, and, in my opinion, it is better adapted for use in schools and academies than any other work on the subject that has fallen under my observation.

The science of chemistry is highly interesting; and it would be difficult to exaggerate the advantages which would result to the community were it systematically taught in our schools. There is no situation in life in which a knowledge of the nature and properties of the elements of matter, and the laws and powers which affect their mutual actions and combinations, may not prove of the greatest practical utility. The application of chemical agents in the various departments of art has been exceedingly serviceable; and every attempt to popularize the study should be encouraged.

Hoping that your efforts to diffuse the knowledge of chemistry will be duly appreciated by the friends of education,

I remain, Dear Sir,

Yours truly,

DAVID SYME, A. M.,

Formerly Principal of the Mathematical Department and Lecturer in Natural Philosophy, Chemistry, and Physiology, in Columbia College, and now Principal of P. S. No. 7.

I cheerfully concur in the above recommendation of Mr. Syme.
G. H. STEBBINS, *P. S. No. 12.*

We entirely concur in the foregoing recommendation.

F. D. CLARKE, *Prin. of P. S. No. 3.*
S. C. BARNES, *Prin. of P. S. No. 4.*
CHA'S MCGREGOR, *Prin. of P. S. No. 2.*
W. C. ROGERS, *Prin. of P. S. No. 9.*
LYMAN E. WHITE, *Prin. of P. S. No. 1.*
JNO. T. CONKLING, *Prin. of P. S. No. 5.*
GEO. W. FITCH, *Prin. of P. S. No. 6.*
CHA'S H. OLIVER, *Prin. of P. S. No. 11.*
JOSIAH REEVE, *Prin. of P. S. No. 8.*
A. B. CLARKE, *Prin. of P. S. No. 13.*

From PROF. J. MULLIGAN, *Principal of Young Ladies' School, New York.*

I have read a considerable portion of Youmans' Class-Book of Chemistry. I think the author has presented his subject in a

more attractive aspect than it has been presented in any of the manuals in common use. His terse, lively style, and his continual reference to the important practical applications of chemistry, are well calculated to interest the learner.

We have a large number of school-books for the purpose of giving elementary instruction in chemistry—possessing various kinds and various degrees of merit; but of all which I have examined, I should prefer the Class-Book of Chemistry, as the most perspicuous in style and in method, and as containing the happiest selection of what is most interesting, and most practically valuable in the vast field of chemical science.

From the *N. Y. Commercial Advertiser.*

Either for schools or for general reading, we know of no elementary work on chemistry which in every respect pleases us so much as this.

From the *N. Y. Tribune.*

We have rarely met with an elementary scientific treatise which in clearness, brevity, and freedom from extraneous matter, surpasses the present volume.

From the *Albion.*

A remarkably interesting and thoroughly popular work on chemistry, recommended to the general reader by the clearness of its style and its freedom from technicalities.

From the *National Intelligencer.*

Besides the fulness with which this work treats of the chemistry of agriculture and the arts, we regard it as chiefly valuable for the clear account it gives of the action of chemical agents upon the greatly varied functions of life. It is very elementary and practical; and whether for the use of schools or of private libraries, it is an appropriate, because an instructive and entertaining book.

From the *Scientific American.*

Such a book, in the present state of chemical science, was demanded; but to present the subject in such a clear, comprehensive manner, in a work of the size before us, is more than we expected. The author has happily succeeded in clothing his ideas in plain language—true eloquence—so as to render the subject both interesting and easily comprehended. The number of men who can write on science, and write clearly, is small; but our author is among that number.

From the *Farmer and Mechanic.*

A Class-Book of Chemistry for the use of beginners and young students, which should be divested as much as possible of its tedious technicalities and dry repulsiveness, so often attending their first efforts in this important study, has long been a desideratum. To supply this need, the present volume is fully adequate. It is designed as a popular introduction to the study of this beautiful science, and presents it in such a manner as to win the attention and engage the interest.

CHEMICAL ATLAS;

OR,

THE CHEMISTRY OF FAMILIAR OBJECTS:

Exhibiting the General Principles of the Science

IN A SERIES OF BEAUTIFULLY COLORED DIAGRAMS,

AND ACCOMPANIED BY

EXPLANATORY ESSAYS,

EMBRACING THE LATEST VIEWS OF THE SUBJECTS ILLUSTRATED.

*DESIGNED FOR THE USE OF STUDENTS AND PUPILS IN ALL SCHOOLS WHERE
CHEMISTRY IS TAUGHT.*

BY

EDWARD L. YOUMANS,

AUTHOR OF THE "CHEMICAL CHART," "CLASS-BOOK OF CHEMISTRY,"
"ALCOHOL, AND THE CONSTITUTION OF MAN."

Wherever it is vouchsafed to the feeble senses of man to cast a glance into the depths of creation, he is compelled to acknowledge the greatness and wisdom of the Creator of the world. The greatest miracle which he is capable of comprehending is that of the INFINITE SIMPLICITY of the means, by the co-operation of which order is preserved in the universe as well as in the organism, and the life and continued existence of organized beings secured.—LIEBIG.

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TO

SAMUEL M. ELLIOTT, M. D.,

TO WHOSE PROFESSIONAL ABILITY

THE AUTHOR IS INDEBTED

FOR THE ENJOYMENT OF VISION

AND THE POWER OF EFFECTIVE LABOR,

THE PRESENT WORK

IS GRATEFULLY AND AFFECTIONATELY

Inscribed.

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TO TEACHERS AND STUDENTS.

EVERY experienced teacher understands the necessity of making the acquisition of the elementary and foundation principles upon which a science rests, the first business of study. If these are thoroughly mastered, subsequent progress is easy and certain. The system of illustrating Chemistry, which will be found in the following pages, is designed to aid in effecting this object. Those portions of the science which it is important should be well learned, and which are also considered usually as most irksome and difficult, are here presented in such a manner as to be quickly perceived and long retained in the memory. Of course very much that belongs to chemical science does not fall within the scope of this method of illustration; but the great laws of combination which constitute its basis, the composition of compound substances, and many chemical changes and transformations, may be so clearly and correctly exhibited in pictures to the eye, as greatly to facilitate acquisition, and thus afford the student a large economy of time and labor.

The Atlas is intended to accompany the author's Class-Book; but it may be employed with equal convenience and advantage in connection with any of the school text-books. It is to be used in exactly the same manner as a geographical atlas. As the pupil proceeds with the work in hand, whatever it may be, reference should be made to the diagrams as often as the subject may require. For example; when combining proportions, salts, combustion, or compound-radicals are reached, the plates which illustrate these subjects will be resorted to for assistance by those who possess the work. The text contains not only full explanations of the diagrams, but it consists of a series of essays or chapters upon the subjects illustrated. It will be observed that the reading matter is not a repetition of what is contained in the class-books. Where the same topics are treated, the statements are here more full, for they present the subject in a new aspect; while much of the contents of the Atlas is new information, which may be profitably superadded to that found in the books. For the convenience of those who may desire to use them, questions have been subjoined at the close of the volume, which will be found to refer to the numbered paragraphs. It is recommended that, as pupils advance to the various subjects in their text-books, they study carefully those portions of the Atlas which treat of the same points. Teachers will also find, that after going through with other books they may make effective use of the Atlas, in the way of review; thus fixing clearly in the mind the general principles of the science.

INTRODUCTION.



THE Atlas of Chemistry is offered as an extension of the principle embodied in the Author's large Chemical Chart. That chart was published four years ago, and has met with a degree of favor from all classes of instructors rarely accorded to a novel method of illustration, especially in the department of science. It has passed through several editions, and the testimonials of its serviceableness and value as an aid in teaching elementary chemistry, which have appeared from all quarters, afford a gratifying assurance that the work was not done in vain. The atlas form has been adopted at the solicitation of numerous persons—teachers and others—who have expressed a desire to possess the work in a more portable and convenient shape. Though the scale of the diagrams has been so reduced as to bring them within much narrower limits, yet their application has been greatly extended, so as to embrace a larger class of subjects, and include those views of the science which have been recently established, and are of most general interest.

Of the value and importance of some such plan of illustrating Chemistry there can be no longer a doubt. Indeed, the surprise almost universally expressed is, that something of the kind was not devised and adopted long ago. The superiority of the eye over all other senses, as a means of education, is undeniable. The beginning of the intellectual progress of the human race consisted in the invention of letters and words as visible symbols of sound and thought; and to teach those symbols remains still the starting point of education. So also with music: it rose to the dignity of a regular art only when musical notes were invented, by which it became possible to express harmonies of sound to the eye. The symbolism in both cases is perfectly arbitrary; nevertheless, when once acquired, it becomes an instrument of wonderful intellectual power. But if the mind is capable of being thus greatly aided by ocular signs, when there is no natural relation between them and the objects they represent, how much more must its power be multiplied when the symbols it employs assume the pictorial character, and become in a manner actual imitations of the things to be considered.

It is especially in natural science, where definite and exact ideas of properties and relations are to be communicated to the mind, that the employment of visible diagrams is most useful. Whenever the object to be contemplated cannot itself be seen, and consists of such fixed elements or qualities as are capable of being represented or delineated to the eye, pictorial illustrations become indispensable. In Mathematics, we diagramize geometrical conceptions. In order to grasp and hold the elements and conditions of calculation with sufficient steadiness for the mind's eye to contemplate them, they must be displayed before the physical eye. In Astronomy, where the scheme of arrangement is too complicated and extensive to admit of direct observation, pictures of

planets and planetary systems are indispensable. In Geography, which reveals to us the figure of great masses of land and water, the direction of mountains and rivers, the situation and bounds of countries, and the position of localities—facts which we cannot acquire by immediate observance—maps are universally employed. In Geology, also, whether to impart ideas of the formations predominant in various regions, or actual or ideal representations of the earth's crust, visual appliances are equally essential. Physiology uses drawings to teach the structure of living beings; and even History avails itself of ocular methods to convey to the mind its facts of time, succession, synchronism, the progress and decline of empires, &c. In all these departments of study, and many others, it is established that written descriptions appealing to the imagination and conceptive faculties are every way inferior to visual representations, as a means of communicating knowledge.

Now the use of diagrams is as essential in Chemistry as in any other branch of study, although for a different reason. In this science, instead of dealing with objects whose magnitudes and distances place them beyond direct inspection, we encounter the very opposite difficulty: we have to consider matter in its minutest possible form. The chemist does not stop with matter in any of its perceivable aspects; he carries his thoughts downward beyond the utmost regions of microscopical observation, until they rest finally upon indivisible atoms—solids of almost inconceivable minuteness. These atoms are not objects of sense; we can neither see nor touch them. They lie beyond the reach of the sharpest scrutiny: they are the offspring of thought—occupants of an imaginary world. The chemist is compelled to contemplate matter in a form of minuteness which the senses cannot recognize, and it therefore becomes to him an intellectual abstraction. It is precisely for this reason, because chemical phenomena do not fall within the sphere of the senses, and therefore cannot be understood by simple observation, that the science is so recent in origin and development, and people generally are so tardy in acquiring it. For thousands of years, it has been the constant business of each of the thousand millions of human beings who have successively appeared upon the earth, to breathe the surrounding air, and at each breath to impress upon it a vital change; and yet it is almost within the memory of men still living that the nature of this change was first discovered; and this for the obvious reason, that the alteration which the air undergoes by breathing is not manifest to the senses. It remains the same invisible, transparent medium after respiration that it was before. It is evident, therefore, that the student of Chemistry stands in quite as much need of ocular assistance in mastering the rudiments of his science as those who habitually employ it in other branches of study. Nor is there any difficulty in employing diagrams, in a systematic and effective way, for the illustration of Chemistry. The science not only needs it, but it is admirably adapted to this method of exposition. The relations of atoms, the composition and structure of compound substances, and the numerical laws of quantity, by which chemical combination is always governed, may all be accurately represented to the eye, so as to convey clear and distinct impressions. Difference of color is employed to indicate diversity of properties among the chemical elements. As each element has its specific properties, which it preserves in all cases wherever it may be found, so it is assigned a particular color, which it retains throughout the work, and by which it is constantly known. Thus black, wherever it is seen, represents carbon; red, oxygen; and so all the other elements have and maintain their respective colors. Those facts and principles which it is most important for all to understand, are thus brought out from the vague and shadowy region of abstract conception, and presented in all the exactness of reality to the most impressible of our senses.

That it is important to avail ourselves of all possible expedients and contrivances to awaken a thoughtful attention to material objects, I suppose can hardly admit of intelligent question. It is the destiny of man that the life-period of his being shall be passed in a world of *matter*. Not only is he born *into* a material universe, but he is born *of* it; not only is it to be his time-residence, but

he is part and parcel of its fabric, created of its elements, and participating in its constitution. But the simple fact that man's body is composed of matter, by no means indicates the intimacy or the extent of his alliance with material nature, nor is it the just measure of his interest in it. The system of man is less a mere physical body of a certain bulk and weight, than it is a vortex of forces, of which matter in a rapid state of transition is but the means of manifestation. The one hundred and forty pounds of material substance, of which the human body may consist, is but as it were the focus, into which several thousand pounds of matter—solids, liquids, and gases—are gathered and transformed each year. So vital is the relationship which subsists between the living man and the world of physical nature, that he cannot cease the introduction of surrounding matter into his system, even for a few moments, except upon penalty of death.

Nor is it provided in the arrangement of Providence, that the life of man is to depend upon his passive and unconscious reception of the materials necessary to its continuance. On the contrary, these materials are to be secured only by effort; by forecast of mind, and labor of body; by intellectual exertion, contrivance, and care; and by physical struggle and toil. In virtue of the profoundest requirements of his being, man is a creature of industry. Individuals may evade its performance, or may misdirect and waste their power; but this only multiplies the burden of the rest. The equation remains undisturbed. Each human being, in simple self-defence from the destructive agencies of nature, implies and requires that a certain amount of labor—an equivalent of work—shall be accomplished. In compliance, therefore, with the inexorable demands of our being, we are busy among the elements of matter. We expend upon it our multiform arts and industries—we ply it with all kinds of force; change its nature in countless ways; transform it into innumerable shapes, and transport it in every direction. All their lives long the mass of men are occupied in producing mutations of matter with whatever of intelligence and skill they may chance to possess.

But it is not the humble laborer alone, the earth-worker in his field, or the mechanic in his shop, that is chained to matter by the invincible necessities of his vocation: the cultivators of art, though their pursuit be deemed 'divine,' are appointed to a kindred experience. It is the high office of art to invest its ideals with material forms. It is crowned only when its thought is incarnated—projected into physical embodiment. The Sculptor clothes his ideal with marble from the quarry; the Painter reproduces his in colors upon canvas; the Architect realizes his in building together the solid stones into imposing and beautiful edifices; and the Musician embodies his harmonic conceptions in atmospheric pulsations. Science, too, 'Godlike' though it be, deals continually with matter. Astronomy is a product of the spiritual faculty of man in its loftiest mood; yet what is it but an inquest into the grander relations of material objects. And so the whole circle of physical science consists but of explorations into the several departments of matter.

Again, health and disease—conditions which of all others which appertain to earth most intimately concern us—are but affections of matter—states and habitudes of the physical system. The first blessing of life consists in the harmonious action of the bodily mechanism. Yet this mechanism is susceptible of a thousand forms of disorder, by which suffering is induced, and that blessing lost. And not only do pleasurable and painful emotions depend upon bodily conditions, but also states of mind, and even the very integrity of the intellectual structure. Mental moods fluctuate with physical conditions, and disease of the mind's organ disturbs and even overthrows the mind itself.

Undoubtedly the grandest fact of man's existence is, that he possesses an intelligent and immortal spirit. But what are the ordinations and appointments of this nobler element of his being? That a material universe shall be the sphere of its evolution and education; that it comes into being as a thought-germ planted in the soil of matter; that by an exquisite apparatus of material senses, it is put into connection—brought as it were into universal contact with the physical

world ; that it grows and expands by impressions poured in from the outward universe through the channels of sense ; and that power is thus acquired by which the developed soul reacts upon external nature.

We thus see that in numberless ways, and in all departments of activity, the mind of man is occupied and identified with material objects : they are the instruments of its education ; the ministers of its pleasures and its suffering ; the recipients of its power ; and the witnesses and monuments of its triumphs. These considerations should be certainly sufficient to convince us of the importance of making natural science a subject of earnest thought and of more general and systematic study. The time has come when ignorance concerning matters of the most vital personal moment to all can no longer be excused. The human intellect has long enough sported with semblance and fiction ; it should pass to the serious contemplation of reality and truth.

But it is only when, through the illumination of science, we rise to something like a grand and solemn conception of the living relation of this universe to its Creator ; when we discover that he has written his claims to our profoundest admiration and homage all over every object that he has made ; when we get a glimpse of the wonders that are perpetually woven into the tissue of being as he throws the shuttle of time, and feel that we are walled in on every side as by an unbroken congeries of miracles ; it is only when we remember that all these orders of being and schemes of existence are but the ' thoughts of the Almighty,' and that each new fact and principle of nature which we learn lets us one degree further into the counsels of Divinity, that we begin to feel the real power and exaltation of those incentives which should prompt us to study the works and ways of God as unfolded by natural science.

I have endeavored in the following pages to exhibit the Chemistry of the more common forms of matter in such a light as to attract the attention and awaken the interest of those not familiar with the subject. The Atlas is not a complete or systematic chemical treatise, yet a natural order has been observed in the arrangement of its topics. The chemical laws which govern mineral, inorganic, lifeless matter, are first described and illustrated. We are then led to consider the rocky crust of the earth, and how it becomes changed into soil, preparatory to the development of plants and the appearance of life. The Chemistry of vegetable growth, by which inert matter is subjected to the life-inciting forces, and becomes organized, next engages our attention ; and then the various processes by which organized compounds are restored to the mineral state. Lastly, we notice the forces by which this grand cycle of changes is impelled, and the present order of things maintained upon the earth.

ATLAS OF CHEMISTRY.

PART I.

INORGANIC CHEMISTRY.

I.—WAY IN WHICH THE MATTER AROUND US IS COMPOSED.

1. THE material objects around us are capable of undergoing three kinds of change: change of *place*, of *form*, and of *nature*. These changes occur in certain regular ways, and by fixed methods, which are called *laws*. It belongs to *Natural Philosophy* to teach us the laws which govern changes of place and form in material things, and to *Chemistry* the laws which control changes in their nature. When a forest tree is felled, cut in pieces, transported to the mill and sawn into boards, the woodman, the teamster, and the sawyer are occupied in producing visible changes—alterations in the mass—changes of form and place—mechanical changes. But if the tree be burned to ashes, in the open air, or altered to charcoal in a pit by a slow smothered combustion, or if it be suffered gradually to rot, or be injected through its pores with preservative solutions which prevent decay, in these cases the changes are within the wood among its invisible particles; they alter its nature, and are known as *chemical effects*.

2. As Chemistry therefore inquires concerning the inner qualities—the interior nature of objects—its first question is, Of what are these objects composed? They exhibit an infinite diversity of appearances; are they really made up of as many different kinds of matter? Of what consists the countless thousands of varying mineral, vegetable, and animal forms with which our globe is covered? No outward scrutiny—no sagacity of observation will afford an answer to these inquiries. To determine this point the chemist must resort to experiment. He accordingly subjects all the material objects of nature to a process called analysis. This term is derived from two Greek words, which signify *up* or *back to its source*, and *to loosen*; and it means the separation of any compound thing into its first or primary elements. In various ways and by numerous agencies the chemist submits every accessible object of nature to analytical operations. Most of these objects

are in this way separated into new substances; and the products thus derived may often be still further decomposed, giving rise to new and still different kinds of matter. But this process cannot be carried on to an indefinite extent. The operator soon reaches a limit beyond which he cannot pass; obtains bodies which resist his utmost efforts to separate or decompose them. These are termed elements, simple substances, or ultimate constituents. Any substance which contains more than one of these is known as a compound.

3. In separating compound bodies into their constituents, the chemist must resort to the application of force. The powers or forces which he thus employs are various. Heat is the most common. Nearly all vegetable and animal products can be separated into other and different substances by the action of heat. Electricity is a powerful decomposer, and often breaks the union of compounds when heat fails. Light, mechanical pressure, and concussion; the forces residing in living plants and animals and denominated vital; and simple contact, as when minerals are acted upon by strong acids, are all capable of producing decomposing effects of greater or less intensity.

4. If, for example, we send a current of electricity through water under proper circumstances, we decompose or destroy it, and at the same time get two new substances, hydrogen and oxygen, of which the water was composed. But neither a current of electricity sent through hydrogen, nor any other known agency applied to it is sufficient to effect its decomposition; and so also with the oxygen. Marble, to the eye, appears to consist of but one ingredient; but if strongly heated, as marble is every day in our lime-kilns, it is decomposed or analyzed into two totally unlike substances, quicklime and a gas called carbonic acid. Now if a current of electricity is sent through the lime, it rends it into a silver white metal calcium, and oxygen; and if the carbonic acid be heated under suitable circumstances it is resolved into charcoal and oxygen. But our analytic progress is here arrested. However we may ply these products with the decomposing forces, calcium, oxygen and charcoal remain unchanged, yielding no new elements.

5. Chemistry thus divides all bodies into simple and compound. But as all matter has not yet been explored, new elements may still be discovered; and as we can hardly suppose that our analytic methods have reached perfection, some of the present elements are liable to turn out compounds. In the past progress of the science, bodies once regarded as elementary have been afterward proved compound, and numerous considerations incline chemists to suspect that many now ranked as simple will yet undergo decomposition. Nevertheless, we are now compelled to include as elements all bodies which resist the severest decomposing tests which the skill of the analyst can bring to bear upon them.

6. The material things about us may thus be likened to a language. We can resolve its literature into sentences, its sentences into words, and words again into letters; but these are primal symbols, ultimate elements, and with them our analysis ceases. Thus iron, sulphur, carbon, contain each but one kind of matter, and may represent letters. But water contains two different kinds of matter; oil, three; crystallized common salt, four; crystallized alum, five; and pure white of egg, six; corresponding to words of two, three, four, five, and six letters.

7. The resemblance between the composition of natural objects and that of language

may be carried still further. The literature of our language is made up of an infinite number of varying sentences, and these are composed of many thousands of different words; but when this vast array of words is examined, they are all found to consist of but *twenty-six* letters. And so the entire alphabet of nature consists of sixty-three or four letters only. Chemical analysis, which has questioned and tested every material thing within human reach, discloses but about sixty-three ultimate elements or simple bodies. From this narrow range has the Almighty Architect selected the materials which compose our globe and all the living beings which inhabit it. From the ponderous masses of rock of which mountains are built, to the fleeting and ethereal atmosphere; from the lowest and simplest forms of vegetable and animal life upward to the most complex and highly-endowed orders of living beings, whatever the diversity of their aspects, properties, powers, or functions, they have all been created out of this small number of elementary bodies.

8. Again, in the structure of words, certain letters occur often, and others but comparatively seldom. Thus, for example, in all words we find one or other of the vowels, while the letter *z* appears but unfrequently. So in the composition of matter certain elements abound while others are discovered but rarely. If it seem wonderful that the Creator should have formed the world and all its occupants out of sixty-three or four elements, how must it deepen our surprise and admiration when we learn that in carrying forward the grand operations of the globe, he can hardly be said to use more than one-fourth of these elements. By far the greatest portion of terrestrial matter, organic and inorganic, earth, sea, and air, with all their inhabitants, are composed of but twelve or fifteen elements. Nor is this all; for a single elementary substance, oxygen, composes at least one-half of the entire terrestrial universe. These marvellous facts give to Chemistry a simplicity which corresponds with its importance. In studying the composition of air and water, of rocks and soil, of our own bodies and the foods which nourish them, in short, the application of Chemistry to vegetable and animal beings, and to that parent of arts and noblest of occupations—agriculture, we find ourselves constantly engaged with the same few elements. Our attention will be restricted entirely to these in the present work.

9. Yet analysis, which has conducted us to these interesting facts, is but half the business of the chemist. As we can separate sentences and words into letters, so we can put the letters together again and form words. The chemist also, when he has analyzed a compound, may often reunite his elements and reproduce his compound. This putting together of elements is the reverse of analysis, and is called *synthesis*. In analysis we pass from complexity to simplicity; in synthesis we turn round as it were, retrace our steps, and go from simplicity to complexity. In the laboratory of nature, as well as in that of art, these operations constantly alternate and frequently proceed together. But in the case of language we do not merely form such words as have existed before, but may combine the letters so as to make new ones; so in Chemistry we may not only repeat compounds which already exist, but we may create new ones. Thus glass, soap, chloroform, are compounds which, so far as we know, are not found in nature, but are products of art. In this direction, the formation of new substances by synthesis of their elements,

the possibilities of chemical progress are boundless. It should however be always remembered that we have no power of creating new elements, or essentially new matter. We can only produce substances with new properties out of our existing materials.

