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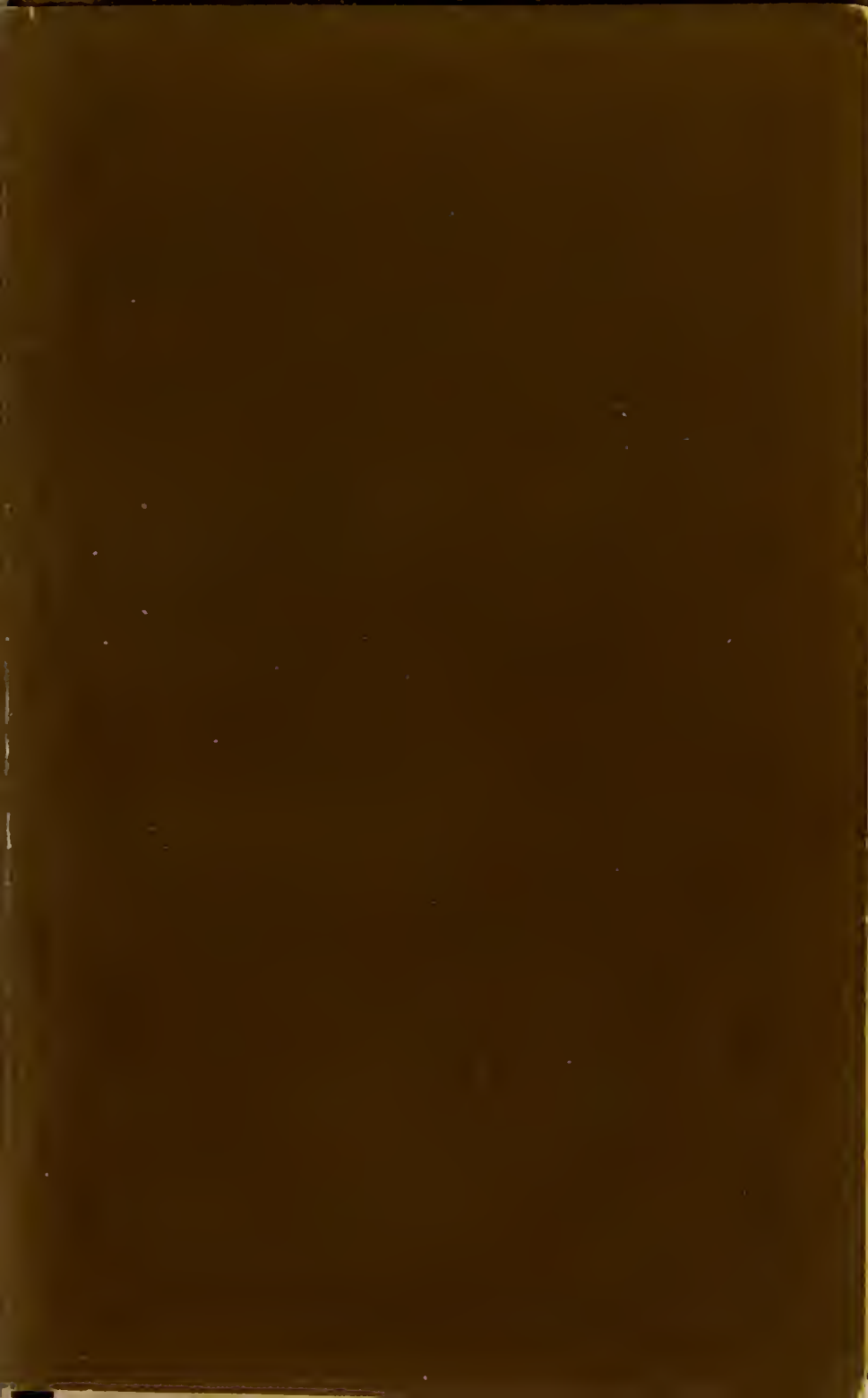
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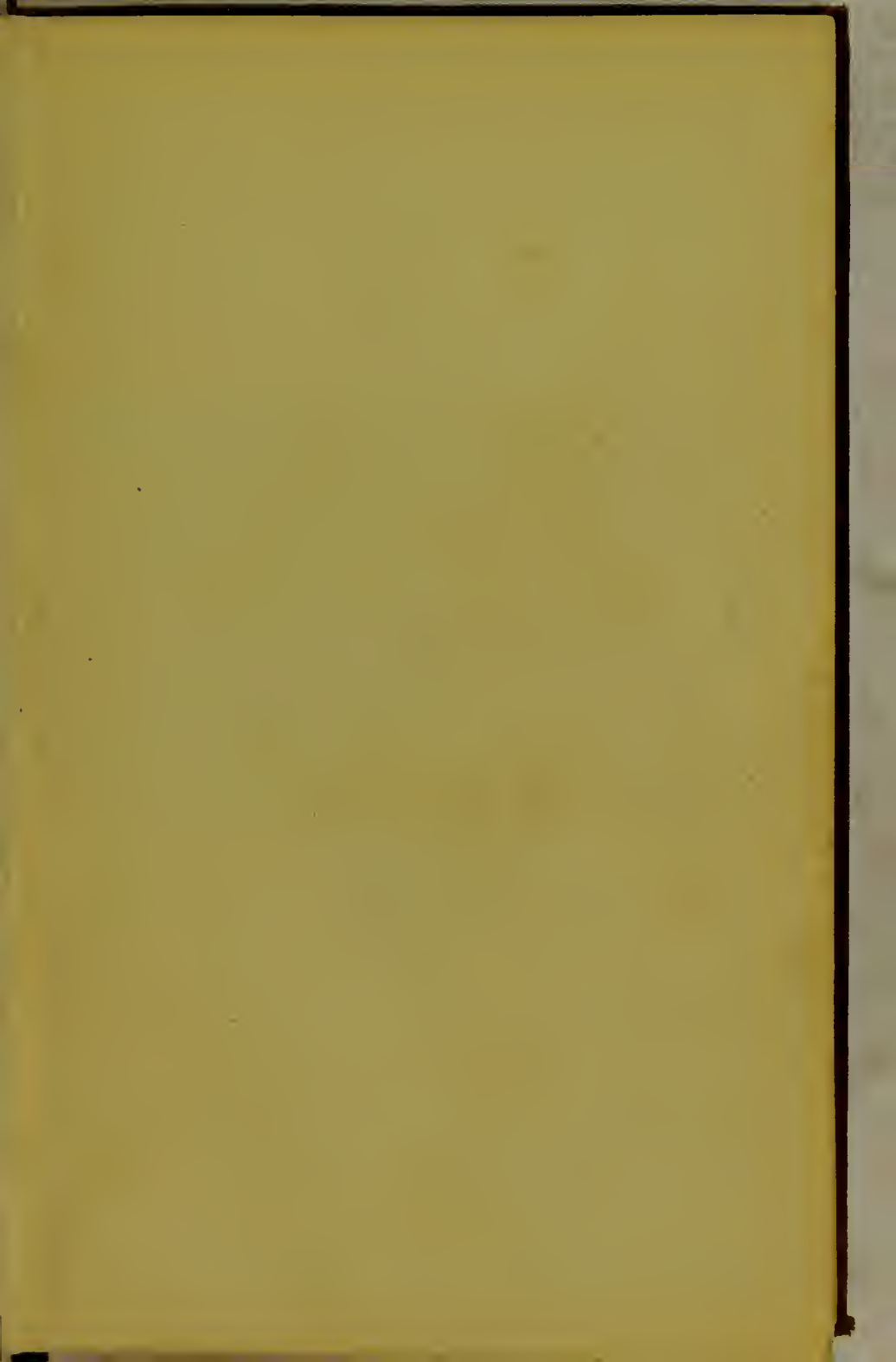
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# COLOUR.

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# COLOUR.



## CHAPTER I.

### INTRODUCTION—CONNECTION OF THE SCIENCE OF OPTICS WITH COLOUR.

THE fibres of the optic nerve if excited by pressure, electricity, internal causes, or above all, by light, give rise to the sensations of which we speak as *colour*. It is owing to the general dependence of colour upon light that we must begin our study of its laws and their applications by a statement of two or three of the chief facts of Optics. We wish now to direct our reader's attention to the reflection, the emission, the transmission, the absorption, the refraction, and the dispersion of light.

Everything that we can see is visible owing to its reflection of light, or to its emission of it: the former action produces or characterises illuminated bodies; the latter, luminous bodies. Illuminated bodies are marked out and distinguished from one another by the different amounts and qualities of the light which they reflect. A piece of black cloth on a white porcelain plate reflects but a very small part of the light which falls upon it; the plate, on the other hand, reflects much. Had the black cloth possessed no power of reflecting light, it would have been invisible; black velvet, which reflects less light, sometimes produces to the eye the effect of absolute blackness that is, of an empty and dark space. Similarly, a sheet of plate glass may appear lustrous and visible enough if the light which falls on it is sent back to the eye; but if we are so placed in front of the glass that these rays escape us, it ceases to be visible, and we may, perchance, stretch out our hand to take something from behind the

glass, wholly unconscious of its existence. But it is possible to render a piece of polished glass permanently visible. Crush it to powder, and then in whatever direction the light falls upon its particles the surfaces of those particles will turn back or reflect some of the rays, and so render themselves visible. The clear glass has become opaque.

For the very same reason dense clouds, which appear black when between the observer's eye and the sky, owing to the complete way in which they cut off the light, may become brilliantly white when the sun's rays fall upon their constituent particles, owing to the very same action; for the light, which cannot get through the cloud, is continually reflected to and fro from the surfaces of its minute parts, and so illuminates it. Thus it happens that the lower half of a cloud against a dark mountain may appear white, while the upper part of the same cloud against a luminous sky may appear a dull grey. The lessening of reflection, on the other hand, diminishes visibility. The numerous small reflections which occur between the surfaces of the fibres in a piece of paper may be greatly reduced by wetting or oiling the paper, when it becomes less opaque and at the same time greyer and clearer: to this cause the transparency of tracing paper and tracing cloth is due.

We said above that bodies differ not only in the amount but in the quality of the light which they reflect. Now one of the chief differences as to quality of light is the difference of colour. Powdered vermilion reflects much light to the eye; this light, however, is chiefly red light, though there is some white light mixed with it. A stick of red sealing-wax shows in some positions a bar of white reflected light in the direction of its length, while in other positions we see only the red light reflected from the particles of its surface and of a small depth below. Why this light happens to be red in the vermilion we shall discuss further on: we would only point out here that while the reflection from a polished surface is regular, that from a rough surface is irregular, and that from a coloured surface coloured. A polished plane metallic surface affords an example of the first kind of reflection, a piece of chalk of the second. So great is the difference in



effect produced by regular reflection from that produced by irregular reflection, that if an illuminated polished body could be found which was wholly incapable of irregularly reflecting any part of the light falling upon it, that body would be invisible. We may, therefore, say that we discern bodies by the aid of the light which they reflect irregularly, or scatter; a perfectly regular reflection gives, on the contrary, an image of the source of light, not of the object illuminated. It is only light which is regularly reflected which can be shown to obey the great law of reflection, which is this:—“The angle which an incident ray of light makes with a perpendicular to the reflecting surface, is equal to the angle which the reflected ray makes with that perpendicular;” in other words, the angle of incidence and the angle of reflection are equal. Another law here to be mentioned is, that both the incident and the reflected rays of light are in the same plane, which is perpendicular to the reflecting surface. We shall have to refer to these laws of reflection, to reflection at varying angles and from different substances, and to the different kinds of reflection enumerated above, when we proceed to discuss the subject of Colour.

A few words may now be said on luminous bodies, or those which emit light. A candle-flame, a glowing piece of charcoal, and the sun, are examples of luminous bodies. From these sources of light luminous rays are sent out; these rays are the lines in which the light is propagated; luminous pencils are bundles of such rays. From such luminous bodies as are near the eye the rays emitted are divergent, but the rays from the sun and distant bright bodies are practically parallel. Highly luminous bodies can only be clearly seen when much of the light which they emit is cut off by a special contrivance, such as a piece of smoked or dark-green glass. It is thus quite possible to see the form and changes of the coke-points of the electric lamp, intense as its light is.

The light emitted from bodies travels in straight lines, and causes the production of shadows. The form and sharpness of shadows is influenced not only by the shape and the relative size of the opaque body which casts the shadow, but by the form of the luminous body, the light of which is intercepted. A luminous point gives a

sharply-defined shadow, while a luminous surface, on the other hand, gives a dark shadow surrounded by a paler and less definite one which goes by the name of a penumbra.

We have so far spoken of the reflection and of the emission of light : the transmission of light has now to be considered. Bodies are said to be *transparent* when they permit light freely to pass, so as to allow objects to be distinguished through them ; *translucent*, when they allow light to pass less perfectly, and objects on the other side of them cannot be clearly discerned ; *opaque*, when light is wholly cut off. But in reality no bodies are perfectly transparent or perfectly opaque. The most colourless and flawless polished glass cuts off some rays, while substances, such as metals, which are commonly considered quite opaque, become transparent when reduced to the form of thin leaves. The sun may be conveniently viewed through a glass thinly coated with silver, while the light transmitted by an ordinary piece of gold-leaf is grass-green.

In addition to this, it may be remarked that different transparent bodies permit the light to pass through them with more or less facility, but they also variously affect the light which finds its way into them. Suppose the case of water. A beam of light made up, we will suppose, of 1,000 rays, strikes the water perpendicularly ; 18 rays will then be reflected towards the luminous source, while 982 will find their way through the water unchanged, unless the layer of water be of considerable thickness. Now introduce into the water a drop of some red solution ; the light transmitted will be filtered light, the red solution having strained off some of the constituent rays and left the others. The intensity of the light and its quality will thus have been altered by transmission, just as they are by reflection. Colour, in fact, may be produced from white light, either by the absorption of some parts of the luminous rays and the reflection of others, or by the absorption of some parts and the transmission of others ; but, as we shall point out presently, there are several other ways of producing colour without the intervention of an absorbent body.

Before, however, we can profitably study these ways, and the curious phenomenon of absorption itself, we must

become acquainted with the main features of the theory of light. This theory is called the *undulatory* theory.

The undulatory theory supposes the existence, throughout all space and throughout all matter, of an infinitely thin, elastic medium called the luminiferous or light-bearing ether. It must be supposed that this ether is not only universally present, but present without break in its continuity. It exists in space, in all solids, liquids, and gases, and it cannot be excluded from what we call a vacuum. It can hardly be material in the sense in which the sixty-three elements of the chemist are material; but to account for the properties of light, we must presume the medium which conveys it to have some at least of the properties of matter. The movement of this ether is light. It undulates in waves, the undulations of the particles of the ether being across the direction in which the light is propagated. Light is supposed to originate in the following manner:—The particles or molecules which constitute a luminous body are in a state of disturbance, a state of intensely rapid motion. This motion of the molecules is communicated to the ether and sets it in vibration, and is propagated in all directions in the form of spherical waves. Reaching the retina, this fine motion of the ether excites vision and becomes sensible as light. With these statements of the main assumptions of the wave-theory of light before us, we shall be able to consider with exactness not only the absorption and refraction of light, but the several modes of the production of colour.

The waves of the ether are of different lengths; in pure white light, such as that emitted by the electric arc, waves of all lengths occur between the limits of about  $\frac{1}{300000}$  of an inch on the one hand, and about  $\frac{1}{600000}$  of an inch on the other hand; or we may measure the waves by their duration. Those which excite vision vary between  $\frac{1}{480000000}$  and  $\frac{1}{700000000}$  of a billionth of a second of time. Now the colour of light is dependent upon the length of the wave. The longest wave that is perceived by the retina is the red wave, the shortest the violet. Longer waves than the red wave possess a high heating power; shorter waves than the violet, invisible to the eye, and with scarcely any action on the thermometer, are gifted with a great degree of

chemical energy : they are called actinic. If we use the electric light, which is really a more perfect light than that of the sun, we shall find that it emits or causes undulations, the waves of which are of much wider differences as to length than those of the red and violet lights above mentioned. By means of various solutions we can absorb some of the rays : those of light can, for instance, be strained off, and those of heat and actinism transmitted. Thus it has been found that waves of certain lengths cannot undulate in a solution of iodine in carbon disulphide, they are arrested or quenched thereby. Such a solution, indeed, permits only the rays of dark heat to pass through it ; but the undulations of this dark heat may be changed, and their wave-lengths may be diminished by allowing the invisible heat-rays to be concentrated in a focus and to fall upon a solid, infusible body. This solid will become hot and then luminous—heat has been changed into light. This passage of calorific into luminous rays is known as *calorescence*, and may be made so complete a change that all the colours of the rainbow may be thus obtained from a perfectly dark source of heat. But exactly the same sort of change may be effected with the invisible actinic rays, the wave-lengths of which are shorter even than those of light. By using a solution of blue vitriol in ammonia, dark rays of chemical energy may be transmitted and freed from the visible rays. Receive these dark rays upon a screen of fluor spar, or Canary glass, or solution of quinine sulphate, light and colour are produced. The wave-lengths of the actinic undulations have been increased ; the invisible chemical rays have passed into visible luminous rays ; this passage is called *fluorescence*. Another name for the change in wave-length which we have just described is *change in refrangibility*.

We will now proceed to describe the meaning of the expressions *refraction* and *refrangibility*.

When a beam of light falls perpendicularly upon water, more than 98 per cent. of the rays pursue a straight course through the water. Let the incidence of the beam be oblique, and then it will be found that fewer rays will penetrate through the surface, and that those which do will not pass the water in a straight line, but will be more or less bent out of that line : this bending is called *refraction*. Refrac-

tion takes place when a beam of light passes obliquely from a rarer to a denser medium, or *vice versa*. Instances of refraction are familiar no doubt to most of our readers, perhaps the best known example being the case of a stick half immersed in water, which appears broken owing to refraction ; and of a coin, which, lying invisible at the bottom of a basin, may be made to appear by pouring water upon it, and so bending back the rays, which are reflected by the coin, till they reach the eye. In passing from air into water or glass the refracted ray is bent towards the perpendicular ; in passing out of water or glass into air the reverse refraction occurs, and to a precisely equivalent extent. If, therefore, a beam of light enters obliquely a piece of glass, the faces of which are parallel, the refraction towards the perpendicular on entering the glass will be exactly compensated by the refraction from the perpendicular on leaving the lower surface, and so the emergent ray will necessarily be parallel with the incident ray. But supposing we employ a prism of glass instead of a flat plate, then the ray is permanently refracted. The prism so much employed in Optics is a wedge-shaped piece of flint glass, and is an indispensable instrument in the study of colour. The angle enclosed by two oblique sides of this prism is called the refracting angle. If we place the prism so that this angle shall be below, and the opposite side of the prism horizontal, then a beam of light falling from above on to one of the oblique sides will be refracted towards the refracting angle, and passing across to the other oblique side will emerge, with its path changed again, but now in an upward direction. But something more will have commonly happened to the beam besides its permanent refraction. If the light be simple, if its wave-lengths be of one measure only, it will be simply deflected ; but if, as is nearly always the case, the light be compound—if its waves are of different lengths—then the prism will differently affect them. It will retard the short waves more than the long ones, and so we shall find that these short waves are more refracted. The more refrangible rays are then the short violet rays, the less refrangible rays are the longer red rays. In every case, therefore, where a luminous body emits rays of various refrangibility, these rays can be separated from each other by means of the prism. As solar light consists

of an enormous number of rays of different refrangibilities, it may be decomposed, analysed, or split into an enormous number of coloured lights, the wave-length of each of which belongs to a particular ray. The electric light gives an infinite number of such coloured lights, for there are no breaks in its series of rays, such as exist in the light of the sun. Usually, burning metals and glowing glasses emit, on the other hand, fewer rays, and give fewer colours, when their light is prismatically decomposed. The decomposition, or splitting up of light by the prism, is called the *dispersion* of light; the coloured image formed is called a *spectrum*. We are enabled to study the origin, the properties, and the changes of colours by means of this spectrum.

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## CHAPTER II.