10. When we separate these elements from the compound forms in which they most naturally exist, and examine them individually by the artificial methods of the laboratory, we are filled with amazement at the contemplation of the properties with which they are endowed. Apparently quiescent and inactive, they are nevertheless clothed with the mightiest energies. From the inert, torpid, slumberous state they suddenly pass as it were to conditions of wakeful irritability or the extreme of violence; now rushing into vivid and intense combustion, and then furiously exploding with peril and ruin to all around. And yet it is these seemingly unmanageable and discordant elements that are chosen by the Omnipotent to carry forward the grand phenomena of life and being upon the earth. How simple and yet how mysterious! How numerous the forms and how changing the aspects under which they appear! How dissimilar and opposed the purposes to which they minister! How wonderful their adaptive powers! Guided by his hand, each performs tranquilly its destined office, moves through all the varying phases of decomposition, decay, and death, then rises into new life, takes on the vital form, and passes again through the same round of transformations. Thus bodies which in the chemist's shop are looked upon as agents of terror, in the laboratory of nature become ministering spirits, as it were, to watch, guard, and preserve us.

11. If the simple elements were to be placed promiscuously upon a table, a child would be able to divide them by their external appearance into two classes; the one possessing the metallic aspect and the other without it. The first are called *metals*, the second *metalloids* or *non-metallic* elements. Three-fourths of all the known elements are metals. The simple substances with which we are mainly concerned are derived from both these classes. They are fifteen or sixteen in number, and have been called the organic or zootic elements, because they form all structures in which life is manifested.

12. In PLATES I. and II. the names of these elements are given in the left columns; in the first the metalloids, in the second the metals. Opposite each name is placed a colored square, which is designed to represent the element. As each simple body has its own peculiar properties, so it is assigned a different color. These colors have not been selected at random; they all have a meaning and are associated with facts which it is useful to remember. Oxygen is the great agent of combustion; it also changes the dark or venous blood of the animal system to a bright red in the lungs; it is hence properly symbolized by a red diagram. When water is decomposed by potassium, its hydrogen burns with a lilach or purplish flame; this color is assigned to the hydrogen. Nitrogen is represented by a sky-blue; it forms four-fifths of the atmosphere, which is of this color. When seen in small quantities the air appears transparent, but when we gaze through large masses, as at a mountain in the distance, or up into the clear sky, its color becomes apparent. Carbon, sulphur, chlorine, phosphorus, and silicon are shown of their natural colors. Potassium, sodium, calcium, and magnesium form compounds which have a common property of restoring vegetable blue colors when other substances have expelled them. This is their test. The intensity of the colors indicate the strength of their properties. Potash

is the strongest, soda next, lime is weaker, and magnesia weakest of all. Aluminum is the basis of clay, and is given a brownish clay color. Iron forms salts of a green, and manganese of a rose color. (For a description of the properties of the individual elements and the compounds which they form by uniting with each other, the reader is referred to the Class-Book of Chemistry.)

II.—MANNER IN WHICH CHEMICAL SUBSTANCES COMBINE.

13. The right columns, PLATES I. and II., represent compounds, and they are seen to be produced from the elements. Lines passing from single squares at the left and uniting at the right indicate *combination*, or that attraction which draws the elements together to form new substances. This peculiar kind of attraction is called *affinity*. We see that it acts only between *dissimilar* bodies. The force which tends to draw together distant or separate masses is termed gravitation; that which binds together *similar* particles as those which compose iron or sulphur, cohesion; that which unites *unlike* particles, affinity. If the earth consisted of but one kind of matter the two former attractions might be exerted, but affinity would be impossible. Chemistry implies plurality of elements, and springs from their differences. Did the earth consist only of mercury, for example, there could be no Chemistry. This substance might change its *form*, freezing to a solid or boiling to a vapor, yet it would remain mercury still, with nothing to compare with it, or act upon and alter it. But if sulphur were added, it would combine with the mercury and form a *compound*, a new substance, and thus Chemistry would come into existence, and its bounds would widen as the elements were multiplied.

14. As to the nature or cause of affinity nothing is understood. We know it only by its effects, which are beyond expression wonderful. The first which may be noticed is the apparent destruction of the elements with which it deals, that is, the destruction of their properties. Were we to take fragments of iron and sulphur, and reduce them to the finest possible powder or dust, and then mix them, we should get a *mechanical* compound. To the naked eye the properties of the iron and sulphur would be lost; but viewed through the microscope they would reappear, each particle presenting all the identical and distinctive characters of the fragment from which it came. The attributes of this compound would be but the sum or average of the properties of the substances which made it up; just as a watch may be said to be the mechanical result of the properties and arrangement of the gold, silver, copper, steel, enamel, jewels, and glass of which it is composed. Each element retains its individuality, and hence we are able to predict the result of mechanical combination.

15. If now we heat the mixture of sulphur and iron and thus bring affinity into play, we get a result which no knowledge of these substances would have enabled us to anticipate. Both disappear so that the most powerful microscope can detect traces of neither. A new substance is produced containing both, and differing widely from each. It is a *chemical* compound. Affinity has abolished the properties of those elements, and created from them a substance endowed with new properties.

16. Newness of properties, either in odor, form, color, density, taste, or other attributes, belongs to all compounds formed by chemical affinity. Thus, when black charcoal and yellow sulphur combine, the compound formed is colorless as water and highly volatile. If the yellow sulphur and bluish-white quicksilver be heated together, they form the bright red vermilion. Waxy phosphorus and colorless invisible oxygen unite to form a white body resembling snow. Nitrogen and oxygen are tasteless, separate or mixed; yet one of their compounds, laughing-gas, is sweet, and another, nitric acid, intensely sour; they are both transparent, invisible, and yet they form a cherry-red compound gas. Charcoal and hydrogen are odorless; nevertheless, many of our choicest perfumes, such as oils of roses and bergamot (PLATE V.), as well as the less agreeable spirits of turpentine and illuminating gas, contain only these elements. The mild and scentless nitrogen and hydrogen give rise to one of the most odorous and pungent compounds, ammonia; while suffocating and poisonous chlorine, united to a silver-looking metal, sodium, yields common salt. Charcoal, hydrogen, and nitrogen, which singly or mixed are not injurious to life, yet combine to form the terrible poison, prussic acid; while charcoal, hydrogen, and oxygen, variously united, produce sweet sugar, poisonous oxalic acid, and intoxicating alcohol.

17. Substances lose their properties, when entering into combination, more or less completely, accordingly as those properties more or less resemble each other. If the substances are very similar, the compound will show its parentage; if quite unlike, all traces of its derivation will be lost. Thus iron and mercury, both metals, form a compound whose metallic aspect immediately betrays its origin; but who, looking at the beautiful paint, vermilion, would guess that it contained the fluid, silver-white metal mercury, and the yellow inflammable metalloid, sulphur; or that common gypsum consisted of the caustic and burning alkali, lime, and the corrosive poisonous liquid, sulphuric acid.

18. Analysis informs us of the composition of compound bodies, what elements they contain, and how much of each. But when we have examined one sample of a substance, and determined accurately its ingredients, how far will this knowledge carry us? Does the information we get extend no further than to the specimen analyzed? Must each new fragment or portion of a substance be experimented upon before its ingredients and their qualities can be known?

19. If the compound we examine contain several chemical substances, mixed as it were by accident or chance, as is the case with soil, mineral waters, ashes, and many articles of commerce, our information is limited to the sample analyzed. We can infer, with more or less probability, the composition of the larger mass from which the specimen was taken; but as the mixed ingredients may vary in proportion, any conclusion which goes beyond the simple results of experiment must be conjectural, and therefore uncertain. This fact of the variable mixture of substances, their impurities and mechanical complexities, greatly multiplies the labor of the analyst.

20. It is the interference of Mechanics with Chemistry that here causes difficulty, forbidding the operator to pass beyond the naked determinations of his experiment. But when we enter the field of pure Chemistry, the result of every exact analysis may be at once expanded into a general law; the individual fact contains a principle which may be

carried with certainty into universal application. Affinity, in binding together chemical substances, does it always in certain invariable and constant proportions. The same kind of substance has ever the same composition. There is often difficulty in establishing that composition with precision; but the fact once determined, applies always to the same class of bodies. Thus, when the composition of a sample of water, or common salt, or lime, is once certainly determined, the knowledge applies to all water, common salt, or lime. There is a mathematical order in the domain of Chemistry as absolute as that which reigns in the realm of Astronomy. This numerical order results from a few simple laws by which affinity is always governed.

21. The first law of affinity is that IT UNITES SUBSTANCES IN DEFINITE AND CONSTANT PROPORTIONS. The relative quantities of the elements in a compound may be expressed by numbers, and those numbers always represent its composition. Water, for example, consists of 8 parts, by weight, of oxygen, united to 1 part, by weight, of hydrogen, and it has this exact composition the world over. We can produce it by the union of its elements in those proportions, and no other. Potash is composed of 39 parts, by weight, of the metal potassium, and 8 parts of oxygen. Common salt of 35 parts chlorine, and 23 of sodium; and so it is with all the chemical compounds. Certain numbers, ascertained by experiment, express the proportions in which their elements invariably unite to form them.

22. As chemical substances are thus composed mathematically, each having its unchangeable constitution, we may, as it were, dissect them, and represent to the eye by diagrams their elements and the proportions in which they combine. In PLATE I. oxygen and hydrogen are seen to be represented by colored squares. The lines passing from them and meeting at the right, represent affinity; and the relative sizes of these squares express the law by which affinity in this case is governed. The compound, water, consists of two elements, there being 8 times as much of one as of the other. These facts are impressed on the mind by a single glance at the diagram.

23. The numbers, 8 connected with oxygen, and 1 with hydrogen, indicate the proportions in which these elements are seen to unite. They are therefore called *combining proportions* or *combining numbers*, and the size or area of their squares exactly corresponds to them. The oxygen square is just 8 times larger than the hydrogen square. In like manner it will be seen that each element has its associated number and its square of corresponding size. The combining number for sulphur is 16, and hydrogen being 1, when these unite, the compound, as we see by the diagram (PLATE I.,) contains 16 times as much sulphur as hydrogen. Chlorine is 35, and when it combines with hydrogen to form hydrochloric acid, we see that the proportions are as 35 to 1.

24. There are two ways in which the combining proportions of chemical substances can be measured; by *volume* or *bulk*, and by *weight*. The laws of combination by volume will be explained in another place. But the fundamental numbers of Chemistry, which form the groundwork of the science, are *determinations by weight*. The colored squares that indicate combining proportions, therefore express relative quantities *by weight and not by volume*.

25. The combining numbers are not often whole numbers; they most frequently

involve additional fractions. For example, the exact combining number for chlorine is not 35, but 35.4 (see Class-Book of Chemistry.) As whole numbers are however sufficiently accurate for general purposes, and are easiest remembered, the fractions are omitted.

26. Oxygen, 8 parts, and hydrogen, 6 parts, combine to form carbonic oxide. Their squares express these quantities, as the diagrams show (PLATE I.) Now, if the reader will glance over the various colored illustrations of chemical compounds throughout the work, it will be seen that the black and red squares maintain invariably their relative size. This could not be otherwise, for the same numerical law of definite and constant relative proportions follows them into all their combinations. In PLATES XI. and XII. the squares which represent carbon, oxygen, and hydrogen, are given, for convenience, of one fourth their usual size. *Relatively*, however, they are the same; the squares expressing the same proportional numbers.

27. How more than wonderful, how almost miraculous is this order! The elements of the wood we burn are associated in fixed mathematical ratios. In the violence of combustion, the bond that held them together is destroyed; they break away, but cannot escape the law of numerical destiny. They rush into new unions, but the combining numbers are still unchanged. The burning candle gradually wastes away before us. Its matter appears to be destroyed; but it is only changed into an invisible shape—dissolved in the air. These changes are beyond the reach of vision; yet down in that invisible region, forces are playing among the invisible particles with the same harmony and exactitude as those which rule the planets. And so it is with all chemical mutations. In the gradual growth of living structures, by the incorporation of new matter; in the digestion of food; in the slow decay of vegetable and animal substances, as well as in their quick combustion, the transposition of elements takes place in rigorous accordance with the laws of quantitative proportion.

28. Chemical substances are united by a force; and the combining numbers are measures of that force. If we take equal quantities of two elements, we do not find them possessed of equal powers of attraction. There is as much chemical energy or neutralizing power in 1 grain of hydrogen as in 8 grains of oxygen. 35 grains of chlorine do not neutralize 8 grains of oxygen 35 times more effectually than 1 grain of hydrogen does, but only *equally* well, and with the same chemical effect, namely, the neutralization of both elements, and the production of new compounds. 1 grain of hydrogen, 8 grains of oxygen, and 35 of chlorine, are therefore, chemically, equal—have *equal values*, or produce *equivalent* effects. Viewed in this way, combining quantities have been called equivalent proportions, or equivalents; and this term expresses more clearly than any other, that a certain weight of one body is equal to, or goes as far as a certain but different weight of another body, in the production of a similar compound.

29. The law of definite and equivalent proportions is of universal extension, and in this aspect it appears as the law of *reciprocal* proportions. When two bodies combine with a third, as they are each equivalents of the third body, so they are also equivalents of each other, and *unite together* in exactly the same proportions; that is, the same number which applied to each in uniting with a third body is retained when combining with each other. Thus, 1 part of hydrogen combines with 8 of oxygen, and 35 of chlorine

combines with 8 of oxygen; but 35 of chlorine is the very quantity that combines with 1 of hydrogen. These numbers may be reversed; 8 of oxygen combines with 35 of chlorine, and 1 of hydrogen combines with 35 of chlorine; but 8 of oxygen is exactly the quantity that unites with 1 of hydrogen: or, again, 8 of oxygen combines with 1 of hydrogen, and 35 of chlorine combines with 1 of hydrogen; but 8 of oxygen is the precise quantity that combines with 35 of chlorine. The doctrine of reciprocal proportions teaches that *the proportion in which any two bodies combine with each other is that in which they combine with every other*. Take a fixed quantity of any substance that has a wide range of affinity—oxygen, for example—and cause it to unite with a large number of elements. The quantity of oxygen in each of these compounds will be the same, but the quantities of the other elements will be very various; nevertheless, when these elements combine with each other, exactly the same quantity of each is taken. Thus, a single combining or equivalent number attached to an element becomes the exponent of its neutralizing or saturating power, in every case of its combination.

30. Chemical decomposition thus often consists simply in the replacement or substitution of equivalents. Potassium, when thrown upon water, decomposes it, forming potash; that is, one equivalent of potassium replaces one equivalent of hydrogen in the water-compound. The group of metallic oxides (PLATE II., right column) may be converted to metallic chlorides by substituting equivalents of chlorine for those of oxygen. We shall see more of this principle of replacement when we come to consider the structure of salts.

31. The equivalent numbers express certain fixed relationships of effect; they therefore have a mutual dependence, and no one can be changed without a corresponding alteration of the whole series. It is immaterial, except as a question of convenience, what scale of numbers we employ, provided their relative values throughout the series are maintained inviolate. Hydrogen combines in the smallest proportion of any element; if we therefore assume its equivalent to be 1, oxygen will be 8, nitrogen 14, &c.; we count but one way, and this scale is considered best for teaching. In analysis, it is common to assume oxygen as 100; hydrogen then becomes 12.5 and nitrogen 175. These numbers have the same relation to each other as 1, 8, and 14. We convert the hydrogen into the oxygen scale by multiplying each of its numbers by 12.5.

32. By glancing at the column of compounds (PLATE I.) there will be noticed a peculiar modification of the law of equivalent and reciprocal proportions. Water, carbonic oxide, and sulphuretted hydrogen, furnish perfect examples of that law; they consist of single equivalents of their elements. But in carbonic acid we have a double proportion of oxygen, and in ammonia a triple proportion of hydrogen. This mode of combination illustrates the law of *multiple proportions*. *It teaches that when one body combines with another quantity larger than its regular equivalent or lowest proportion, that larger quantity, whatever it may be, is an exact multiple of the single equivalent number*. The compounds of oxygen and nitrogen (PLATE I.) furnish a remarkably beautiful illustration of this law. The proportion of nitrogen is the same in all. The smallest proportion of oxygen is its equivalent 8; in the next higher compound it is 16, or twice 8; in the third, 24, or three times 8; in the fourth, 32, or four times 8; in the fifth, 40, or five times 8.

33. If a substance can combine with more than 8 parts of oxygen, the least next

quantity it combines with is 16. It may go past 16, but in that case it cannot stop at any intermediate number short of 24. It need not halt at 24, however, if it can go on to 32, or at 32 if it can combine with 40: or it may pass at once from 8 to 40, or to any other number that is an exact multiple of the original 8. In every series of compounds we discover the operation of the same law. All combinations of sulphur contain either 16 parts of it, or if not, then 32, 48, or some other multiple of 16. Iron occurs in quantities of 28, 56, 84, &c.; that is, its quantity, if above 28 parts, can always be expressed by a number divisible by 28 without a remainder. The numerical laws of combination apply to compounds as well as to elements. *The equivalent or combining proportions of a compound body is the sum of the combining proportions of its elements.* Thus, the equivalent of carbonic oxide is carbon 6, oxygen 8 = 14; of carbonic acid it is carbon 6, oxygen twice 8 = 22. The equivalent for lime is calcium 20, oxygen 8 = 28; of marble it is carbonic acid 22, lime 28 = 50. The number for slacked lime (hydrate of lime) is, lime 28, water 9 = 37. The equivalent for sugar (see PLATE VII.,) is 12 equivalents of carbon, each 6 = 72, 10 of hydrogen, each 1 = 10, and 10 of oxygen, each 8 = 80, which together make 162, the equivalent number for sugar.

34. The establishment of these simple and comprehensive laws of numerical proportion, has led chemists to the invention of a symbolic language, which enables them to express in the shortest manner the constitution of every compound body, the replacement of any of its elements, and the mode in which its constituents are supposed to be arranged. The letters associated with the elements (PLATES I. and II.) represent them, and are termed their symbols. They are the first letters of either the English or Latin names of the elements. Thus, C stands for carbon, H for hydrogen, O for oxygen, P for phosphorus; but as P could not also be taken for potassium without producing confusion, K is adopted for the latter element, from its Latin name, *kalium*. Sometimes by adopting the Latin term we do not quite avoid this difficulty, and so a small letter is added, as Fe for ferrum (iron), F alone standing for fluorine; nor could we adopt I for iron, as that is the symbol for iodine. Chemical composition is represented by combination of the symbolic letters; thus, HO expresses the composition of water, CO of carbonic oxide (see PLATES I. and II.). A symbolic letter represents not only an element, but a single equivalent of an element; O represents 8, or an equivalent of oxygen; N 14, or an equivalent of nitrogen; and S 16, or an equivalent of sulphur. If therefore a compound contains more than one equivalent of a body, the number which it does contain is expressed by small figures appended to the symbols; thus, carbonic acid is C O_2 ; nitric acid, N O_5 ; nitrate of potash, K O N O_5 ; sugar, $\text{C}_{12} \text{H}_{10} \text{O}_{10}$; alcohol, $\text{C}_4 \text{H}_6 \text{O}_2$, &c.

35. The symbolical language is exceedingly simple, and affords the memory great assistance in retaining the facts of chemical composition. Before its introduction, the proportions of compounds were represented in parts per hundred. Thus the composition of water, stated according to the percentage of its elements, is 88.889 oxygen, and 11.111 hydrogen; but in symbolic language the same fact is expressed simply by the letters HO, a double amount by 2HO, a triple quantity by 3HO, and so on.

36. It will be noticed that in the arrangement of letters in a formula which represents the elements in a compound, there is always a certain order. Thus water is represented

by H O, not by O H. The H occurs first, and is always located at the left. In expressing the composition of metallic oxides, the metal is always placed first, or at the left, as K O, oxide of potassium; Fe O, oxide of iron. The same order is preserved in the arrangement of the diagrams, and there is a reason for it. When a binary compound, as water or potash, is decomposed by a current of electricity from a galvanic battery, certain elements are always liberated at the same pole of the battery. For example, the hydrogen of water is always set free at the negative pole, and oxygen at the positive pole; potassium and all the metals at the negative pole, and oxygen, chlorine, bromine, cyanogen, or whatever they are combined with, at the positive pole. Now it has been supposed that these elements were attracted by the poles, and, as when electricity causes attraction, the bodies attracted must be in opposite electrical states, it is assumed that hydrogen and the metals which go to the negative pole are in the electro-positive state—are electro-positive, and that oxygen, chlorine, &c., which are set free at the positive pole, are in the electro-negative state—are electro-negative. The electro-chemical theory, as it is called, assumes that it is this, namely, their opposite electrical states, which causes these elements to combine with each other. The position of the elements of binary compounds, therefore, as represented in the formula or in the diagrams, corresponds to their electro-chemical relation; the electro-positive element being placed first or at the left, and the electro-negative element being placed at the right or last. The salts (PLATE III.) will be seen also to follow this rule, the electro-positive base being placed first, and the electro-negative acid last or at the right. According to this view, when decomposition occurs, electro-positive elements can only take the place of others electro-positive, and electro-negative elements be substituted for electro-negative. The theory is plausible, but it utterly fails in organic chemistry, as we shall see (173.).

37. It has been previously stated that the fundamental laws of chemical combination have been determined by the process of weighing. The balance is symbolic of Chemistry. Says Prof. Liebig, "The great distinction between the manner of proceeding in Chemistry and Natural Philosophy is that the one *weighs*, the other *measures*. The natural philosopher has applied his measures to nature for many centuries; but only for fifty years have we attempted to advance our philosophy by weighing. For the great discoveries of Lavoisier he was indebted to the 'balance,' that incomparable instrument which gives permanence to every observation, dispels all ambiguity, establishes truth, detects error, and shows us that we are in the true path."

38. Yet there are cases in which it becomes convenient to substitute the operation of measuring for the more difficult one of weighing. This occurs when dealing with gases; it being much more easy to measure out a certain *bulk* or *volume* of gas than it is accurately to weigh it. They combine with each other only by equivalents in weight; hence it becomes important to know what amount of bulk or volume is occupied by these equivalent weights of the various gases. This mode of measurement does not apply to solids, unless they are capable of being converted in some way into gases or vapors; it cannot, therefore, be employed upon the great mass of chemical substances.

39. When we take equivalent quantities of the gases and ascertain the bulk they occupy, we do not find that the spaces they fill have the same relation to each other as

the equivalent weights, nor are these spaces all alike; yet a very simple relation subsists between the volumes they do occupy.

40. The manner of proceeding to determine this result is as follows: The equivalent number of oxygen being 8, eight grains of it are taken and placed in a glass stoppered vessel that will exactly contain the quantity. The vessel holds precisely 8 grains of oxygen. The gas is then removed from it, and solid phosphorus introduced in its place. The equivalent number for phosphorus is 32; so we put 32 grains of it into the glass vessel. Heat is then applied, and the solid phosphorus converted into vapor. It is now found that the vapor of phosphorus exactly fills the vessel. The equivalent *weights* of oxygen and phosphorus are unequal. One is 8, and the other 4 times 8, or 32; but when these equivalent quantities are brought into the same condition of vapor, they fill equal spaces. Their *equivalent volumes* are therefore equal.

41. To express the fact that equivalent weights of these bodies give rise to equal volumes of vapor, we make against each an outline square of the same size, thus: oxygen \square ; phosphorus \square .

42. If now we take an equivalent of hydrogen, or 1 grain, and attempt to introduce it into the vessel which held equivalents of oxygen and phosphorus, we find that it will only receive exactly half of it, so that it would require two such vessels as contained the oxygen to hold the hydrogen. The equivalent volume of hydrogen is hence twice that of oxygen, and is thus expressed: hydrogen $\square\square$.

43. The equivalent of nitrogen is 14. If now we take 14 grains of nitrogen and try to put them into the same vessel, we find that, as in the case of hydrogen, it will only hold half of it. The equivalent of chlorine is 35; if we weigh out 35 grains of chlorine, of this, too, the vessel will contain but half. The equivalent volumes of nitrogen and chlorine are therefore the same as that of hydrogen, and are also represented thus; nitrogen $\square\square$; chlorine $\square\square$.

44. Suppose now we desire to combine equivalent *weights* of hydrogen and chlorine gases so as to form hydrochloric acid, we take them in equivalent volumes or equal bulks. And if we wish to unite oxygen with hydrogen in equivalent weights, we would take one measure of the former to two of the latter. Thus, to form water, we fill a vessel one third full of oxygen and two thirds full of hydrogen, and cause them to combine by applying a lighted match or an electric spark.

45. When gases combine with each other, they are often condensed into less space than they occupied before the union; but frequently no change of bulk occurs. In this case the equivalent volume, or, as it is called, the "combining measure" of the compound, is the same as the combining measures of its elements. Thus one equivalent of hydrochloric acid gas, or 36 grains, would four times fill the vessel that contained 8 grains of oxygen. It is therefore thus represented: hydrochloric acid gas $\begin{array}{|c|c|} \hline \square & \square \\ \hline \square & \square \\ \hline \end{array}$.

46. But when hydrogen and oxygen combine, condensation occurs. Two measures of hydrogen, for example, and one measure of oxygen, form only two measures of water-gas or steam; watery vapor occupying only the same space which its hydrogen would fill if it were free. Thus oxygen \square ; hydrogen $\square\square$; steam $\square\square$.

47. When nitrogen and hydrogen combine to form ammoniacal gas, still greater condensation occurs. Ammonia is formed of one equivalent of nitrogen and three of hydrogen, their measures being thus: nitrogen $\square\square$, three equivalents of hydrogen $\square\square\square$ $\square\square$ $\square\square$. Yet, when chemically united, they are reduced to half this space, the measure of ammonia being $\begin{array}{|c|c|} \hline \square & \square \\ \hline \square & \square \\ \hline \end{array}$.

48. A few of the gases occupy the same space as oxygen, more of them occupy a space twice as great, and a still larger number a space four times as great as that of oxygen. The law of combining volumes thus appears a very simple one. Yet there are a few instances in which the combining measure is less than that of oxygen, and others in which it is also greater, and in different proportions than those stated. Still, for the sake of convenience oxygen is adopted as unity.

49. The spaces occupied by gases vary with variations of temperature and atmospheric pressure; these conditions must therefore be taken into the account in conducting measuring operations upon that class of substances.

III.—THEORY OF ATOMS.

50. THE laws of combining proportions, which have been explained, are the naked results of experiment, and are independent of all speculation. They are the expressions of facts, established by direct and multiplied observation, and may be verified at any time by accurately analyzing a few chemical compounds.

51. But the human mind is never satisfied with a knowledge of bare facts. It seeks to know the hidden causes which lie beyond the sphere of observation and experiment. It requires an explanation of the phenomena—a principle that will account for the facts, and that is termed a *theory*.

52. The fame of Sir ISAAC NEWTON is intimately associated with the formation of a *theory*. Bodies fall to the earth, and with accelerated velocities. The planets of the solar system move through space and pass in curved paths round the sun at various rates of speed. These are facts of observation; what is their cause? NEWTON showed that they might be explained, and the phenomena coördinated by assuming the existence of a universal force, acting in a certain manner. He assigned a cause which he proved capable of producing these grand effects; and this mighty conjecture, with its train of demonstrations, constitutes the *theory of universal gravitation*.

53. Now, for that remarkable behavior of affinity by which chemical substances combine in the manner we have seen, there *must* be a cause. There must certainly be *some* cause which makes it impossible for bodies to combine in any other proportions; *something* which opposes an invincible obstacle to the increase or diminution of the combining quantities. What is it? This question has been answered in a clear and most admirable manner. What NEWTON did for Physical Astronomy, by developing the theory of gravitation, Dr. JOHN DALTON has done for Chemistry, in establishing the theory of ultimate *atoms* or the *atomic theory*.

54. The term atom, signifies a portion or particle of matter exceedingly small and not capable of being divided. What is the testimony of observation in regard to the existence of such atoms? Practically, there appears no limit to the division of matter. We meet with continual and most surprising instances of the extent to which this process may be carried. For example:—

55. Gold may be beaten into leaves so thin that 282,000 of them would form a pile of only the height of an inch. Nevertheless such a leaf completely conceals the object which it is used to gild. It moreover protects such objects from the action of external agents as effectually as though it were plated with gold an inch thick.

56. In the manufacture of embroidery, fine threads of silver gilt are employed. To produce these, a bar of silver weighing 180 ounces is gilt with an ounce of gold; this bar is then wiredrawn until it is reduced to a thread so fine that 3400 feet of it weigh less than an ounce. It is then flattened, by being submitted to severe pressure between rollers, in which process that length is increased to 4000 feet. Each foot of the flattened wire therefore weighs the 4000th part of an ounce. But, as in the process of wire-drawing and rolling, the proportion of the two metals is maintained; the gold which covers the surface of the fine thread thus produced, consists only of the 180th part of its whole weight; therefore, the gold which covers one foot is only the 720,000th part of an ounce, and consequently the gold which covers an inch will be the 8,640,000th part of an ounce. If this inch be again divided into 100 equal parts, each part will be distinctly visible without the aid of a microscope, and yet the gold which covers such visible part will be only the 864,000,000th part of an ounce. But we need not stop here. This portion of the wire may be viewed through a microscope which magnifies 500 times, and by these means, therefore, its 500th part will become visible. In this manner an ounce of gold may be divided into 432,000,000,000 parts, and each part will still possess all the characters and qualities found in the largest masses of the metal.

57. Dr. WOLLASTON obtained platinum wire so fine that 30,000 pieces, placed side by side in contact, would not cover more than an inch. It would take 150 pieces of this wire, bound together, to form a thread as thick as a filament of raw silk. Although platinum is among the heaviest of known bodies, a mile of this wire would not weigh more than a grain. Seven ounces of it would extend from New York to London.

58. A soap-bubble, as it floats in the sun, reflects to the eye an endless variety of the most gorgeous tints of color. NEWTON showed that to each of these tints corresponds a certain thickness of the substance forming the bubble. Near the highest point of the bubble, just before it bursts, is always observed a spot which reflects no color and appears black. NEWTON showed that the thickness of the bubble at this place was the 2,500,000th part of an inch! Now as the bubble at this point possesses the properties of water as essentially as does the Atlantic ocean, it follows that the ultimate atoms forming the water must have less dimensions than this thickness.

59. An Irish girl has spun linen yarn, of which a pound was 1432 miles in length; and of which, consequently, 17 lbs. 13 oz. would have girt the globe. A distinctly visible portion of such thread could not have weighed more than the 1-127,000,000th of a grain; and yet these, so far from being ultimate particles of matter, must have contained more

than one vegetable fibre; that fibre being itself of complex organization, and built up of an indefinitely great number of simpler forms of matter.

60. A thread of a spider's web measuring four miles will weigh little more than a single grain. It has been ascertained that the thread which a spider spins, and by which it suspends itself, is composed of about 6000 filaments.

61. The red color of blood is due to numberless minute globules or discs floating in a colorless liquid (*liquor sanguinis*.) In the blood of man these discs are the 3500th part of an inch in diameter; in that of the musk-deer they measure only the 1-12,000th part of an inch. It would require 50,000 of these discs, as they exist in the human blood, to cover the head of a small pin; and 800,000 of those of the musk-deer to cover the same surface. It follows from these dimensions, that in a drop of human blood which would remain suspended from the point of a fine needle, there must be about 3,000,000 of discs; and in a like drop of the blood of the musk-deer, there would be about 120,000,000.

62. But the microscope has revealed still greater wonders. Each improvement in the instrument displays new races of animals too minute to be observed before, and of which it would require the heaping together of millions upon millions to be visible to the naked eye. And yet each of these is composed of members as admirably suited to its mode of life as those of the largest species. Their motions display all the phenomena of vitality, sense, and instinct. Nor are their actions blind and fortuitous, but evidently governed by choice and directed to an end. They have their appetites to gratify and their dangers to avoid. They possess circulating systems, often highly complex, and blood with globules bearing to them by analogy the same proportion in size that ours do to us. And yet these globules themselves, organized, possessed of definite structure and complex composition, lead us to a point where all distinct conceptions of magnitude and measurement cease.*

63. These facts show that down to the utmost limits of human observation and ad-measurement, matter continues divisible; but they show nothing more. They cast no light upon what is beyond. By the strict rule of scientific inquiry, we can be certain of the divisibility of matter no farther than it is proved by observation. There is no warrant to infer that beyond the bounds of direct investigation matter continues divisible. Observation has not disclosed the existence of ultimate atoms, nor has it disproved it. The microscope shows that within the utmost range of its powers, and even farther down in the regions of tenuity, no indivisible particles exist. But from this point onward to *infinite* divisibility, the distance is infinite, comprising a boundless range of possibility. Direct experience therefore affords no aid in settling the question of the existence of atoms; it must be decided, if at all, by other considerations.

64. Now the chemist has numerous and powerful reasons for believing that all matter is composed of atoms, that is, of exceedingly minute unchangeable particles. It has been objected that we cannot conceive particles so small that, if possessing weight, bulk, and figure, they may not be halved or divided into lesser quantities. Granting that, chemists yet find themselves compelled to assume that nature does ultimately limit the divisibility

* Condensed from Kane's Chemistry and Lardner's Hand-Book of Natural Philosophy.

of matter. It is not insisted that in an *imaginary* point of view, atoms are incapable of division, but only that in point of fact they are not for ever divided. An atom may consist, if you please, of numerous small imaginary atoms; but, PHYSICALLY, it is considered indivisible and unchangeable.

65. We may compare these ultimate units of matter to merchandise put up in certain forms, which in commerce are never broken or divided. Thus many kinds of goods pass through the dealer's hands, sealed up in parcels, packages, bottles, cans, and boxes, and which the merchant never opens. In a practical commercial sense they are indivisible, although absolutely they are not.

66. The constitution of matter upon the largest scale may also afford an illustration of the way chemists suppose it to be constituted upon the smallest scale. The celestial universe is composed of mighty orbs distributed into innumerable systems throughout the starry regions. Yet, so vast are the distances asunder at which these orbs are set, that they shrink to apparent points—mere luminous particles. Compared with the spaces through which they move, they exhibit the minuteness of atoms, and in the scheme of nature they are indivisible. As there exists no force capable of separating them into parts, or of perceptibly altering their size or form, they are in this sense indestructible units. The whole universe coalesces, in this view, into one immense compound, the atoms of which, that is, suns, planets, and satellites, are indivisible and unchangeable.

67. All matter is thus believed to be composed of ultimate, impenetrable, and imperishable atoms, which are endowed with certain determinate properties that we can neither alter nor destroy. The visible objects of nature are looked upon as being formed by the close arrangement of these particles or molecules, as a massive edifice is constructed by placing together a multitude of hewn stones or moulded bricks. Being hard and impenetrable, these particles do not fuse or run into larger particles, as two drops of a liquid metal like quicksilver flow together into a larger drop; but under the influence of various constraining forces, as cohesion, affinity, or electrical power, they arrange themselves side by side, or in groups.

68. Assuming that matter thus consists of associated atoms, the atomic theory teaches, 1st, that all the atoms of the same element possess exactly the same weight; 2d, that atoms of different elements possess different weights; and 3d, that the number that indicates the weight of an atom of any element is the same as the combining or equivalent number for that element. For the vague and misty conception of abstract proportion, we substitute the distinct idea of a solid, ponderable atom. Its weight, compared with other atoms, is its combining number. 1 is to be considered stamped upon every particle of hydrogen, as if the whole amount of it in the globe had been coined at the same mint into pieces of exactly the same value. Carbon, in like manner, is supposed to have its atoms stamped with 6, oxygen with 8, sulphur with 16, &c.

69. It is a sufficient recommendation to our acceptance of the foregoing simple propositions, that they afford a rational and most satisfactory explanation of the laws of combining proportion. Indeed, if they are once admitted, these laws follow as a necessary consequence. Thus, if water is formed by the combination of oxygen and hydrogen. atom to atom, then its composition must be definite and constant. Every specimen of

water must yield exactly the same number of atoms of oxygen weighing 8, and of hydrogen weighing 1, so that it will be found to contain 1-9th of its weight of one gas, and 8-9ths of its weight of the other; and this must be the invariable result, whether we analyze grains or tons. Again, if the atoms of each element possess immutable weights, they must in all their combinations exhibit equal and reciprocal values. Replacement can only take place in equivalent proportion. Multiple proportions also result directly from the unity of atoms. As the least quantity of an element in combination can be increased only by the addition of whole atoms, so the number expressing the higher quantity must be an exact multiple of the single atomic number. No fractional quantity of any element or substance can be added, because the combining atom cannot be fractured.

70. A reference to any of the accompanying diagrams of composition exhibits the atomic theory in its utmost simplicity. Each colored square represents an ultimate atom. They are seen to be grouped or aggregated together, and not mutually diffused throughout each other—the integrity of each being maintained. As atoms are indivisible, so all squares that symbolize the same element preserve an invariable size, and are never divided.

71. It has been lately remarked that “if the atomic theory is not true it deserves to be,” so clearly does it account for the phenomena of chemical combination. The strength of the faith of modern chemists in its reality, may be well illustrated by quoting the language of LIEBIG. “Without disputing the infinite divisibility of matter, the chemist merely maintains the firm and immovable foundation of his science when he admits the existence of physical ATOMS as a truth entirely incontrovertible.”

72. Such advantages does the theory offer to the mind, both in the acquisition and retention of chemical knowledge, that it has been universally adopted. The mind seizes upon the conception of solid particles more readily than upon that of abstract numerical ratios. Hence the language of the atomic theory is in current use. We say “atom” rather than “proportion,” and “atomic number” rather than “combining number” or “equivalent number.”

73. We must not confound the idea of atomic number with number of atoms. The number of atoms in water is 2, its atomic number is 9, and results from adding together the numbers which are supposed to be stamped upon each of these atoms. The same remark applies to equivalent number and number of equivalents. Beginners are sometimes confused by the statement that the composition of water is 1 to 1 and also 1 to 8. 1 to 1 refers to the number of atoms; 1 to 8 to the comparative quantities of matter, by weight, in these atoms. The diagram (PLATE I.) will make this perfectly clear.

74. It is common to apply the term atom to the smallest number or group of atoms that can form a compound. Thus we speak of the two atoms that compose water as an atom of water. So also we say an atom of carbonic acid, an atom of sugar, of gluten, &c.

75. As from the minuteness of atoms they do not admit of inspection, nothing can be known of their form or shape. Many suppose them to be globular, and represent them by circular figures. But if conjecture is to be indulged upon this point, we should suggest that the globular form is more characteristic of *physical* phenomena, as shown,

for example, in the spherical shape of the planets; while the phenomena of crystallization would seem to associate angular forms with the idea of Chemistry. When atoms of the utmost minuteness gather from solutions into solids, they assume the angular figure of crystalline structure; and the crystals are built up in exact geometrical forms by the constant addition of atoms. May we not then almost venture to suspect that the ultimate atoms themselves have angular forms? With no reference however to speculative notions, I have adopted the square form of symbolic diagrams as the most convenient to represent unity of composition, by arrangement side by side, and also exact comparative quantities to the eye.

IV.—CONSTITUTION OF SALTS.—THEORY OF SALT-RADICALS.

76. By the union of the elements there result two classes of compounds with widely different properties, termed *acids* and *bases*. In PLATE I. is represented the composition of several of the most important acids; in PLATE II., of the most frequently-occurring bases. Acids are usually distinguished by sourness of taste and by the power of altering vegetable colors—changing blues to red; while alkaline bases have a peculiar acrid burning taste, and so far as vegetable colors are concerned, they undo the work of acids, restoring vegetable reds to blue. But these tests, although useful in ordinary cases, are by no means universally applicable. Some acids and bases have no taste whatever and exert no influence upon vegetable colors.

77. Acids and bases have an affinity for each other, and this is their true test. Any substance is an acid which is capable of combining with a base, and of destroying or reducing its basic properties; and any compound is a base which can combine with an acid, and thus neutralize or diminish its acid properties. In the union of acids and bases the distinctive properties of both are lost and a new compound with new properties results, which is known as a *salt*. Thus, if muriatic acid is added to soda, common salt is produced; if nitric acid is added to potash, saltpetre results; sulphuric acid added to lime, gives rise to a salt, sulphate of lime; gypsum and sulphuric acid with soda, give "Glauber's salt."

78. It would thus seem that the chemical structure of salts may be a very simple affair. Yet the question how they are constituted, the question indeed as to what is the true idea of a salt—what bodies the class shall comprehend and what reject, is by no means easy to answer. Two views are entertained upon the subject, which have given rise to much and earnest controversy among chemists. In the ordinary mode of treating chemical topics, this question is a very difficult one to present, especially to those untrained in the elements of the science; but by means of our colored illustrations the rival theories become at once clear, simple, and interesting even to beginners.

79. PLATE III. represents the composition of two salts, nitrate of potash and sulphate of iron, according to the old and long established view. They consist each of an acid combined with a base; in the first example, nitric acid with potash; in the second, sulphuric acid united to oxide of iron. Each salt has been supposed to consist of a pair of binary compounds, and is thus represented. These elements go into combination, and

upon analysis we recover them again. Other acids, phosphoric and carbonic, as well as nitric and sulphuric, unite with various bases and give rise to numerous salts in a similar way. Thus, an acid in combination with an alkali or base, was regarded as constituting a true salt.

80. Furthermore, if hydrochloric acid and soda, both binary compounds, are brought into contact, they unite, and common salt is formed. They apparently combine as in the other cases, and with a like result. But here arose a difficulty. It was discovered that common salt is produced not by the simple *combination* of hydrochloric acid and soda, but actually by their destruction—by their decomposition and the rejection of a portion of their constituents. In the analysis of common salt, we find not the two binary compounds which we used to produce it, but only a half of each. Instead of consisting of two binary compounds, common salt is itself but a binary compound—chloride of sodium. Its formation, by double decomposition, is represented by the diagram (PLATE III.). The acid and base, hydrochloric acid and soda, when brought together are seen not to unite. They are split and exchange elements; two new compounds are formed, common salt and water. The course of the arrows shows the direction in which the elements pass. This is an instance of what is known as double decomposition. Common salt, in its usual form, contains water, called *water of crystallization*, and it may be driven off by heat, without destroying the salt.

81. Now it is evident that if we adhere to the old idea of a salt, common salt, the very type and original of this class of compounds must be excluded from it and denied the saline character. Chlorine also combines with other metals, forming compounds similar to chloride of sodium. The elements, bromine, iodine, and fluorine, behave like chlorine, producing binary compounds with the metals. These have been all ranked together, and, in consequence of their resemblance to sea-salt, have been designated *haloid* salts. The elements just enumerated, which unite with metals to form these salts, are termed *halogens* (salt-producers). But these haloid compounds certainly cannot be regarded as salts unless we modify our old conception of what a salt essentially is.

82. The doctrine of salt-radicals is an attempt to relieve the subject of its difficulty. It offers us a new view of the constitution of salts, claimed to be more comprehensive and just. The doctrine seems to be gaining favor with leading chemists, although it is not yet sufficiently well established to revolutionize the nomenclature. It begins by remodeling the old idea of the structure of acids.

83. When oxygen was discovered, and first made a subject of inquiry toward the close of the last century, its presence was detected in many acids. It was supposed to be the universal acidifying principle, and hence named oxygen (*acid-producer*). But this opinion was afterward found to be erroneous. Powerful acids were discovered which contained no oxygen; and so far from being peculiar to acids, this element was found to be even more universally a constituent of bases, and might hence, with better propriety, be named a base-producer. The class of acids in which oxygen exists are termed *oxacids*.

84. Now chlorine and several other elements combine with hydrogen and form a class of acids in which this latter element is the common principle, and they are hence termed

hydracids. The elements which here combine with hydrogen are called *radicals*; so H R (hydrogen and radical) represents the composition of each of the hydracids.

85. There are two kinds of radicals. Chlorine, iodine, &c., being undecomposable bodies, are called *simple* radicals. But there are certain remarkable compound bodies which behave in exactly a similar way with these simple elements, and are hence called *compound radicals*. One of these is known as cyanogen; it consists of two atoms of carbon united to one of nitrogen, and comports itself, in relation to other substances, precisely as if it were a simple element. It combines with hydrogen (PLATE III.), forming an acid, hydrocyanic or prussic acid, just as chlorine with hydrogen forms hydrochloric acid. The prussic acid, to be sure, as we see, has three elements, but it is nevertheless considered, in the manner of its union, as strictly a binary compound—a hydracid containing a *compound radical*.

86. It has long been known that the acid properties of the oxacids, sulphuric, nitric, &c., are only developed in the presence of water. They combine with water, forming what are called hydrates, and it is only in this state that they become strong and active. The advocates of the later theory insist that, as these compounds do not take on distinct and decided acid properties, except by association with water, therefore they are not true acids, except in combination with water, in the condition of *hydrates*. It is objected that this view does not hold true of carbonic and silicic acids, which are not thus united with water. To this the adherents of the radical theory reply, that these compounds “possess very feeble and ill-marked acid properties, being incapable of neutralizing the alkalies, and forming with them an almost unlimited number of compounds.”—GREGORY.

87. As therefore the class of hydracids all contain hydrogen, and as the oxacids do not manifest decided acid powers, except in union with water, which also contains hydrogen—as therefore hydrogen is present in *both* classes of acids, it is maintained by the partisans of the new doctrine, that hydrogen, instead of oxygen, is the real acidifying principle.

88. The way in which water has been generally supposed to be united to the acids is shown in PLATE III. It has been looked upon as combining in the same manner as a base, so that hydrated sulphuric acid appears as a sulphate of water; hydrated nitric acid as nitrate of water. They were considered as double binary compounds, analogous in structure to the salts, sulphate of iron, and nitrate of potash.

89. Those who adopt the salt-radical view, object to this. They say we have no evidence whatever that water combines with the dry acid in this manner; that we are under no necessity of regarding the hydracids and oxacids as differently constituted, forming two classes with but one property; and that, as they exhibit a common character, they have a common structure also.

90. The new theory therefore supposes, that the elements which unite with hydrogen in the oxacids *exist in the form of a compound radical*, and that the hydrogen is united directly to this radical, forming a binary compound—a true hydracid. Thus in sulphuric acid, the hydrogen is supposed to be united to a compound, consisting of one atom of sulphur and four of oxygen, $S O_4$ (PLATE III.). This supposed compound has received the name of *sulphion*. In nitric acid, the hydrogen is believed to be united to a compound

radical, N O_6 , named *nitration* (pronounced nitrati-on, with a hard *t*, and the *tion* as a dissyllable). This brings the acids all into one class. As hydrochloric acid is a chloride of hydrogen, and hydrocyanic acid is a cyanide of hydrogen; so sulphuric acid is a *sulphionide* of hydrogen, and nitric acid a *nitrationide* of hydrogen. Phosphoric acid is also assumed to have its radical *phosphion*, P O_6 ; and, in the same manner, all the oxacids which combine with the elements of water.

91. The advocates of the old view object that these alleged compound radicals, sulphion, nitration, &c., have not been isolated or separated, and cannot be proved to exist. To this it is replied, that compounds of this nature have been isolated, and do exist, in the separate condition, as cyanogen and several others. The existence of such a class is therefore established. Again, that chemists must and do admit the existence of many compounds which have not yet been set free;—that the dry nitric acid N O_5 was long admitted to exist, although unknown in the separate form, and has been but lately obtained in a free state; and that the radicals S O_4 , or N O_6 , are liable to be set free at any time.

92. From this point of view, the composition of salts becomes a very simple matter. By replacing the hydrogen of hydrochloric acid with the metal sodium, we get common salt (PLATE III.). By replacing the hydrogen of hydrocyanic acid by the metal potassium, we produce a salt—cyanide of potassium. So by replacing the hydrogen of sulphionide of hydrogen, by iron, we have the salt sulphionide of iron, or copperas; and by replacing the hydrogen of nitrationide of hydrogen by potassium, we get nitrationide of potassium, or saltpetre.

93. Hence, according to Dr. GREGORY (one of the latest and ablest expositors of this view), “an acid is the hydrogen compound of a simple or compound radical, possessing the power of neutralizing bases; and its general formula is H R (hydrogen and radical).” Hence, also, the definition of a salt, according to the newer view, as given by Dr. GREGORY: “A salt is the compound formed by replacing the hydrogen of an acid by a metal, and the general formula for a salt is M R (metal and radical).”

94. It may be noticed, that whatever view we take of the structure of an acid, if it contain water, it is turned into a salt by substituting a metal for its hydrogen. All the diagrams in PLATE III. concur admirably to illustrate this fact. It will be also now understood why chemists incline to consider hydrogen as belonging to the class of metals, although in its separate state it is an invisible gas, and the lightest substance known. As it assumes the relationship of the metals, keeps their company, and performs their offices, it is thought entitled to be ranked with them. If it be light, so also is potassium, which floats upon water like cork; if it be an invisible gas, so also is vaporized mercury; and yet nobody doubts that these are metals.

95. The group of compounds with phosphoric acid (PLATE III.) illustrates, in a striking and beautiful manner, the part played by water in union with oxacids, and also the phenomena of replacement. This acid combines with water in three proportions. An equivalent of acid combining with a single equivalent of water, forms the monobasic phosphoric acid; an equivalent of acid to two equivalents of water, gives rise to bibasic phosphoric acid; and one of the acid to three of water, produces tribasic phosphoric acid.

Now, by substituting alkalis or metallic bases for the combined water, we get three distinct and independent series of salts, namely, monobasic phosphates, bibasic phosphates, and tribasic phosphates. The proportion of water which the acid contains, determines the proportion of alkaline base with which it will unite.

96. The monobasic acid gives rise to a series of monobasic salts, of which monobasic phosphate of soda is an example. The bibasic acid produces a series of bibasic salts, in which one atom of water may be expelled by an alkali and the other retained; or two atoms of alkali may replace both atoms of water, as the symbols indicate (PLATE III.). A third series of salts is formed by the tribasic phosphate of water, in which the water atoms may be successively replaced by one, two, or three atoms of an alkali, forming three different salts, as is shown by the colored illustrations.