### COMPOSITION OF LIGHT—COMPLEMENTARY COLOURS— THE SPECTRUM.

IT was Newton who first discovered the compound nature of white light. In order to split up a ray of the solar light into its constituent parts, the following contrivance (Fig. 1) may be adopted :—Through a hole in the shutter of a darkened room a beam of light, S, is allowed to enter. This small beam must fall upon a prism of flint glass, A, so arranged that the side, P, opposite to its refracting angle is uppermost and horizontal. The beam will be refracted and dispersed, as described in the last chapter; and if the refracting angle of the prism be  $60^\circ$ , a vertical band of rainbow colours will be produced on a screen placed at a distance of five yards or so from the prism, A. This band, H I, is the solar spectrum. It consists of a very large number of different tints, amongst which it is easy to distinguish seven principal colours. Beginning at the end of the spectrum which is nearest to the spot, K, the beam would have reached, had no prism bent it out of its path, we find the order of the colours is as follows :—Red, orange, yellow, green, blue, indigo, violet. Now the mode

in which these colours have been separated from white light is sufficient proof that they cannot be further separated into other kinds of colour. This anticipation is realised by actual trial; for if, as in Fig. 2, one of the colours of the spectrum,  $v$ , be allowed to pass through a hole in the screen, E, on which the band of decomposed light has been received, it cannot be altered by being trans-

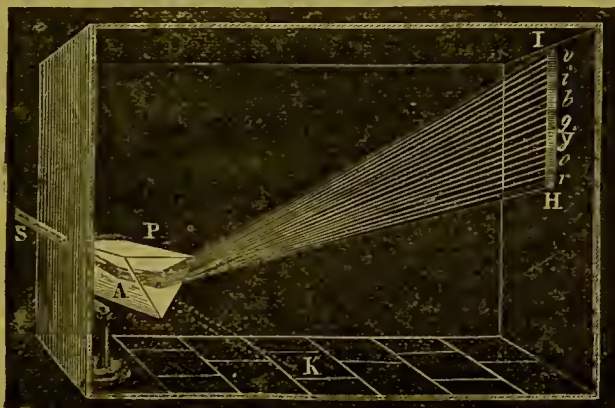


Fig. 1.

mitted through a second prism, B. The ray will be refracted, of course, but it will show but one colour, as before, and its image will not be elongated.

We have already learnt that every ray of coloured light has its own wave-length, and therefore that all the colours of the spectrum, however similar they may seem, are really distinct tints. But this consideration does not take in all the facts of the case. The green of the solar spectrum is not compound, but simple; and yet we know that many substances of a green colour may be split into two components, one blue and the other yellow. Supposing for a moment we can exactly imitate the green of the solar spectrum by mixing yellow and blue pigments together, this fact would not of itself suffice to prove that the solar green was really a mixed hue; but it would show that the sensation of vision is similarly excited by the waves that reach the eye from these two colours—one simple, the other apparently compound. Precisely the converse of this holds

good. We can, as might be expected, re-form white light by re-uniting all the seven dispersed coloured lights of the solar spectrum (we will describe how to do this presently) ; but we can reach the same result by re-uniting merely certain pairs of these coloured lights. Thus, the following unions of two colours generate white, or nearly white light :—

- |                          |  |                             |
|--------------------------|--|-----------------------------|
| 1. Red—greenish-blue.    |  | 3. Yellow—ultramarine-blue. |
| 2. Orange—Prussian blue. |  | 4. Greenish-yellow—violet.  |

There is no monochromatic complementary to the pure green of the spectrum, but one may be made by the union of red and violet. These pairs of colours, and many others less easy to distinguish by intelligible names, when united lose their respective colours and become white. They are



Fig. 2.

called *complementary* colours. It will be seen that we have followed in our grouping of them the sequence of the colours of the spectrum, beginning with the red or least refrangible rays ; but in order to produce white light by the combination of any couple of the above colours, two conditions must be fulfilled—the intensity and the quantity of the component rays must be adjusted with care. By receiving two such coloured pencils of light upon a lens which condenses and brings them to the same focus on a white screen placed at a suitable distance, the result is a perfectly white light ; but, to secure this result, the constituents of a coloured ray are as important as its apparent quality of colour. Thus Helmholtz has found that the red and bluish-green of the spectrum produce yellow, not white ; while red, with the bluish-green, or perhaps greenish-blue, formed by the union of green and indigo, does yield white. Green and red have indeed a relation to each other which



is different in some particulars from that of many other pairs of colours. They, however, are often included among the pairs of so-called *complementary* colours for reasons to be hereafter noticed. That there is something very peculiar in the relation of green to red may be also concluded from the frequency with which these two colours are confounded by persons who suffer from colour-blindness or Daltonism.

One of the most curious of all the results of studying the re-composition of white light is the relation of yellow to blue. It is a matter of observation that a yellow and blue liquid and a yellow and blue powder, when mixed together, produce respectively a green liquid and a green powder. But a very different result ensues on mixing blue and yellow light together. When the blue and yellow rays of the spectrum are mixed together, white light is produced. The same effect results from receiving upon the eye the reflected image of a disc painted with gamboge along with the direct image of a second disc painted with cobalt-blue. Though a disc painted with these two pigments mixed together would have appeared green, yet when the lights these pigments respectively reflect are conveyed to the retina as above described, then, where the two images coincide, whiteness is the result.

We must now describe some of the peculiarities of different spectra, and afterwards a few of the more recondite methods by which colour is produced.

Our purest source of coloured light is a spectrum. We may use the spectrum of the solar beams, or that from the electric lamp : the latter is more convenient, and yields, as we have previously stated, a light more complex than the sun ; for in the solar spectrum there are some three thousand or more gaps where rays are missing. These are the black lines first noticed by Wollaston, in 1802, afterwards mapped out by Fraunhofer, and at last explained by Bunsen and Kirchhoff. These black lines indicate lost rays—rays which have been blotted out by absorption. The absorption takes place in the following manner :—In the sun's gaseous envelope certain vapours exist. These vapours are opaque to certain rays of light : they do not allow them to pass, but quench them. There is, for instance, the metal sodium in the sun's gaseous covering. Now sodium vapour is opaque to a certain yellow ray

which it itself originates when it is burnt. Consequently, the place which should be occupied by a bright yellow band in the solar spectrum is a dark line, or rather group of lines, called D. In like manner the other black lines, or many of them, have been traced to the special absorptive powers possessed by the sun's gaseous envelope, and exercised upon certain rays of light emanating from within. These black lines, however, in the solar spectrum, though rendering it imperfect in continuity, are of great service in referring to the localities of particular colours. Yet we must not forget that the material of the prism exercises some influence upon the position of the lines and the relative extent of the coloured bands. At page 28 a coloured plate will be found in which are shown the positions occupied by the most important of the black lines and coloured spaces in the solar spectrum when obtained by means of a flint-glass prism in the spectroscope. The conditions of success in obtaining these lines distinctly are a narrow, clean-edged slit, a collimating lens to make the luminous rays parallel, and a prism of highly-refractive and dispersive glass, quite free from striæ and flaws. The instruments known as spectroscopes are, however, always of more complicated construction than these conditions seem to involve; for it is desirable to use a battery of prisms instead of one prism, and to obtain a magnified image of the spectrum by means of a combination of lenses in a telescope. Let us turn now to the consideration of the spectra as obtained by means of the spectroscope.

Most of our sources of artificial light yield spectra without lines. An oil-lamp, gas-flame, the electric light, are instances of this kind. But it is easy to secure a flame which shall yield a very simple spectrum, reduced by the absence of so large a number of rays that it shall merely consist of a few bright bands, or merely of one. Dissolve a little common salt, for instance, in some methylated spirit of wine, and introduce the solution into a spirit-lamp. The flame will, to the eye, appear tolerably luminous and distinctly yellow. The spectrum of this flame shows little more than a single brilliant yellow band, occupying the dark space of the solar spectrum called D. The metal sodium is distinguished from other metals by its flame emitting rays of that particular refrangibility only. If a

salt of lithium be taken, and dissolved in spirit, the flame of the lamp will be crimson, and two coloured bands will characterise the spectrum. One of them is red, and very distinct ; the other is of a faint orange tint. Other metals produce different spectra, though in many cases the colour which they impart to the flame of a Bunsen gas-burner or a spirit-lamp may seem to the unassisted eye identical.

In trying experiments with coloured flames, in order to study their effects on the appearance of different objects, the following contrivance may be used :—A (Fig. 3) is a

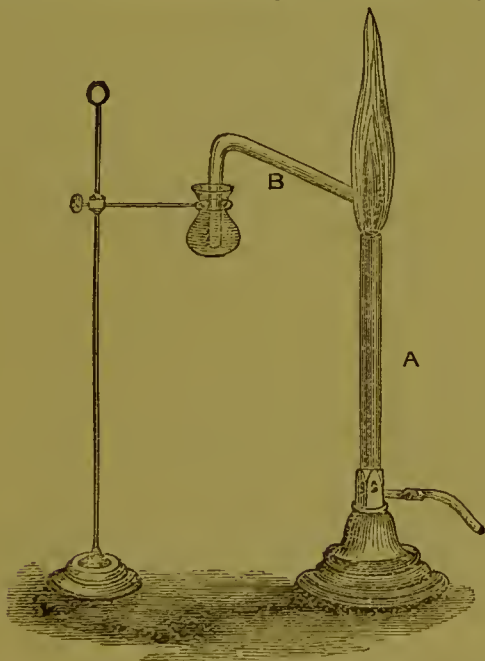


Fig. 3.

Bunsen gas-burner (which is best made of steatite) ; B is a bundle of fine platinum wires, bound together by a spiral coil of rather coarser wire of the same metal, and dipping into a small vessel containing a mixture of a solution of the metallic salt to be experimented with, and pure ammonium chloride. A ball of pumice attached to a bundle of asbestos fibres may be substituted for the platinum wires.

The following is a list of substances which give colours of different hues to the flame of a burner under the circumstances described, the metallic salts most applicable being those known as chlorides, chlorates, and nitrates :—

<i>Substances.</i>	<i>Colours of Flames.</i>
<i>Calcium</i> nitrate . . . . .	Red.
<i>Lithium</i> chloride . . . . .	Carmine.
<i>Strontium</i> nitrate or chlorate . . . . .	Crimson.
<i>Sodium</i> chloride . . . . .	Yellow.
<i>Barium</i> chloride or chlorate . . . . .	Yellowish-green.
<i>Boracic</i> acid . . . . .	Green.
<i>Thallium</i> perchloride . . . . .	Green.
<i>Copper</i> chloride . . . . .	Bluish-green.
<i>Indium</i> chloride . . . . .	Indigo-blue.
<i>Potassium</i> chloride . . . . .	Violet.

The above substances give, for the most part, spectra with many bright lines of different colours ; but the red lines will dominate in one spectrum, and the green in another.

Thus far we have been studying light and colour by means of the prism : we will now see how the colours of the spectrum may be separated without that instrument, and yet without loss of any of their component parts. Some of the most beautiful phenomena of colour are produced by a modification which light undergoes when it passes the edge of an opaque body, or when it traverses a small opening. Light then turns a corner, just as a wave in water will turn the angle of a wall, or spread itself on the further side of a hole in a plate through which it has passed. This bending of the waves of light has been termed *diffraction*. The source of light in studying the phenomena of diffraction should be a luminous or highly illuminated point. A silvered bead, or steel globule, or the focus of rays obtained by the action of a lens on a beam of light entering a dark chamber by means of a small hole—all these contrivances furnish a suitable light. If a narrow rectangular slit between two metallic edges be placed in a beam of light, between the focus of a lens and a screen, the space between the edges will be occupied by bands of coloured light. If one colour only be used, as by the interposition of a screen of red

glass, then alternate bands of that colour and black will be seen. By using, instead of a simple rectangular slit, apertures differing in size, number, and shape, very beautiful chromatic appearances may be developed. These may be obtained by looking at a bright point or line of light through a bird's feather mounted in a card-frame, through a piece of glass dusted with lycopodium spores, through a fine wire-grating, through a piece of very fine cambric, or through a plate of smoked glass ruled with fine lines.

The halo of colours sometimes seen round the moon and the sun is usually a phenomenon of the same kind, produced by the diffraction of light by the globules of water constituting the fog. Imperfectly polished metals, the feathers of many birds, and the surfaces of mother-of-pearl, owe part, at least, of the peculiar coloured effects which they exhibit, and which are known as iridescence, to the diffraction of the light reflected from the small striæ, filaments, or folds of their surfaces.

Now, without entering into the minute particulars necessary to elucidate these appearances thoroughly, we may state that the phenomena of diffraction are due to two causes. One of these is the bending of light round a corner, as waves of water bend round a rock in a lake; the other, the interference of the waves of the light-rays so bent with one another. Interference of one set of oscillations with those of another set may even extinguish the light altogether. This takes place when the crests of the undulations of a ray coincide with the hollows of the undulations of another ray: thus there will be rays on either side of a slit which, bent by diffraction, will by this kind of interference exactly neutralise each other and abolish the light. The dark bands and lines produced by diffraction are explicable in this way. As to the cause of the colours seen under the conditions just mentioned, we may refer to the obliquity of the paths of the diffracted rays. If red light be employed, black and red rings or bars alternate; but with violet light, black and violet rings or bars are seen. The violet rings are nearer together than the red, because their waves are smaller than the red. We can obtain bands of colours intermediate in width between red and violet by employing, for example, green

light. Hence, when *white* light passes through a slit, we obtain a series of coloured spectra side by side, because the constituent colours are not superposed, owing to the obliquity of the path of the rays and their different wave-lengths. More or less obliquity in the path of a diffracted ray will cause it to differ, by various parts of a wave-length, from other diffracted rays of the same beam.

The colours of thin plates correspond in sequence, as do those of diffraction, to the colours of the prismatic spectrum. They are produced by the interference of the ray which enters the thin transparent film, and is reflected from its second surface, with the ray which is directly reflected from its first surface. A soap-bubble may be of such a thickness as to retard the beam reflected from its second surface by half a wave-length, or by any number of half wave-lengths. In such a case it will be found that the bubble is black, because the two reflected beams are in complete discordance; and a destruction of light follows. Then, again, soap-bubbles may vary very much in the thickness of different parts. As the waves of light differ in length, so they will require different thicknesses to produce accordance and discordance. The result of this is that a thickness of film which is competent to extinguish one colour will not extinguish other colours. Thin films of variable and changing thicknesses, illuminated by white light, will therefore display in their different parts variable and changing colours. The colours of the precious opal are due to the interference of the internal reflections from its minute vacuous fissures. The colours of tar-films upon water, of many insects' wings, and of lead-skimmings, are due also to interference. So also are the splendid chromatic appearances of certain crystals when viewed in polarised light, and, to some extent also, the colours previously alluded to as iridescent.

We will next turn our attention to the production of colour by "selective absorption," to the re-composition of white light by the re-union of its scattered elements, and then to the mutual relations of those coloured elements.

## CHAPTER III.

## PRODUCTION OF COLOUR BY TRANSMISSION, ABSORPTION AND REFLECTION — MUTUAL RELATION OF COLOURS.

THE absorption and reflection of light are very closely related, yet there are many coloured bodies which instead of absorbing some rays and reflecting others, transmit those rays which they do not reflect. Even a third condition exists, in which a substance reflects some rays of the incident light, transmits others, and absorbs the remainder. We may now briefly consider the production of colour by these three methods.

Let us suppose a substance which appears red by reflected light and red also by transmitted light. Of the white light which has fallen upon it and which it has decomposed, it has absorbed or quenched all the colours save the red; while of the red it has transmitted part and reflected part. But the instances in which a substance appears of a very distinct colour owing to reflection are rare. A few metals may be cited as examples along with such substances as murexide, magnesium platinocyanide, potassium permanganate, and indigo. The yellow colour of gold is due to selective reflection. A plate of this metal reflects much of the incident light unchanged, but it quenches in another portion much of the violet and other very refrangible rays, and so leaves the residual red, orange, and yellow rays to produce their colouring effect. It might seem likely that gold would transmit when in sufficiently thin leaves all those coloured rays which it does not reflect. This is true to a great extent; still the grass green light which a leaf of gold transmits is not perfectly complementary to the orange-yellow which it reflects, some of the constituent rays of the original white light having been absorbed. Solid indigo affords us a similar example of selective absorption and reflection. If a lump of pure indigo be pressed with an agate burnisher, a copper-coloured streak makes its appearance. As long as the substance of the indigo is not coherent—that is, as

long as it is in minute powdery particles—so long it shows no symptom of a copper-coloured reflection, but is blue. Now the blueness of powdered indigo thus seen by reflection is not really produced by or in reflection, but rather during transmission of light from particle to particle of the powder. A chromatic selection is thus made, and the light finally reflected to the eye has been deprived of several of its coloured elements. Increase the coherence of the blue indigo powder either by pressure, or by the chemical process of sublimation, by which crystals may be formed, and then, though the transmitted light will remain blue as before, the reflected light will be chiefly copper-coloured, having been deprived by reflection itself of its blue and some other constituent rays. The foregoing facts often suffice to explain the great difference in colour between a solid substance and its powder.

Substances which are commonly regarded as transparent are never perfectly so. Neither water, nor flint glass, nor rock crystal, permit all light-rays to travel freely through them. Some substances, such as solutions of the rare metal didymium, and certain specimens of the mineral known as zircon, absorb or cut off several of the rays of solar light, and yet do not appear perceptibly coloured. The residual transmitted rays in such cases are of such quality and exist in such proportion that they suffice to produce white light. Very thin layers of coloured substances, such as films of tinted liquids, may seem colourless, and yet, when we increase their thickness, colour becomes perceptible. Not only does colour become perceptible, but the colour varies with the thickness. A crystal of blue vitriol shows on its thinnest edges a greenish tint, which alters to a pure blue in the mass. Such a change as this is easily explained. A thin plate of blue vitriol transmits all the blue, a good deal of the green, and a very little of the remaining rays of the spectrum. If we double the thickness of the plate the effect is increased, not in arithmetical but in geometrical proportion. Ultimately, by the extinction of all the rays save the blue, the transmitted light becomes sensibly an homogeneous blue.

A very easy mode of observing the striking differences in colour between thin and thick layers was devised by



Professor Stokes. A fine slit (one-fiftieth of an inch across) between two blackened metallic edges is adjusted vertically in a blackened piece of board ; behind the slit is a source of light, such as a bright flame or the sky. Hold the prism, having an angle of  $60^\circ$ , against the eye ; by adjusting the position of the prism a pure spectrum will be obtained, showing, if solar light be used, the principal fixed lines. Now, to observe the absorption of any liquid, fix a test tube or flat cell containing the liquid to be examined behind the slit. Begin the experiment by using a very pale solution, and then gradually increase the strength, noting the gradual appearance of dark lines or spaces in the spectrum and the blotting out of colour after colour. If a wedge-shaped trough be used to hold the coloured liquid behind the slit, it may be gradually moved so as to interpose thicker and thicker layers of the coloured liquids, and thus to produce the same results as those obtained by gradually increasing the strength of the solution. This method is of service when we wish to know the result of diluting any coloured liquid which has to be employed for artistic purposes. Thus, it will be found that some reds, when diluted, instead of becoming pink, pass through orange to yellow ; while some blues, instead of becoming paler blues when weakened, become either green on the one hand or violet on the other.

We turn now to the re-composition of white light from its constituent elements. There are several ways of accomplishing this result. If we receive the spectrum of coloured rays produced by one prism, A, on another precisely similar prism, B, but inverted (Fig. 4), the emergent beam, E, will be white. The concentration of a spectrum



Fig. 4.

by a bi-convex lens or a concave mirror gives a white and not a variegated image. Or the seven so-called principal colours of a spectrum may be received upon seven little

mirrors (as shown in Fig. 5), and then these mirrors may be so adjusted that their separate images are superposed. In this case also a single white image is obtained.



Fig. 5.

A less perfect mode of re-uniting colours so as to form white may be accomplished in the manner suggested by Newton. A disc (Fig. 6) is painted in radiating segments with the nearest approach afforded by pigments to the seven colours of the spectrum, the centre and edges being made black. The relative areas of the several colours must be adjusted so as to correspond as far as possible with the normal spectrum, introducing, however, such



Fig. 6.

differences as the imperfections of the pigments used may demand. As red, green, and blue are the most prominent colours of the spectrum, they should be used in larger

proportion than the orange, yellow, indigo, and violet. Indeed, a very respectable kind of whitish grey may be obtained by the use of fewer colours than seven; but of this point we shall have occasion to speak more definitely further on. The best pigments, however, even when used in proper proportions, do not produce a perfect white when the disc painted with them is rapidly revolved (see Fig. 7), so that the retina receives in quick succession the impression of the whole series. All coloured bodies absorb much light and do not reflect really homogeneous

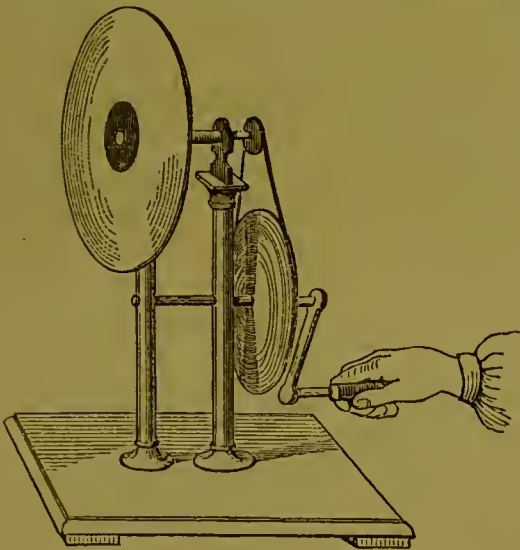


Fig. 7.

rays, and a grey is the result. If several series of similarly coloured segments be painted on the disc the grey more nearly approaches white. In the latter case the eye receives simultaneously the impressions of the several colours, and so the effect does not wholly depend upon the long persistence on the retina of these impressions.