97. I have here selected the phosphate of lime, as being most interesting in an agricultural point of view. The phosphate of lime, as it occurs in bones, is tribasic; that is, there are three atoms of lime united to one of phosphoric acid. This is distinguished as the basic phosphate of lime. From this salt an atom of lime may be expelled; but an atom of water takes its place, so that the tribasic type is retained: it is then called neutral phosphate of lime. By expelling another equivalent of lime, and replacing it by water, we get the superphosphate of lime;—an equivalent of phosphoric acid, an equivalent of lime, and two of water.

98. The tribasic phosphate, or “basic” phosphate, as it exists in bones or the mineral apatite, &c., is very insoluble in water, and therefore acts but slowly in the soil. To insure a more prompt effect, it is changed to the superphosphate. This is done by adding sulphuric acid to bone-dust, which takes away the lime from the phosphoric acid. A certain proportion of sulphuric acid removes two atoms of lime; thus changing the “basic” to the “super”phosphate. A larger quantity of sulphuric acid withdraws all the lime, and leaves the phosphoric acid.

99. The salts of phosphorus are represented according to the old view; but it will be seen that the acids are all changed to salts, by simply replacing their hydrogen by a metal. They may be expressed, according to the new view, by supposing the existence of three compound radicals, PO_6 , PO_7 , and PO_8 . These combine with hydrogen in the acids thus: H PO_6 , $\text{H}_2 \text{PO}_7$, $\text{H}_3 \text{PO}_8$; and their salts (M standing for metal) will be M PO_6 , $\text{M}_2 \text{PO}_7$, $\text{M}_3 \text{PO}_8$. This view is preferred by GREGORY and LIEBIG.

100. We have seen that the elements are endowed with strong affinities, and unite in pairs to produce acids and basis; these again have powerful tendencies to combination, and give rise to salts; but at this point combining power nearly ceases. Salts, it is true, combine with each other to form double-salts, but by no means indiscriminately. With rare exceptions, the combining salts have all the same acids: sulphates combine with sulphates, and chlorides with chlorides. Their bases, or their metals, must, however, be widely different from each other. There is no resemblance between the structure of double-salts and that of simple salts themselves: one does not, as has been supposed, act the part of an acid, and another of a base. Examples of double-salts will be observed in PLATE IV.

V.—CHEMISTRY OF GEOLOGY—HOW ROCKS ARE CHANGED TO SOILS.

101. The rocks which appear at the earth's surface, and which are said to compose its crust, are of two kinds. Some of them occur in sheets or layers (strata), of various thickness, and are called the *stratified* rocks; others exhibit no evidence of layer-structure or stratification, but are found in great rounded or irregular masses, and are termed the unstratified rocks.

102. These two classes of rocks seem to have quite different origins. The unstratified rocks give evidence of having been formed by fire. They seem to have been melted, and to have cooled and assumed the crystalline state under great pressure, and not exposed to the air: they are therefore termed *igneous* rocks. The great mass of the stratified rocks, on the other hand, are not crystalline, and appear not to have been melted, or to afford any evidence of the action of fire. They give assurance of having been deposited from water, in the shape of sediment, which has been gradually solidified and hardened into rock by the pressure of the watery mass and other causes. They are therefore called *aqueous* or *sedimentary* rocks.

103. The stratified rocks contain innumerable traces and remains of living beings, animals, and plants, which seem to have been imbedded or wrapped up in the sedimentary matter as it has been deposited. These relics and vestiges are termed *fossils*, and the rocks which bear them *fossiliferous* rocks. We find nothing of this kind in the igneous or crystalline rocks. They are called *non-fossiliferous* or *azoic* (without life).

104. There is a class of rocks which possesses the stratified arrangement, and yet contains no fossils: they are crystalline, and have evidently been acted upon by fire. They are considered as stratified, water-formed rocks, which have been changed or altered by heat, their fossils burnt out or obliterated, and their particles thrown into the crystalline order. They have obviously been *metamorphosed*, and are therefore named *metamorphic* rocks.

105. Our knowledge of the strata has not been obtained by digging or excavating down through the successive layers. It so happens that the strata do not, except in rare cases, remain in the position in which they were formed. They have been broken and thrust upward, so that their edges appear at the surface, or, as it is termed, "crop out." Had the rocks remained as they were deposited, we could know little or nothing of them. It is this circumstance of their inclined position, by which we can inspect them directly in passing over a country, that makes geology possible.

106. It is believed that the changes which the earth's surface has undergone in past ages are of the same kind as those now going forward upon its surface. There is a question, however, as to the *intensity* with which forces have acted, and the speed with which alterations have occurred, in former times. It has been generally imagined, and many still suppose, that the earth was formerly the scene of agencies acting with vastly greater power and violence than they do now. Yet some of the profoundest inquirers of the present day think we need resort to no such hypothesis to explain the geological changes which the earth has undergone; but that the forces now operating to alter and modify

its surface at their present rates of activity are altogether adequate to have effected whatever has been done.

107. It is demonstrated that the existing rocks are now wearing and wasting away, and that new ones are in process of formation. Various causes (141) are cooperating to decompose and disintegrate the rocky masses, and crumble them down into the condition of soil. Running water transports these loose materials to the lower levels, deposits them in the beds of lakes, rivers, and oceans, where they are gradually compressed and cemented into new rocks. By the present action of subterranean fire, as manifested in earthquakes and the throwing up of volcanic islands, these new layers are heaved from their beds, dislocated, and forced into all varieties of position. Slow sinkings and elevations of vast tracts of land are also frequently noticed. And not only is the sea gradually filling up its bed with matter brought down from the continents, but by the undermining and lashing action of currents and waves, it in many places makes inroads upon the land, while in others it continually adds new matter to the beach, and thus slowly retires from the shore. Causes are therefore now at work, which require only the addition of the element of time to change the present continents to oceans, and the existing oceans to continents. Geologists find abundant evidence that great alterations of this kind have already taken place. Mr. LYELL says: "It can be shown that the earth's surface has been remodelled again and again; mountain chains have been raised and sunk; valleys formed, filled up, and then reëxcavated; sea and land have changed places; yet throughout all these revolutions, and the consequent alterations of level and general climate, animal and vegetable life has been sustained."—*Manual of Geology*, p. 501.

108. Now as these forces have been at work, and such effects produced actively and constantly in past time, it is evident that geological phenomena must present a progressive and successive order. THERE IS AN ORDER OF THE ROCKS THAT CORRESPONDS TO THE ORDER OF TIME. There are earlier and later, older and newer rocks. They certainly could not have been contemporaneous in origin. Each formation (as a series of strata produced under the same general circumstances are termed) has therefore its "age" or "epoch," and the whole system a chronological order of succession.

109. If, therefore, the rocks had a fixed order of occurrence—were successively formed—it follows that they must have a corresponding order of *position*. Succession of time involves succession of place. As there are older and newer rocks, so there are lower and higher rocks. The lower correspond to the older, and the higher to the more recent. If we represent the order of formation, beginning with the most ancient, by the numbers 1, 2, 3, 4, 5, 6, the same arrangement of figures may represent the ascending series of those formations: as 6 is the latest, so it will also be the highest. This will illustrate what is meant by the order of *superposition* of rocks.

110. It is not to be understood that all the rock-formations known are every where piled one above another, in a uniform, complete, and uninterrupted series. There is, indeed, no one place where the continuous and unbroken series can be observed. There is every where an absence of some of the members of the series: there are defects and gaps in it, but never an inversion of it. If we represent the order of position by the above-mentioned arrangement of numbers, then, in particular cases, we shall have a lack of some

of them, as of formations 2 and 3: formation 4 will then rest upon formation 1, and the actual order will be 1, 4, 5, 6. But although the order may be imperfect or deficient, we never find it contradicted, as, for example, 1, 3, 2, or 5, 4, 6. A formation may be found resting *upon* any which belongs below it, but it is never found *beneath* them.

111. The completeness of the series is established by comparing the observations of various localities. If at one place formations 2 and 5 are missing, observation at another place may give formations 1, 2, 3, 4, and further investigation at other points present 3, 4, 5, 6, by which the entire series is determined.

112. As the series of formations is nowhere complete, and as the strata have been almost universally removed from the positions in which they were formed, the task of determining the true order, and of assigning to each its proper position, has been one of great labor and perplexity. Their aspects and properties, physical and chemical, have afforded aid in identifying and arranging them; but the chief clew to their relationships has been found in the study of their fossils. So diverse and almost innumerable are the living tribes of plants and animals that inhabit earth, sea, and air, and so endlessly varying in different portions of the globe, that we can easily understand how traces of these should become the peculiar characteristic marks of the rock-formations that retain them—the indices of the earth's earlier changes and conditions. They are the monuments of geological transition and progress, and have been aptly denominated the “medals of creation.” By the aid of these lights, science disentangles the curious history of the rocks, and establishes their true order. It has been said that the geologist proceeds to arrange the rocks as he would the loose and disordered leaves of an unpagged book, by means of the natural connection and continuity of its narrative or history.

113. PLATE IV. presents an ideal section of the earth's crust, in which all the formations are supposed to be present in their true relative positions. At the right we see the successive layers that would be discovered by sinking a shaft downward, or cutting vertically through them. In consequence of their inclined positions, the same strata appear at the surface, and may there be observed in the same order. They are, however, much covered or masked at the surface, by beds of water and layers of soil, as is shown upon the diagram. The different formations are represented by different colors.

114. Geologists agree upon the order and position of rocks, but not upon their classification and nomenclature. They divide and name them differently. The system of division presented in PLATE IV. is perhaps the one most generally received.

115. It might be supposed that, in the immense mass of rocks which make up all the accessible parts of the earth's crust, there would be found the largest diversity of materials. Yet the bulk of all the great rock-formations consists of only about ten or twelve chemical elements—the same which we have represented in the preceding plates. These elements unite in the form of minerals, and these minerals, either in their simple state, or combined together, or variously decomposed, give rise to the rocks. (The term “rock,” in its geological acceptation, applies not only to the solidified stony-formations, but to less cohesive and compact structures, as sand and clay beds).

116. Now the number of minerals known is quite large, and there prevails an impression that in studying geology we encounter a formidable array of them. This is an error.

The entire series of rock-formations with which Geology acquaints us, is constituted in the great mass of only seven simple minerals. These compose, at least, nineteen twentieths of all the geological systems. Other minerals, indeed, occur, distributed through the formations, but in comparatively minute quantities.

117. The minerals that are of geological importance are: 1. Quartz; 2. Talc; 3. Serpentine; 4. Hornblende, or Augite; 5. Feldspar; 6. Mica; 7. Carbonate of lime. The composition of these is presented in the geological chart (PLATE IV.).

118. Quartz is a mineral with which all are probably familiar. It is often seen in six-sided, transparent crystals, which scratch glass: they are picked up in the field, and are vulgarly called diamonds. It however exists in a great number of aspects, containing minute traces of various metals which impart varieties of color. It constitutes a large variety of precious stones. It is by far the most abundant mineral upon the globe: its two elements exist in the largest quantity of any which form the solid mass of our earth. It is more than half oxygen: there being 22 parts of silicon to 24 of the former element. It is called silica, or silex, and breaks or crumbles down into fine grains, which are called *silicious* sand—the most common and abundant of all the sands. These sands are sometimes cemented together, or solidified to a stony hardness; they then form *silicious rocks* or *sandstone*.

119. Quartz or silica, in its ordinary form, is insoluble and inert; yet, when melted, it becomes an acid, combining with alkalies and metallic bases to form a large family of salts—the silicates. Thus glass results from the melting and union of silica with potash, soda, or lime: it is a true salt, silicate of potash, soda, or lime. Now, when combined in minerals, silica exists in the same relationship. It forms minerals by uniting with bases, which therefore have the saline constitution.

120. *Talc* is a soft, pearly-looking, greenish-white mineral, with an unctuous or soapy feel. It is a silicate of magnesia. *Serpentine* is a silicate of magnesia, with oxide of iron. It is of a decided green color, often variegated or mottled. *Hornblende* is a dark green or black mineral—a triple silicate of iron, magnesia, and lime. *Augite* is identical with hornblende in composition, differing from it only in crystalline form. *Feldspar* is a reddish or flesh-colored mineral—a double silicate of alumina and potash. In different varieties the potash is replaced by soda or lime. *Mica* is a mineral made up of thin elastic plates or scales, which are easily separated, and is of a shining black, brown, or silver color. It is likewise of a saline structure—a silicate of potash, alumina, and iron. *Carbonate of lime* is found of nearly all colors and aspects, as chalk, marble, and limestone. It consists simply of carbonic acid and lime.

121. The composition of all the above minerals is not settled with precision, as there is considerable variation in different samples. Other substances not mentioned are sometimes found in them in small quantity; but the diagrams of PLATE IV. exhibit them with sufficient accuracy for purposes of general information.

122. The structure of these minerals is placed before the eye in PLATE IV., opposite the geological series to which they give rise. Let us now see how the rocks are constituted of these mineralogical elements. The oldest and deepest rock is granite. It is primary, igneous, unstratified. It lies beneath all the other formations, and also rises

above them, constituting the highest summits and the rocky mass of the great mountain chains of the globe. The minerals which compose granite are quartz, feldspar, and mica. Distinct crystalline fragments of each mineral are perceptible in granite: when these are large, it is called coarse-grained; when small, fine-grained. The proportion of these minerals may vary: when mica prevails, the rock has a dark color; if feldspar abounds, it has a flesh-color; while, if quartz predominate, it has a whitish aspect. Sometimes hornblende is added to these regular constituents of granite; we then have syenitic granite. If the hornblende is substituted for mica, we have syenite, composed of quartz, feldspar, and hornblende. If the rock contains numerous crystals of reddish feldspar, it is termed *porphyritic granite*, or *porphyry*.

123. Thus, in composition, granite is the most complex of rocks. It is oldest in the order of time, highest in position, and is known to contain very nearly, if not quite, all the elements which enter into the later formations. It is hence supposed to be the primal source from whence the materials of all the other and later rocks were derived. By decomposition, its quartz yields sand and sandstones, and the silicious elements of innumerable rocks. Its feldspar and mica produce the clay of clay-beds, slates, and argillaceous rocks; while the lime of limestones, chalks, marls, and calcareous rocks, may perhaps have come from those varieties of granite which contain this ingredient.

124. The metamorphic rocks lie immediately above the granite. They consist of several members. *Gneiss* is a rock usually lying directly upon granite. It is similar to it in composition, and passes insensibly into it; so that it is impossible often to determine the exact line which separates them. It consists of quartz, feldspar, and mica; the feldspar being less abundant than in granite, and the quartz in fine grains. The term gneiss is derived from a word signifying to sparkle; the mica it contains giving it a glistening aspect. Gneiss has been called stratified granite.

125. Gneiss often changes or passes into mica slate. In this rock the feldspar disappears, and the mica is more abundant. It possesses a more perfect slaty structure than gneiss; that is, a capability of being split into leaves or lamina. *Hornblende* slate is composed principally of hornblende, with a variable quantity of feldspar, quartz, and mica. It often passes imperceptibly into mica slate. Talcose slate consists of talc, sometimes pure, but often mingled with quartz, feldspar, and mica. *Steatite*, or *soapstone*, is a variety of this rock, of a grayish-green color, a "greasy feel," and consists largely of talc. Chlorite slate is another variety of the same rock.

126. *Clay slate*, or *argillaceous shist*, is found both in the metamorphic rocks and also higher up in the series. It consists of a very fine mixture of mica or talc, with quartz, a very large proportion of argillaceous matter, a little oxide of iron, and some of the alkaline earths. It often occurs interstratified with mica slate and quartz rock; and, in proportion to its nearness to granite or other igneous rocks, it becomes more highly glazed, changing gradually into talcose, hornblende, or mica slates. Passing in the other direction (higher up, or further from the fire-formed rocks), its lustre becomes more dull, and its texture less compact,—it is called shale: and still further up in the series it exhibits itself in beds of clay (ST. JOHN).

127. *Serpentine* occurs as a stratified metamorphic rock. *Quartz rock*, when pure, has

little or no tendency to stratification ; but when mixed with other minerals, as it often is, it tends to divide into parallel beds.

128. *Primary*, or *crystalline limestone*, among the metamorphic rocks, occurs in thick beds, and in thin leaves, interstratified with gneiss, mica slate, and clay slate. It is a simple carbonate of lime, crystalline, close-grained, and pure white ; the foreign matters, which darken and discolor common limestone, having been burnt away by the heat to which this class of rocks has been subjected.

129. With the igneous granite, and these metamorphic or fire-changed rocks, another class, formed by the agency of heat, may also be associated. They originally existed in the melted condition, and were thus thrust through and between the strata, in the form of dykes and veins. Prominent among these is the *trap* family ; so called from the word *trappa*, a stair ; because the molten mineral matter thrown up to the surface assumed, in cooling, the form of tabular masses, rising one above another, as terraces or steps. There are several varieties of trap rocks. *Greenstone* is of a dark-green color, either massive or in tables, and consists of an intimate mixture of feldspar and hornblende. *Basalt*, which is often found in regular pillars, called basaltic columns, consists of augite and hornblende. *Trachyte* is composed of feldspar, with a small proportion of hornblende, iron, and mica.

130. The lava from volcanoes is mainly composed of feldspar and hornblende, or augite, although many other simple minerals are found distributed through it. In the dark-colored lavas, augite is the leading ingredient ; in the light-colored lavas, feldspar predominates.

131. Upon the metamorphic rests the *silurian* system ; so called from the *situres*, an ancient tribe which inhabited a portion of Wales where these rocks were first investigated. This system is supposed to contain the oldest fossils ; that is, the earliest traces of organic life. It embraces numerous rocks, consisting of sand, clay, limestones, flagging-stones, and slates, some of which are very fine-grained. It also contains pebbles and fragments of rocks cemented together into what is called conglomerate.

132. The *Devonian system*, or *old-red sandstone*, is composed of conglomerates, sandstones, and marls, which consist of calcareous (limey) matter, mixed with a large proportion of clay or other earthy substance. The prevalent color of its marls and sandstones is a dull-red, due to the peroxide of iron. It is called old-red sandstone, to distinguish it from the new-red sandstone, which is higher in the series. It is known also as the *Devonian system*, because it was first thoroughly studied in Devonshire, England.

133. The carboniferous (coal-bearing) system consists of limestones alternating with sandstones and shales, which consist of hardened, slaty clay. These are interstratified with beds of coal, derived from an ancient vegetation, and containing very many fossil plants.

134. Upon the carboniferous system rests the new-red sandstone, lower and upper ; the lower being also termed the *permian* system, and the higher the *triassic* system. The leading member of the lower new-red sandstone is the magnesian limestone—a rock composed of carbonate of lime and carbonate of magnesia, and known as *Dolomite*. It

also contains marls, with red and green sandstones. The upper new-red contains marls, sandstones, of various colors, chiefly red, and quartz conglomerate.

135. Next in order occurs the oolitic system. Its lower member, the lias formation, consists of argillaceous limestone, and beds of marly sandstones alternating with clays. The higher divisions of this group consist of blue and yellow clays, calcareous sandstones, and coarse limestone, abounding in shells. The term *oolitic* is derived from *oon*, an egg, and *lithos*, a stone, from the fact that some of its beds resemble in appearance the eggs or roe of a fish.

136. The *cretaceous* or *chalk system* takes its name from its leading member the chalk, which is a familiar earthy form of the carbonate of lime. Silicious stones in the form of rounded masses (nodules) of flint are interspersed through the chalk beds. This formation also contains thick beds of marly clay and imperfect limestone, together with greensand beds, which consist of silicious sand mixed with silicate of iron.

137. Next in the ascending order is the tertiary formation. This consists of sand and clay beds, and limestones, of various degrees of compactness, sandstones and buhrstones or millstone grit, a porous silicious rock. The sands and clays predominate, and the beds are generally more horizontal than those of the older formations. The tertiary is divided into *eocene*, *miocene*, and *pliocene*; a division based upon the distribution of fossils.

138. Above all the rest, highest in the order of position, and latest in the order of time, appears the quaternary formation. It consists of two members called *diluvium* and *alluvium*. The lowest diluvium comprises beds of marl, sand, gravel, pebbles and clay, and also great numbers of bowlders, which are fragments of rocks of various sizes that have been torn from ledges, and transported or drifted to various distances. The alluvium, which is the formation now progressing, and which has been in progress since man inhabited the planet, consists of sands, gravel, clays, marls, peat, soil, and various forms of vegetable and animal matter, which streams, rivers, lakes, seas, and coral reefs are constantly accumulating.

139. It will be seen that this vast series of geological structures consists of continual repetitions, in different forms, of the same mineral materials. The only additional beds of different composition in any considerable quantity are those of rock-salt (common salt), found in the new-red sandstone and cretaceous systems, and those of gypsum in the silurian new-red sandstone and tertiary formations. All the other rocks are but modifications of the same few simple ingredients.

140. In the diagram (PLATE IV.) the formations are represented as passing upward in an inclined direction to the surface of the earth. It is not intended to show the exact degree of inclination, for this varies in all possible ways. These several formations are spread over large areas of country, and give particular geological characters to the regions where they exist.

141. As has been said, the rock formations are undergoing perpetual changes through the action of fire beneath, and of various agencies above. By the contractions and expansions of heat and cold, by the wearing action of waters in motion, by the penetration of moisture into the pores or interstices of stones, and its after expansion in freezing, the

surface of rocks is broken and crumbled away, sometimes, indeed, very slowly, but often with much rapidity.

142. The same effects are produced by other destructive causes, which spring out of the chemical composition of rocks on the one hand, and of the air on the other. The atmosphere contains from 1–1000th to 1–2000th of its bulk of carbonic acid, a gas of which water absorbs a large amount. All the water which falls from the clouds therefore contains it. Carbonic acid is also formed in the earth in immense quantities, and the waters of springs come up to the surface charged with it in various proportions. Now water containing carbonic acid possesses a remarkable power of dissolving and destroying stones. It has been shown by extensive experiments, that no species of rock whatever will resist the solvent action of water impregnated with carbonic acid. Artificial mineral waters are made by bringing various minerals into contact with water containing carbonic acid, which dissolves out their salts, and thus acquires new properties.

143. Water charged with carbonic acid acts differently upon different rocks. The chalk, marbles, marls, and entire limestone family, are simply dissolved, and may be again precipitated and hardened into calcareous rock. But the action of carbonic acid upon granite is of a different nature: it here acts to break up the chemical unity of the rock, by decomposing it and separating its elements. It is because the minerals which compose these rocks—serpentine, hornblende, feldspar, and mica—are saline in their composition; because they consist of bases united to an acid, with an affinity so feeble that carbonic acid is able to overcome it: this is the reason of these decompositions. The carbonic acid combines with the alkalies, forming carbonates, which are dissolved in water, and borne away perhaps to the sea. The unity of the minerals is thus broken; the silica and alumina (sand and clay) are set free, and being insoluble in water, accumulate, and thus constitute the essential basis of soils.

144. In PLATE II., the chief mineral constituents of soils are seen to be arranged in four pairs, namely, a pair of alkalies, of alkaline earths, of earths, and of metallic oxides. Manganese in minerals is often associated with iron: it exists in small quantity, but is very widely disseminated. These few ingredients of soil are indispensable to the growth of plants, and consequently to all life; and are thus derived, by forces now in action, from rocks that are universally distributed over the earth.

145. But in the crumbling down of rocks into the mixtures of soil the decomposition is not complete. Beside a portion of alkalies and alkaline earths lingering free in the soil, the sands and clays contain large amounts of potash, soda, lime, and magnesia, locked up in combination, so as to be imperfectly, or not at all available to growing vegetation. Yet the same forces which disintegrated the rocks are still at work upon these constituents of soils. It is one of the chief benefits of mechanical culture with the plow and other implements to loosen the soil, so that air and moisture can get access to it, to carry forward the same decomposing changes, liberating the needed elements of fertility, so that they may become available for vegetable nourishment.

146. Hence, also, the import of “fallow,” by which the farmer means the rest of land after a series of crops. But the powers of nature never get fatigued: the true explanation is, that the soluble constituents are removed from the soil by successive crops, until

remunerating growths can no longer be obtained. Time must then be allowed for the elements of fertility to be again set free, when the land is said to be in *fallow*. Fallowing is now much less in use among farmers than formerly: it is superseded by systematic rotations of crops; that is, instead of letting the ground remain idle, such a crop is taken from it as will not require the missing constituents of the soil.

147. As there is considerable variation in the chemical composition of rocks, so there will be a corresponding variation in the compositions of the soils derived from them. For example, the slates and feldspathic rocks, when reduced, give rise to argillaceous soils, or those in which clay predominates; the sandstones produce silicious soils, those abounding in sand; and decayed limestone forms calcareous soils, or those characterized by a large proportion of lime. Now, as the agricultural capabilities and adaptation of soils to the growth of special crops depends primarily upon chemical constitution, it is easy to see that, through Chemistry, agriculture has a relation to Geology. Nevertheless, in fact the problem of this relation is a very complicated one; for there has been such transportations and admixtures of materials of soil, that it is frequently difficult to trace it to its parent rock. Geology is undoubtedly capable of affording important contributions to agricultural science; but a considerable degree of knowledge, and much caution in judgment, are required to make these contributions practically available.

PART II.

ORGANIC CHEMISTRY.

VI.—STRUCTURE OF ORGANIZED COMPOUNDS.

148. Organic Chemistry is that branch of the science which considers the composition, properties, and changes of organized substances, or those which have originated in living beings, or been derived from them. It embraces a highly interesting portion of the science; for to a living, conscious being, all that appertains to life, its conditions and laws, must have a profound concern. My treatment of this part of the subject, also, must be mainly confined to such points as may be illustrated by diagrams—the reader being referred to the class-book for its more general consideration.

149. The first fact which claims our attention, is the exceedingly small number of elementary bodies that are brought into notice in this department of the science. Four elements mainly constitute organic structures, and bring about organic changes: these are carbon, oxygen, hydrogen, and nitrogen,—from this circumstance called *organogens* (generators of organization). In addition to these, minute proportions of sulphur, phosphorus, potash, soda, iron, and lime, are found in organic substances, and which appear as ash after their combustion. These, though important, exist in very small proportion—so small, indeed, as to have been formerly thought accidental ingredients of organized compounds—mere impurities. We pass them by, and give our attention to the four organic elements.

150. Of these, three are gases; and one, carbon, is a solid—in its free state, for ever a solid. The other organic elements—oxygen, hydrogen, nitrogen—may be present, either or all, in organic compounds; but carbon is always present. It exists in every organized substance; so that this branch of the science has been defined as the chemistry of carbon compounds.

151. From these four constituents the world of life springs into being. This fact is more than wonderful, it is amazing! That the countless tribes of beings, vegetable and animal, which inhabit all the climates of the earth, varying almost infinitely in their attributes and powers, and giving rise to numberless natural products, which are multiplied by art without end, should be made up by the combinations and permutations of only four kinds of matter, is assuredly the standing marvel of time! Nevertheless, we

are not without some clew to the method by which such august results are brought about by so apparently trifling and insignificant means.

152. Many organic compounds are derived from the four elements, by variations in the proportions in which these elements combine. Organic substances may consist of either two, three, or four different elements, and may contain of these from three or four atoms up to several hundred. The possible difference in the *proportion* of the organic constituents is therefore very great. The slightest alteration in the proportion of a single element, is sufficient to change the nature and properties of a compound.

153. But we are not really restricted to four organic elements; by a wonderful device, these elements are capable, in effect, of being largely multiplied. The same element is capable of existing in several states, so totally different in properties, as to appear like different substances. Carbon, for example, manifests itself under the form of an opaque jet-black powder or dust, lamp-black, which is so highly inflammable as to take fire often spontaneously in the air; and it also appears as that transparent and most beautiful of gems, and hardest of minerals, the diamond, which is also so extremely incombustible, that it is difficult to burn it even in oxygen gas. Charcoal, anthracite, gas-carbon, and black lead, are other and dissimilar states of the same element, which certainly differ from each other in aspect and apparent properties more widely than some known elements, especially the metals, differ among themselves.

154. These remarkable conditions of the elements are termed *allotropic states*. It is said that all the elements, except hydrogen, are subject to this modification; and it has been lately announced that an allotropic condition of hydrogen is also discovered.

155. Now it is easy to see that we have here another possible source of variation in the properties of chemical compounds. We may consider the substances of identical composition, and yet having different properties. We have but to suppose that the elements carry their allotropic conditions with them when they enter into union, and although proportions are identical, there may obviously be wide difference of properties. Thus we may have two compounds of carbon and hydrogen, both in exactly equal proportions, but if the carbon enters into one as charcoal, and into the other as diamond or anthracite, the same result may be produced as if two distinct elements had been employed.

156. The phenomena of allotropism are exceedingly interesting, and engage increasingly the attention of chemists. It is by no means improbable that their elucidation will yet throw much light upon the relations of chemistry to vegetable and animal physiology.

157. But the variations in the properties of organic compounds are to be mainly explained by difference in the *grouping* of their elementary atoms. Indeed, the science of organic chemistry is little else than a study of the groupings of atoms. In inorganic chemistry we find the character of compound bodies depending chiefly upon the *nature* of their elements, but the properties of organic compounds are determined less by what their elements are than by *the way in which they are arranged*. The leading mark of distinction between potash and soda is, that one contains potassium and the other sodium; but between oil of lemons and spirits of turpentine there is no such distinction.

Their elements are of the same nature, and name, and properties; they differ only in arrangement.

158. The statement that two or more compounds may consist of the same elements, united in exactly the same proportions, and yet have unlike properties, would have been regarded a few years ago as chemical heresy; but it is now universally recognized as a fact. It was supposed that difference of properties necessarily implied difference of chemical constitution, but analysis most carefully conducted, and many times repeated, has established that there may be difference of properties with *identical* composition. Two substances different in attributes will yield on examination equal proportions of the same products. The term *isomeric* from *isos* equal, and *metrom* measure, is used to designate this class of compounds.

159. The fact of isomerism rests upon evidence more positive even than that of analysis; these compounds can be converted, and reconverted into each other without addition and without subtraction. In cyanuric acid, hydrated cyanic acid, and cyamelide, we have three such isomeric compounds. Cyanuric acid is crystalline, soluble in water, and capable of forming salts with metallic oxides. Hydrated cyanic acid is a volatile, and highly corrosive fluid, which cannot be brought into contact with water without being instantaneously decomposed. Cyamelide is a white substance very like porcelain, absolutely insoluble in water.

160. Now if we place the first, cyanic acid, in a vessel perfectly (hermetically) sealed, and apply a high degree of heat, it is converted by that influence into hydrated cyanic acid; and then, if this is kept for some time at the same temperature it passes into cyamelide, no constituent being separated, nor any substance being taken up from without; and again, inversely, cyamelide can be converted into cyanuric acid and hydrated cyanic acid (LIEBIG).

161. These changes and differences of properties are believed to be due to differences in the position and arrangement of the constituent atoms. As the power and effectiveness (properties) of an army may depend upon the arrangement and distribution of its soldiers, the same number of which may be thrown into innumerable positions, so different groupings of the same chemical elements may form compounds very different in their powers and properties.

162. Where the elements of two compounds are in different quantities, yet in the same *relative* proportions, affording the same results when considered in parts per hundred, the compounds are said to be *polymeric*. In PLATE V. aldehyde, $C_4H_4O_2$, and acetic ether $C_8H_8O_4$, are examples of polymerism. The latter contains just twice as many atoms of each element as the former, yet their proportions per cent. are the same. Oil of peppermint $C_{10}H_{10}O$, and oil of lavender $C_{20}H_{20}O_2$, are also illustrations of polymerism.

163. Where compounds possess the same absolute composition, or equal numbers of atoms, their difference of properties is more manifestly due to alterations of grouping, and they are said to be *metameric*. PLATE V. exhibits a series of eight hydrocarbon compounds, commonly represented by the formula C_5H_4 , although some of them may prove to be polymeric with these proportions. They are oil of juniper, oil of black pepper, oil of turpentine (spirits of turpentine), oil of bergamot, oil of lemons, oil of

copaiva, oil of limes, and oil of oranges (the rind). I need hardly say that the diagrams do not attempt to express the manner in which the atoms may be really arranged, but only to illustrate the idea of variable grouping.

VII.—THEORY OF COMPOUND RADICALS.

164. This theory, in all its applications, is an illustration of the important part played by groups of atoms in organic chemistry. It has been already alluded to (87). The doctrine supposes that certain combinations or groups of elements take on the properties, and play the parts, of simple bodies, so that we may trace them in their relationships and changes as we do the simple bodies of inorganic chemistry. Potassium, for example, is an element; it combines with oxygen, forming oxide of potassium. This compound combines again with water, forming hydrated oxide of potassium. If, in place of water, we employ nitric acid, we get nitrate of oxide of potassium; or with other acids, a large class of salts of oxide of potassium. Now potassium is here evidently the starting point, the foundation, the root, the *radical* of this series; and as it is undecomposable, it is called a *simple radical*.

165. Now there are compounds that behave in the same way, and are hence called *compound radicals*. According to this view, all organic substances are made up by combinations of these radicals with each other, and with simple elements, in the same manner as acids and salts. Illustrations of this theory are shown on plate VI. Ethyle is a compound radical, consisting of four atoms of carbon and five of hydrogen, and comporting itself like a metal. It is the root of a large series of compounds. Common ether (sulphuric ether) appears to be an oxide of ethyle; and, with the addition to it of an atom of water, we get hydrated oxide of ethyle, or common alcohol.

166. Formyle (PLATE VI.) is a compound radical $C_2 H$, which forms also a large series of compounds, of which only the most important—chloroform and formic acid—are given. In chemical language, and according to this theory, chloroform is the perchloride of formyle. Another organic radical, represented in PLATE VI., is acetylc $C_2 H_3$. Aldehyde is seen to be a hydrated protoxide of acetylc; acetylc acid is a hydrated deutoxide of acetylc; acetylc acid—acetic acid, or vinegar—is a hydrated peroxide of acetylc.

167. A few organic radicals are known in the separate state, but most of them have not been thus obtained. Ethyle, for example, has been set free, while formyle and acetylc have not. They are decomposed in the act of separation. The adherents of this theory hold that the fact of the non-separation of the great majority of organic radicals affords no objection to their existence and importance. They assert, first, that such things as compound organic radicals do exist in the isolated condition; second, that there is strong warrant for believing that numerous others which have not been, or perhaps cannot be separated, do exist; and, third, that their assumed existence is of great convenience in study, in classifying the facts of the science, in assisting the memory, and in exhibiting organic changes in the clearest light.

VIII.—THEORY OF CHEMICAL TYPES—DOCTRINE OF SUBSTITUTION.

168. The theory of organic radicals has been most current in England and Germany. The French have attempted to explain organic compositions and changes by the theory of types and substitution, which has won its way to considerable favor. Like the doctrine of compound radicals, it is only important as an instrument of abstruse study, and I shall therefore pass it with but a brief explanation. Both doctrines spring from the necessity of finding some relationship among the crowd of facts which are incessantly accumulating in organic chemistry, and which must be in some way arranged and associated, so as to become manageable by the mind.

169. A *chemical type* is a compound which, in composition or properties, may represent or symbolize a class, and which admits of the exchange or substitution of its elements without destruction of its typical character. Thus, in inorganic chemistry, we may say, for example, that hydrochloric acid is the type of a numerous class of acids, the character of which is, that they contain hydrogen united to a salt-radical. If for chlorine we substitute iodine, bromine, or cyanogen, the type remains unchanged—the compound is still an acid analogous to that which was selected as the type.

170. Again, common salt, Na Cl, is the type of a very large series of salts, in which a metal is united with a salt-radical; and if we substitute potassium, lead, or silver, for the sodium; or iodine, bromine, or cyanogen, for the chlorine, the type is unaltered: we obtain different salts, but still a salt of the type represented by Na Cl.

171. In organic chemistry, also, types exist in which replacement and substitution occur, while the typical attributes remain. Thus in acetic acid (PLATE VI.), the three atoms of hydrogen may be replaced by three atoms of chlorine, in which the type is so little affected that the new substance, chloroacetic acid, has properties highly analogous to acetic acid. Again, in aldehyde, the three equivalents of hydrogen in the radical C_4H_3 may be replaced by three of chlorine, forming chloral—a body of the same type as aldehyde.

172. It has been recently shown, moreover, by WURTZ and HOFFMAN, that the hydrogen of ammonia may be partially or entirely replaced by compound groups of atoms, or organic radicals, without destroying the basic and typical character of the ammonia. I have represented this interesting substitution in PLATE VI. A single atom of hydrogen of the ammonia is seen to be replaced by the compound radical ethyle, forming ethylamine. Two atoms of ethyle substituted for two atoms of hydrogen, forms diethylamine; and three atoms of ethyle replacing all the hydrogen of ammonia, yields triethylamine. Again, the three atoms of hydrogen in ammonia are seen to be replaced by three different compound radicals, ethyle, methyle, and propyle, forming ethylo-methylo-propylamine. And what is most singular, these compounds so strongly resemble ammonia in properties, as to have been frequently taken for it, and thus overlooked when occurring accidentally.

173. It has been supposed that the elements in inorganic types are in opposite electrical states—the sodium, or metal, in the common salt type, being in the positive state, or electro-positive; and the chlorine, or salt-radical, being in the negative state, or electro-

negative: electrical conditions being assumed as the cause of chemical combination (36). This holds generally true in inorganic chemistry; but it entirely fails when applied to organic types. According to the electro-chemical hypothesis, hydrogen is strongly electro-negative; hence, in inorganic types, they are incapable of replacing each other; but, as we have seen (171), chlorine may replace hydrogen in an organic type, without destroying its properties, which contravenes entirely the electro-chemical theory.

IX.—PAIRING, OR CONJUGATION OF ORGANIC COMPOUNDS.

174. The progress of organic chemistry has recently revealed certain remarkable facts of combination, which are described as the pairing, coupling, or conjugation of compounds. In contradiction of a fundamental principle of inorganic chemistry, we here see two compounds combine, while one only loses its properties. In true inorganic combination (14–16) the properties of both constituents disappear, giving place to new properties in the compound. But in the phenomena of coupling, while one compound loses its properties completely, the other entirely retains its properties—is unchanged by the union. The compound which loses its properties, or disappears, is called the *copula*, *pairling*, or *conjugate*.

175. Thus the compound benzoile (benzoic acid), (PLATE VI.) combines with formic acid to produce formobenzoic acid, which in its character as an acid agrees entirely with formic acid, without possessing any of the properties of the benzoic acid. The formic acid has been retained; the benzoile has lost its chemical character in the new compound. Formobenzoic acid is therefore regarded as a coupled acid, in which benzoic acid is the copula or pairling.

176. There is reason to believe that this principle is brought largely into action in the formative processes of vegetable growth, by which the more complex bodies are derived from combinations of the lower and simpler compounds.

X.—HOMOLOGOUS SERIES OF COMPOUNDS.

177. Homology is a term used to express a curious relationship among organic substances, which is so general, and of such simplicity, as to have been made by GERHARDT the basis of classification in his published system of chemistry. Homology implies the existence of compounds in series. A series of compounds is called homologous, when each member of the series, that is, each compound differs from the others, either by a certain number of atoms of carbon and hydrogen, or by a multiple of it; and when the properties of these different compounds are entirely analogous, yet differ in degree, and that in proportion to the amount of carbon and hydrogen.

178. PLATE VII. represents the most remarkable of these homologous series. It consists of volatile acids. The difference between each compound of the series, and any other, is either two atoms of carbon and two of hydrogen ($C_2 H_2$), or a multiple of

these. The proportion of oxygen is alike in all ; but from the starting point of the series, onward, we add $C_2 H_2$, at each successive step, as will be seen by counting the equivalents or atoms.

179. Now accompanying this singular homology of constitution, there is a remarkable analogy of properties. All the compounds of the series are volatile (see Class-Book, *volatile oils*). All but the two first are oily, and they increase in solidity, and their melting and boiling points rise with each successive increase of the common difference, $C_2 H_2$.

180. It will be noticed that the present series has been carried up uninterruptedly to thirty-eight atoms of carbon, that is, compounds have been discovered, which by their composition arrange themselves in this order. Above this we notice interruptions, or gaps, which are not filled up. It is believed that compounds belonging in these intervals exist, and will be discovered. Only a few years ago but two members of this series were known, acetic and formic acids. The links have, however, been rapidly supplied, and the chain extended.

181. There are many other homologous series known, but they are not complete in all their terms. It is thought that most, and perhaps all organic compounds belong to such orders, and when two members of a series are determined, the others are confidently expected in the course of discovery.

XI.—THE NON-NITROGENIZED ALIMENTARY PRINCIPLES.

182. It is the grand office of the vegetable kingdom to organize inorganic matter ; that is, to form out of dead mineral substances, earth, water, and air, compounds endowed with living or vital properties, and that are capable of forming the structures of animal systems. The substances which the plant makes use of, its nourishment, or the raw materials which it employs, are very simple in chemical character, and consequently, of a fixed, enduring nature. The peculiar compounds on the contrary, which the plant produces, are of a much more complicated nature, hence easily deranged, and as a further consequence transient and unstable.*

183. The organic compounds generated in plants are exceedingly numerous, and possess a vast variety of properties. But few of these, however, very few, are employed by animals as food. It is true that a great number of plants are made use of as sources of nourishment ; but they all yield the same few vegetable principles or nutritive compounds, that life demands universally. These principles of nourishment, furnished by vegetation all over the world, are starch, sugar, gum, lignin, oil or fat, vegetable acids and albumen or the albuminous group as they are termed, gluten, fibrin and casein. Plants form these from the mineral materials which they draw upward from the soil by their roots, and absorb from the air by their leaves.

184. The plant is thus the factory of organization. It elaborates or manufactures

* For a much fuller consideration of this part of the subject, see Class-Book of Chemistry.

material for the animal to appropriate and consume. The animal possesses no power of creating or constructing the substances which it needs out of decomposed inorganic matter. Though the animal feeds exclusively on flesh, yet that flesh was organized in the plants; it is organic matter not yet destroyed, and which is used over again, by a second organism. The animal continually receives, transforms, and destroys; it is the plant that combines and creates.

185. The vegetable compounds above enumerated as being of importance to us in a dietetical point of view, are divided into two classes, which depend upon the presence or absence of nitrogen as an element of their composition. Those containing it are termed nitrogenized principles; those lacking it, non-nitrogenized principles.

186. The carbon of all parts and constituents of vegetables, and through vegetables of animals is derived from *carbonic acid*; all the hydrogen of non-nitrogenized organic bodies (starch, sugar, woody fibre, gum and oil), is derived from *water*, and all the nitrogen of nitrogenized organic bodies is obtained from ammonia (LIEBIG).

187. Under the influence of the radiant forces of the sun (275) acting upon the green leaf, carbonic acid, water, and ammonia are decomposed, and their atoms thrown into new positions and groupings, constituting the above-mentioned organized compounds.

188. PLATE VIII. exhibits the composition and source of those non-nitrogenized bodies, which are important to us from being universally employed as food. They are called *ternary* because they consist of but three elements. They are divided into three groups, which differ from each other in composition and properties, although the compounds of the same group have a similarity of properties. There is the vegetable acid group, the neutral ternary group (sugar, starch, &c.), and the fat and oil group. These are all derived, as has been said, from carbonic acid and water, which are decomposed in the plant, the oxygen being separated and thrown into the air, as is shown by the arrows pointing upwards in the diagram. Those pointing downward represent combination. As these compounds are all derived from carbonic acid and water by decomposition and grouping in the vegetable, so they all, by decay and destruction, finally return again to those simple conditions.

189. An atom of carbonic acid (PLATE VIII.) is a group of three elementary atoms, of which one is a carbon atom, and two are oxygen atoms. Now carbon, as has been said, exists combined with other elements in every organized compound. But no vegetable or animal substance contains for one atom of carbon more than two atoms of another element. The great majority of organic bodies contain for one atom of carbon less than two atoms of another element.

190. Now all organized compounds may be looked upon as formed of atoms of carbonic acid, more or less altered or modified, or of groups of such modified carbonic acid atoms. This change or modification is the result of a separation of part of the oxygen of the carbonic acid atoms, in the place of which oxygen there is taken up hydrogen, or hydrogen and nitrogen. The oxygen thus separated is expelled from the leaf into the air in a pure state.

191. The simplest case of the production of an organized compound from carbonic acid in this manner, is perhaps furnished by oxalic acid. This substance belongs to the

group of organic acids, and is found in combination with potash, lime, &c., in the leaves and stalks of certain plants. By reference to PLATE VIII. it will be seen that oxalic acid consists of two atoms of carbonic acid united, from one of which an atom of oxygen has been removed. It is $2\text{CO}_2 - \text{O}$ two of carbonic acid, minus one of oxygen. Oxalic acid is thus formed by reducing one atom of carbonic acid to half its natural quantity of oxygen, and joining that product to a whole atom of carbonic acid.

192. This exhibits the starting point of organization, and discloses the essential office of vegetation. Plants are universally machines for separating oxygen—machines of *de-oxidation*. It is through these operations of de-oxidation and reduction, and by grouping together the products thus formed, that the plant becomes a builder and constructor of organized substances.

193. In malic acid, which exists in the apple and numerous fruits, we have not only de-oxidation, but a replacement of oxygen atoms by those of hydrogen. The source of the hydrogen is the decomposition of water, from which it was reduced by de-oxidation. If to a group of two atoms of oxalic acid, two atoms of hydrogen be added, and from the whole two atoms of oxygen be removed, malic acid is the result, the composition of which is $\text{C}_4\text{H}_2\text{O}_4$; or double this formula $\text{C}_8\text{H}_4\text{O}_8$, as it is commonly given. To make the changes seem as clear as possible, I have represented acids in the diagram as dry or anhydrous—that is, free of water. Nevertheless, these and most other organic acids exist in union with one, two, or three atoms of water, which appears, as in the case of the mineral acids (86), to perform the part of a base, so that malic acid, tartaric acid, &c. are, really malate and tartrate of water. They form salts by the replacement of their water by bases, or, their hydrogen by metals, according as we adopt one or other views of the structure of acids and salts. Oxalic and malic acids contain each two atoms of basic water.

194. In the same manner, by de-oxidation of carbonic acid and water, and the grouping of the products, all the organic acids may be derived. It will be noticed as a fact characteristic of their general composition, that they contain only a small quantity of hydrogen, but a very considerable proportion of oxygen. The de-oxidating process has therefore not been carried very far; most of the carbonic acid atoms may be supposed to have lost but half their oxygen, and but few water atoms have been split to furnish hydrogen.

195. The neutral ternary compounds, sugar, starch, gums, &c., have as a class a different composition from the vegetable acids. They are formed in the same manner, but the operation is carried further. They all agree in containing precisely the same proportion of atoms of carbon, each compound atom possessing twelve of this element. Of hydrogen and oxygen they contain an equal number of atoms, that is, for every atom of hydrogen there is one of oxygen; these elements are in the exact proportion to form water. The quantity of these constituents, however, varies. Grape sugar contains twelve atoms of hydrogen and twelve of oxygen, while cane sugar and gum have but eleven, and starch and lignum (woody fibre) but ten, atoms of each.

196. Viewed in the simplest way, and with reference to the probable manner of its production, an atom of grape sugar, for example, may be regarded as an atom of carbonic

acid, in which one atom of oxygen has been removed, and replaced by one hydrogen atom. These changes are very clearly shown by the diagram (PLATE VIII.) The direction of the arrows shows that two atoms of oxygen, one taken from an atom of carbonic acid, and another from an atom of water, are set free by the plant, and dismissed into the air; while the carbon and oxygen atoms, which remain of the carbonic acid, and the hydrogen from the water combine, as is shown by the arrows pointing downward to form the simple sugar atom. The formula of carbonic acid being CO_2 , that of grape sugar is $\text{C}_6\text{H}_{12}\text{O}_6$, an atom of hydrogen derived from the decomposition of water, being substituted for one of oxygen. This, however, is only to show in the simplest manner how grape sugar may originate; it does not consist of 12CO_2 , but of $12\text{C}_6\text{H}_{12}\text{O}_6$; that is, it contains twelve atoms of carbon, twelve of oxygen, and twelve of hydrogen. An atom of grape sugar would thus require for its production twelve atoms of carbonic acid to furnish its carbon and oxygen, and twelve of water to furnish its hydrogen; these, by decomposition in the process of growth, yield twenty-four atoms or equivalents of pure oxygen, which is furnished by the plant to the atmosphere.

197. In PLATE VIII. I have represented the atom of grape sugar as being thus formed, that is, by the replacement of an atom of oxygen in carbonic acid, by hydrogen from water. But we may also suppose it to be produced by depriving the carbonic acid at once of all its oxygen, and replacing it by water, or the elements of water. In the representation of starch (PLATE VIII.), I have changed the relative position of the oxygen and hydrogen atoms from OH to HO , which regards the elements as existing in the compound in the shape of water. We know that this group of substances is composed of carbon and the elements of water, but whether these elements are arranged *as water* is not determined. On that view these substances would be simple hydrates of carbon, charcoal, and water. Cane sugar, $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, and starch, $\text{C}_{12}\text{H}_{20}\text{O}_{10}$, contain an excess of carbon over the other constituents. They may be converted into grape sugar by the addition of one or two atoms of water, or may have been derived from it by the separation of one or two water atoms.

198. The sugars differ in composition. The sugar of milk and the sugar of fruits (grape sugar), are $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, while cane sugar is $\text{C}_{12}\text{H}_{22}\text{O}_{11}$, and gum has the same composition. Starch and woody-fibre (cellulose) are also identical, their formula being $\text{C}_{10}\text{H}_{16}\text{O}_5$. Starch and woody-fibre are therefore isomeric (157), as is also cane sugar and gum, their difference of properties being probably due to the arrangement of their molecules.