We may now turn our attention to the mutual relations of the several colours.

Reverting for a moment to the pure solar spectrum obtained by means of a prism and a slit, and with the exclusion of all extraneous light, we may first of all notice

that it consists mainly of three colours—red, green, and blue. These coloured bands occupy by far the largest area of its most brilliant portion. The orange, yellow, and sea-green, though more brilliant, are very limited in extent, while the indigo and violet region of the spectrum is much less conspicuous. The gradual passage of one colour into another observed in the case of the solar spectrum and in the spectra of most ordinary lights prevents us from easily marking off and naming many of the constituent hues. But by means of a grating of black bars interposed in the path of the coloured beams, or by a sliding screen with a few slits in it capable of adjustment, we may compare the solar colours with one another and obtain something like a nomenclature for those which are at first sight difficult to isolate and name. The following list commences with the red, or least re-frangible end of the spectrum, the most important colours being printed in capitals :—

RED.	}	Crimson.	
		Scarlet.	
		Orange-red.	
		Orange.	
GREEN.	}	Yellow.	
		Greenish-yellow.	
		Yellowish-green.	
		Green.	
		Seagreen-green.	
BLUE.	}	Seagreen.	
		Seagreen-blue.	
		Blue.	
		Indigo.	
		{	Deep violet.

In this list the true purple or red-violet does not find a place. In point of fact this colour does not occur in the solar spectrum, although it may be made by mixing the red and blue, or red and violet together. It may also be produced by receiving the red rays of one spectrum and the blue rays of another upon the same surface. The true purple is a redder colour than that known as violet : it may be termed red-violet, an expression by which we may have hereafter to designate it. Sometimes, when light and brilliant, it has been called pink or almond-blossom,

—the latter name seems less liable to misconception than the former.

There are certain colours in the spectrum of the sun's light, and of most ordinary lights, which are much more rich, deep, or saturated in proportion to their brilliancy than the rest; these are the richest and most characteristic colours of the spectrum, red, green, and blue, and have been selected from the remaining hues and called primary colours. With them, in various admixtures, it is believed that all other colours may be obtained. Now for many practical purposes the theory of the existence of only three primary or elementary colours will be found very useful. The selection of these primary colours has, however, been far from unanimous, one set of observers choosing scarlet, green, and blue, another yellow, red, and blue. Nearly all writers on the artistic aspects of colours, such authors as Chevreul, Field, Redgrave, and Hay, have accepted the latter selection; but though it undoubtedly affords an easier means of studying the nature of the mixed colours which pigments and paints afford, it is but partially supported by experiments with the pure colours of the spectrum, and in some points is positively contradicted by them. The rival theory, in which the three primaries assumed are scarlet, green, and blue, has been profoundly studied by Maxwell, and has been made the basis of a small treatise, most sumptuously illustrated, on the science of colour, by Mr. W. Benson, a London architect, who has done much to further the acceptance of this comparatively modern theory. We shall proceed to give an outline of both views as to the relations of the colours of the spectrum; thus our readers will be able to form their own judgments on the two theories. For our own part we regard Maxwell's experiments as conclusively proving most of the positions he has laid down when pure coloured lights are the subject of comparison and experiment. Yet in actual work with pigments themselves, the older theory affords a more immediate, though often a less exact, answer to any question which may arise.

In order to study the primary or simple, and the secondary or mixed colours, several methods may be pursued. We here name three of the most important of these methods.

Tint two pieces of paper with the two colours to be

examined, place the coloured pieces an inch or two apart on a piece of black velvet, and set up, equidistant between them, a slip of thin, colourless plate glass; then adjust the eye so that one coloured patch may be seen by reflection from the near surface of the glass, coincident with the other patch as seen directly through the glass. By inclining the glass the reflected image of one colour may be altered in intensity, and so the relative proportions of the two colours may be varied at pleasure. The coloured figures 8 and 9 are so arranged as to enable our readers to perform this experiment for themselves, and at the same time to note the different results of the mere commixture of pigments. If the plate of glass above referred to be erected along the middle of Fig. 8, and the reflection of the blue stripe be properly combined with the image of the yellow stripe, a greyish white, and not a green colour, will be the result. But where the two pigments have been printed upon the same surface of paper we have a very distinct green hue as the product. So in Fig. 9, the red and green patches viewed by means of the glass give some approach to a yellow or citrine colour, a good deal mixed with grey, however: but a much duller and greyer hue is formed by the superposition of the pigments, where at one side of the figure the coloured triangles overlap.

Another plan, devised, like the last, by Helmholtz, consists in obtaining two intersecting spectra. Two clean-edged narrow slits, forming together a right angle, thus **V**, are made in a metallic plate. When this compound slit, brightly illuminated from behind, is viewed by means of a prism about twelve feet off, two overlapping spectra will be seen, the prism being held vertically. As each coloured band of one spectrum crosses all the coloured bands of the other, the result of combining two of the spectrum colours together may be studied. For this purpose it is desirable to employ solar light, the fixed lines of which afford a means of identification of the several colours, and may be readily seen in the above-named spectra by means of a telescope. The telescope is furnished with cross wires, and a diaphragm for limiting the field of view, placed a short distance from the eye-piece of the telescope and close to the eye. A third slit may be used, if it be desired, to unite three coloured rays. A modification of this method

FIG. VIII.



FIG. IX.







of producing overlapping spectra consists in cutting out from a piece of white cardboard three pieces of the shape indicated in Fig. 10 by the black spaces. The perforated cardboard, which should be of large size, is placed in a bright light with a piece of black velvet below it. It is then to be viewed six or seven yards off with a prism having its refracting angle turned away from the eye, and placed at right angles with the edge A B of the cardboard figure. No description can give an idea of the beauty of the overlapping spectra thus produced. The results obtained by Helmholtz and Maxwell, by means of experiments conducted by the method of overlapping spectra will be described, below.

A third method of combining colours is by means of a revolving disc such as that represented in Fig. 7. The disc may be painted with the colours it is desired to combine, and then rotated. Of course the proportions of the colours used may be varied not only by painted segments having different areas, but by the superposition of a second or third disc upon the original one, the additional discs having segments of different areas cut out, and being themselves either white, black, or coloured. The various kinds of colour-tops and kaleidoscopic tops may be used for these experiments. We may now give the chief results obtained by Helmholtz and by Maxwell, by means of the first and second methods above described, premising that the statements refer to the coloured rays of the pure spectrum, and not to those of pigments.

Helmholtz concludes that there are five primary colours. These are red, yellow, green, blue, and violet. With these, two or three together, and in various proportions, he obtained nearly perfect representations of the mixed colours. Many combinations of three of them yielded white light. A great range of mixed colours may be obtained by variously combining red, green, and violet, the coloured elements originally selected



Fig. 10.

by Dr. Young. Helmholtz considers these three as affording better results than red, green, and blue, which Maxwell regards as the only essential primary colours, and as infinitely preferable to the older selection of red, yellow, and blue. With regard to the mixture of colours, it appears that the following are among the most important of Helmholtz's results :—

Red + bluish-green	yellow.	}	= white.
Red + bluish-green + indigo			
Red + greenish-blue			
Yellow + indigo			
Orange + blue			

The two most remarkable of these results are the facts that red and bluish-green make yellow, and that yellow must therefore be regarded as a compound colour. When this yellow is united with the deep blue called indigo, it produces white. Here we have two conclusions quite opposed to the result obtained by mixing pigments. When vermilion and emerald green are mixed, a grey with merely a suspicion of yellow is the product. When chrome yellow and indigo are mixed, a distinct green is the product. We have before alluded to the causes of such discrepancies, but may now explain them so far as relates to the examples just cited, since these are typical cases of the kind, and illustrate the two chief points in which the new theory of primary colours differs from the old. Vermilion reflects chiefly red and yellow light to the eye; emerald green chiefly green, but also a little blue and yellow. Mix these coloured powders together, and most of the red, green, and blue they reflect, as long as separately viewed, is either absorbed or re-combined into whiteness, little else remaining but the small quantity of residual yellow rays common to both. Similarly with chrome yellow and indigo; the chief colour they reflect in common is green, and so most of the other rays which they reflect when separate are either quenched when they are mingled, or overpowered by the combined and enhanced effect of the green common to both pigments.

We shall proceed in our next chapter with the account of the new theory of colour by giving some of Maxwell's results.

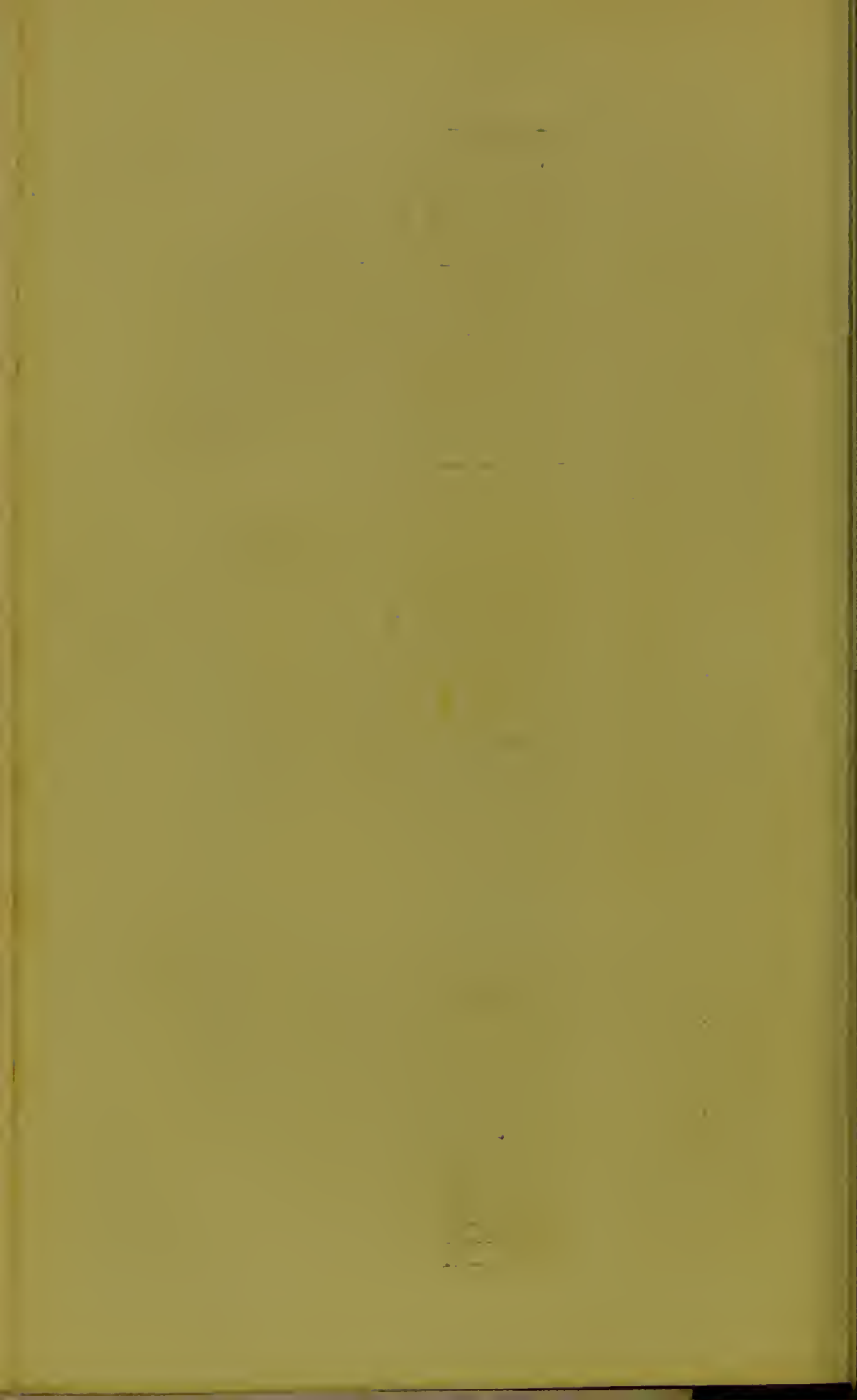
CHAPTER IV.

MAXWELL'S THEORY OF PRIMARY COLOURS.

IN continuation of our remarks upon the various theories which have been propounded as to the true primary colours, we may now refer to the conclusions of Professor Clerk Maxwell. According to this observer, the three primary colours are scarlet, green, and blue. By the combination of these colours he considers that all others may be formed ; but at the same time he admits that the other colours of the spectrum are due to simple or undecomposable rays, though they excite the same sensations as those of certain mixtures of rays. A bluish-green ray, for example, though not compounded of blue and green rays, produces a sensation which may be regarded as compounded of those sensations which are produced by blue and green. In their selection of the three most important colours of the spectrum, in their divergence from the ordinary theory as to the primary colours, and in their views as to complementary colours, Helmholtz and Maxwell agree to a considerable extent : it is as to the possibility of forming from three colours all the others that they differ —Maxwell affirming this, and Helmholtz denying it. A few words as to the primary, secondary, and complementary colours admitted by Maxwell may now be given. In order to observe these colours satisfactorily, the following contrivance should be adopted :—Two slips of pure white unglazed paper should be laid upon a piece of black velvet, after the manner represented in Fig. II. If this diagram be thus copied in paper and velvet on a large scale, and viewed from a distance, by means of a prism having its refracting edge turned away from the spectator, the colours will be seen as indicated in the figure. These



Fig. II.



These three secondary colours, in order to be truly complementary to their several primaries, must not only be of the right quality and purity, but must be of the right intensity or brightness. So the sea-green named above must have the added brightness of its two components, blue and green; the almond-blossom must have the added brightness of its two components, red and blue; and the yellow must have the added brightness of its components, red and green. Of course these statements refer only to Maxwell's theory of the colours of light. In the case of pigments we shall have frequent occasion further on to repeat what we have indeed often stated before—that the complex nature of the

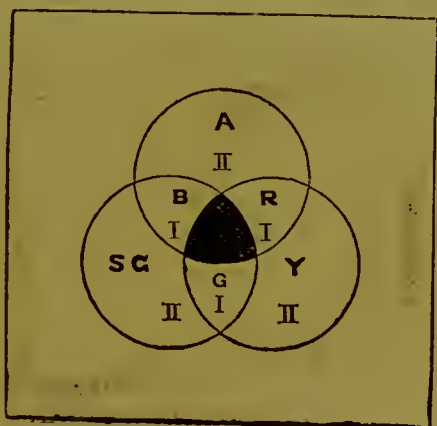


Fig. 14.

coloured rays they generally reflect does not permit these simple relations of colours to each other to hold good. In continuing our outline of some of the chief features of the new theory of colour, we may draw our readers' attention to the annexed diagrams (Figs. 14 and 15) by means of which, when filled in with the colours named, they can represent for themselves the primary and secondary colours of Maxwell's theory.

In these diagrams the following abbreviations are used:—

- I. *Primary Colour*.—R, Red; G, Green; B, Blue.
- II. *Secondary Colour*.—S G, Sea-green; A, Almond-blossom; Y, Yellow.

When the diagrams are filled in with the purest pigments attainable, then Fig. 14 should show the effect of taking away the three primary colours from white, leaving three overlapping circles of secondary colours where only one colour is removed; leaving three-sided spaces of primary colours where two colours are removed; and leaving also a similar space of black or darkness in the centre, where all three primaries are equally removed. The exact converse of this effect is shown in Fig. 15, where the primary colours are supposed to be represented in equal strength upon a black ground. They form, by the overlapping of two of the three circles or discs containing them, three



Fig. 15.

spaces of the secondary colours, and where all three circles overlap or coincide, a central space of white. Coloured lights are, of course, alone competent to produce secondary colours brighter or more luminous than their constituent primaries. A similar but false imitation of this effect is produced by mixing white with the secondary colours used in preparing the above diagrams, as this admixture destroys the saturation of the colour, reducing its tone.

We have, however, made use of this contrivance in the coloured diagrams, Figs. 17 and 18, which respectively represent the taking away of the primary colours from

white and the adding of these colours to black. In Fig. 17 we have, first of all, a white ground which we assume to represent a mixture of equivalents of the primaries, red, green, and blue. If from this white we take away the primary green, the residual red and blue will remain, constituting the secondary colour, almond-blossom or pink, which fills the greater part of the upper surface in the diagram, and has the brightness of both its constituents. Similarly the two other circles are chiefly filled in with blue-green or sea-green, and with yellow respectively. These colours are the secondaries obtained by the removal of the primary red and the primary blue, respectively, from white light. The sea-green or blue-green has the brightness of both green and blue, while the yellow is similarly more brilliant than either of its constituents, for it has the brightness of both red and green in it. The three small triangular spaces, in Fig. 17, represent the primaries, or white from which two out of its three coloured elements have been removed; while in the centre is a similar space of black formed by the abstraction of all the primaries red, green, and blue. Now in Fig. 18 we have a representation of the converse of all this. On a black ground we suppose three overlapping discs of the primaries; then, where two of these overlap, we have the resulting secondary colour produced, and in the centre of the diagram, in the space common to all three discs, we have a triangular space of white formed by the mixture of the three primaries. But in our diagrams we can also see, opposite to each primary colour, its proper complementary, forming the pairs :—

RED and Seagreen.

GREEN and Almond-blossom.

BLUE and Yellow.

Perhaps, however, the best way of exhibiting, in a neat and intelligible form, the relations of the primary and secondary colours and hues, is by means of a chromatic circle, Fig. 16, triangle or cube. Chevreul has adopted a plan of this kind with reference to the common theory of the primary colours, introducing moreover into his scheme numerous modifications of hue, tone, shade, &c., produced by the admixture of colours with white and with black as well as with one another. But this arrangement requires

considerable alteration before it can be taken to represent the constitution of colours upon the true system. The triangle of Maxwell represents many important truths concerning colours and pigments as deduced in part from experiments. The cubes of colours which Mr. Benson employs in his two works on Colour afford excellent means of developing and arranging the vast numbers of modifications of hue and tone of which colours are susceptible. His chromatic cube presents the full white at one solid angle, pure black, or the absence of all colour, at the opposite



Fig. 16.

solid angle, while the six other similar points of the cube are occupied by the primary colours and their secondaries, blue being opposed to yellow, and so on with the other pairs. On the plane surfaces of the cube and its edges are duly placed the products obtained by the mixture of the colours on the poles with each other, or with white or with black, in various proportions, while towards the centre of the figure the dull colours produced by admixture with grey will be found. Our present purpose



may, however, be sufficiently answered by a simpler arrangement based on the chromatic circle of Dr. Brücke. We print the primaries in a thick, and conspicuous type, arranging them at equidistant points on the circumference of the circle. Joined by thick lines, as diameters, to these primaries are the three important secondaries, which are distinguished by smaller letters. Then come the hues in which the primaries are mingled together in proportions different to those which constitute the secondaries. All colours then, in this arrangement, which are complementary to one another will be found as pairs joined by diameters of the circle.

In the above chromatic circle we have assigned no place to black, though white will be found at some one point or other upon each of the several diameters joining the complementary pairs of colours. Theoretically this white will be found at the centre of the circle where all these lines intersect. But in practice the exact pairing of colours is often impossible, for we have to take into account not only their hue but also several other qualities, such as *saturation*, *brightness*, and so forth. A few words on these points may be fitly introduced in this place.

The brightness of a colour depends upon the quantity of its light. It is sometimes spoken of as brilliancy.

The saturation or depth of a colour is another name for its purity, fulness, or richness, the richness itself being commensurate with the quantity of its unneutralised or free light of particular colour.