199. Included in the oil and fat groups we observe four compounds; glycerine with stearic, margaric and oleic acids. These acids exist together in most fats and oils; some of them are found in all. Fats and oils are believed to be composed after the manner of salts; they consist of acids and a base. The common base is glycerine; the acids which are in union with it are stearic, margaric, and oleic. Stearic acid with glycerine forms stearine, margaric acid with glycerine forms margarine, and oleic acid with glycerine yields oleine. Oleaginous bodies consist of stearine, margarine, and oleine, in all varieties of proportion.

200. In forming soaps we but decompose the oil-salt, substituting potash, soda,

or ammonia, for the natural organic base glycerine. (See Class Book, *oils, fats, and soap*.)

201. The oils and fat are derived, like the vegetable acids and the neutral ternary compounds, from carbonic acid and water. They differ from them only in the extent to which the process has been carried. They are seen to contain a very large proportion of carbon and hydrogen, and a very small quantity of oxygen. To form a simple atom of stearine (stearate of glycerine), forty-two atoms of water would require to be decomposed to furnish their hydrogen, and forty atoms of carbonic acid, thirty of which would have to be deprived of their entire amount of oxygen to furnish carbon. In producing a single atom of stearine, therefore, the plant sets free and surrenders to the air 112 atoms of pure oxygen gas.

202. It will be noticed that the chemical difference between these groups of ternary compounds consists in the relative proportions of their constituents. In the organic acids we have the smallest or minimum quantity of hydrogen, and the largest or maximum proportion of oxygen; in the sugar and starch group we have an increased proportion of hydrogen, and a diminished relative quantity of oxygen; and in the fat and oil group, we observe a very large amount of carbon and hydrogen, with a minimum proportion of oxygen. The proportions in the organic acids are inverted in the fats and oils; the neutral compounds, as they are intermediate in position, upon the chart also possess intermediate proportions of their constituents.

203. Those who have referred to the Class-book, to learn the properties of the individual elements of which we are speaking, will remember that carbon and hydrogen have each powerful attractions for oxygen, but hydrogen more than carbon. Ordinary fire or combustion is caused by the union of the oxygen of the air with the carbon and hydrogen of organized compounds. The products of burning are therefore oxygen combined with carbon and hydrogen; that is, carbonic acid and water. Those substances only are combustible—that is, capable of being burned—which contain elements as carbon and hydrogen, *not associated with oxygen*. Burning is thus an oxidizing process, and is the very reverse of what takes place in the plant. The carbon and hydrogen of carbonic acid and water having been burnt once, cannot be burnt again until they are separated. This the plant does: it imparts combustibility to carbon and hydrogen; that is, it forms out of these two elements combustible compounds, by freeing them more or less completely from oxygen, and then uniting them together.

204. Now as the combustibility, or power of burning and producing heat, which a substance possesses, depends upon the hydrogen and carbon which have been withdrawn from water and carbonic acid, and laid up in the compounds, it follows that the *degree* of combustibility, or the amount of heat which the substance is capable of giving out, will be exactly proportional to the quantity of hydrogen and carbon which have been separated from oxygen to produce it. An atom of hydrogen existing in water is incombustible: withdrawn from water, it is combustible. An atom of carbon in carbonic acid is incapable of burning, because it can combine with no more oxygen. If it lose one atom of oxygen, it becomes combustible to a certain degree; that is, it can resume the atom of oxygen: if the carbonic acid lose both atoms of oxygen, it becomes doubly combustible,

because it is capable of uniting with a double quantity of oxygen. Hence the combustible, or heat-giving powers of a compound, depend upon the completeness with which the hydrogen and carbon existing in it have been separated from oxygen.

205. It will at once be seen, by reference to the diagram (PLATE VIII.), that the vegetable acids are of low combustibility—possess but small heat-imparting power. They contain but very little hydrogen, and their carbon has been freed from less than half its oxygen.

206. The neutral ternary compounds stand higher in the scale of combustible power; the proportion of hydrogen is much greater, and that of oxygen is reduced. The fats and oils consist almost entirely of hydrogen and carbon, there being but the smallest proportion of oxygen, and their power of producing heat is correspondingly high.

207. Now, when these different substances are burned, their combustive or calorific effects are shown to be in exact accordance with the relative proportions of their ingredients. The vegetable acids are burned with difficulty, and yield but a small amount of heat. Starch, sugar, and pure woody-fibre, burn freer, and with augmented heating effects; while the oils and fats—the pitches, rosins, bituminous coal—the whole hydrocarbon group—burn furiously, and with the evolution of large quantities of heat.

208. But it is not as fuel that these substances are employed: they are universal and very large—nay, the chief ingredients of food; they must subserve certain important purposes in the system, and we cannot doubt that their special properties are adapted to the accomplishment of these purposes. We certainly cannot think that their variations of chemical composition, and corresponding intensities of combustive power, are without physiological significance.

209. These alimentary principles are taken into the system, are digested, and pass into the blood. At the same time oxygen is introduced into the lungs by respiration, and passes also into the blood. These compounds disappear, and, in the place of the oxygen introduced by inspiration, carbonic acid and water are thrown from the body by expiration. We breathe in pure oxygen, and breathe out oxygen in union with hydrogen and carbon; and, at the same time, heat is generated within the body, by which its temperature in all healthy circumstances is maintained at a fixed point. We therefore conclude that animal heat is the result of combustion going on at a slow rate within the body; and that the class of aliments we have been considering are designed to minister to this purpose—that is, to feed the physiological fire, to generate animal heat. When we consider that the body is maintained at the same temperature in winter and in summer, amid tropical burnings and polar frosts, it will be apparent that the amount of heat which the system is required to generate is liable to much fluctuation. Equally apparent, also, is that providential wisdom which has so modified the composition, and graduated the power of our heat-producing aliments, as to adapt them to all the exigencies of man upon the globe.

210. The chemistry of animals is thus the reverse of that of plants. The latter produce organized compounds, the former destroy them. Plants use carbonic acid and water for the production of organic compounds; animals use organic compounds for the production of carbonic acid and water. This point will be considered more fully in a subsequent chapter (272).

XII.—NITROGENIZED AND SULPHURIZED ALIMENTARY PRINCIPLES.

211. The ternary compounds which we have regarded as designed simply for animal combustion and the maintenance of bodily heat, are not nutritious—that is, they are incapable of nourishing the body. In a proper sense, nutritive foods are those only which are capable of being converted into the structure or fabric of the system—of forming muscle, nerve, or some of the organized solid tissues of the body. Now the non-nitrogenized substances are totally incapable of this. The oil group may be laid up as fat, and sugar and starch may be converted into fat in the body; but fat cannot form structure, and it exists in the body as an unorganized mass, deposited within the cavities or sacs of cellular tissue.

212. The composition of the ternary compounds deprives them of nutritive power. They cannot furnish to the fabric the materials that it demands: they are deficient in two essential ingredients of organic structures. These all contain nitrogen to a large extent; it is the foundation element of muscles, nerves, and all tissue. Some parts of the fabric contain also sulphur as an indispensable element, and the ternary compounds can furnish neither. They are non-nitrogenized and non-sulphurized, and as the elements which they do contain are believed to be incapable of transmutation into nitrogen and sulphur, they are regarded as essentially innutritious.

213. Animal nutrition is carried on by substances which have a vegetable origin—are formed in plants, and contain all the elements necessary to produce the various tissues in due proportion for this purpose.

214. There is a compound formed by plants called vegetable albumen. It is a universal and quite abundant element of the various mixed foods we consume, and is exactly the same as the albumen found in blood and flesh, where it always exists. Identical with albumen is the gluten of grain or vegetable fibre, which has precisely the same composition as the fibrine or muscular portions of flesh.

215. The composition of these compounds is very complex, and has been difficult of determination; if indeed it be now correctly known. They contain five constituents; carbon, oxygen, hydrogen, nitrogen, and sulphur, and a great number of atoms. So numerous are the atoms that it becomes impossible to represent all by diagrams, and I have hence in PLATE IX. employed figures to express quantities. It will be seen that an atom of albumen or fibrine contains of carbon 216 atoms or equivalents, of hydrogen 169, of oxygen 68, of nitrogen 23, and of sulphur 2. The old formula of LIEBIG, $C_{48}H_{36}O_{14}N_6$, though approximately correct, is not high enough to give the true proportion of sulphur, which has been since ascertained. No free phosphorus is present in these compounds as was formerly supposed.

216. Peas and beans contain a principle which is identical in composition with curd or casein of milk, and is hence termed *vegetable casein*. Albumen of eggs, in its carbon, oxygen, and hydrogen, is identical with vegetable albumen and albumen of blood; but it is richer in nitrogen, and contains one half more sulphur. *Theine* and *caffeine* are nitrogenized principles obtained, the former from tea and the latter from coffee, and which have

the same composition. They are feeble bases, and may represent a class of substances containing nitrogen, and known as vegetable alkalies.

217. The nitrogenized bodies are obtained by plants from carbonic acid, water and ammonia, and their sulphur from the sulphates, plaster, &c. Their mode of formation is not so simple as in the case of the non-nitrogenized compounds shown at PLATE VIII., and I shall not attempt to represent it. It is highly probable that the principle of coupling (124) comes largely into play in the formation of these compounds.

218. The relations between these substances are very striking, and suggest changes which probably take place within the animal system. Thus casein the nitrogenized principle of milk, and from which all the albumen of young animals is derived, contains an excess of carbon, hydrogen, oxygen, and nitrogen, over albumen. In its conversion, therefore, into albumen in the body, that excess is separated, and when we compare the composition of these two compounds (PLATE IX.), we find that an atom of casein will yield an atom of albumen, and with ten equivalents of oxygen, also an atom of chondrine, the organized principle of cartilage. Curd of milk, therefore, contains albumen for the blood and flesh of young animals, and with a little oxygen, chondrine also for the cartilages.

219. Gelatine is the nitrogenized principle of bones. *Choleic* and *cholic* acids are nitrogenized constituents of bile, the former containing also a large proportion of sulphur. *Uric acid* and *urea* are constituents of the liquid animal excretions.

220. Now, chondrine, gelatine, choleic, and cholic acids, uric acid and urea, are compounds formed in the animal body. It will be seen by the diagrams (PLATE IX.), that they are all simpler in structure than the albuminous compounds of plants, of blood, and of flesh. They are all unquestionably derivatives of those more complex substances, and derived chiefly by processes of oxidation. We have already seen (209) that the animal is a machine of oxidation—the oxygen combining with hydrogen, and carbon of the ternary compounds, to maintain animal heat.

221. The agency of oxygen has also evidently a large share in the transformation and gradual simplification of the nitrogenized substances, as seen in PLATE IX. The more complex compounds may be at once split up into simpler ones, or more gradually changed, but in either case oxygen is regarded as the all-controlling agent of change. As animal heat is derived chiefly from the oxidation of the non-nitrogenized constituents of the blood, so motion, force, and animal power, are probably due directly to the oxidation of the nitrogenized tissues.

222. The sulphur of the system is oxidized before escaping from it, and passes out in the form of sulphuric acid in combination with alkalies. The nitrogen is expelled from the body in the shape of urea, which is almost carbonic acid and ammonia; it is changed in putrefaction to carbonate of ammonia by absorbing the elements of water, as is beautifully shown in PLATE IX. One atom of urea with two of water give two of carbonate of ammonia. The highly complex nitrogenized principles are thus restored by the action of the animal organism to the simple binary compounds from which they were derived by plants. Here too we see the antagonizing action of plants and animals, the latter breaking down and destroying what the former build up and create.

XIII.—VINOUS, LACTIC, AND BUTYRIC FERMENTATIONS.

223. As all that live must die, so all organized compounds are destined in their nature to return to the inorganic state. Some of these substances go rapidly and some slowly, very slowly; but we may look upon the whole organized world as moving or tending to dissolution. And although the forms which these compounds finally assume are few and simple, yet the intermediate products, which naturally arise, or may be formed by art, are varied and numberless. The organic compound, sugar, for example, may pass backward to its ultimate state of carbonic acid and water, by a great number of routes; three of these are represented in PLATE X.

224. It has been stated that owing to their complexity of composition, organic compounds are of a transient nature; and it may be added that of all organic substances the albuminous are the most perishable. The reason is obvious. An atom of albumen consists of five different elements and 482 equivalents or atoms. Affinities so numerous and complicated are liable to disturbance from very slight causes. Every one knows that milk, fresh meat, or wet flour, if left to themselves, in a short time putrefy. This is owing to their albuminous, glutinous and fibrinous elements, which speedily change. In these circumstances they run into spontaneous decomposition, and are hence termed putrefiable or putrescible compounds.

225. The ternary compounds, which are less complex, and besides contain no nitrogen (see Class-book,—Nitrogen) have a more permanent composition. They do not tend to rapid and spontaneous decomposition. Nevertheless, when in the vicinity, or in contact with putrescent compounds, some of them are affected by the change, as it were contagiously, and pass into decomposition. Those compounds which do not spontaneously putrefy, and yet are transformed by the presence of putrescible substances, are termed *fermentescible*, and the change is called *fermentation*. Sugar is a fermentescible substance.

226. If we add to a solution of sugar, at a temperature of from 40° to 86°, bread, milk, or flesh, in a condition of putrefaction, the change is imparted to the sugar, whose atoms are released from the saccharine affinity, and regroup themselves into the forms of carbonic acid and alcohol. Four atoms of carbonic acid (PLATE X.) and two atoms of alcohol arise from a single atom of sugar. This is called the alcoholic or vinous fermentation. Fruit sugar (grape sugar), $C_{12}H_{12}O_{12}$, is alone capable of this decomposition. Cane sugar, $C_{12}H_{11}O_{11}$, before it becomes susceptible of this transformation, acquires an atom of water, and is thus changed to fruit sugar. Crystallized fruit sugar is $C_{12}H_{14}O_{14}$; but the two atoms of water of crystallization separate and take no part in the change.

227. When a solution of sugar is placed in contact with pressed curd or unsalted skim-milk cheese, which has previously been exposed to the atmosphere for some time, and the mixture is kept at a temperature of from 75° to 90°, a change takes place, the liquid soon becomes acidulous, and the sugar is converted into lactic acid. This is called the *lactic acid fermentation*. In this case no gas is formed as in the alcoholic fermentation, a single atom of sugar, $C_{12}H_{12}O_{12}$, being separated into two atoms of lactic acid,

$C_6 H_6 O_6$, or $C_6 H_5 O_5 + HO$. This is the change that takes place in the souring of milk; the milk sugar, which has the same composition as grape sugar, being changed to lactic acid by the casein.

228. Again, if the above mixture of curd and sugar be kept for some time at a temperature of from 90° to 105° , a new fermentation is established, and other compounds produced. The sugar is resolved into carbonic acid, $C O_2$ (PLATE X.), four atoms of free hydrogen, and an atom of butyric acid, $C_3 H_3 O_4$. This is hence called the *butyric fermentation*. The elements of the sugar in this case pass to butyric acid by the route of the lactic acid fermentation, and not directly as might be inferred from the diagram.

XIV.—CHEMISTRY OF COMBUSTION AND ILLUMINATION.

229. We have seen that organized compounds may pass slowly from their condition of temporary constraint to the more permanent and simpler forms which belong to the mineral condition. This change may also take place rapidly, where there is an abundant supply of oxygen, as in the open air, and it is there attended with the development of heat and light—combustion and illumination.

230. Common combustion and illumination as we see them occur in the open air, are simply the result of the union of the hydrogen and carbon of the burning body with free atmospheric oxygen, producing carbonic acid and water. The organized compound thus returns at a single step to the inorganic form—its organic structure is at once and entirely destroyed without the appearance of intermediate compounds forming successive stages of the process.

231. We have seen that the beginning of organization consists in the separation of oxygen from carbon and hydrogen, and as the former of these two elements enters into all organized compounds, and the latter into very nearly all, this process is essential to the production of organic substances universally. As a consequence all organic substances are combustible—that is, their carbon and hydrogen may return to the embrace of oxygen with the production of heat. The amount of heat generated is various; the presence of oxygen and nitrogen in an organic compound hinders combustion. The vegetable acids and the albuminous compounds burn with difficulty, and produce the lowest calorific effects; while those compounds in which they are entirely absent are most combustible.

232. Of the four organic elements, therefore, carbon and hydrogen are those which impart to organic compounds the property of combustibility; the oxygen and nitrogen present in them only regulating the intensity with which they burn. The compounds which we employ as sources of heat and light, are those which contain organized hydrogen and carbon, sufficiently free from oxygen and nitrogen to be adapted to the various purposes for which we desire to use them. Woody-fibre is combustible, and used as a very general source of heat. If mixed or charged with substances richer in hydrogen and carbon, as rosin, pitch, &c., its combustive powers are greatly augmented.

233. Carbon and hydrogen, when burnt separately, give rise each to a large amount

of heat, but they exist in different forms, and burn in different ways. Carbon being always a solid, remains so during combustion. It becomes red and white hot, as we see in the combustion of charcoal or anthracite, but remains fixed and solid in the fire without altering its form, except as it gradually wastes away. Hydrogen on the contrary exists as a gas, and when burning, burns as a gas. If set free it tends to escape and diffuse into the air, and thus burns while in motion, giving rise to *flame*. Charcoal, unless containing moisture within its pores, which decomposes by heat, and yields hydrogen, never burns with flame, while hydrogen can burn in no other way. Of course, then, where hydrogen and carbon are united, if burnt, they must produce flame. Wood, bituminous coal, the turpentines, resins, and oils, all burn with flame; and the larger the quantity of hydrogen, the more furious the combustion, and the more voluminous the flame.

234. The substances to be used for illumination, require to be very pure hydrocarbons. The compound which yields the largest amount of the clearest light, when burned, is olefiant gas, which consists of nothing but carbon and hydrogen, and an equal number of atoms or equivalents of each. The camphenes, oils, tallows, &c., consist almost entirely of hydrogen and carbon, but these are in variable proportions, and beside, they also contain some oxygen. Illuminating gas, the common substance which is burned in towns as a source of light, consists of olefiant gas mixed with other gaseous compounds; and its value for illumination rises and falls, in proportion as this constituent increases or diminishes in quantity.

235. PLATE XI. is an attempt to represent to the eye the chief conditions and changes which belong to the chemistry of illumination. I take for illustration the most perfect illuminating substance we have, olefiant gas—a pure hydro-carbon. It is represented as escaping from a gas-pipe in a jet, and is seen to be composed simply of hydrogen and carbon. For convenience, the atoms are shown of one fourth the size which has been employed in the former part of the work; their combining proportions are, however, preserved.

236. The diagram shows what occurs in burning a gas which has been previously manufactured for illuminating purposes. But essentially the same things take place when any other illuminating material is used, as liquid oil or solid tallow. They, also, consist mainly of hydrogen and carbon, and *must be converted into gas before they can be burned*. The oil of the lamp is raised by the wick, and converted into vapor before combustion can take place; and the solid tallow of the candle is first melted into oil, and then raised and distilled into vapor in the same way.

237. If any one will take the trouble to lower a piece of mica or fine wire gauze, or even a fragment of broken window-glass, over a gas-jet or candle-flame, it will be seen that the flame is not a solid mass of fire, but is rather a hollow shell of light, and is dark within. A ring of light is seen surrounding a dark interior space. This central space is filled with the combustible principle to be consumed, the unburnt hydro-carbon gas. It is represented in PLATE XI., as if the flame were split down from the top to the bottom, forming a vertical section, so that we are supposed to see what exists within. The unchanged gas is seen to fill the dark interior of the flame.

238. The gases which produce illumination—compounds of hydrogen, are lighter than the air. When set free, they therefore rise, or tend to escape upward. At the same time the heat of combustion rarefies the surrounding air, which being lighter, ascends also. Rising currents are therefore established, both within, and surrounding the flame, which carry it upwards, and thus occasion its conical or pointed figure.

239. The surrounding atmosphere in which combustion takes place, consists of free oxygen gas, which is therefore ready to combine with any substance for which it has an affinity. It is however, when pure, too powerful, and would burn with intense and ungovernable violence. Four times its bulk of nitrogen is hence mixed with it in the air, to restrain and temper it to the proper degree of activity.

240. In the diagram, the free oxygen of the air is represented as rising toward the flame, in ascending currents in the direction of the arrows.

241. As a consequence of this it will be seen that the oxygen will be in excess, that is, will accumulate in the largest quantity at the lowest point of the flame. But here it will be noticed, by directing attention to the burning of a candle or lamp, that the flame burns blue, and gives out but little light.

242. The cause of this is, that in consequence of the abundance of oxygen the combustion is *complete*; the carbon and hydrogen being both consumed or burned at once.

243. Now in the higher regions of the flame, which emit white light, this does not take place. The supply of oxygen is so regulated that the hydrogen and carbon may be burned in the order of their affinities. The affinity of hydrogen for oxygen is greater than that of carbon. Where the oxygen is presented in limited quantity to both, the hydrogen will seize upon it first, and will be burned first. This is what actually takes place in the illuminating flame. The nucleus of hydro-carbon vapor, which fills the interior of the flame, is decomposed at its outer surface where oxygen comes in contact with it. The hydrogen is oxidized first with the production of intense heat; the carbon at the same instant being not burned, but set free. Those who have referred to the history of hydrogen in the Class-book, will recollect, that in combining with oxygen it gives rise to intense heat, but no light: its flame is hardly visible. The carbon is thus set free in exceedingly minute, solid particles, in the midst of a great heat. Those particles are therefore heated to whiteness, and thus give rise to vivid white light. The illumination comes from the solid, unburned particles of carbon, heated to brilliant whiteness by the burning hydrogen.

244. The red-colored cone in the diagram, surrounding the central unburnt gas, is this region of partial combustion, and is the source of the light. The particles of carbon set free, for a moment float, or are pushed outward by those constantly liberated, until they find sufficient oxygen to burn them. This occurs in the exterior portion of the flame, which is represented in the diagram by a dark outer cone. Combustion is here completed by the oxidation of the carbon particles.

245. Common combustion is thus an oxidation of hydrogen and carbon. Illumination results from their *successive* and regulated combustion; and oxidized carbon and hydrogen—that is, carbonic acid and water are the products formed. These are shown in the diagram (as they can at any time be proved by experiment) to be formed in the flame,

and to escape in the upward current of heated air. The arrows pointing upward indicate their direction.

246. Though water is the enemy of fire, yet it is itself the offspring of the fiercest and hottest combustion. All our common artificial lights result from the chemical production of water—the luminous effect proceeding from just that portion of the flame where water comes into existence.

247. The flame thus undoes the work of the plant. It *disorganizes* vegetable products; and these simple changes which the diagram exhibits as going forward in a common flame or burning candle, are the same that characterize combustion in the open air universally. All our fuels and illuminating materials in burning are oxidized to carbonic acid and water, and are thus fitted again to minister to vegetable nutrition—again to become sources of heat and light.

XV.—PLANTS, ANIMALS, AND THE AIR.

248. It is the pride of Astronomy to have shown that the harmony of our planetary system is preserved, and its stability guaranteed, by the eternal war of hostile forces. One, the centripetal, or centre-seeking force, if suffered to predominate, would bring all the planets to rest in a central mass; another, the centrifugal, or centre-flying force, would whirl them away through space, in straight lines. But by the mutual checking and counteraction of these opposing powers, the planets are retained from age to age in their circling paths round the sun, and may thus continue to move harmoniously and for ever.

249. It is thus also with the course of life upon our globe. It is maintained by an omnipresent conflict of adverse forces, acting upon the chemical atoms of which living beings are composed. Constructive agencies, which originate life, and destructive agencies, which tend to death, are for ever in strife; and vital existences perpetually perishing, but ever renewed, are the consequences. Like the solar system, living beings are the product of a balance between antagonizing energies—they spring from the harmonious adjustment of conflicting powers.

250. Plants and animals are both endowed with vital or living properties; they both grow, reproduce their kind, and perish. Yet the life of these two orders of beings is of a different nature, and depends upon different—nay, opposite conditions. The actions and changes in which vegetable life essentially consist, are exactly reversed in the case of animal life.

251. Plants and animals can exist only in the air: this is equally indispensable to both. There are, indeed, numerous tribes belonging to both kingdoms which live in water; but this is only because the elements of the atmosphere extend downward into the sea, and are found in all waters where life is present performing the same offices as in the aerial ocean above. The relation between the atmosphere and the life of each class is equally intimate and vital, and yet this atmosphere in the two instances performs diametrically opposite offices.

252. The common impression of the uneducated, who see the solid plant springing up from the solid earth, is, that the plant is formed entirely out of the soil, and has no more to do with the air than that it happens to be surrounded by it. Yet we might infer from the very structure of plants, that their *connection with the air* is in some way of the first importance. They are formed upon a plan which brings them into contact with the largest amount of air. Rising upwards to a greater or lesser height, the stems or trunks divide into branches, which are again divided into lesser branches, and those into minuter fibres or twigs, which expand out into innumerable flattened plates or leaves. Immense surface is thus secured. The branches and foot-stalks of the leaves being very elastic and easily bent, sway and tremble in every breeze, by which fresh air is continually supplied, and its surface contact with the leaf is greatly multiplied. Now all this wonderful contrivance and adaptation cannot be without some important purpose.

253. We discover this purpose at once, when we compare what the air is made of with what the plant is made of. The plant and the air in which it grows are composed almost entirely of the same substances. Elementarily, they are almost identical. From one to five per cent. of the plant, its inorganic or mineral portion, its ash, comes from the soil; the balance, the main bulk of the vegetable structure, 95 to 99 lbs. in a hundred of its weight, has the same constituents as the air. We get constant proof of this, in the burning which takes place in fireplaces and stoves; the consuming wood, all but its ash, dissolves into gases, and rising upward, is thus actually converted into air.

254. If the vegetable leaf is examined with a sufficiently powerful microscope, its surface is found to contain innumerable pores, openings, or mouths, through which a portion of the air enters to become food for the plant. Vegetation is thus nourished directly from the air; the air itself enters the leaves, and is changed into organized vegetable products.

255. One of the constituents of the air, which may sometimes enter the plant through the leaves, exists also largely in the soil—this is water. It is the medium which dissolves the mineral or ash-elements, and carries them upward through the roots into the organism. Water is the leading substance of the green growing plant, and is also the medium for carrying on the operations which take place within its structure. To secure a constant upward current of it from the soil, it is perpetually evaporating away into the air from the extensive leaf-surface. The water which thus rises from the soil, contains also, dissolved, some of the gases which belong to the air, and which may have been washed down by rains, so that we cannot say that the plant actually takes in all its gaseous ingredients directly from the air through its leaves. Nevertheless, the process of gaseous absorption from the air constantly goes on, and the fact remains the same, that the plant and the atmosphere are nearly identical in their chemical elements.

256. When a log of wood is charred in a pit, it is converted into a black mass of carbon of the same form and size as the log was before charring. This carbon, as has been before stated, is the solidifying element of all organized fabrics. In the charring process, certain gases have been expelled into the air, the solid carbon remaining. Now, that mass of charcoal, the chief solid constituent of the log, was derived by the growing tree

from the air. It entered the leaves in the shape of a gas—carbonic acid gas, which is found every where diffused in small quantity through the air. About 1-2000th the weight of the atmosphere is carbonic acid, and 6-22 of carbonic acid is carbon.

257. The carbonic acid is decomposed in the plant, and furnishes this proportion of solid carbon. It is the office of the leaves and green parts of vegetation to perform this work, to effect the chemical separation of carbon from carbonic acid, that is, to deoxidize the carbon. Wherever a green plant exists, whether it be those which man cultivates as sources of food, or the venerable forest trees, or the wild weeds of the prairie, or the humble grass by the wayside, or the sea-weeds which grow in the ocean; this is its essential function—that in which vegetable life consists, to absorb carbonic acid gas, decompose it, use the carbon in forming organic vegetable compounds, and restore the oxygen back again to the air.

258. The plant also decomposes water in the same way; employs its hydrogen in the manufacture of its peculiar products, and sets free the oxygen into the air. It also decomposes ammonia and nitric acid to get nitrogen, and sulphuric acid to get free sulphur. These elements, carbon, hydrogen, oxygen, nitrogen, sulphur, and the ash-compounds from the soil, it makes use of to build up its own fabric—to grow. It is thus the prerogative of the plant to create organization; so to decompose and recompound the elements of matter, that they shall acquire the quality of life. All vital structures in both worlds of organization, originate here in the green leaf. At this point disorganization and death cease, and life begins.

259. How wonderful that the vegetable world thus springs into being from the bosom of the invisible atmosphere! We can hardly grasp the fact as reality, that the beautiful forms which ornament the landscape, are really the children of the ethereal air; that the fragrant and delicate flower has been really distilled from the pure and stainless medium which pervades it, or that the oak which has wrestled with winds and storms for hundreds of years, has nevertheless been nourished and developed by the very blasts which threatened it, and stands before us in its majesty, as consisting of but organized and embodied gases of the air.

260. To fix distinctly in the mind the character of the changes wrought by growing vegetation upon the atmosphere, I have ventured again to resort to diagrams, which appeal to the eye. The effects produced upon the air by the vegetable world, are represented in the left portion of PLATE XII. The direction of the arrows shows carbonic acid and water, as it were, descending from the air, so as to enter the plant, at the same time that pure oxygen is set free, and rises, as it were, to take their place. It is not to be supposed, as the picture might seem to show, that the plant has any power of attracting downward from a distance the carbonic acid and water particles, or that those particles have any tendency to descend from the heights of the atmosphere to vegetable foliage. The inward and outward currents of gases take place at the surface of the leaf, and this great law of gaseous diffusion (see Class-Book) causes their dispersion and commingling. The diagram is simply designed to show what the plant receives and what it returns to the atmosphere, but this discloses to us at once the peculiar nature of vegetable life—the direction in which its forces are employed.

261. Animals, it is well known, depend entirely upon vegetables for the substances which they use as food. An animal may consume flesh, but that, like all other flesh, comes ultimately from vegetation. The animal cannot, as the plant does, take carbonic acid, water, ammonia, and a few salts, and construct from them its own fabric. It has no such creative organizing power. It can only receive compounds that have been put together by the vital operations of vegetable growth, and in a certain manner transform them into its own substance. These compounds I have before described (182–221).

262. Thus animals have the same ultimate origin as plants—they all alike derive the materials of which they consist from the air. They are composed of gases, condensed and solidified from the ethereal medium around us. Extraordinary as it may seem, not only the vegetation of the world—its forests of ancient trees, its multitudinous variety of herbs and shrubs, grasses and grains; but also the entire animal kingdom—the thousand millions of human beings, and the numberless myriads of animated forms which compose the inferior races now inhabiting the earth—all, all must be regarded as derived from the subtile and viewless air, which has been temporarily imprisoned in organic forms. They preëxisted in the realm of sunshine, and clouds of lightning and tempest. The atoms of which those living beings are now composed, and which minister to all the multiform vicissitudes of their existence, formerly wandered storm-swept and homeless in the ethereal regions above. By the action of the loftiest order of forces that play in the universe (275), these atoms have been arrested in their airy career, transmuted into solid and visible forms, and compose not only the book that you are now reading, but also the vital fabric of the person who reads it.

263. But animals have a closer relation with the atmosphere than that,—the materials of which they are formed are indirectly derived from it. They depend upon it immediately and constantly for the continuance of life. Their connection with it is as intimate and indissoluble as that of the plant, but in a different way, and for an opposite purpose. The animal, it is true, like the plant, is provided with an extensive absorbing surface to act upon the air; but instead of being spread out externally like leaves, it is closely packed within the body in the shape of lung-membrane. There are some classes of animals, as insects and worms, whose breathing mechanism is placed upon the outer surface of their bodies; but all the higher races have the pulmonary machinery arranged within. In these cases, the air is introduced by mechanical contrivances into the body, and exposed to the action of the absorbing membrane. Through this membrane the oxygen gas of the air passes inward, and enters the current of the blood, which carries it to all parts of the system.

264. The compounds formed by the plant, and which the animal has used as food, are now to be decomposed—destroyed. A portion of them may have become parts of the living system; the rest may exist dissolved in the blood. The oxygen which passed the membrane and entered the circulating blood, now seizes by its powerful affinity upon the carbon and hydrogen of these compounds, producing carbonic acid and water, which pass out through the same membrane, and are dismissed by expiration into the air.

265. The animal thus undoes the work of the plant. It withdraws from the air the substance which the plant gave to it, destroys the compounds which the plant created,

and returns to the atmosphere those compounds which plants take from it. If the vegetable absorbs carbonic acid from the air, and returns pure oxygen, the animal, on the contrary, absorbs pure oxygen, and returns carbonic acid. If the plant decomposes water, which it may procure either from the air or from the soil, and pours into the atmosphere its separated oxygen, the animal extracts that oxygen, turns it again to water in its system, and expels it in the form of vapor into the air.

266. This is shown upon the right side of the diagram (PLATE XII.). Pure oxygen is represented by the direction of the arrows as passing from the atmosphere to the animal world, while carbonic acid and water are restored to the air in its stead; thus exactly reversing the chemical changes which are seen to take place between vegetation and the air. The nature of the antagonism between these two orders of life thus becomes apparent at a glance.

267. As vegetable growth involves largely the condensation of atmospheric gases, it is obvious that, if the animal is to undo the work of the plant, it must liberate the condensed gases, and set them free again in the air. This it is the fundamental office of animals to do. It unbinds, as it were, the packages of atoms which were bound up by the plant, returning them again to the gaseous form. If the essential changes of vegetable life involve the accumulation or aggregation of particles, construction, and necessary growth; the essential changes of animal life, on the contrary, involve separation, disintegration, and perpetual self-destruction—the products of which are poured constantly into the air. At every breath a portion of the living fabric perishes, and escapes away into the region whence it was first obtained by the plant.

268. In the nature of things, therefore, and by the innermost law of their being, all animals are doomed to a slow but constant dissolution. The act of breathing is an act of regulated and graduated destruction of the animal system: it is an incessant dying by particles, and in this consists the essence and peculiarity of animal life.

269. It is beyond expression amazing to contemplate the powers and adaptations with which the atmosphere is endowed in relation to the origin and continuance of life upon the earth. Light, mobile, invisible, hardly tangible—of a tenuity pushed almost into the domain of spirit, we move about within it, yet unconscious of its presence. Nevertheless, it is here; the most absolute and positive of realities; mathematically certain in quantity, and every where invariable in composition. It is the fountain of life—the parent of all organized beings. From its serene and inscrutable depths come the silent and mysterious processions of life which crowd the earth. And not only does this atmosphere which envelopes our planet give birth to all the living hosts which inhabit it, but it contains also the agent which is to destroy them. Like the fabled god of antiquity—the symbol of time—it devours its own offspring. If the atmosphere lends the materials to beautify and adorn the earth with graceful and exquisite forms of vegetable life, and even to people it with intelligent existences, it is only for a transient duration. In a brief time she again demands her own.

270. The very act by which the plant brings into being bodies endowed with life, sets free also an agent which is appointed to destroy that life. This destructive agent of the air is oxygen gas. In the plan of nature, this substance occupies a position which

brings it at once into intimate relationship with all species of living things. "To it is committed the duty to destroy all animal races, and transfer the parts of which their bodies are composed to plants. It begins to discharge this function the moment we begin to breathe, pervading each instant every part of our bodies, and bringing on interstitial death, and the continuous removal of particle after particle which it carries away. For there is an incessant change in the substance of all living structures: that which we are to-day differs from yesterday and to-morrow; and this untiring agent is all the time at work assaulting and undermining, nor stopping its action with our dissolution, but going with us into the tomb, until it has restored every particle back to the air. Death is not, as the popular superstition says, a phantom skeleton; nor, as the Asiatics think, a turbaned horseman, who pays his sudden and unwelcome visits. He is this invisible principle in the air which surrounds us, and which is the very breath we respire."

271. "When I consider the relations which oxygen gas maintains to the phenomena of this globe—constituting eight ninths of the waters of the sea, more than one third of the solid materials of the earth, and one fifth of the volume of the atmosphere;—when I reflect on the office it discharges as the great destroying agent—that it causes the decay of animal and vegetable beings, and is the antagonist of life—that nearly all of the violent, and even of the slow changes that take place, are due to it; to use a daring metaphor, it is an embodiment of the destroying angel, who gives vigor to the conflagration, and delights in the production of all kinds of violence and disasters."—DRAPER. It is even thus. And yet it must not be forgotten, that the life we live resides in this very destructive action of oxygen.

272. It is then no more true that plants and animals are products of the air, than that in the due course of nature they will all be restored to it again. By active combustion and slow decay—by putrefactive decomposition, and by measured respiration, oxygen gas accomplishes its task of bringing back the organized world to the aeriform state. In that great receptacle to which we shall all return, there exists no traces of the brief distinctions which marked the transition of atoms through the life-period. Nature is an inexorable leveller. The breath of the outcast is mingled with the breath of the prince, and the bodies of both are finally dissolved and dispersed irrevocably through the restless air. And so of all that live. The crystal medium above, and through which the stars shine down upon us with their pure and blessed light, is the great sepulchre of past generations. It has received the disrupted and scattered elements of the dead that are gone, and is hourly gathering to itself the living of the present.

273. It has been seen that the vegetable world impresses a universal and specific change upon the atmosphere. Taking into account the whole mass of the air, this change is undoubtedly slow. Nevertheless it is constant, and time alone is required to carry it to such a point, that if it were acting alone, it would entirely change and overturn the present constitution of the atmosphere. The quantity of carbonic acid would be so diminished, as to be incapable of supporting vegetable life. Any such imaginable result is provided against by the counteracting and antagonizing tendencies of animal life. The amount of carbonic acid, which might in time become deficient in the air, is kept up by animals

which generate this gas in large quantities; or rather, this result is secured by the presence of oxygen gas in the air, which by various combustive operations, acting rapidly and slowly, destroys all organization, and perpetually carries back its constituents to the atmosphere. From this point of view, the organized world may be regarded as a grand automatic machine—a mechanism of self-continuance and self-adjustment. All excessive action is restrained by a system of checks and counterpoises, by which life and the existing order of things are maintained.

274. The diagram (PLATE XII.), is suggestive of the essential hostility of the two organized kingdoms of nature, of the direction in which their life-forces respectively tend, and of the harmonious balance which results. But it only indicates through a simple and striking fact the general law. Every thing cannot be thrown into pictorial form. It may aid us in seizing a prominent idea, but the details must be presented in other ways. The extent of the antagonism of vegetable and animal life may be more clearly displayed as follows:

THE VEGETABLE	THE ANIMAL
ABSORBS CARBONIC ACID FROM THE AIR.	RETURNS CARBONIC ACID TO THE AIR.
SUPPLIES OXYGEN GAS TO THE ATMOSPHERE.	WITHDRAWS OXYGEN GAS FROM THE ATMOSPHERE.
PURIFIES THE AIR.	POISONS THE AIR.
DECOMPOSES CARBONIC ACID, WATER, AND AMMONIACAL SALTS.	PRODUCES CARBONIC ACID, WATER, AND AMMONIACAL SALTS.
PRODUCES THE NEUTRAL NITROGENIZED COMPOUNDS ALBUMEN, GLUTEN, CASEIN.	CONSUMES THE NEUTRAL NITROGENIZED COMPOUNDS ALBUMEN, GLUTEN, CASEIN.
PRODUCES THE NON-NITROGENIZED COMPOUNDS STARCH, SUGAR, GUM, OIL, AND VEGETABLE ACIDS.	CONSUMES THE NON-NITROGENIZED COMPOUNDS STARCH, SUGAR, GUM, OIL, AND VEGETABLE ACIDS.
ENDOWS MINERAL MATTER WITH THE PROPERTIES OF LIFE.	DEPRIVES ORGANIC MATTER OF THE PROPERTIES OF LIFE.
IMPARTS TO CHEMICAL ATOMS THE PROPERTY OF COMBUSTIBILITY.	DEPRIVES CHEMICAL ATOMS OF THE PROPERTY OF COMBUSTIBILITY.
IMPARTS TO CHEMICAL ATOMS THE POWER OF NOURISHING THE ANIMAL.	IMPARTS TO CHEMICAL ATOMS THE POWER OF NOURISHING THE VEGETABLE.
CONVERTS SIMPLE INTO COMPLEX COMPOUNDS.	CONVERTS COMPLEX INTO SIMPLE COMPOUNDS.
IS AN APPARATUS OF DE-OXIDATION.	IS AN APPARATUS OF OXIDATION.
IS A MECHANISM OF CONSTRUCTION.	IS A MECHANISM OF REDUCTION.
ABSORBS HEAT AND ELECTRICITY.	PRODUCES HEAT AND ELECTRICITY.

XVI.—CHEMISTRY OF LIGHT—SOLAR DYNAMICS.

275. We have seen in the foregoing passages, that there resides in the atmosphere which surrounds the earth, an omnipresent agent of destruction—a substance, which, by its essential nature, is the unrelenting, and ever-active foe of all organization. We call it oxygen gas. All forms and varieties of living things upon the earth, vegetable and animal, consist of elements in such a condition, that they are capable of being torn from their vital combinations by the affinities of this substance. Its disorganizing agency never ceases. Wherever there is a living being or an organized substance accessible to air, there this agent is always at work with greater or less activity, rending away particle by particle of the organic structure, until at last it is utterly broken down and destroyed. The active agency of the air is exerted upon the living world in a single direction for its destruction. It contains a force which, if left to itself, would speedily sweep from the globe all living existences, and to this destructive energy it opposes no counteracting or antagonizing power. It can dissever, but it cannot unite; it can demolish, but it cannot build up; it can disorganize, but it cannot construct; it can cause to perish, but it cannot cause to grow. The oxygen of the air would soon change the green and beautiful and vocal earth to a dreary and silent sepulchre. Nor does the earth itself, the land or the sea any more than the atmosphere, contain a principle or power capable of checking or counteracting these mighty destructive tendencies of the gases which enshroud the earth. The insatiate air devours the vital organism and the passive earth receives the scattered dust; but neither can revivify or reorganize the disrupted elements. The earth carries within itself the causes of its own decay and dissolution, but not of its own renovation. It can destroy its living inhabitants, but it possesses within itself no power to replace them.

276. Yet this destructive tendency of the air *is* checked and antagonized. The organism that oxygen consumed re-appears; the atoms that it scattered are re-assembled; the earth is green and beautiful, bursting with exuberant vitality, and teeming with animate beings. The stream of life flows on without arrestment or interruption.

277. If then the earth is not the source and possessor of its own life-forces, whence come they? That high power which originates organization, which gathers dead matter into living structures, and calls into existence all the beauties and glories of the earth, whence is it? It is not of our world; it is super-terrestrial; it comes from the great central body of our planetary system, the SUN.

278. Beside the force of gravitation exerted by the sun, and which controls the earth in its orbital path, every one knows that we are connected with him through the medium of visible radiations or rays. The radiations which flow from the sun to the earth are capable of giving origin to several different kinds of effect. One of its effects is produced upon the animal eye, and is called light. In what manner light, or the luminous force acts upon the eye to generate vision, or cause the animal to see, we do not understand. We know many of the laws of light, but how the visual organ is finally affected in producing the sensation of vision, is not comprehended.

279. If now we place a thermometer, under suitable circumstances, in a visible ray of light, we shall observe that the temperature rises; that is, the solar action has had the effect of forcing the particles of mercury in the thermometer to separate from each other so as to occupy a larger space; the fluid metal therefore ascends in the thermometer tube, and we say the temperature rises. The sun's rays act in this manner not only upon mercury in the thermometer, but upon all objects on which they fall. They force apart or drive asunder the constituent atoms, so as to impart to objects a greater bulk. When the sun's rays act thus upon our bodies, they produce a feeling or sensation of warmth or heat. The agent which causes this effect is termed caloric.

280. If the two gases, chlorine and hydrogen, be mingled together in the dark, they remain mixed or diffused through each other so long as they are retained in darkness. But if a ray of light be suffered to fall upon them, they combine together explosively, forming a new chemical compound. A force residing in the sunbeam thus produces the direct combination of chemical elements. If a piece of white paper be washed over with a solution of nitrate of silver, or any of the white salts of silver, and then exposed to the sun's rays, it will change color and become black. There is here a chemical decomposition, which is brought about by the solar force associated with light. Many other substances are also acted upon in a chemical way by the luminous beam. All daguerreotype pictures are products of the action of this force. The agent which brings about these results is variously named. It has been called the actinic force, or actinism; the tithonic force, and the chemical force, or the chemical ray.

281. It has been conjectured that the forces which produce these various results—light, heat, and chemical action—are essentially one: that the effects are but modifications or different manifestations of a single agent or power. According to the prevalent theory, heat and light are both but motion—vibratory or undulatory motions of the same ethereal medium—their differences consisting in the rate or velocity of the vibrations, light only appearing when they exceed from four to eight hundred billions in a second. However this may be, the fact remains that we have three classes of effects produced by the solar radiations which are widely different, namely: luminous effects, which act upon the eye; thermal or calorific effects, which expand all bodies; and chemical effects, which play between different elementary substances, causing chemical changes.

282. These three kinds of force are capable of being separated by analyzing, or as it were, splitting the sunbeam with a glass prism. If a ray of light be admitted through a small aperture into a dark room, and be suffered to fall upon a triangular prism of glass, it will not pass through it, and go forward in a straight direction across the room; but it will be turned out of its pathway (refracted), and be thrown upon the opposite wall, not in the form in which it entered the room, as simple white light, but decomposed into an oblong image of the most brilliant colors, which is called the *solar spectrum*. This arrangement is exhibited in PLATE XIII. The ray of light is represented as entering the room, and passing into the interposed prism A B. But instead of emerging at exactly the opposite point, and passing on in the direction of the shaded line c D, it disappears, resolving itself into the colors which are roughly shown in the diagram.

283. The colors produced under these circumstances are supposed to be the compo-

nents or constituents of white light. Pure white light consists of all these colors; and by passing the colored rays through another prism, they are again combined, and reproduce white light. When the image or spectrum is thus formed, the colors are not seen with a clear and sharp outline; they blend and melt into each other, so that it is difficult to fix the line at which one ceases and another begins. Indeed, different eyes seem to receive different impressions; for if several persons attempt to mark the exact spot where one color terminates and another commences, they will, in most cases, assign different points. The diagram exhibits what is known as the Newtonian spectrum, consisting of seven colors, in the order in which they are turned from their normal course—that is, in the order of their refrangibility. The red color is seen to be least bent from its natural path—the straight line—that is, it is least refracted. Orange is next; it is more refracted;—then yellow, green, blue, indigo, and lastly violet, which is the most refrangible color. By using prisms of different materials, the length of the space occupied by the respective colors of the spectrum is made to vary.

284. If now, in this disappearance and destruction of the white ray, we search to know what has become of the luminous effect, we shall find that it is not equally distributed through the colored spaces. If we pass a piece of very fine print through the spectrum, we shall find that we can read it at a greater distance in the yellow space than in any of the other colors, showing that at this point there is most light. From the yellow space to either extremity of the spectrum the light declines. The curved line in the diagram, which extends from end to end of the colored spaces, from the extremity of the violet to the extremity of the red, represents by its curvature or height the intensity of the luminous effect. It is called the curve of luminous intensity, and its highest point corresponds with the yellow color, which is the maximum of luminous effect.

285. Such is the influence of the prism upon the luminous principle of the solar beam. But what in this case becomes of the thermal or heat-producing principle which was associated with the light? It enters the prism with the light; how then is it disposed of? Does it pass through it, and proceed in a straight course across the room, as indicated by the shaded line *CD* in the plate; or is it dispersed over the spectrum in the same manner as the light? A thermometer placed at *D*, where the unrefracted ray would naturally fall, shows no rise of temperature. The calorific principle has therefore been diverted from its normal path—has been refracted. If now delicate thermometers are placed in the several colors of the luminous spectrum, it will be found that they are disturbed, and indicate an increase of temperature, but not in all the colors alike. A feeble heating effect will be shown in the violet color; it will be increased in the indigo, and still more in the blue: in the green the mercury will rise higher, and in the yellow still higher. But is this point of the greatest luminous effect, also the point of utmost thermal effect? Do the luminous and calorific maxima coincide? By no means! The thermometer in the orange color indicates more heat than the yellow, and the red more than the orange. But what is most important, a thermometer removed quite out of the region of the visible red, where no light falls, shows a greater heating effect than at any point within the spectrum. The curve of thermal intensity in the diagram exhibits the progressive increase of temperature from the violet to the red, and beyond this into the

region of darkness, where the maximum of thermal influence occurs. We thus observe that the heat rays are refracted as well as those of color. They are dispersed over a region forming, we may suppose, an invisible calorific spectrum, which does not coincide in position with that produced by light, but laps over it, and extends beyond it, through the white space at ε , in the direction of least refrangibility. The light-principle and the heat-principle, whatever they are, may be thus regarded as distinct, separable, and independent forces.

286. But where is the third element of the sunbeam—the chemical principle or force? This is also turned by the prism from its straight course, and refracted as are the two others. If we wash over a sheet of white paper with a solution that may be acted on by this force, and notice where the chemical change or discoloration proceeds most promptly and rapidly, and is consequently strongest, we shall discover several curious facts. In the first place, the chemical action coincides in intensity with neither the luminous nor the calorific action. The maximum, or highest point of chemical effect, occurs in the violet region at the opposite extremity of the spectrum from that in which the thermal effect is produced. And in the next place, at the point of greatest luminous intensity (the yellow color) the chemical effect totally disappears—is completely neutralized. The curve of chemical intensity, as seen in the plate, exhibits this, and shows that there are two maxima of chemical influence. The greatest is in the highly refrangible violet region; and there the chemical power extends beyond the extremest limit of light, in the direction of the prolonged white space at ε . The chemical influence also extends beyond the red, at the other end of the colored series, as the curve shows. There appears then to be a chemical spectrum which does not correspond in position with either of the others, and a portion of which is separable and distinct from both. Thus the chemical constituent of the solar radiations is physically independent of the two other forces with which it is conjoined. The sunbeam produces three kinds of effects, so totally different in their nature as to be attributed to three distinct species of force, and which, moreover, appear actually and experimentally capable of separation.