The clearness of a colour depends upon the relation between the quantity of its light and its saturation. A colour which is at once clear and saturated is often said to be intense. Very great brilliancy in a colour is not generally compatible with saturation, as the effect of such colours upon the eye is similar to that of a mixture of white and coloured light. The ocular appreciation of coloured surfaces is also much altered by the quantity of light by which they are illuminated, the values of colours, and the distinctions between different colours being more easily obliterated in some cases than in others by the diminished or increased quantity of the incident light. A red, for example, which in a strong light appears brighter than a blue, may in a weak light become darker. Thus it

happens that in a very weak light all, or nearly all, distinctions of colour are lost before the objects have become invisible, for the contrast between light and darkness, or between white and black, being stronger than any other possible contrast, remains as a residual effect. So in twilight and moonlight we may often feel convinced that the objects of a landscape are not wholly destitute of colour, yet we find it very difficult to represent their extremely indefinite and obscure hues.

Connected with the subject of the quality of colours and especially with the quality of saturation, is the constitution of those minor pairs of complementary colours where hues and not secondary colours are found to constitute together white light. As hues are colours in which the primaries are mixed in proportions other than their equivalents, we may of course speak of bluish sea-green as made up of two equivalents of blue and one equivalent of green, or, using the symbols B and G for these primary colours, we may formulate them thus :

$$\text{Bluish Sea-green} \left\{ \begin{array}{l} 2B + G \text{ or} \\ B + \frac{G}{2} \end{array} \right.$$

Now the complementary hue to this hue will be made up of those elements of white light which it lacks and in the proportion in which they are deficient, and thus may be formulated :

$$\text{Orange} \left\{ \begin{array}{l} 2R + G \text{ or} \\ R + \frac{G}{2} \end{array} \right.$$

The truth of these propositions is at once seen when we remember that on Maxwell's theory, which we are now discussing, white light (W) may be made up of equivalents of red green blue light, its constitution being expressed by the formula— $R + G + B = W$ ; while our bluish sea-green and orange give together the same results, thus,

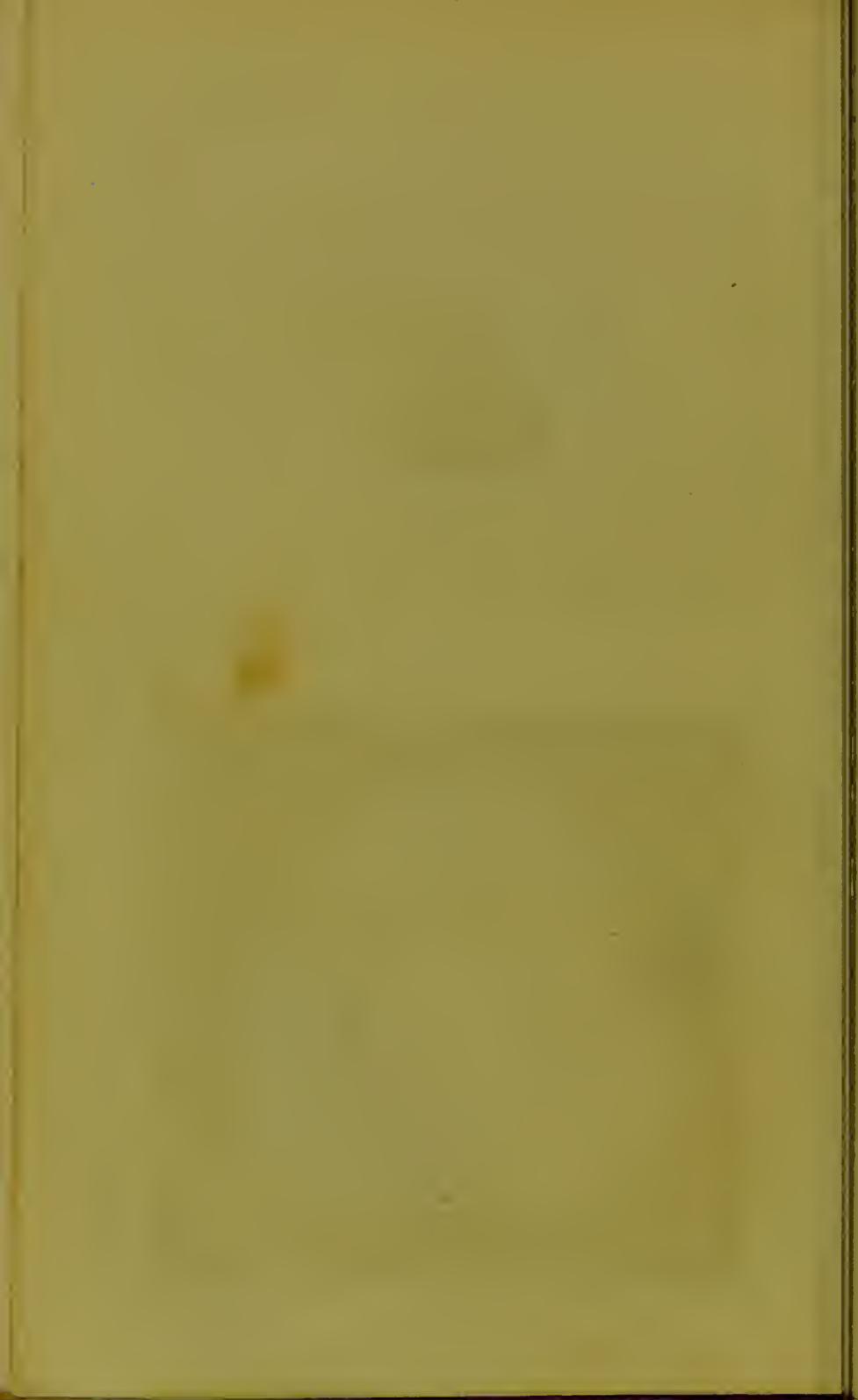
$$\begin{aligned} & \text{Bluish sea-green} + \text{orange} = \text{white} ; \text{ or} \\ & 2B + G + 2R + G = 2W ; \text{ or} \\ & B + \frac{G}{2} + R + \frac{G}{2} = W \end{aligned}$$

FIG. XVII.



FIG. XVIII.

Chromo-lithographed, by permission, from W. BENSON'S "Principles of the Science of Colour."



But those of our readers who desire to pursue this subject are referred to the works of Mr. Benson for further information on these and kindred matters. And we take this opportunity of again acknowledging the obligations we are under to this ardent apostle of the true theory of colour as developed by Maxwell and Helmholtz.

This seems a suitable occasion for introducing some account of the physiology of colour-sensations of different kinds and of the way in which they may be supposed to originate. The researches of Helmholtz have rendered Dr. Young's idea of three sets of optical fibres in the nervous structure of the retina very probable. These three sets of fibres, which for brevity we will speak of as the red, green, and blue fibres, respectively, are impressionable to these three kinds of primary coloured light in different degrees. If the light be red the red fibres by their responsive action will transmit the corresponding message to the brain. If the red and green fibres be equally affected, as by yellow light, or by mixed green and red lights, the sensation of yellow will be produced. Green and blue lights will affect more especially both the green and blue fibres, and sea-green will be the sensation provoked. By admixture of other coloured lights, and in various proportions, the compound action of the optical fibres will, in a similar manner, originate other secondary colours and hues. Colour blindness, or Daltonism, in its varying degrees, may be explained by an extension of the same theory. For we may imagine the optical fibres to be less completely differentiated from each other in the case of those persons who have not the normal appreciation of colours. Rays of red and green light, for instance, are often not distinguished by the colour-blind, for both these colours affect the red and green fibres of such persons in a similar manner. In these cases the spectrum of the sun may be said to consist of two and not of three distinct bands of colour, one extending from the red to the beginning of the blue, and possibly appearing to persons suffering from Daltonism as something like a shaded stripe of yellow of normal vision, while the rest of the spectrum may present the ordinary series of blue colours.

## CHAPTER V.

THE COMMON THEORY OF THE PRIMARY COLOURS, TONES,  
SHADES, TINTS, AND SCALES—PRIMARY COLOURS—  
SECONDARY COLOURS—TERTIARY COLOURS—HUES.

THUS far we have been studying the constitution of colours by means of experiments with coloured lights. And we have arrived at some results, which, it will be presently seen, are in striking discordance with those commonly accepted. Yet there is a sound basis of fact in the case of Maxwell's theory which the more popular view does not possess in a nearly equal degree. We must, however, turn our attention to the latter view as to the primary colours—the "red-yellow-blue" theory, as it has been called. But although, through subsequent chapters, we shall adopt in the main the terms and explanations of this usual theory, we shall take occasion to note, here and there, the more serious difficulties which it involves. And it will be easy to translate our language into the more correct forms demanded by Maxwell's theory, if due use be made of our explanation of that theory just given, and especially if the chromatic circle of complementary colours be studied with care.

One great advantage is possessed, we readily admit, by the old theory—it works far better with actual pigments than does the new one. It breaks down more or less completely when tested, by the means we have already mentioned, with coloured rays of light. Concerned as we usually are with coloured materials and not with coloured rays, we shall describe the old theory at some length, particularly as it affords an easy means of studying the mixed colours which pigments afford.

In our coloured diagram\* we have arranged the most important colours in a six-pointed star made of twelve equilateral triangles. The whole figure being regarded as consisting of two intersecting triangles, the three primary colours will be found in the angles of one of these, the

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\* Frontispiece.

three secondary colours in the angles of the other, and the more mixed hues in the area where the two triangles coincide or overlap. However, before showing how the compound colours may be supposed to originate from the admixture of simple ones, it will be necessary to define the meanings of a few words which we shall have frequent occasion to employ.

*Tones*, often called shades, signify colours mixed with varying proportions of white or black. In mixing a colour with white we weaken or reduce its tone, but by the addition of black a colour has its tone broken or darkened, not deepened. Red mixed with white in increasing proportions gives weaker and weaker tones of red; red mixed with black in increasing proportions gives duller and duller tones of red; while red mixed in a similar manner with both white and black—that is, grey—gives a series of tones of red which are at the same time duller and weaker than the original colour.

A *scale* is a regular series of such tones as those just described. Every colour admits of three scales :—

1. The reduced scale—that is, the normal colour mixed with white, thus forming *tints*.

2. The darkened scale—that is, the normal colour mixed with black, thus forming *shades*.

3. The dulled scale—that is, the normal colour mixed with both white and black, or, in one word, with grey.

*Primary* or elementary colours are usually regarded as three in number, and are assumed to be capable of yielding by combination all other colours. They are commonly assumed to be yellow, red, and blue.

*Secondary* colours are mixtures of two primaries in equivalent proportions. Orange, green, and violet are the three secondary colours. We say equivalent, not equal proportions; for it will be found that equal quantities of yellow and red lights, or of the purest yellow and red pigments attainable, will not produce the normal orange. In making, therefore, such a secondary colour as orange, we have to judge by the eye what quantities of its primary constituents will produce a colour equally removed from yellow on the one hand, and from red on the other.

*Tertiary* colours are mixtures of the three primary colours in certain proportions, which will be noticed pre-

sently. All tertiary colours are dull, owing to the following fact. All pigments representing the three primary colours produce, when mixed together in equivalents, not whiteness, but greyness or blackness. In tertiary colours, therefore, the equivalents of yellow, red, and blue which are present, unite to neutralise one another, and so to form grey; while it is only the unneutralised residue of the one or two colours that are in excess which gives a special character to the final result. The neutral grey of the tertiaries, as thus produced, dulls all their tones, and distinguishes them at once from the primary colours, and from all combinations of two primaries. Indeed, the six normal tertiary colours are nothing more than the *dulled* tones of the three primary and the three secondary colours.

*Hues* include all tertiary colours, and all those colours in which the primaries are mixed in other proportions than are requisite to form the secondary colours. Yellowish-orange and bluish-green are secondary hues; reddish-grey and violet-grey are tertiary hues.

With these definitions of terms before us, the consideration of the chief colours, of the quality and optical composition of coloured materials and of the pigments in actual use, may be commenced.

THE COMMON PRIMARY COLOURS.—*Yellow*.—The most luminous of all colours is the pure yellow. It occupies a very narrow space in the solar spectrum, but is distinctly the brightest part of it. Most yellow pigments and coloured materials reflect or transmit much orange and red light, as well as yellow. Chrome yellow is an example of this fact. Some transparent yellows on a white surface, such as gamboge, allow the transmission of, or reflect much white light, in addition to the yellow rays which characterise them. They are in reality reduced yellows—yellow, that is, mixed with white. Yellows occasionally verge upon green, especially in their lighter tints. This effect is partly due to their reflection of some green rays in place of the red which they usually emit, and partly to the result upon the eye of contrasting the lighter or reduced tones of yellow with the darker tones which verge upon orange and red. An orange or even a red tint is often perceived in yellow pigments when they become dry, though they may have appeared of a nearly pure yellow when wet. Fibres



of wool, silk, cotton, etc., dyed yellow, exhibit the same appearances, as to the optical constituents of the colours they reflect, as do other white surfaces of paper, canvas, and porcelain, upon which opaque or transparent pigments have been spread. In all cases varying proportions of white light are reflected; while of the light which is decomposed by the coloured surfaces, different but considerable amounts of violet, indigo, blue, and, in a measure, green, are quenched or absorbed. The remaining rays produce the colour effect of the object, and will, of course, consist mainly, but not entirely, of yellow light. With stained glass and other transparent materials, such as coloured gelatine and coloured liquids, similar groups of violet and blue rays are on the one hand absorbed, while on the other hand the less refrangible colours are transmitted.

*Red.*—The second primary colour in point of vividness is red. It is less luminous than yellow, but warmer and more retiring. All our ordinary red colours contain orange and yellow, or else blue and violet. A stick of sealing-wax examined by a prism is found to reflect all the rays up to the line D in the yellow—that is, the colour which it presents is made up of much orange and a little yellow in addition to the true red. The fugitive paint known as geranium colour is a purer red than that just named, the vermilion of sealing-wax, but it is not free from a tint of orange. Carmine and crimson lake, with other similar pigments, reflect to the eye a trace of the blue and violet, as well as nearly all the red, and some of the orange rays of the light which falls upon them. The best idea of pure redness may be got from the bright and broad red band in the spectrum of a burning lithium salt. Red glass, at least that kind of red glass which is coloured by copper suboxide, does not transmit unmixed red rays, but many orange rays as well. Two or three thicknesses of it do, however, transmit a purer red beam.

*Blue.*—The third and least vivid of the primary colours is blue. It is also the most retiring and cool. We cannot point to any tolerably pure blue pigment. Beautiful as ultramarine undoubtedly is, its spectrum reveals the existence of several colours besides blue. Yet it would be hardly fair on this account to regard this or any other colour as impure. If the various coloured rays which a pig-

ment reflects to the eye impart the sensation of blueness, it is enough. They may contain red, violet, and other constituents, but the resultant effect of the combination may be a blue indistinguishable in purity from the normal blue of the solar spectrum. A difficulty does, however, arise when such pigments as those above referred to are illuminated by artificial light, or are mixed with others to form secondary and tertiary colours; the anticipated result being occasionally very far from being realised. Cobalt blue reflects much green and violet light, as well as blue, and in fact shows a very remarkable combination of colours when its spectrum is examined. On mixing it with carmine, to form a violet hue, the green constituent in its light interferes with

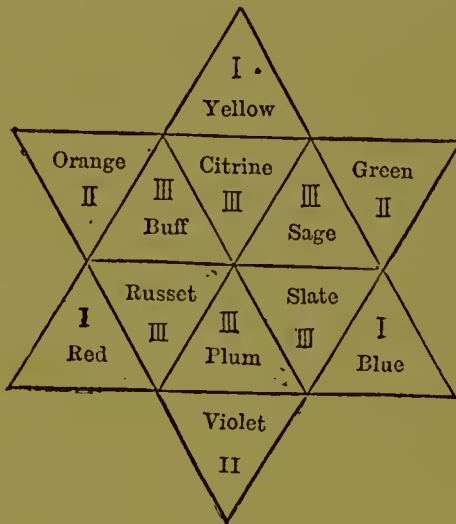


Fig. 19.

the purity of the resulting colour, which is much greyer than one would have expected. By lamp-light cobalt-blue appears violet. Prussian-blue and indigo absorb most of the red, orange, and yellow rays, but emit a very large part of the green, blue and indigo. A crystal of blue vitriol (copper sulphate) cuts off all the red, orange, and yellow rays, together with the green rays up to line E, and transmits the remainder.

*Secondary colours* may now engage our attention. On referring to the frontispiece, it will be seen that the three primaries occupy the angles of the first triangle, and the three secondaries the angles of the second. If we represent the same arrangement without colour (Fig. 19), we shall be able to point out very clearly the constituents of each compound colour. The three small triangles marked I. contain the three primary colours, while those marked II. contain the three secondary colours. When equivalent quantities of yellow and red are mixed, orange is the result—a secondary colour equally distant from yellow on the one side and red on the other. It is commonly held that, with material pigments, three parts (by surface measurement) of a good yellow require five parts of a good red to form the normal orange. The eight parts of the normal orange formed in this way will serve as a complementary equivalent to eight parts of the normal blue. But, after all, these and similar numbers are merely approximate, serving just to indicate the direction in which one coloured constituent must preponderate over another in such mixtures as the secondary colours. When yellow and red are mixed in proportions differing from those necessary to constitute the normal orange, the resulting colour becomes a yellowish-orange or a reddish-orange, according to the predominance of either of the constituent primaries; countless variations of a secondary colour in this direction are possible. Indeed, as we have already shown, most of our coloured materials, usually regarded as exhibiting primary colours, in reality furnish us with secondary hues of this kind, though their mixed character is not perceived by the unassisted vision.

The following list shows the imaginary or theoretical composition of the three secondary colours, and their six chief modifications or hues. The letters Y, R, and B represent the equivalent proportions of the three primaries—yellow, red, and blue; the equivalent of yellow being assumed to be 3, of red 5, and of blue 8 :—

## SECONDARY COLOURS.

Y + R = Orange.

R + B = Violet.

B + Y = Green.

## SECONDARY HUES.

2Y +	R =	Yellowish-orange.
Y +	2R =	Reddish-orange.
2R +	B =	Reddish-violet.
R +	2B =	Bluish-violet.
2B +	Y =	Bluish-green.
B +	2Y =	Yellowish-green.

*Orange.*—This colour is the most powerful and brilliant of the three normal secondaries. It is seen in the pigment known as cadmium yellow (the cadmium sulphide) and in the skin of a rich-coloured ripe orange. To make a pure and bright orange by mixture, it is essential that the yellow pigment should incline to red rather than to green, and the red pigment to orange rather than to blue. If the contrary be the case, and a greenish-yellow pigment be mixed with a red, or a yellow with a violet-red, a certain amount of grey is produced by the combination of the three primaries present, and a dulled tone of orange is the result. The worst effect of this kind is produced when a greenish-yellow is mixed with a violet-red. Gamboge and carmine form an orange far inferior in purity to that produced by the admixture of chrome yellow and vermilion.

*Violet* is the least powerful of the secondary colours. The aniline dye known as mauve may be taken as somewhat near the normal violet. Many other artificial colouring matters made from the products of coal-distillation also approach this beautiful colour. Violet usually appears much redder and duller by candle or gas light than by daylight. The yellow and orange rays which are present in peculiar abundance in most artificial lights, neutralise some of the blue in the violet, forming therewith grey, and at the same time setting free, as it were, the red element of this secondary combination. To make a pure and bright violet by mixture, it is essential that the red pigment should incline to blue rather than to orange, and that the blue pigment should incline to red rather than to green. Vermilion and cobalt produce a very dull and earthy-looking combination, owing to the presence of orange in the former colour and green in the latter. Carmine and ultramarine afford a more satisfactory mixture.

*Green* is more vivid than violet, but less so than orange. It occupies a considerable space in the solar spectrum, where, however, much of the green light has a yellowish hue, and some of it inclines towards blue. Emerald green is in reality far from reflecting pure green light only to the eye. Its spectrum is simply deficient in red and orange rays, yet even these are by no means absent. The new "aniline green," which retains its characteristic and brilliant colour by artificial light, absorbs, when of sufficient purity and in sufficient amount, nearly all rays except the green. When a piece of cotton dyed with this green is interposed between a light and the spectroscope, it will be found that about six thicknesses of the fabric are requisite to strain off all the red rays. But this result may be accomplished more easily by a solution of the colouring matter; for in this case there are no interstices through which light can pass, and thus escape the selective absorption of the pigment. Viridian, the beautiful and permanent chrome green introduced recently, transmits the green rays or green portion of the spectrum unchanged, but along with them a small portion of the red and of the blue rays. In producing a green by admixture of yellow and blue, it is important to take a yellow and a blue both free from red. A greenish-yellow and a greenish-blue, or else a pure yellow and a pure blue, may be successfully used. Notwithstanding its brilliancy, cadmium yellow, which is really an orange, cannot be made to yield a satisfactory green by the addition of any kind of blue pigment.

*Tertiary Colours* have now to be considered. Referring back to our diagram (Fig. 19), we find six spaces marked III. Each of these spaces is immediately contiguous with a space (marked I.) assigned to a primary, or to a space (marked II.) assigned to a secondary colour. We have already alluded to the fact that the so-called tertiary colours ought, strictly speaking, to be regarded as nothing more than dulled tones of the primary and secondary colours. Indeed, it is impossible, on the theory of the three primaries together forming grey, to have any colour which shall exhibit the colour-effect of more than two of them together. An examination of the composition of the tertiary colours will explain this point. Using again our former symbols

for the primaries, and letting Gy stand for grey, we may express the constituents of the six normal tertiaries thus :—

$2Y + R + B = Y + Gy$	= Yellow-grey, or <i>citrine</i> .
$2Y + 2R + B = Y + R + Gy$	= Orange-grey, or <i>buff</i> .
$Y + 2R + B = R + Gy$	= Reddish-grey, or <i>russet</i> .
$Y + 2R + 2B = R + B + Gy$	= Violet grey, or <i>plum</i> .
$Y + R + 2B = B + Gy$	= Bluish-grey, or <i>slate</i> .
$2Y + R + 2B = Y + B + Gy$	= Greenish-grey, or <i>sage</i> .

It is commonly stated that the tertiary colours are compounded of the secondary colours. Thus the two secondaries, orange and green, are assumed to give rise to the tertiary colour known as *citrine*. This hue is really nothing more than a yellow-grey; for its orange constituent contains yellow and red, and its green constituent yellow and blue. Subtracting equivalents of the three primaries, so as to form grey, we have, therefore, nothing but a residue of the primary yellow, to produce the whole colour-effect of the mixture of the secondaries orange and green. This residual yellow is dulled by the presence of the grey which is the product of mixing equivalents of pigments representing the three primaries. The colour complementary with citrine or yellowish-grey is violet, which, of course, supplies the blue and red which have been extinguished in the former hue.

The secondary colours orange and violet produce, when mixed together, the tertiary hue known as russet. It is really a reddish grey. Some autumnal leaves present good examples of this colour. Its complementary is green, which supplies the yellow and blue which are wanting in russet.

The secondary colours green and violet produce, when mixed together, the tertiary hue often called olive, but which may, perhaps, be more correctly designated slate. It is really a bluish-grey. The complementary colour is orange, which supplies the missing red and yellow constituents.

We may here name, as other and very useful tertiary hues, those known as buff, plum, and sage. Buff, or orange modified by grey, may be produced by the addition of red to citrine, or by mixing the three primaries so that yellow and red predominate. Sage-green is produced by the addition of yellow to slate-colour, or by mixing the three

primaries so that both yellow and blue predominate. Plum-colour is a violet grey produced by the addition of blue to russet, or by mixing the three primaries so that both blue and red predominate.

Numerous other tertiary hues, besides the six just named, are constantly observed in natural objects, and may be reproduced with great advantage in decorative art. It is, however, very difficult to describe the composition and character of such colours. These tertiary hues are, however frequently used in modern art-manufactures with the happiest effects, and, employed, say, as walls in pairs of related or contrasted tints, or in two shades of the same hue, afford a quiet background for the full development of the beauty of the more vivid and elaborate contrasts of colour, to be found in pictures and the higher works of decoration. In subsequent chapters we shall point out the extreme importance of these *dulled* colours, colours mingled with grey, since they at once relieve the fatigue experienced by the eye when occupied too exclusively with colours of great brightness and saturation, and at the same time enable such bright colours to give their maximum of pleasurable sensation even when used sparingly.

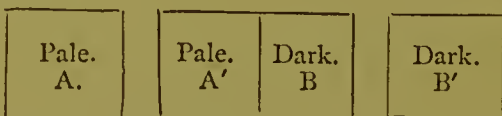
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## CHAPTER VI.

### THE LAWS OF CONTRAST—CONTRASTS OF TONE—CONTRASTS OF COLOUR—SIMULTANEOUS CONTRAST.

*Contrasts of tone and of colour.*—If there be the slightest difference either of tone or of colour in two contiguous or neighbouring coloured or shaded surfaces, that difference will not be seen exactly as it really exists. Under such conditions, either the retina of the eye receives an impression, which does not actually reproduce the facts of the exterior phenomenon, or the message transmitted to the brain is itself modified. Whatever the exact cause, the study of the *subjective* modifications of tone and colour is one of the most important branches of our subject. We shall describe, first of all, contrasts of tone, and then contrasts of colour.

*Contrasts of tone* may be either successive or simultaneous. Of the first kind, we have examples in the facts that a dark-toned piece of cloth or paper looks lighter if we have immediately before been looking at a still darker piece; and that a light-toned piece looks darker, if we have immediately before been looking at a still lighter piece. The following are illustrations of the facts of the simultaneous contrast of tones:—We first take two strips of pale-grey paper, and fix them a few inches apart towards one side of a piece of linen stretched across a window. Two similar strips are next prepared, but they are to be of a considerably darker tone. One of these is placed so as to touch one of the first strips; the other is fixed at some few inches' distance. The following sketch shows the arrangement of the strips:—



Upon steadily looking at the four sheets for a short time, it will be perceived that A' close to B seems lighter than A, while B close to A' seems darker than B'. The effect of contrast in altering the tone of the contiguous strips A' and B may be further studied in this way. Make such openings in a piece of card as to divide the strips A' and B each into three portions. It will then be noticed that the two nearest portions are most contrasted in tone, and the others less so in proportion to their distance from the line of contact. But the effect of contrast of tone is still better seen when a more complete series of toned strips is placed in contiguity. In such a case the effect on all the strips, save the end ones, is that of a double contrast. The second strip, or second tone, has one side of it made apparently darker by reason of the contiguity of the lighter tone of strip 1, while the other side seems lighter by the contiguity of the darker tone of strip 3. The general result of these double contrasts is that the whole series or scale of tones presents the appearance of a number of hollows, although, in fact, the apparent hollows are perfectly flat spaces of shading or colouring. The effect of this experiment is approximately represented in



Fig. 20, where the real flatness of each tone of the six may be verified by covering up all the other spaces by a card. The same diagram of contrast of tone may be made more effective, by dividing a slip of card into several



Fig. 20.

equal sections—say, six—by faint pencil lines, and then giving all six a light wash of Indian ink. Next, when this is dry, five sections receive a second similar wash. Afterwards the same process is repeated until the third section has received three washes, the fourth section four, the fifth section five, and the sixth section six. In carrying out the process, all sections, except those being submitted to the operation of washing, should be hid from view. Without this precaution it is difficult to secure a flat tint in each strip. If a series of pieces of grey paper of the same colour, but of different tones, are obtainable, they may be used in the construction of the same figure. They should be of equal size, and be pasted close together on a strip of cardboard; or a strip of glass or gelatine may be so arranged as to present at one end one thickness of the material, and the other end six or more thicknesses. On looking through the series, especially if a piece of white enamel glass, or a sheet of white paper, be placed behind, the effect of simultaneous contrast of tone will be clearly perceived. It is scarcely necessary to state that the tones of any particular colour may be used as well as grey to illustrate this kind of contrast. Its characteristic effect is not seen unless the contrasting tones differ considerably in intensity, and are in close contiguity or absolute contact.

*Contrasts of colour* are always more or less complex in character. There is, to begin with, the actual or objective difference between two colours, and then, super-

added to this, we have certain subjective modifications, of an ocular or mental kind, which all contrasted colours produce. Further than this, it is rare to find any contrast of colour in which the effects of contrast of tone are not likewise present. We shall have to speak in a future chapter, and with considerable detail, of the practical results of all the circumstances which affect contrast of colours, and so now we merely introduce this subject by a few words on the successive and simultaneous contrast of colour.

If the eyes have steadily regarded some coloured object, and then look at a colourless object, the latter object will assume a colour complementary to that of the former, or will present an image of that object in the complementary colour. If the second object be itself also coloured, but differently from that first viewed, then the complementary colour will mingle with that of the second object, and modify its proper colour accordingly. But even a third case of successive contrast may occur. Supposing we look steadily at a series of pieces of scarlet cloth, one after another being placed before us; the eye, fatigued with the repeated calls on its perception and appreciation of scarlet, becomes incapable of estimating the series of identical specimens, and reports the last specimen to be duller than the first. The eye has become less appreciative of red, and more appreciative of the other colours. It sees less red, and more green and blue than before, which mixing with the red of the later specimens of cloth, dull and modify them. The eye may be rested and restored to its proper condition by gazing upon a piece of green or bluish-green cloth, when its power of appreciating red will once more return.

The simultaneous contrast of colours was first thoroughly worked out by the French chemist, Chevreul. It is the most fertile of all the laws of colour in the elucidation of the actual phenomena of contrasts, and in the suggestion of new combinations. When two coloured objects are seen at the same time, they usually mutually affect each other both in colour and tone. A yellow object, for example, placed close to a blue one, will appear as if it inclined to orange, while the blue object will seem to incline towards violet. The reason of this, on the as-

sumption that yellow, red, and blue are the primary colours, is that the eye looking at yellow becomes less able to appreciate it, and sees the remainder of the primary colours, red and blue, that is, violet. This violet mixing with the contiguous blue colour tinges it with a faint trace of red. So with the blue object: the eye looking at the blue becomes less able to appreciate it, and sees the remaining primaries, yellow and red, or orange, the complementary of blue, which orange is imparted to the yellow, giving it a reddish hue. But blue and yellow differ much in their respective value as regards tone. The luminous and brilliant yellow becomes still more brilliant by contact with the richer and deeper blue, which itself is at the same time deepened, so that under ordinary circumstances these two colours afford a combined example of simultaneous contrast of tone and colour. But two complementary colours, such as red and green are presumed to be according to the common theory, do not modify one another's colour by contiguity. Theoretically, they contain the three constituents of white light, and the eye perceives no deficiency or excess of any coloured elements in the combination. So red and green merely enhance each other's characteristics when in contact. Thus it is with orange and its complementary blue, and with other pairs of complementary colours.

By placing strips of coloured paper together, a few of the chief phenomena of simultaneous contrast may be easily observed. We here give a list of some of the modifications of hue which coloured surfaces seem to undergo when placed in contact in pairs:—

{ Red	inclines to violet.	{ Orange	inclines to red.
{ <i>with</i>		{ <i>with</i>	
{ Orange	,, ,, yellow.	{ Yellow	,, ,, green.
{ Red	,, ,, violet.	{ Orange	,, ,, red.
{ <i>with</i>		{ <i>with</i>	
{ Yellow	,, ,, green.	{ Green	,, ,, blue.
{ Red	,, ,, orange.	{ Orange	,, ,, yellow.
{ <i>with</i>		{ <i>with</i>	
{ Blue	,, ,, green.	{ Violet	,, ,, blue.
{ Red	,, ,, orange.	{ Yellow	,, ,, orange.
{ <i>with</i>		{ <i>with</i>	
{ Violet	,, ,, blue.	{ Green	,, ,, blue.

{	Yellow	inclines to orange.		{	Green	inclines to yellow.
	<i>with</i>				<i>with</i>	
	Blue	„ „ violet.			Violet	„ „ red.
	Green	„ „ yellow.			Blue	„ „ green.
{	<i>with</i>			{	<i>with</i>	
	Blue	„ „ violet.			Violet	„ „ red.

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## CHAPTER VII.

COLOURS WITH WHITE, GREY, AND BLACK—OCULAR MODIFICATIONS OF COLOUR—PERSISTENCE OF COLOUR-IMPRESSIONS—IRRADIATION—SUBJECTIVE COLOURS—CONTACT AND SEPARATION OF COLOURS.

WE have seen, in the last lesson, that there are two kinds of contrast—the contrast produced by difference of tone and the contrast produced by difference of colour. We have also seen that these contrasts are produced under several conditions, and that they are modified through the mode in which they are perceived by the eye and impressed upon the mind. No sooner, in fact, are two colours so placed as to be seen at the same time or in quick succession, than they are apparently changed. The change may be one of tone only, of colour only, or of both tone and colour. Nor is it necessary, in such experiments, that two colours should be used: we may employ two tones of the same colour or a single tone of colour with white, grey, or black. We have already studied the apparent changes which the primary and secondary colours mutually cause when placed in contiguity, and so may now proceed to state what modifying influences white, grey, and black respectively produce upon the most important colours (see Figs. 27, 28, and 29, page 70).

I. YELLOW.—*Yellow* with *white* is rendered darker, less luminous, and less prominent, and acquires a faint greenish hue. The lighter the tone of the yellow, the less pleasing is the combination.

*Yellow* with *grey* is rendered darker, less luminous, and perhaps a trifle more orange. When the grey is of about the same intensity or tone as the yellow, the com-

ination is not satisfactory ; but it becomes so when the grey is rather deep, the yellow then recovering brightness.

*Yellow with black* is rendered lighter or paler, more luminous, and more prominent. The combination affords the most intense contrast next to that of white with black. The blackness of the black acquires a somewhat bluish-violet hue, which has a tendency to enrich it.

2. ORANGE.—*Orange with white* is rendered darker, and perhaps a trifle more reddish. The contrast between orange and white is much greater than that between yellow and white, and the combination is consequently more effective.

*Orange with grey*, when the latter is pale, is darkened and reddened. With deep tones of grey, orange becomes more luminous,

*Orange with black* becomes more luminous and yellower ; the contrast is next in intensity to that afforded by yellow with black.

3. RED.—*Red with white* becomes more intense and of a deeper tone. The combination, as to intensity of contrast, is similar to that of green with white ; being less decided than that of blue and violet with white, but more so than that of yellow and orange with white.

*Red with grey*, where the latter is pale, becomes more intense, deeper, and occasionally acquires a slight bluish hue.

*Red with black* becomes more luminous and slightly yellower.

4. VIOLET.—*Violet with white* affords a contrast of very decided character, owing to the great difference of tone between a full violet and white. The violet is rendered deeper in tone in this combination.

*Violet with grey*.—The distinctive colour of the violet makes itself felt in this combination, which is a quiet and agreeable one.

*Violet with black* affords an instance of the harmony of analogy rather than of contrast. The violet is enriched by its proximity with black ; but the latter thereby acquires a rusty hue, which takes away from its richness.

5. BLUE.—*Blue with white* constitutes a pleasing combination. The contrast is very decided where the tone of blue is deep. The effect of white clouds in deepening

the tone of the sky is a good example of one of the chief characteristics of this combination.

*Blue with grey.*—Grey enhances the tone and quality of blue, deepening it to a remarkable extent under certain circumstances.

*Blue with black.*—This combination resembles that of violet and black, but is less agreeable, especially where the blue is of a deep tone. Light shades of blue are rendered paler and more luminous by contiguity with black.

6. GREEN.—*Green with white* becomes more intense and of a deeper tone; green is distinctly improved by the presence of white.

*Green with grey* becomes deeper in tone.

*Green with black* is rendered rather lighter in tone, and more brilliant; but the black suffers in purity, and becomes slightly tinged with a ruddy hue—the result of adding to the black, red, the complementary colour of the neighbouring green.

From what has been said in the preceding paragraphs, it will have been seen that the effect of white upon a colour is to enhance its quality and deepen its tone; for white, presenting the maximum of brightness itself, naturally lowers the apparent brightness of coloured surface in contact with it. But the white is capable of enhancing the quality of a colour for a different reason (explained already when speaking of “Simultaneous Contrasts”). In virtue of this principle, the white, in contiguity with a colour, has a tendency to become tintured with the complementary of that colour; the presence of this trace of the complementary colour enhances the quality of the original colour itself, in obedience to the law of contrast: the same effect is observed, also, with grey and black when placed in contiguity with colours.

This remarkable law of contrast, of which we are now speaking, may, indeed, in its widest terms and most general application, be summed up in the statement that two differing colours or differing tones tend, when placed together, to differ still more. Light tones and colours become lighter, dark tones darker, complementary colours are mutually enhanced in distinctness or saturation; and where a colour is present without its complementary, that complementary is, as it were, evolved, owing to extra

sensibility of the eye for those colours which are not presented to it when it has been excited and fatigued by those at which it has been gazing. Before studying the more complex combinations of colours and their applications in the arts, it will be expedient to develop a little more fully some of those principles on which the "subjective" or "ocular" modifications of colours depend. To such phenomena we have just now, as well as on former occasions, briefly alluded; but we are now in a position to extend and amplify our previous observations.

The subjective modifications which colours suffer arise from at least three causes.

First of all, we have the persistence of the impression on the retina of the eye. The discharge of a Leyden jar gives a spark which is sensibly instantaneous, and yet the impression which it makes upon the eye endures a distinct fraction of a second. The spokes of a rapidly-revolving wheel are seen with perfect distinctness and perfectly separate if it be illuminated by an electric spark, although in an ordinary light they may present a shadowy surface, where all the elements of the wheel are blended together. Yet the apparent solidity of this surface may be proved to be unreal by its approximative transparency to objects placed on the further side of it. These objects if properly lighted, can be readily perceived through the shadowy surface previously described. Similarly with a series of flashes of electric sparks; if these follow one another at intervals less than the period during which the impression of each spark remains upon the retina, the resultant effect will be that of a continuous light. A familiar example of this persistence of impressions upon the retina is to be found in the experiment of rapidly whirling a glowing stick or piece of red-hot charcoal; a continuous circle of light being produced under these circumstances, if the rotation be sufficiently rapid. Now the effect of this peculiarity of the optical arrangements of the human eye is very marked in the case of colours; but it does not take place exactly in the direction in which we might expect it. It would be imagined that if one of the eyes has been looking at a yellow disc or other yellow object it would perceive, when directed upon a blue object, a mixture of yellow and blue, or a colour lying between them. However, under such

circumstances the blue object, so far from acquiring a greenish tinge, becomes rather tintured with a violet hue. This effect is really one of subjective colour, as well as of persistent vision; for the eye having seen a yellow object is partially blinded or paralysed, so far as that component of white is concerned; acquiring, on the other hand, greater sensitiveness to the perception of the complementary of yellow—that is, violet. White surfaces, or even coloured surfaces, which, of course, reflect much white light, will then have their violet or red and blue constituents brought into unusual prominence by the previous perception of yellow, and will be consequently tintured with violet. As it is difficult to carry out mentally, from this principle, the whole scheme of alterations of colour effected by the peculiar kind of contrast just described, we shall here give a list of the principal colours as modified by the previous perception of others. Before doing so, it may be advisable to give our readers a method of proving for themselves that such modifications really occur.

Close the right eye, and then look steadily with the left at a sheet of *red* paper. When the red paper appears dull, owing to the special sort of fatigue it induces in the eye, look immediately, still with the left eye, upon a sheet of *violet* paper. The violet paper receiving the complementary of red—namely green—becomes much bluer. To verify this observation it is only necessary, after having closed the left eye, to open the right, and to look with it upon the sheet of violet paper. The violet will be perceived very differently now, and so far from being bluer than in reality, may actually appear modified in the contrary direction—becoming more red, instead of more blue. To be performed with successful and distinct results, such experiments as these require great care and frequent repetition. Moreover different individuals have very different powers of appreciating colours and of recording their impressions. One eye, also, will often be found to differ from its fellow in many important particulars. Notwithstanding the delicacy and difficulty which may be experienced in determining the special relations of contrast (often called “mixed contrast”) now under consideration, they are of considerable importance in the practice of the various kinds of decorative and pictorial art.



We now give our list of the modifications induced by mixed contrasts of colour.

*If the eye has first seen      and then looks at      the latter colour will appear*

Yellow,	orange,	reddish-orange.
Yellow,	red,	reddish-violet.
Yellow,	violet,	bluish-violet.
Yellow,	blue,	violet-blue.
Yellow,	green,	bluish-green.
Orange,	yellow,	greenish-yellow.
Orange,	red,	reddish-violet.
Orange,	violet,	bluish-violet.
Orange,	blue,	tinged with violet.
Orange,	green,	bluish-green.
Red,	yellow,	greenish-yellow.
Red,	orange,	yellow.
Red,	violet,	indigo-blue.
Red,	blue,	greenish-blue.
Red,	green,	bluish-green:
Violet,	yellow,	slightly greenish.
Violet,	orange,	yellowish-orange.
Violet,	red,	orange-red.
Violet,	blue,	greenish-blue.
Violet,	green,	yellowish-green.
Blue,	yellow,	orange-yellow.
Blue,	orange,	yellower.
Blue,	red,	orange-red.
Blue,	violet,	reddish-violet.
Blue,	green,	yellowish-green.
Green,	yellow,	orange-yellow.
Green,	orange,	reddish-orange.
Green,	red,	tinged with violet.
Green,	violet,	reddish-violet.
Green,	blue,	violet-blue.