287. But besides these three forms of action exerted by the sun upon the earth, there is still a fourth kind, and it is the one with which we have mainly to do at this time. It is under the influence of the radiant force of the sun—either one of those which we have been considering, or another associated with them—that vegetable growth takes place. Plants require light to carry on their characteristic functions. They cannot flourish and form their peculiar organized productions out of unorganized matter in darkness. They demand the *stimulus* of light; in other words, light is their motive power—the force which produces those fundamental and essential changes which appertain to and constitute vegetable life. The solar radiations supply the force which de-oxidizes carbon and hydrogen in the vegetable leaf. This is a chemical effect; and we should at first certainly suppose that it is brought about by the chemical force which we have been contemplating. But, singular as it may seem, this is not the fact. Dr. DRAPER has shown that the change wrought within the leaf, the decomposition of carbonic acid and water, and the setting free of oxygen, takes place with far the greatest activity in the yellow ray; the point at which the chemical influence of which we have been speaking totally disappears.

The effect is said to be due to light, as contradistinguished from the other agents of the sunbeam—that is, it takes place neither in the dark thermal space at one extreme of the spectrum, nor in the dark chemical region of the other: the changes only go on in the luminous field, and are most active where the light is most intense.

288. Nevertheless, the action upon the leaf is in its nature so different from that upon the eye, that it seems hardly possible to ascribe them to the same cause. It is true, that the solar force which acts specifically upon the leaf, to bring about decomposing changes, has not yet been isolated or separated. But the work which it does is so essentially different from that of the other solar agents, that we seem justified in recognizing it as a fourth and distinct principle or power which resides in the sun's rays. That agent of the solar emanation, which conducts the decomposition, and controls the organizing processes that take place in vegetable structures, may perhaps at present be best distinguished as the de-oxidizing force, or the de-oxidizing ray. It is not to be supposed that this force acts with absolute independence. It is brought into play only under certain conditions, and one of these is the intensity of the conjoined calorific influence.

289. I have been thus particular in describing the constitution of the sunbeam, because we are now to contemplate it as the grand source of nearly every form of *power* which is manifested upon our globe. Wherever we turn our attention all is motion, activity, demonstration of force. The atmosphere surges in storms and hurricanes; the streams thunder over precipices, and set in motion the thousand-fold devices of mechanical industry; steam urges on the dilatory ship, drives the swift train, or digs into the earth, or impels the factory; electricity carries intelligence to the world's end with the speed of thought; the vegetable world draws unorganized matter into its vital vortices, and fabricates the materials of life; and the animal world is every where in motion, cleaving the air, dividing the waters, burrowing in the earth, traversing the land, and putting forth power in countless forms. Yet the placid and tranquil sunbeam is the grand source of all these manifestations of force—the great dynamical energy of the world. Those who have not had their attention especially drawn to the subject, are little aware of the tremendous agencies which slumber in the solar ray, or to what extent all kinds of terrestrial power are derived immediately from this source.

290. In whatever respect we regard the solar emanation, it presents itself to us dynamically—as a spring of power. It is true that this is not so apparent in the case of the luminous principle which affects the eye. We cannot immediately demonstrate or measure the force which produces vision. But there can be no doubt that sight is the result of something *done*; the result of a power expended upon the optic organism; the product of action and re-action between the luminous beam, and the atoms of nervous matter and arterial blood of the retina. All analogy compels us to this supposition.

291. In the case of the chemical effect, as in the daguerreotype, the exercise of force is obvious. We here have a determinate movement of atoms, decomposition, power to overcome affinity. The solar impulse is sufficient for the transposition of chemical molecules and the destruction and production of compound substances.

292. But the dynamic influence of solar radiation is more conspicuous in its thermal, or heat-producing effects. As the great luminary of the solar system, shoots down his

calorific impulses, all objects upon which they fall increase in magnitude with an irresistible power. Material objects are larger, occupy more space at mid-day when exposed to the sun's direct influence, than at midnight when withdrawn from it. This change of the relations of atoms, although taking place with immense force, is yet so small in quantity, that when occurring in the solid substances around us we hardly notice it. But when the atoms of bodies are in such a condition as readily to yield to calorific agency, the effect at once strikes us with its vastness. The particles of air for example are easily put in motion; the sun's heat therefore acting upon it, throws these particles into such active movement, that great masses of air are expanded, agitated and thrown into extensive motion. The unequal action of the sun's heat from various causes affects the atmosphere differently in different localities; and the consequence is currents of air or winds in all directions. The gentle breeze, the driving gale, and the destructive tornado, are thus but manifestations of force which come directly from the sun in the form of impulses of heat. The sails by which the ship is urged, on her commercial errand over the ocean, and the wind-mill which propels machinery, are alike driven by power which comes from the sun.

293. The effect of the sun's heat falling upon the surface of oceans, seas, lakes, rivers and moist soils, is to change the liquid water to the state of vapor. This diffuses through the air, and is carried by its currents in all directions. Falling as rain upon the uneven land, it flows along in streams to the lower levels with sufficient power to be available for mechanical purposes. In this manner force which comes from the sun becomes converted into water power, and is used by man in a thousand ways, and for a thousand purposes.

294. But the sunbeam is not only the source of wind and water power, it is also the great fountain of all steam and animal power. In a chemical point of view, steam and animal power are one thing, they both spring from the oxidation of carbon and hydrogen, which is supplied to the one in the shape of fuel, and to the other as food. For the production of a given mechanical effect, a steam-engine oxidizes a certain amount of carbon as coal, or of carbon and hydrogen in the shape of wood. And so with the animal; for the performance of a certain amount of labor, a given quantity of organized carbon and hydrogen must be consumed—oxidized by the respiratory process. Combustion, or the chemical agency of oxygen gas is the immediate cause of both these manifestations of force. Oxygen is attracted to carbon, and hydrogen with a certain degree of energy, and in combining chemically with them it develops a corresponding degree of power which appears in the available form of heat.

295. But it may be asked if steam power and animal power are thus due to the attractive energy of oxygen gas, how can we consider them as derived from the sun, or ascribe them to the agency of his beams? Let us see. The carbon and hydrogen which have united with oxygen are retained in its embrace with the same force which drew them into union; for while in combination with their full proportion of oxygen, carbon and hydrogen cannot be made to unite with it again. Water and carbonic acid though containing the elements which produce combustion, cannot be burned, because their carbon and hydrogen are already saturated with oxygen, and consequently cannot attract more of it. The elements, before active, now come to rest; there is no further source of power. When a certain quantity of oxygen burns a certain quantity of coal, both elements be-

come locked up in the shape of carbonic acid, and they are locked together with the same force which they produced in burning. They have no power of self-releasment; they have power to unite, but not to separate or escape from combination. It is therefore obvious that when all the accessible atoms of carbon and hydrogen in organized substances, have been seized upon by oxygen, oxidation must terminate, and there will be an end of all steam power, and animal power, all combustion and life.

296. Steam power and animal power, combustion and life, thus depend upon a continual supply of carbon and hydrogen *in an unoxidized state*. But whence comes this supply? One of two things must be true; either there is somewhere in nature an exhaustless fund of free oxygen and unoxidized hydrogen and carbon, and some place provided for the reception and endless accumulation of the oxidized products; or in the economy of the world some plan has been devised by which the same limited amount of materials may be used over and over again. The Almighty Contriver has resorted to the latter method; the most wonderful economy of resources is characteristic of the ways of nature. The carbon and hydrogen which exist in union with oxygen are taken out of its grasp, separated, de-oxidized, put in a condition in which they can combine with it again. The carbon and hydrogen existing in oil or woody fibre have been burned under a steam-boiler, or in an animal body, and produce carbonic acid and water; these now enter the vegetable organism, are carried to the green leaf, and there exposed to the action of the sunbeam, which decomposes them, restores their oxygen again to the air in a free and active condition, and again groups the hydrogen and carbon into the forms of oil and woody fibre. The oxygen thus set free and the organic compounds thus formed may now unite again and power will be again developed. Oxidation is thus the immediate cause of force, but it is the sunbeam which supplies the materials upon which oxygen can act. It is the sunbeam which impels the vegetable mechanism in the preparation of organized combustible compounds, and thus maintains the existing order of things.

297. We may look on the present vegetation of the globe as a stock of de-oxidized carbon and hydrogen, prepared by the sun for the sustenance of animals, and for the use of man as a source of warmth and mechanical and chemical power. It is the sun which imparts to terrestrial matter combustible properties; and for whatever purpose we employ combustibility, the effect which it produces is ascribable to solar action. By means of a burning lens we can gather the heat rays of the sun into a focus and produce intense calorific effects. But all our more manageable forms of heat are due to the de-oxidizing ray. The chemist burns gas, oil, alcohol, or some other organized hydro-carbon in his laboratory, and thus brings about innumerable chemical changes and effects. The de-oxidizing force of the sun which grouped the organic molecules is transformed, or as it were transmuted into heat in the burning lamp, and then again appears as a chemical result. The coal beds are deposits of de-oxidized carbon, the remains of an ancient vegetation; they are reservoirs of force borrowed many ages since from the sun, and now available for the various uses of civilized man.

298. It has been stated that electrical power generated in the galvanic battery, and employed through the telegraph for the transmission of intelligence, is due also to the sunbeam. The immediate cause of the electric current is the oxidation of the zinc, iron,

or other metal of the battery, the oxygen being furnished by an acid or saline solution, which corrodes and dissolves the metal. But whence came the metallic iron, zinc or other oxidizable metal employed. It was reduced from the condition of ore, de-oxidized or de-sulphurized by the combustion of fuel in the smelting furnace. The recording instrument of the telegraph is moved by the magnet; the magnet is formed and controlled by the electric current originating in the distant battery, and sent along the wires. The cause of the electric movement is the oxidation of the metal, and the metal was reduced from its ore, endowed with the *capability of being oxidized* by the combustion of carbon or hydrogen and carbon, and this, as has been shown, is the effect of solar excitation. Thus by a chain of effects we trace the motive power of the telegraph to the same celestial force which gives origin to organic life upon the earth.

299. The amount of power which is expended in the de-oxidizing action of the solar rays is enormous. Whatever may be the force with which oxygen combines with carbon and hydrogen, and which retains them in union, it is evident that an equal or greater force must be exerted to separate them. Some of the metals possess a sufficiently strong attraction for oxygen to take it from hydrogen—that is, to decompose water at common temperatures; and the electrical current is also capable of decomposing it, and setting free both its elementary gases. But it transcends the power of the chemist, by means of all the resources of his science, to take oxygen from carbonic acid at common temperatures—a thing which is done every day, in every green leaf, by the force of sunlight. By taking some substance which has a powerful affinity for oxygen, and aiding its action by an intense degree of heat, the oxygen may be forced *into a new combination*, and the carbon set free. But without the aid of any powerful de-oxidizing substance, or of any excessive heat, the plant decomposes carbonic acid, and *sets the oxygen free*. In doing this the sunbeam exerts a prodigious power. A bushel of coal combines in burning with about 200 pounds of oxygen; and if the combustion takes place under a steam-boiler, in the most favorable circumstances for the manifestation of mechanical effects, it will produce power enough to raise from 96 to 100 millions of pounds a foot high. The coal and oxygen take the form of carbonic acid, of which less than 300 pounds are produced. In decomposing this carbonic acid the sunbeam exerts the same measure of force—sufficient to produce the mechanical result of raising 90 or 100 millions of pounds weight to the height of one foot.

300. Dr. GREGORY remarks, that “the animal body may be regarded as a galvanic engine for the production of mechanical force: this force is derived from the food, and with the food has been derived from the solar rays. A working man, it has been calculated, produces in twenty-four hours an amount of heating, or thermal effect, equal to raising near 14,000,000 of pounds to the height of one foot—heat being one form of mechanical effect. But from causes connected with the range of temperature, he can only produce, in the form of actual work done, about as much mechanical effect as would raise 3,600,000 pounds to the height of one foot, and that in twenty-four hours. Even this is a prodigious amount of force; and whether we regard it as derived from heat, electricity, or chemical action, it is ultimately derived from the luminous solar rays on which vegetation depends.”

301. The same high authority remarks further: "That essential process by which the plant decomposes carbonic acid and water, liberating their oxygen, can only take place under the influence of luminous rays. Now if we consider that the chemical effects of light—light being motion—is a mechanical effect, and that the power necessary to decompose carbonic acid and water is enormous, we see that the amount of mechanical effect produced in growing vegetables by the solar rays must be very great indeed. In fact it has been calculated that the mechanical force derived from the sun by the amount of wood growing in a year, on one square foot of surface, corresponds to that which would be required to raise a weight of 486,000 pounds to the height of one foot; and this is only one eleventh of the whole effect of the sun's rays, of which only one fifth reaches the planet, and half of that is lost. Recent researches tend to show that all the mechanical effect (except in a few cases, such as tide-mills, volcanic action, and a few more) which is available to man, is derived from the solar rays, directly or indirectly. We have seen that a vast amount is expended in producing vegetables; and it is obvious that the whole mechanical power of the animal body has been drawn mediately or immediately from that which has been stored up in plants."

302. We thus see how it is, that the sunbeam antagonizes the destructive agency of oxygen gas. That agency can only take effect upon matter that the sunbeam has organized. Creation must precede dissolution. Oxygen can destroy only that which the solar ray makes capable of being destroyed. We charge our systems at every breath with this substance, that by its disorganizing action it may give rise to the power we expend. But we supply a continual resistance to this action in the form of food—the product of solar force, to renew the wasted parts of the fabric. As the destructive spirit of the air by decay, respiration and active combustion, disintegrates organic structures and scatters their elementary atoms, the sun's rays exercise an equal power of an opposite kind; they re-unite the dissevered molecules, and endow them again with the mysterious properties of life.

303. By reference to PLATE IV., it will be seen that the rock formations of the earth are composed of oxidized metals. About one half their weight consists of various metals, and the other half of oxygen gas combined with them. Now the sun exerts upon the earth a force of de-oxidation, a power which tends to separate oxygen from the substances with which affinity binds it. The earth is acted upon constantly by this force, in all parts of its orbit; and that each portion of its surface may receive a share of the solar influence the ponderous globe revolves rapidly upon its axis. Now the de-oxidizing force is capable of acting only upon the surface, and it cannot directly separate the oxygen from metals in stones and minerals. It is brought into play only in an appointed way and by appropriate mechanisms. The de-oxidizing agent acts mainly upon carbonic acid and water, producing hydro-carbon foods and fuels in the organism of the plant. At this point comes the agency of man. The de-oxidizing force stored up in vegetable compounds he expends to de-oxidize the metals which his multiform necessities may require. The laboring man becomes a director of forces which emanated from the central star of our planetary group; nay more, this is the origin of the very physical power which he himself exerts.

304. It has been stated that the two worlds of organization are condensed from the intangible gases with which our planet is enshrouded. If thus all living beings are derived from these fleeting airs, which are so rare and ethereal that they seem almost designed to connect the worlds of matter and spirit, it is fit that the forces which control such wonderful changes should have a celestial origin. If the grand office of pursuing to its final dissolution the entire organic world—of bringing its elements to the quiescent state—be committed to an agent which, when called up before us by the sorcery of the chemist, is but an invisible gas—a thing which no man has seen—it cannot surprise us that the force of antagonization by which all life and beauty and glory upon the earth are perpetually called into being, should be the divinest effluence of the stars—an activity which pervades the universe.

305. Astronomical science teaches us that the sun is but a star, and that the fixed stars are also suns, many of them being immensely larger than our own. The luminous principle which emanates from stars placed at the profoundest distances in space, affects the eye—is related to the optical mechanism of the animal,—its nervous tissue and circulating blood, in precisely the same manner as the light of our sun. Luminous impulses which expend themselves upon the retina in a few minutes after they have left the central orb of our system, affect the brain in exactly the same way as those which have been as many thousands of years travelling from the uttermost bounds of the telescopic universe. Furthermore, the light of the stars exerts the same specific chemical effect, decomposes the salts of silver just as does solar light. Several of the fixed stars have been daguerreotyped; that is, through spaces so vast that the imagination is tasked to conceive them, they have sent impulses which move chemical atoms, and control chemical changes. The CHEMISTRY OF THE STARS is therefore an experimental reality.

306. If, therefore, our sun, the great centre of vital dynamics, and fountain of life-impulsions, which has charge of the destiny of our planet, alike its atoms and its masses, be but a solitary star among the countless hosts of the celestial spheres; if the earth be a scene of life, beauty and intelligence, only by virtue of its astronomical relations; if the messenger of God, the solar beam, comes through the spacious amplitudes a hundred millions of miles, to illuminate and vivify and people an otherwise desolate globe; if the life-exciting forces traverse stellar distances and belong to astral systems, can we imagine even for a moment, that the phenomena of life are limited to our earth? Can there be a question that organization is the product of a plan of agencies which comprehends the physical universe, and that the effect must be as universal as the cause?

QUESTIONS.

I. Way in which the Matter around us is composed.—1. What changes do material objects undergo? Give an illustration. 2. What is the first inquiry of Chemistry? How does the chemist answer this question? What is the meaning of the word analysis? What is the limit of analysis? 3. What forces are made use of in analysis? 4. What is the result of analyzing water? What is its limit? Of marble? 5. Is it possible or probable that our knowledge may be extended in this direction? 6. In what manner do material substances and the sentences of a language resemble each other? 7. What analogy is there between the number of letters in a language and the number of elements in nature? 8. What analogy is there between the frequency with which certain letters usually occur in words and certain elements in the most common compounds? 9. What is the synthesis of elements, and how does that resemble the formation of words? 10. What is said of the properties and powers of these elements? 12. What do the left columns in plates I. and II. represent? What does each square indicate? Why is each element represented of a different color? Why have the special colors which are given to the elements in plates I. and II. been adopted?

II. Manner in which Chemical Substances combine.—13. What do the right columns in plates I. and II. represent? How are the lines on these plates arranged, and what are they designed to express? How does chemical differ from other kinds of attraction? What are the first fundamental conditions which make chemistry possible? 14. What is the first effect of affinity? What is said of mechanical combination? Example? 15. How does affinity affect the sulphur and iron mixture? 16. By what are all chemical compounds characterized? Give examples? 17. Upon what circumstances does the loss of properties of elements, when they enter into combination, depend? Examples? 18. What is the information got from analysis? What questions arise at this point? 19. When is the information we get from analysis restricted to the sample examined? What is it that here causes the difficulty? When may we generalize the information afforded by analysis? Upon what does the possibility of this depend? 21. What is the first law of affinity? How are chemical quantities expressed? Example? 22. What mode of representation becomes possible in consequence of the definite composition of bodies? How are oxygen and hydrogen represented in plate I. What do the lines passing from them signify? What do the sizes of the squares represent? 23. What do the numbers connected with oxygen and hydrogen indicate? What are they called? What relation have the areas of the squares to these numbers? What is the relation between the size of the square which represents hydrogen, and that of oxygen, chlorine and sulphur? 24. What is said of the importance of determinations by weight? What kind of measurement do the squares express? 25. Are the combining numbers whole numbers or fractions which are given in the plates? Why? 26. What is shown by the fact that the carbon and hydrogen squares are maintained of the same size throughout the work? 27. What is said of the wonderful order of chemical combinations? 28. What is it that combining numbers measure? Give examples? Explain the meaning of the term 'equivalent'? 29. What is meant by reciprocal proportions? Example? 30. In what does chemical decomposition often consist? Example? 31. What is said of the scales of equivalent numbers? 32. What does the law of multiple proportions teach? 33. By what numbers may the quantities of oxygen, sulphur, and iron, found in compounds, be divided without a remainder? How are the equivalents of compound bodies ascertained? Carbonic acid? Lime? Marble? 34. What has been one result of the establishment of the principle of definite proportions? What are symbols? How do they represent compounds? What is the use of the figures joined to them? 35. What is the advantage of symbols? How is the composition of water expressed by the two methods of writing? 36. What is said about the order of arrangement of symbolic letters? What is the relative position of hydrogen in plates I. and II.? Of oxygen? Of the metals? Is there a reason for this? What is it? Which side does the electro-positive element go? 37. What does Liebig say of weighing in chemistry? 38. When is it more convenient to measure than to weigh? To what class of substances does bulk measurement apply? 40. How would we proceed to get the combining volumes of oxygen and phosphorus? 41. How may the result be expressed? 42. How do we find the equivalent volume of hydrogen, and what is it? 43. Nitrogen and chlorine, and what are theirs? 44. How does a knowledge of combining volumes become useful? 45. What is the combining volume of hydrochloric acid gas? 46. What is the combining volume of steam? 47. What of ammonia? 48. Is there any variation from the apparently simple law of combining volumes?

III. Theory of Atoms.—50. What is the basis of the laws of combining proportions? 51. What is said of the demands of the human mind? 52. What is said of Newton's theory of gravitation? 53. Can we suppose that the remarkable facts of combination exist without a cause? By whom has a cause in this case been assigned, and what is it? 54. What does the word atom mean? Can we discover atoms by observation? 55-62. What examples are given of the degree of minuteness to which matter is divided? 63. What do these facts show? Do these facts warrant us in supposing that matter is endlessly divisible? 64. What has the chemist reason for believing? What objection is made to this? What kind of indivisibility is it that the chemist affirms? 65. To what may chemical atoms be compared? 66. What analogy is suggested to the atomic constitution of matter? In what sense may we consider the planets as indivisible units? 67. How is matter believed to be composed? In what manner are these atoms associated? 68. What does the atomic theory teach? How are we to regard the atoms? 69. By what are these propositions commended to us? How do the laws of combination follow from the admission of atoms? Examples? 70. How do the diagrams upon the plates illustrate the atomic theory? 71. What does Liebig remark concerning atoms? 72. Is the atomic theory in general use? 73. Is there any difference between 'atomic number' and 'number of atoms'? What? Examples? 74. How is it common to use the term atom? 75. What is supposed to be the form of atoms? What figures seem associated with physical phenomena, and what with chemical or crystalline? Why have square diagrams been adopted in this work to represent elements or atoms?

IV. Constitution of Salts—Theory of Salt-Radicals.—76. What is the source of acids and bases? How are acids and alkalis usually known? Are these tests satisfactory? Why not? 77. What is their real test? What do they produce when united? 78. Is it easy to decide what a salt is? Is there agreement upon this point among chemists? Is this subject a difficult one to study? How can we get assistance? 79. To what salts is our attention first called in plate III.? How are they represented? Have they long been supposed to be thus constituted? What other acids combine in a similar manner? 80. If hydrochloric acid and soda are brought together what results? How is common salt really produced? In its analysis what do we get? Describe the double decomposition in plate III.? 81. What follows if we adhere to the old idea of a salt? What are halogens? What is necessary in order to regard the haloid compounds as salts? 82. What does the doctrine of salt-radicals propose to do? How does it begin? 83. How was oxygen found when first discovered? What was it supposed to be? What was afterwards discovered? What are oxacids? 84. What are hydracids? What are the elements which combine with hydrogen called? How are the hydracids represented? 85. What are simple radicals? What are compound radicals? Example? How does cyanogen behave like chlorine? 86. Upon what condition are the acid properties of the oxacids developed? What is claimed by the advocates of the later or salt-radical theory? What is objected to this? What is the reply? 87. From what facts is it inferred that hydrogen is the real acidifying principle? 88. How has water been generally supposed to exist in the acids? 89. What is objected to this? 90. How does the new theory suppose the hydrogen to be combined? How in the case of sulphuric acid? Nitric acid? How does this bring all acids into one class? 91. What do the advocates of the old view object concerning the isolation of compound radicals? What is replied? 92. Upon this view how do we convert acids into salts? 93. What are Dr. Gregory's definitions of acids and salts? 94. What is illustrated by the diagrams of plate III.? Why is hydrogen supposed to be a metal? 95. What are the combinations of phosphoric acid with water? What is the result of substituting alkalis for this combined water? 96. What does monobasic phosphoric acid form? Example? The bibasic acid? The tribasic acid? 97. What is the basic phosphate of lime? The neutral phosphate? The superphosphate? 98. How is superphosphate of lime formed from bone dust? 99. How may the phosphates be represented by the salt-radical view? 100. Do salts combine with each other? When?

V. Chemistry of Geology.—101. In what two forms are rocks found? 102. What is the aspect and origin of the unstratified rocks? Of the stratified? 103. What do the stratified rocks contain? Do unstratified rocks contain fossils? 104. What is said of the metamorphic rocks? 105. How is our knowledge of the strata obtained? 106. What is said of the rate of action of geological changes? 107. What geological changes are now taking place? What does Mr. Lyell remark? 108. What is the result of the *continuous*