It must not be forgotten that the above modifications of colour arising from mixed contrast, differ not only in intensity, but in persistence. The modification produced by the successive view of violet and yellow is stronger and more persistent than that produced by the successive

view of blue and orange ; green is but slightly modified, and for a brief space of time only, by the previous view of red, and so on. And the above-described effects of contrast are influenced, to a great degree, by the difference of tone between the colours successively observed. A dark blue viewed after orange may actually appear somewhat greenish, when the normal modification would be precisely in the opposite direction—that is, towards violet ; yet this change occurs most conspicuously when the blue is of not too full a tone. Among the most important cases, constantly occurring in common life or artistic practice, of modifications of colours arising from persistence of the impressions made on the retina, we may cite the difficulty experienced by painters, from gazing too long at any bright coloured object, natural or artificial, of reproducing or matching its tone and hue. Again, we may allude to the well-known instance of the purchaser of coloured fabrics. If a series of bright yellow fabrics be displayed, and then some pieces of orange or red stuff ; this latter is regarded as dull, and to have a crimson or even a violet tinge. Under such circumstances, the retina, fatigued by the sight of yellow, has a tendency to appreciate and perceive violet, its complementary, more distinctly. Thus, much of the yellow in the orange stuff is suppressed, and it appears redder than it really is ; red similarly acquires a violet tinge. Doubtless much of the weariness experienced by a long examination of the pictures in an exhibition of modern works of art is due to eye-fatigue, and the consequent ocular modifications of colour.

The second subjective or ocular cause of apparent changes in the colours of objects is due to defects of the organ of vision. The eye may suffer from what in optical language is termed “spherical aberration”—a scattered light, of varying degrees of intensity, always surrounding the defined images of luminous and strongly illuminated objects upon the retina. The result of this nebulous border about such images is to increase their apparent size ; but it is nearly always imperceptible under the ordinary conditions of moderate illumination. When, however, we look at incandescent or glowing and luminous bodies, the effect is very striking. A piece of charcoal no thicker than one’s finger, if lighted at one end and plunged

in oxygen, appears actually to swell as the combustion becomes more intense and the light brighter. A spiral of platinum wire heated to whiteness by a galvanic current not only has its diameter, so far as the wire itself is concerned, enormously increased, but the separate turns of the spiral seem to approach and even to coalesce, if not originally too distant. The crescent of the moon appears, for the same reason, to belong to a much larger sphere than the dimmer mass of the satellite which it clasps. Much of the peculiar indefiniteness and mystery which impart considerable beauty to flames of different kinds, to strongly illuminated clouds and surfaces of water, and to the intense reflected lights of metallic ornaments, is due, in part at least, to irradiation, which, moreover, is one of the chief causes by which coloured margins are so frequently observed to surround coloured objects. A rim of greenish light may be observed round a red wafer placed on white paper, owing to the extension of the image of the red wafer beyond its geometrical image on the retina of the eye. Of course the rim is green, owing to the effect of simultaneous contrast. With a pure yellow, such as that of the spectrum, or that made by mixing green and red *lights* together, the rim of irradiate colour would be blue. This effect is roughly shown in Fig. 21.

There is another and entirely different kind of defect in some eyes which causes modification of actual colours. For it has recently been shown with great clearness by Leibreich that the yellow colour which tints the lens of the eye in advancing years produces remarkable effects upon the appreciation of blue and bluish colours. This aged condition of the eye is not always strongly marked, but occasionally, as in the case of the painter Mulready, it has produced very curious results. The later pictures of the artist are often spoken of as too cold, too blue, or too purple. If they are examined through a piece of glass tinted of a pale sherry-yellow colour they re-assume a natural appearance, and exhibit the same harmonious and natural system of colouring which Mulready adopted in his earlier works. Leibreich points out that we have an excellent illustration of how Mulready saw his own works with the naked eye in his later years, if we will only look through a yellow glass at a picture of his in the South Kensington Museum called

“The Young Brother.” Without the glass it is far too blue to be natural, with the glass it closely resembles an earlier and more accurately-coloured work by the same hand which is preserved in the same collection. This latter work was painted twenty-one years earlier, when the lenses of the eyes of the artist were normal. Even when they became yellow the objects of exterior nature were scarcely modified in colour in consequence of the ocular change, for the yellow medium could cut off but an infinitely small proportion of the blue in the intense light and colour of the day, while the eye through the constant presence of this yellowness, became less appreciative of this colour, and consequently more appreciative of its complementary blue. But with pictures the case was entirely different. The light reflected from pigments is so immeasurably less in quantity and intensity than that of exterior nature that a yellow lens will seriously interfere with the blues which paints represent : it will intercept them. So the painter will try to set this right by strengthening his blues and increasing their proportions in his mixed colours. To his yellow lens his pictures thus become right in harmony and key of colour. To a normal lens they are too blue—his reds, of course, too, being changed, becoming purple or violet. If then we look at one of Mulready’s later pictures through a sherry-yellow glass it recovers in a great degree its truthfulness of hue, and appears to us as it appeared to him : but if we look at one of his early pictures through the same medium we see that it is altered in nearly every respect for the worse : no wonder then that the artist himself became dissatisfied with his earlier colouring as his lens grew yellower.

The third ocular cause of the modification of colour has been already dwelt upon at some length, and in different places, in the present series of lessons : it is the production of subjective complementary colours. We may just allude to the phenomenon here, in order that this most important and fundamental fact may be thoroughly impressed upon the minds of our readers. Simply stated, the cause of the phenomenon may be traced to the impaired sensibility to light temporarily caused by the action of light upon the optic nerve. Not only is this true of white light, but of light of every colour. Not only

does a moderately lighted room appear dark when we first enter it from broad sunshine, but, as we have before stated, the last piece of yellow or red cloth we look at will seem duller than the first, though they have all been cut from the same roll. When light of any particular colour falls upon the eye, it becomes less sensitive to, and less appreciative of, that colour; it is partially blinded to its perception. So, not only will a red wafer placed upon a sheet of white paper be surrounded by a rim of colour through irradiation, but that rim will be green; and if the wafer be moved away, a green spot will occupy its former position. For the eye, by gazing at the red wafer, has had its sensibility to red light temporarily impaired, and so the white light received on that particular spot of the retina previously occupied by the red image of the wafer will have its red constituent virtually removed, and will produce the effect of the residual rays—namely, a green image, the complementary of the previous red one. Several other contrivances for producing subjective complementary colours have been devised. One of the most satisfactory of these is to view a surface of white, grey, or coloured paper, moderately illuminated, through an aperture in another sheet of paper of a different colour, and placed at a little distance above or before it. The lower surface, as seen through the aperture, will be tinged with the complementary of the coloured surface above. So, also, the shadow of an object interposed in a beam of coloured light will, if received on a screen slightly illuminated with white light, appear to have assumed the colour complementary to that of the beam; and, for the same reason, a beam of daylight finding its way into a room illuminated with yellowish light from candle-flames, will appear violet. The importance of this fact, as regards the proper treatment of shadows in painting, will have to be insisted on and illustrated in a subsequent chapter.

We have now studied the mutual effects of many pairs of colours, the effects of white, grey, and black upon single colours, and the effect on a second colour of the previous perception of another. We have then passed to the causes, dependent upon the structure of the human eye, which modify the natural appearance of coloured objects. We may fitly close this chapter with a few remarks on the uses

which may be made of some of the facts and laws which have just been stated, confining our attention at present, however, to those effects of the apposition and separation of coloured spaces which are illustrated in our coloured figures.

We have before stated that yellow is the most forcible, luminous, and prominent of the primary colours. It will appear nearer to the eye than either red or blue. In Fig. 22 (coloured plate) a yellow leaf pattern is represented upon a ground partially red and partially blue. While there is no doubt of the prominence of the yellow, it will probably be allowed that the red ground appears nearer than the blue; and if the blue had been of a purer and fuller tone still, the retiring effect which it possesses would have been yet more perceptible. How far the retiring effect of blue is due to association or fancy, to our constant view of the sky and the hazy distance of a landscape, it is difficult to determine. But there can be no doubt that we are obliged, in decorative and pictorial art, to recognise the idea of distance conveyed by blue and bluish hues, and that such colours afford means of attaining effects of mystery, obscurity, hollowness, etc., which other hues do not furnish. Another association with the colour blue is that of coolness, just as red recalls the glowing warmth of a fire, and yellow the bright shining of the sun. Another feature of our diagram (Fig. 22) is the distinctness of the sensation imparted by the three colours, yellow, red, and blue. If the red approaches the yellow rather more closely than the latter does the blue, it arises from the impossibility of representing by actual pigments these three colours.

Figs. 23 and 24 teach another fact relating to coloured spaces in contact. Often when we attempt to mix pigments, our mixture is anything but successful. The difficulty of getting a good violet by adding blue and red together is well known. The result may be achieved in a different way. If lines or dots of red and blue be distributed suitably over a surface, the effect of violet will be produced—at all events, when the figure is held at some distance. One mode of accomplishing this result is seen in Fig. 24, where the distinction of the two colours is lost, and a mixed colour effect produced, in obedience to the

FIG. XXI.



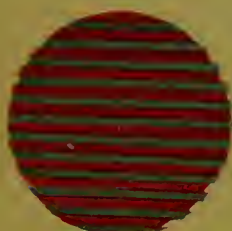
*Subjective Colour.*

FIG. XXII.



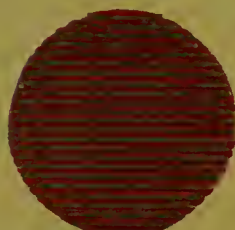
*Colour as related to idea of Distance.*

FIG. XXIII.



*Effect on Colours of Apposition.*

FIG. XXIV.



*Mixture of Colours by Apposition.*

FIG. XXV.



*Effect of Black and White in separating Colours.*

FIG. XXVI.



*Indistinctness of Related Colours in contact.*

modify the objective realities, of complex colour combinations, but the element of *taste*—to some extent a personal element peculiar to the individual—introduces fresh difficulties in reaching a right judgment. Yet it must not be forgotten that taste in great measure depends upon knowledge, association, and culture, and may be developed from very small rudiments by proper study. Never was there a time when the opportunities for such study, in relation to taste in colour, were more abundant. Commencing with the acquirement of the knowledge of the theory and the laws of light and colour, we may proceed to study and to analyse the most pleasing and attractive colour-combinations to be found in the works of Nature and of art. Here it is that our parks and gardens, our museums of specimens of natural history and ornamental art, as well as such art libraries as that at South Kensington, become of such special use. The dwellers in a great city, if shut out from the pure blue of the sky, and the foaming white of the ocean, if debarred from the wide beauties of the open landscape, yet have an opportunity of studying the wonderful colours of Nature. Such are shown in the softened tones, and tender hues, and metallic lustres of flowers, birds, shells, and minerals, in the pictures which represent outward facts as interpreted by the intelligence and skill of man, and in the thousand and one forms of decorative art which so often express, in various degrees, the development, historical and national, of the appreciation of colour.

We may suitably commence to apply the laws of colour by a reference to the effect of certain triple combinations of primary and other colours. Some details of this kind have been already furnished when we were describing the value of black and white in separating related colours. Orange and red do not accord well together, for they are closely related by the possession of many qualities in common, being bright, warm, and exciting to the eye, and so similar as to have their boundaries confused when placed together. A white line placed between a red and an orange space or device of colour, not only serves to separate them, but to deepen and enrich their tone, by virtue of the law of contrast. But it does not do this so effectually as a line of black, which, affording very nearly the strongest possible



contrast with orange and a powerful contrast with red, brightens both of these colours considerably, without actually causing the whole combination to reflect more light to the eye, but rather less. Now, if we wish to separate two related colours from each other by the use of white or black, and these colours should happen to be, like blue and violet, of a cool retiring quality, and less exciting than orange and red, black will prove itself much inferior to white. Deep tones of blue and violet are so closely related to black that the latter effects little towards their separation, while it is itself injured by contact with them, acquiring a rusty hue. But white, on the other hand, while it deepens these colours, renders them purer, and by itself acquiring a faint tinge of the complementary yellow or orange (in obedience to the law of simultaneous contrast) causes their differences to appear more distinctly. Still there is a triple combination slightly preferable to that of blue, white, and violet; it is formed by the substitution of grey for white. The contrast becomes less violent, and is undoubtedly more agreeable. Without going through the whole series of primary and secondary colours in their relations to one another, and to grey, white, and black, it will be useful to furnish an outline of the principles by which such combinations may be classified and valued. Triple assortments of this kind may be arranged in three groups:—

1. Two primary colours, with (*a*) white, (*b*) grey, (*c*) black.
2. One primary and one secondary colour, with white grey, or black.
3. Two secondary colours, with white, grey, or black.

1. Of the first species of triple assortments there may be nine varieties, even if we limit the list to those varieties in which the colours are separated by the white, grey, or black:—

Yellow—with white, grey, or black—and red (three varieties).  
 Red—with white, grey, or black—and blue (ditto).  
 Blue, with white, grey, or black—and yellow (ditto).

2. Of the second species of triple assortments there may be twenty-seven varieties:—

Yellow—with white, grey, or black—and orange (three varieties).  
 Yellow—with white, grey, or black—and violet (ditto).

Yellow—with white, grey, or black—and green	(three varieties.)
Red—with white, grey, or black—and orange	(ditto).
Red—with white, grey, or black—and violet	(ditto).
Red—with white, grey, or black—and green	(ditto).
Blue—with white, grey, or black—and orange	(ditto).
Blue—with white, grey, or black—and violet	(ditto).
Blue—with white, grey, or black—and green	(ditto).

3. Of the third species of triple assortments there may be nine varieties :—

Orange—with white, grey, or black—and violet	(three varieties).
Violet—with white, grey, or black—and green	(ditto).
Green—with white, grey, or black—and orange	(ditto).

In these lists we have presented the simplest kinds of triple assortments in their baldest forms. Before we can form any just idea of their relative merit, so far as the degree of pleasure they convey to the eye is concerned, it will be necessary to look a little more closely at the various conditions under which these assortments of colours may be made or met with. Supposing our colours to be produced by the purest pigments, and each one of them to present its characteristic depth of tone (which we have previously described as its *equivalent*), we shall yet find that the effect of any one of our series, above given, of simple triple colour-assortments depends upon many minute particulars. Amongst these we may name, as the most important, the relations of the colour-elements of each assortment, so far as concerns their—

1. Distribution, as to form and surface.
2. Proportion or balance.
3. Quality, as to warmth, brilliancy, saturation, etc.

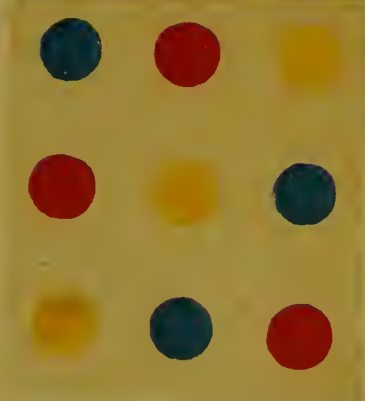
The consideration of the texture of the coloured material, its lustre, transparency, and similar physical character, together with the modifications of colour produced by different kinds of illumination, being deferred for the present, we proceed now to say a few words as to the distribution of the constituents in combinations of three colours. The simplest case is the presence of the three elements on three equal and similar spaces, such as a square space of yellow separated by a similar square space of white from one of red ; or we may have a disc of red, surrounded by a ring of white, and that bordered by a second ring of

yellow, each surface being of equal area. Differences of area, as well as of form, may also be taken into consideration. The white space may be reduced to a narrow band separating the yellow and red, or it may be increased so as to form several strips, and then arranged in the order—white yellow, white red, and so on. This is not only an alteration in the relative space occupied by one of the elements in a triple assortment, but it involves an alteration in the way in which the element is distributed. The mode of distributing colours, however, belongs rather to another branch of the subject, although it undoubtedly influences to a great extent the quality of the colour-effects produced in any assortment of hues. We will, however, say a few more words about the effects of the mode of distributing colour on a surface when we have touched upon the two allied subjects of the balance of colour and the quality of colour.

The balance of colour has been already alluded to in Chapter IV., and need not be discussed at length in this place. The principle which underlies the idea of the balance or proportion of colour is that the eye and mind demand for their satisfaction the presence of the several elements of the chromatic scale in some form or other of combination, and in such proportions as shall be competent to re-constitute white light, whiteness, or greyness. But there are three facts which must not be lost sight of in studying the balance of colour in any actual composition. The first of these facts is that our purest pigments are far from representing the several colours of the spectrum, and so we can only approximate our groups of coloured surfaces very roughly to the proportions required by theory. The next fact is that this theory itself is merely a provisional one. For, as we have already pointed out (see Chapter IV.), Professor Maxwell and other observers have shown that the commonly received theory as to the primary colours is not altogether true or competent to explain some of the most important phenomena of colour. Convenient this ordinary theory certainly is, while its defects do not obtrude themselves upon our notice when we examine the impressions produced by coloured terrestrial objects. We will not go over this ground again here, but merely mention the inherent defectiveness of the

usual theory of the coloured constituents of the white light, in order to point out how it is that we feel unable to claim any real or complete scientific basis for our present views as to the balance of colour in a composition. We must, however, for the present accept and utilise these views in default of better ; yet it would be improper to claim for them an unhesitating acceptance or adoption. But even supposing the theory of the balance of colour to have greater pretensions to truth than it really possesses, there is a third fact which tends to lessen still further its value and applicability—we refer to the satisfactory and agreeable nature of many colour-combinations which glaringly transgress its demands. Yet the fact that the contemplation of a single pure and bright colour viewed alone gives us pleasure no more negatives the idea of the greater and more complex kind of pleasure derived from an assortment of colours than the sweet quality of a particular note in the human voice, or a musical instrument disproves the superior beauty of a chord. So, too, just as some airs have but a very limited range of musical tones, yet possess a simple and quiet beauty of their own, so a few colour-tones of the same scale, or a series of three or four closely-related colours, may give us great pleasure, and seem to employ and satisfy the eye. There can be no doubt, then, that while the colour-elements are beautiful by themselves and in a large number of simple combinations, fresh beauties of other and less obvious sorts are brought out by assorting colours in obedience to certain principles. So far as balance or proportion is concerned, we may say that of the most brilliant and luminous colours, such as yellow, we need least in any assortment ; of colours of intermediate power, such as red, a larger quantity may be used ; while the deep and more retiring blue demands a space at least equal to that occupied by both the yellow and the red. White will be used most sparingly, as being more brilliant than yellow ; and black will likewise be employed temperately, as the deepest of all tones, and giving the most violent contrasts possible. Here it is that the immense value of grey and the tertiary hues is especially felt. For suppose we desire to convey some particular impression by a colour-assortment, we can often do so, without widely departing from the balance of colour, by introducing

FIG. XXVII.



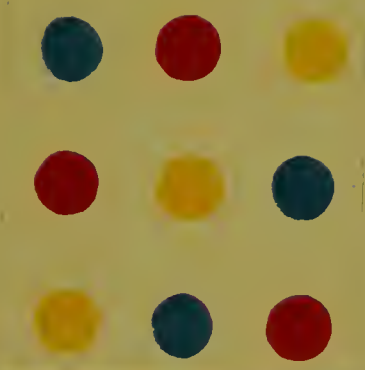
*Effect of a Grey Ground  
on Colours.*

FIG. XXVIII.

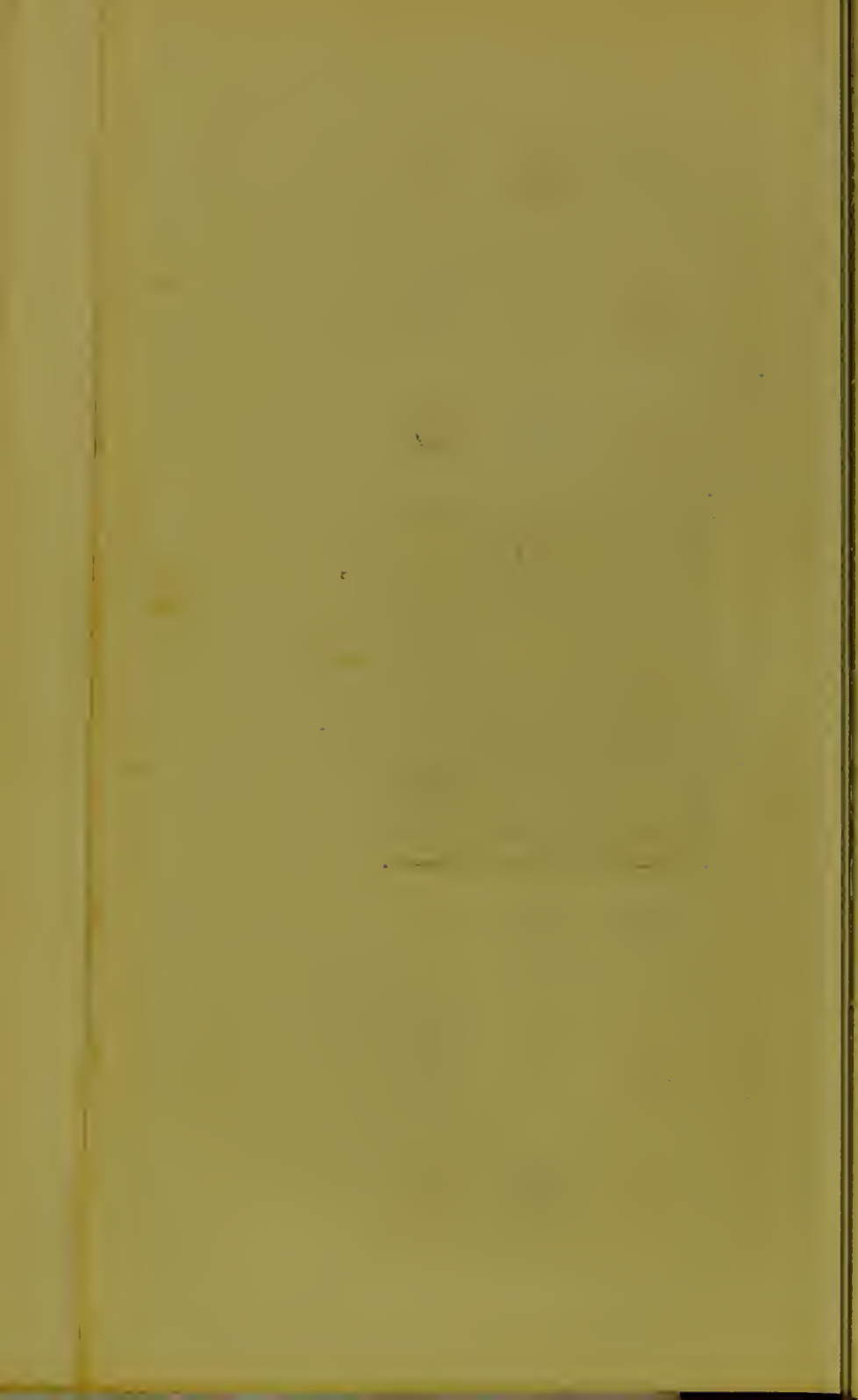


*Effect of a Black Ground  
on Colours.*

FIG. XXIX.



*Effect of a White Ground  
on Colours.*



grey into the assortment, either by itself or mixed with a colour, so as to produce a "broken tone." Thus, if we desire a quiet, but not cold assortment of colours, we may mix with our yellow enough grey to turn it into citrine, and then the complementary violet, which in a binary assortment is the other necessary constituent, will not produce so striking a contrast as with the original yellow. We may, also, then increase the proportion of surface covered by the citrine, so as to lighten the whole effect. In such a combination, white, too, may be introduced with more satisfactory effect, as it accords better with yellow when the latter has been made less brilliant by admixture with grey than it does with pure yellow, which too much resembles it in brilliancy. In considering the balance or proportion of this or any such arrangement, or of those arrangements in which there is a manifest deficiency of some one colour-element, it should not be forgotten that we have continually occasion to devise combinations of colour which are *not intended to stand alone*; indeed, it is usually impossible, even if it were desirable, to isolate the colour-assortments of natural or artificial origin. Thus the very elements which may be needed to supply the chromatic balance in, say, an old blue and white jar of the porcelain of Nankin may be furnished by the deep brown stand on which it is placed, or by the furniture or paper of the room. We must not, then, expect in all the fixed or movable decorations of a house that perfectly balanced proportion which the whole of them taken together may offer. The position, use, and material of each coloured object will necessitate a particular preponderance of certain colours, while a perfect colour-balance in each part would constantly lead to a very imperfect one in the whole system or arrangement.

Something has already been said of the quality of colours, as influencing our estimation of the value of their several assortments. We here return for a short space to this subject. In describing the primary and secondary colour, we have shown that their fullest and purest tones differ greatly in different cases. No tone of yellow can be obtained of equal depth with the corresponding tone of blue. The brightness or brilliancy of the yellow will always cause it to contrast, not only so far as the tone is con-

cerned, but also in relation to colour, with the blue. To deepen the yellow we must mix black with it, turning it into brown. Colours such as green and red may be obtained of full tones and yet equal intensities, so as to offer no contrast of tone, only one of colour. The inherent brightness or sombreness of colours forms, then, one of their most important qualities when they are introduced into combinations or assortments. Of course, the quality of colours is variously modified by admixture with other colours, or with white, grey, or black. Combinations of secondary and tertiary colours and hues, while influenced by the same principles of distribution and balance as those just laid down, are less capable of yielding discordant and unsatisfactory assortments. The contrasts between them are less violent, while their assortments admit of more varied treatment and more subtle expression. We shall have occasion to notice the great value of several of the more indefinite and mixed hues in the remaining papers of this series.

We may now proceed to illustrate by a few examples the application of the principles of the distribution, balance, and quality of colours to their triple assortments, which are of three series.

SERIES I.—*Assortments of two primary colours* with white, grey, or black constitute the first series. They are generally preferable to assortments in which one primary and one secondary colour occur, unless these happen to be complementary, when the effect is more agreeable still. The more brilliant colour must be used in moderation, and may be distributed in narrow lines or delicate forms. The deeper colour usually requires a broader treatment, and to be present in larger quantity. In separating the two bright primaries, yellow and red, from each other, black is preferable to white; while in separating blue and red, white is preferable to black. In such instances we have to pay attention to the balance of tone, and must not allow the bright or the deep elements of colour to preponderate. Grey is very often of use in colour assortments, where white or black might produce too marked a contrast.

SERIES II.—*Assortments of one primary and one secondary colour* with white, grey, or black. It is needless



to say that in the cases belonging to Series II. the effect of a primary with its complementary secondary is far superior to all the other combinations. Thus yellow and violet constitute a more agreeable assortment than yellow and orange. But yellow and violet cannot be much improved by the introduction of black, which too much resembles the violet, and differs too much from the yellow; while white is liable to an objection precisely the converse of this. Nor does grey produce a very satisfactory effect in this arrangement. The more agreeable the combination of two colours when in contiguity the less improvement do they require, and the less do they experience from the introduction of white, grey, or black. Such assortments as that of yellow and orange are, on the other hand, greatly improved by the introduction of another element to define or emphasise them. The arrangement yellow, black, and orange is vastly superior to that with yellow and orange alone. When white is used in an assortment of this nature containing two bright colours, it often produces a happier effect when introduced so as not to separate the colours, but to precede the brighter of them—thus, white, yellow, orange. If white be also inserted between the yellow and the orange, the effect is impoverished. When two deep colours are used together, and in combination with black, the black may advantageously follow the deeper colour, but such an assortment as blue, violet, and black is a sombre one; yet to many eyes it will appear more satisfactory than one in which alternate spaces of white are introduced, in order to restore the balance of tone.

SERIES III.—*Assortments of Two Secondary Colours.*  
—Orange and green may be advantageously separated by black, orange and violet by grey, and violet and green by white.

We hope the examples just given will be sufficient to enable our readers, with the aid of actual experimental trials, to judge of the merit of any triple assortment of colour, and to arrange many agreeable combinations suitable for special purposes. We may just allude here to one of the applications flowing out of the principles which we have been enunciating. It is an application of great service to ornamental designers, and has been

extensively carried out in practice. It may be briefly stated in three rules or propositions:—1. If in an ornamental design the ground be of a deep tone of colour, and the forms or figures upon it be of a less intense or lighter complementary colour, then these forms should be outlined with white, or with a light tone of grey, or, in any event, with some colour of a tone lighter either than the ground or the pattern. 2. If in an ornamental design the ground be of a light tone of colour, and the forms or figures upon it be of a more intense or deeper complementary colour, then these forms should be outlined with black, or with a deep tone of grey, or, in any event, with some colour of a tone deeper than either the ground or pattern. 3. In painting with tones of one colour, or monochrome, the same rule must be observed, varying the depth or tone of the outline according to the relations as to tone of the pattern and the ground, as in the preceding rules.

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## CHAPTER IX.

COMPLEX COLOUR-COMBINATIONS—HARMONIES OF ANALOGY—HARMONIES OF CONTRAST—HARMONIES OF SERIATION—HARMONIES OF CHANGE.

HITHERTO our studies of colours have been confined almost entirely to those which are considered elementary and those which are compounded with equivalents of their constituent primaries. We have alluded once and again to the existence and use of the vast series of mixed hues. It is however, chiefly in the employment of these colours that the higher chromatic developments, constituting the poetry of colour, are manifested. The obvious assortments of the primary and secondary colours, with their contrasts, resemblances, and harmonies, are not difficult to understand; but it requires a well-trained eye to discern the subtle differences and concords of composition in which several mixed hues preponderate, and a well-cultivated imagination to appreciate and to pursue their intricate delights. Here, where aid from descriptions is most desirable, it is most difficult. Endeavours to reproduce the more recondite harmonies of hues by me-

chanical processes are never wholly successful, and usually are even less useful than accurate verbal descriptions combined with references to natural examples. An illustration strikes us as we write. Many an observant student of Nature must have noticed the triple combination of hues presented by an old beech or elm tree as seen against the sky or clouds in early spring. We have the yellowish grey-green of the moss and lichen-grown trunk and branches standing out relieved against the dull grey of the shifting and variable clouds beyond; and this tender green of the moss and grey of the cloud are not flat or uniform, as they too often appear in our imitations of them, but fluctuating with a hundred variations of texture, quality, and tone. A few dead leaves perchance remain, suggesting, if not completing, by their brown or russet hues, the balance of colour, which just needed such idea of warmth and ruddiness as they convey.

But let us regard a little more minutely, a little longer, this natural combination of hues, which we commend, with countless others in the world around us, to every student of decorative art; let us see whether it does not possess other elements of beauty than those which we have recorded. Yes; if we look a little closer we shall doubtless see some delicate portion of nearly pure primary or secondary colour, some stray fragment of brightness—perchance an early flower or insect—just as the ancient pines of the unbroken American forest have been described as bearded with hoary lichens, yet touched with grace by the violets at their feet. So, too, there will be observed in the outermost twigs of our tree that hopeful thickening by myriads of leaf-buds, neither purple-russet nor clove-brown, nor any colour which we can definitely fix, but very beautiful in themselves and promising the verdure of summer. Deep hollows of shade, and the brightness of light will be seen too, yet sparingly, and so, like the simpler colours, made the more precious. From this example, of which nothing but the original work of a master in the art of painting could convey an adequate notion, most important deductions may be drawn. It will help us to realise, in a thoughtful, artistic way, the value of temperance in colour, as well as of balance and distribution. It will lead us to introduce, among our blues

and reds and yellows, some of those rarer tints which we cannot exactly name, but which the watchful student of Nature may see trembling on the leaves of the willow, or paving the autumnal paths of the forest, or shining at eventide from the cloudy but splendid pavilions of the sun.

It behoves us now, passing from this somewhat pictorial treatment of the obscure subject of the complex combinations of mixed hues and colours, to attempt the description and classification of harmonies of colour.

It is usual to divide harmonies of colour into two classes—those of analogy and those of contrast. Having already described the conditions under which assortments of colours become more or less harmonious, we need here do little more than illustrate by an example or two the several kinds of harmony of contrast here referred to. But it must be remembered that the distinction of harmonies into two classes is rather arbitrary. Some difference always exists between any two colours and any two tones, so that collocation, whether agreeable or otherwise, inevitably includes the element of contrast. Harmonies differ in degree or in complexity, but not in kind, so far as contrast is concerned. The ordinary harmonies of analogy pass by insensible degrees into distinct undoubted harmonies of contrast. We here cite M. Chevreul's classification of harmonies, a classification which has been adopted by most writers on colour :—

#### I.—HARMONIES OF ANALOGY.

1. *The Harmony of Analogy of Scale.*—This harmony is essentially the harmony of a series, or the harmony of gradation. It is produced by the simultaneous view of several tones of the same scale, and is obtained in varying degrees of perfection according to the number of the tones present and the intervals between them. When the tones are not easily separable by the eye, and run into one another, then the effect commonly called “shading” is produced.

2. *The Harmony of Analogy of Tones.*—When two or more tones of the same depth, or nearly the same depth, but belonging to different but neighbouring or related scales, are viewed together, the harmony of tone is pro-

duced. Many such assortments, however, are displeasing to the educated eye unless they be so selected as to fall into a series with a gradually increasing quantity of some one of their colour-elements, when they may be ranged in the third kind of harmonies of analogy—

3. *The Harmony of a Dominant Colour.*—This harmony is produced by viewing a landscape, a bouquet of flowers, or any contrasted colour-assortment, through a piece of glass so slightly tintured with a colour as not to obliterate but merely to modify the natural colours of the arrangement or composition.

## II.—HARMONIES OF CONTRAST.

1. *The harmony of contrast of scale* is produced by the simultaneous view of two very distant tones of the same scale.

2. *The harmony of contrast of tones* is produced by the simultaneous view of two or more tones of different depths, belonging to neighbouring or related scales.

3. *The harmony of contrast of colours* is produced by the simultaneous view of colours belonging to very distant scales, and assorted in accordance with the laws of contrast. This kind of contrast includes also those cases in which the effect is still further increased by differences of tone as well as of colour.

It must be confessed that the above classification of colour-harmonies is forced and imperfect; for every harmony depends to a greater or less extent upon contrast, either of tone or of colour, or of both; and our harmonies of analogy will be found to be derived from the milder and less startling kinds of contrast. Two ruling ideas will, however, be apparent in colour-arrangements, and upon the recognition of these ideas we may, perhaps, find a more satisfactory classification of colour-harmonies than that of Chevreul. These two fundamental ideas are those of *seriation* and *change*. Of the first we have an example in the assortment yellow, orange, red; of the latter in the assortment yellow, red, blue. Seriation or succession corresponds in some measure to the scales, and change to the chords, of musical composition. Seriation may be succession of tones or of colours, or of both;

but in all cases the idea of a series, of steps, of orderly succession, with the presence of a pervading and dominant element, is the leading feature of the arrangement. In harmonies of change, on the other hand, an element common to all the members or a majority of the members is wanting; nor is there any distinct idea of orderly succession or of development in those harmonies which convey very distinctly the notion of change, more or less abrupt. Between harmonies of seriation and harmonies of change there are numberless connecting links, so that the one kind may imperceptibly slide into the latter. For beyond the regulating principles of balance, distribution, appropriateness, harmony, etc., no rigid rules, as of cast iron, need trammel the imagination of the colourist, and so no precisely-defined classes can be arranged to receive all the possible harmonies of assorted colours and hues. What further remarks we have to make with reference to this subject we now proceed to give under the two heads of harmonies of series and harmonies of change.

Seriation, succession, development, sequence, gradation, or shading includes many cases of the harmony of analogy, and is of two kinds. The tones of a scale succeeding one another in regular order furnish one example of shading; another is seen in a series of assorted colours so arranged as to convey the notion of a gradual increase of some quality in the series. The gradual development of the full leaf-green of a plant in the spring furnishes an example of gradation, not only of tones but of colours. A greenish-yellow passes into yellowish-green, this into green, and this finally acquires both depth and a greater proportion of blue. Leaves in autumn may often be observed to reverse this order, passing through various tones and hues of russet, red, orange, and yellow. The open country continually offers illustrations of the two kinds of gradation we have named, and the landscape painter, apprehending the value of this fact, is enabled to realise the relations to each other of the different parts of the view spread before him, both as regards gradation of tone and gradation of colour. In the near objects constituting the foreground he notices the extensive range of the scales both of tone and colour, and the preponderance of those hues which imply the notions of brightness and warmth. In the

middle distance the range of tones and colours is more abridged; while the far distance is commonly distinguished by retiring and cold colours, with a very limited range of scale as well as of colour. From these natural examples of gradation we may take many hints useful in applying colour to decorative purposes. Supposing we wish to conventionalise a compound leaf, we may do so not only so far as its details and form are concerned, but also in reference to its colour. Fig. 30 represents such a conventional colour arrangement—an arrangement the key to which is to be found in a natural sequence of colours often occurring in plants.

What is called a harmony of analogy runs through the series of colours in Fig. 30. The four colours there assumed to be present resemble in kind and in order those



Fig. 30.

found in the spectrum of the sun to lie between the yellow and the green. The arrangement of the series conveys the idea of an increasing brightness and warmth as we descend from the pure green terminal leaflet to the smallest pair of leaflets close to the leaf-stalk. Fig. 31 represents the same series of colours in a diagrammatic way, but inverted, and furnishes us with a scientific analysis of the effects observed. The full green is represented, in accordance with the common theory, at the base of Fig. 31 as

containing eight parts of blue and three of yellow. The yellowish-green comes next, with one-third less blue and the same amount of yellow as before. The greenish-yellow contains only one-third the amount of blue of the original green. Then we reach the pure yellow, which is to be regarded as the common element of the series, bringing all its members into relation. On Maxwell's theory we are to suppose increasing additions of red as we ascend from green to yellow.



Fig. 31.

In our next illustration (Fig. 32) the range of colour is more extensive. The series is not for general use in decorative assortments, but there are several useful lessons to be drawn from it and applied in practice. The contrasts between contiguous colours in the present example are much more startling than in Fig. 30, the intervals are larger, while the harmony is one which must be said to lie between those of analogy and those of contrast. The element of serial succession or development is weak here, and that of change very apparent. The gradation in the assortment depends upon the increasing brightness of the colours as we ascend, and upon the link which connects each group of three neighbouring colours together—the presence of a common element. We arrive at this result



by interposing a secondary between its constituent primaries all through the arrangement. Thus orange is placed between yellow and red, which latter is succeeded by violet, the compound of red and blue. Blue follows, and after this green; then we should recommence the series by returning to the yellow with which it began. The analysis of the colour-series in Fig. 32 is represented roughly in Fig. 33, where the thin lines represent yellow, a thicker line red, and the thickest line blue. Where two lines overlap, a compound colour appears.

We may, however, learn something more from Fig. 32 than is here put down. The greater development of the stalks and leaflets towards the base, with the gradually increasing character of the latter towards the summit, helps to carry out the idea of series suggested by the succession of the colours. If in some minor details, such as the larger size of the second pair of leaflets, we find a break in the symmetry of the series, this is just the common feature of vegetable and animal growths by which they are in part distinguished from the mathematically accurate, but less interesting products of mere mechanism; for very often the poetry, the mystery, of beautiful organic forms lies hid in such seeming exceptions to law.



Fig. 32.

We must not fail to notice that there exist several methods of more completely harmonising the contrasted colours of such a series as that shown in Figs. 32 and 33. In copying the former figure in colours for the sake of the instruction this exercise affords, we recommend our readers to try the following generally applicable methods of bringing greater unity into such a series:—

1. An outline and veining of black, common to all the leaflets.
2. An outline and veining of gold, common to all the leaflets.
3. The addition of grey to the whole of the colours used, the largest proportion being added to the green, the least to the yellow.

4. Instead of making the secondary colours by mixture, introduce their constituent primaries by dots placed side by side.

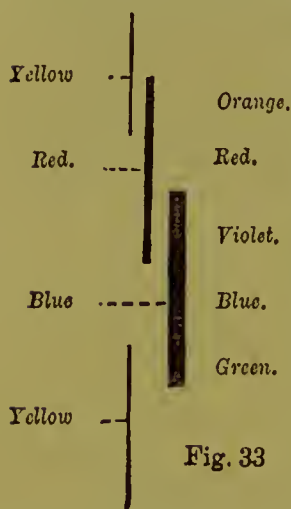


Fig. 33

Splendid examples of such gradations of colour as those we have been describing are to be found in numerous specimens of decorative art and manufacture in the fabrics of India, the silks of Damascus, the *faience* of Persia, the lacquer-ware of Japan, and the porcelain of China. To take a single example, we may refer our readers to the peculiar but beautiful selection and sequence of colours upon such plates of the so-called "Persian ware" as may be seen in the Ceramic Gallery at South Kensington. The particular variety of this ware which we have now in view is known as "Damas," "Lindus," or more generally "Rhodian." The range of colours is limited except so far as one series is concerned—the series beginning with green, and passing through turquoise blue, to a pure deep cobalt, and thence to a lilac hue. The most conspicuous of the remaining colours is a dull brick-red, opaque and much raised in relief above the others. A chocolate-brown, and a black or grey like that of Indian-ink complete the list, except that now and then a specimen of the ware is found with a little yellow on it. On a ground of creamy white, conventionalised forms derived from the hyacinth, the tulip, and a few other plants occur. The leaves are filled in with a copper-green, some flowers are of deep blue touched with turquoise, others of a lilac hue. On some specimens no other colours are found than these four, yet these establish so lovely a series that it is doubtful whether the specimens which exhibit these colours only are not equal or even superior to the others. The colours of the plants represented probably suggested, in cases like the present one, some of the predominant harmonies in which the dull red, with its yellowish tincture, balances the cooler blues and greens, while the Indian-ink colour, in light circles and delicate spirals of smoke-grey, tones down the

whole composition, and actually brightens and purifies its dominant series of colours. We ought not to fail to notice a most precious quality of these Persian wares—that fluctuation of colour, that absence of mechanical hardness of outline and uniformity of tone which distinguishes human handiwork of the thoughtful kind from the perfectly correct and thoroughly insipid work of a machine. But we must not linger any more over our illustrations of the harmonies of series or relation, but conclude our present lesson with a word or two on the “harmonies of change.”

Harmonies in which the sequence or relationship of the constituent colours is indistinct or absent include most varieties of the harmonies of contrast. The change of tone or colour in them may vary greatly in abruptness: in the more complex assortments of this class it is very difficult to attain anything like an agreeable unity, for if there be many startling changes or contrasts, the effect becomes tiresome and spotty. The harmonies of change become more agreeable the more closely the rules of judicious distribution and balance of colour and tone are followed. The free use of separating lines of white, grey, gold, or black is often indispensable. The value of reduced tones of colour, and of the mixed and tertiary hues to modify the crudeness of a startling contrast, is very remarkable. But we have already described at considerable length, in Chapters V., VI., and VII., the principles upon which harmonious contrasts depend, and so here simply confine our attention to two illustrative examples derived from the floral world.

We might turn to the splendid family of the orchids, with their quaint forms and complex systems of colour, or we might choose one of the *Malvaceæ*, such as the *Abutilon megapotamicum*—a plant in which the green of the leaves offers a violent contrast with the red of the swollen calyces, and the five bright yellow petals of the corolla contrast again very forcibly with the violet hue of the central branch of clustered stamens—a startling assortment, very rich in effect, when completed by the opening of the flower. In this example, besides the mere notion of contrast, we have the idea of repetition which resembles that of seriation; red contrasting with its complementary, green, and yellow with its complementary, violet, both the comple-

mentaries having, therefore, the third element, blue, in them. But every flower presenting three different colours may serve to illustrate the harmony of contrast, and we need not go far for an example. Even the quiet violet, with its minute orange-tinted eye, the faint green bases of its petals and their own chief hue, somewhere between blue and red, affords a colour-assortment of the kind under discussion, the balance of which is in a measure completed when the leaves of the plant are included in the series. Similar studies of other plants should be made; it will surprise many persons to discover what a world of instruction, as well as of enjoyment, is to be derived from what we may call the chromatic analysis of flowers.

The next subjects to be discussed are the modifications of colour arising from methods of illumination and differences of structure and surface.

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## CHAPTER X.

CAUTIONS AS TO THE TRUE PRIMARY COLOURS AND CHROMATIC EQUIVALENTS—MODIFICATIONS OF COLOUR BY ILLUMINATION—DIFFUSED DAYLIGHT—LIGHT OF THE SKY AND CLOUDS—SUNLIGHT—A DOMINANT COLOURED LIGHT—ARTIFICIAL LIGHTS—TWO LIGHTS.

BEFORE entering upon the consideration of the changes produced in coloured objects; by the nature of the light which falls upon them, it is desirable to repeat a caution which we have given our readers more than once as to the value to be put upon our supposed set of three primary colours and their chromatic equivalents; for, in discussing the laws of harmonious assortments of colours, we have assumed the truth of both these doctrines, because we were dealing with pigments or dyes, and not with coloured lights (see Chapters VI., VII., and VIII.), and because for pigments, the conclusions reached by Field, and generally adopted, so far as regards the relations and equivalents of colours, are of no small service. Field's conclusions were indeed obtained by imperfect methods, and relate, so far as they are true, only to colours produced by absorption; but it is, of course, precisely with this mode of producing colours that we are concerned when occupied with pig-

ments. It will be well, however, to point out the special convenience of the primary triad of colours in general use by painters and ornamental colourists. Yellow, red, and blue have been selected, for artistic as well as practical reasons. With these colours, unmixed, but properly distributed over a painted surface, it is perfectly possible to get that kind of "neutralised bloom" which all satisfactory colour-combinations should exhibit when viewed at a sufficient distance; just as a similar result may be secured by the mingling, through rotation or otherwise, of the same three colours. A second artistic or æsthetic reason for the selection of this triad lies in the variety thus secured. Yellow represents to the eye nearness, lightness, and brilliancy, and does not actually admit of anything like the intensity of the purest red. Red imparts an idea of warmth and richness, and is as far removed, in its several qualities and the sensation it awakens, from yellow as it is from blue. Blue gives us the element of coolness and retirement, and is less brilliant and more intense even than red. If we take the triad red, green, and blue, we have not the same range of effect at our disposal, red and green being removed from each other by a far greater interval than that which separates green and blue. As to the practical uses of the two rival triads, there can be little hesitation in preferring the common one; for red and green pigments when mixed do indeed produce grey, and blue and yellow pigments, green; though were lights, not pigments, concerned, red and green would yield a yellow, and blue and yellow a white light. Any one, however, who will turn to the exquisite colour-arrangements, founded on Maxwell's theory, which are given in Mr. Benson's "Principles of Colour," will see that even with pigments, some most charming combinations may be regularly deduced from the more correct but less popular theory.

We have already explained how the mixed nature of the rays reflected and absorbed by pigments causes this difference, this departure from the anticipated result; but the only thing we have to do under the circumstances is the adoption, for the special purpose, of a plan of mixing colours which can be successfully carried out in practice. The impressions which the retina of the eye receives, and which become translated by the brain into sensations of

colour, are certainly produced in different ways. The mingled rays, for example, of red and bluish-green light produce a colour-sensation absolutely identical with that produced by the perfectly simple and pure yellow light of the spectrum ; but it would be grossly incorrect to regard yellow as of necessity a compound colour for this reason, since we know it to be incapable of any kind of decomposition as it occurs in the solar spectrum and in most pigments. It is quite possible, also, to produce the colour-sensation of blue by the mingling on the retina of certain green and violet rays, yet this does not warrant us in regarding the solar blue rays as being otherwise than simple. But when we come to mix pigments on a palette we find that very different results occur, yet that in no case is a pure yellow, or red, or blue colour produced by any mingling of other colours. So our practical treatment of the colour-relations of pigments must differ from that of coloured lights.

We are also compelled to lay but little stress on the doctrine of chromatic equivalents. When pure coloured rays are experimented with, it is possible to learn the proportions in which they must be mingled to produce certain effects ; but when the same problem is attempted to be solved in the case of pigments, the complexity of the subject baffles us, and our results are scarcely more than very rough approximations to the truth. Still, there is an obvious propriety in the more sparing use of luminous and brilliant colours, such as yellow, as compared with those of great depth and intensity, such as blue ; and if we find that mixtures in certain proportions of particular coloured pigments give colours approximating to certain standards, or produce neutral greys, we may consider such proportions as corresponding in some measure to the chromatic equivalents of the pigments in question. Thus it is found by experiment that two grains of nickel in the form of chloride yield a bluish-green solution, which is perfectly competent to neutralise the rose-pink colour of a solution of chloride of cobalt containing one grain of cobalt. In this instance, the nickel-green is related to the cobalt-pink in the proportion of 2 to 1. We trust that, without further dwelling upon these subjects of the primary colours and chromatic equivalents, we have said

enough to show at once not only the use of our explanations in Chapters VIII. and IX. of colour-proportion balance, and harmony, but also the reserve under which these explanations must be accepted. In passing on to the study of the modifying influences of different kinds of illumination upon the colours of objects, we would premise that the remarks just made must likewise be kept in view.

The quality and intensity of the light by which objects and their colours are discerned are liable to great variations, and produce corresponding changes in the colours reflected from the surfaces which they illuminate. Putting on one side, for the present, the variations produced by the nature of the substance or surface on which the light falls, we may consider the condition of a plane and uniformly-coloured surface as illuminated by

1. Diffused daylight, and sunlight ;
2. A dominant coloured light ;
3. Artificial lights, as candles, lamps, fire ;
4. Two lights, of different quality or intensity.

§ 1. It is scarcely necessary to state that the light of day varies greatly in colour ; the causes, however, of its variations may not be at once apparent. In reality, there is one chief active cause which originates its chromatic changes—*the air is not perfectly transparent*, it is more or less cloudy or troubled. Now even if the sun's luminous rays be purely white, they will suffer change by passing through a cloudy medium. The ease with which they pass will vary with the more or less complete approach to transparency of the atmosphere and its depth. Let us study in succession the blue light of the sky, the apparently white light of clouds, and the reddish light of direct sunshine.

How does the blueness of an unclouded sky originate ? We may best explain it by means of an experimental illustration.

Upon a sheet of black glass or a surface of black japanned metal, place a drop of milk, diluted, if necessary—which will seldom be the case—with a drop of water. The milk is a cloudy medium ; its minute particles reflect certain rays of very short wave-length—those towards the more refrangible or blue end of the spectrum ;

therefore, by reflected light, a drop of milk on a dark background appears blue. So, through a delicate skin, and a series of translucent but not transparent membranes, the light reflected where the dark background of a vein filled with venous blood exists, is blue. So, also, the translucent, but not absolutely transparent, tissue of the iris of the eye often reflects a blue light, there being in this instance also a background of a black pigment, but no real blue colouring matter whatever. The blueness of the sky has a similar origin. Against the dark background of infinite space, a translucent medium is placed ; this medium is the atmosphere. It is never transparent, countless millions of minute particles, chiefly of water, being suspended in it. When these particles are of a certain degree of minuteness, and uniformity, they arrest the free passage of white light ; this they do by a peculiar kind of "interference" (see Chapter II.) Each minute foreign particle of water gives rise to two reflections, one on each surface—one external, on the anterior surface ; one internal, on the posterior. These reflected rays, passing from air into water, and from water into air, suffer different retardations, and, on emergence, cause the usual phenomenon of interference, namely, the production of colour. When the particles thus affecting the incident light are sufficiently minute and sufficiently numerous, the proportion of reflected green, blue, and violet rays, which together give the colour-sensation of blue, predominates greatly over the red, orange, and yellow rays, with their longer undulations. Thus, the reflected light of the open sky is blue ; but let the thickness of the reflecting layer, or the number of the reflecting particles increase, and the blueness of the light decreases, for the solar light, which has been deprived by the kind of reflection just described of a great proportion of its more refrangible rays of short vibration, has become yellowish, or orange-tinted, and is no longer capable of furnishing an excess of blue rays. From this cause we see that while the light of the zenith is a distinct blue, it becomes gradually of a less pronounced tint towards the horizon, where it would be white if other conditions did not there produce other modifications of the reflected light. This exquisite gradation of tone in the sky is



often missed by unobservant painters, who think that the same mixing of some blue pigment will do to represent the colour of the whole sky shown in their pictures.

Now if the reflected light of the blue sky owes its colour to a sort of sifting of the solar rays, it will be rightly concluded that the transmitted light, deprived by this process of its green, blue, and violet elements will partake more or less distinctly of the colours of the residual rays of the solar spectrum. Such is the case. The light *transmitted through* a turbid medium shows a predominance of yellow, orange, or even red light. Direct sunlight partakes of this character, but it is generally more distinctly seen when the same object is illuminated by two lights, which can be compared and contrasted together. Yet there are cases in which the redness of sunlight is manifest enough. Not only is bright sunshine spoken of by painters as warm in an artistic sense, because of its ruddiness, but the light of the sun, transmitted through a great thickness of a turbid atmosphere, often appears, as at sunset, of an intense red or crimson colour. The street lamps in a fog illustrate, by their gradually increasing redness as they become more distant, the same fact.

While, then, the light reflected from the sky is bluish, and that transmitted directly from the sun through an aqueous atmosphere reddish, the light of day is often white. The particles suspended in the air may be either too large or too small to produce the effect we have been discussing. Thus, through certain kinds of fog and mist the light of the sun reaches us, reduced in intensity it is true, but unchanged as to its quality of whiteness. So, also, the light reflected from dense masses of cloud is often nearly white, and at other times is grey, owing to a comparatively deficient illumination or to absorption. It will not be necessary to detail here the modifications of colour which objects undergo when illuminated by direct sunshine, or by the light reflected by the blue firmament or white clouds, as it may be readily learnt from the next succeeding paragraph, in which we treat of the effects of a dominant coloured light.

§ 2. When a landscape is viewed through a piece of neutral-tinted or grey glass, the rays of different colours

belonging to different parts of the spectrum are intercepted to a nearly equal extent ; when the glass itself is coloured, a different result ensues. Through a deep yellow glass all objects at first acquire a yellowish tinge, not because the yellow glass actually adds any yellow rays to the light which it reflects, but because it cuts off the other coloured constituents of the light in different degrees, and so increases the proportion of yellow light conveyed to the eye. Objects which are originally yellow remain virtually unchanged, but relatively intensified ; those which are red lose a small part of their red rays ; those which are green assume a yellowish-green hue, since some of their green and blue rays are cut off ; while blue objects acquire a greyish-green hue, owing to the suppression of many of their proper blue rays, and of the further sifting which the white light they reflect suffers. When a painting is viewed through a yellow glass the smaller amount of light which it reflects renders the changes more startling and permanent. When, on the other hand, objects variously coloured are illuminated by a pure light of one colour, that is, monochromatic light, the results are different. All objects reflect naturally, if they have the opportunity, as in daylight they have, some white light ; but when a pure coloured light is thrown upon objects usually distinctly coloured, they can either reflect no light at all, or only that which is incident upon them. But, in point of fact, when experimenting with coloured illumination of this kind, we have not to deal with pure red, or orange, or green lights. It will be most serviceable for the purposes of the practical application of our principles if we give some clue as to the modifications produced in the colours of objects by different qualities of light, in which certain rays severally preponderate, but, nevertheless, do not wholly constitute the light. Illuminated by a light in which yellow rays predominate, yellow objects become less distinctively yellow when put by the side of white objects, which then assume a yellow tint. Pale yellow gloves by the yellow light of a lamp are hardly to be distinguished from white gloves. Orange-coloured objects become, if anything, rather more yellowish in yellow light. Vermilion increases in brilliancy if the light be not very largely composed of yellow rays, but merely have them in

preponderating number. Reddish and bluish violets become duller and redder, losing a part of their blue. Blue itself, when pale, becomes paler, and inclines towards a greenish blue; while dark and rich blues lose somewhat in intensity and purity. If, instead of white light tinged with yellow, we try the effects of yellow light accompanied by a small amount of white light, the effects are still more decided.

The following is, in the main, Chevreul's list of the modifications experienced by various coloured surfaces, when viewed in coloured light nearly pure, or in a dim diffused light with an intense coloured direct illumination:—

Yellow rays falling on	<i>white</i>	make it appear	<i>pale yellow.</i>
"	"	"	<i>yellow</i> " " <i>orange-yellow.</i>
"	"	"	<i>orange</i> " " <i>yellower.</i>
"	"	"	<i>red</i> " " <i>orange-brown.</i>
"	"	"	<i>violet</i> " " <i>brownish-violet.</i>
"	"	"	<i>deep blue</i> " " <i>greenish-slate.</i>
"	"	"	<i>green</i> " " <i>yellowish-green.</i>
"	"	"	<i>black</i> " " <i>blackish-olive.</i>
Red rays falling on	<i>white</i>	make it appear	<i>red.</i>
"	"	"	<i>yellow</i> " " <i>orange.</i>
"	"	"	<i>orange</i> " " <i>redder.</i>
"	"	"	<i>red</i> " " <i>redder.</i>
"	"	"	<i>violet</i> " " <i>reddish-violet.</i>
"	"	"	<i>blue</i> " " <i>violet.</i>
"	"	"	<i>green</i> " " <i>reddish-grey.</i>
"	"	"	<i>black</i> " " <i>rusty black.</i>
Blue rays falling on	<i>white</i>	make it appear	<i>blue.</i>
"	"	"	<i>yellow</i> " " <i>green.</i>
"	"	"	<i>orange</i> " " <i>plum-brown.</i>
"	"	"	<i>red</i> " " <i>violet.</i>
"	"	"	<i>violet</i> " " <i>reddish-violet.</i>
"	"	"	<i>blue</i> " " <i>bluer.</i>
"	"	"	<i>green</i> " " <i>bluish-green.</i>
"	"	"	<i>black</i> " " <i>bluish-black.</i>
Orange rays falling on	<i>white</i>	make it appear	<i>orange</i>
"	"	"	<i>yellow</i> " " <i>orange-yellow.</i>
"	"	"	<i>orange</i> " " <i>reddish-orange.</i>
"	"	"	<i>red</i> " " <i>scarlet.</i>
"	"	"	<i>violet</i> " " <i>reddish-brown.</i>
"	"	"	<i>blue</i> " " <i>greyish-orange.</i>
"	"	"	<i>green</i> " " <i>greyish-green.</i>
"	"	"	<i>black</i> " " <i>brown.</i>

Violet rays falling on	<i>white</i>	make it appear	<i>violet</i> .
” ” ”	<i>yellow</i>	” ”	<i>brown, rather reddish.</i>
” ” ”	<i>orange</i>	” ”	<i>light greyish-red.</i>
” ” ”	<i>red</i>	” ”	<i>reddish-violet.</i>
” ” ”	<i>violet</i>	” ”	<i>deeper tone of violet.</i>
” ” ”	<i>blue</i>	” ”	<i>bluish-violet.</i>
” ” ”	<i>green</i>	” ”	<i>greyish-violet. [violet.</i>
” ” ”	<i>black</i>	” ”	<i>slightly tinged with</i>
Green rays falling on	<i>white</i>	make it appear	<i>green.</i>
” ” ”	<i>yellow</i>	” ”	<i>yellowish-green.</i>
” ” ”	<i>orange</i>	” ”	<i>greyish leaf-green.</i>
” ” ”	<i>red</i>	” ”	<i>brown.</i>
” ” ”	<i>violet</i>	” ”	<i>greenish-slate.</i>
” ” ”	<i>blue</i>	” ”	<i>bluish-green.</i>
” ” ”	<i>green</i>	” ”	<i>more intense a green.</i>
” ” ”	<i>black</i>	” ”	<i>dark greenish-grey.</i>

The above results were originally obtained by Chevreul by exposing pieces of coloured cloth to diffused daylight, and illuminating half of each piece also by the light passing through glasses of the several colours named. The effects are consequently partly due to contrast, and are only true for the special conditions of the experiments performed. They, however, give us some notion of the various directions in which different coloured lights affect the colours of objects already moderately illuminated by diffused daylight. On this point see the statements given under § 4 further on.

§ 3. In considering the effects on coloured surfaces of yellow light, we have in point of fact considered the effects of the light of gas, oil lamps, and candles upon them, for all the ordinary kinds of artificial light possess a superabundance of yellow rays. This preponderance is less marked in the case of paraffin oils and solid paraffin candles, the light of which, though far from white, is not so yellow as that emitted by burning stearine or tallow. By the side of objects illuminated by direct daylight, which is, we know, slightly reddish, the light of a candle, though really yellow, may appear orange, while direct sunlight itself may, by contrast, appear positively violet or blue. Now the general results of the yellow illumination of artificial lights upon coloured surfaces may be learnt by reference to the table given above, but it may be interest-

ing to give in fuller detail one particular and familiar instance of the sort of effect thus produced. We allude to the strange effect of artificial light in altering the colour of certain violet colours, and of blues which possess a tinge of violet. Take as an example the precious stone known as the amethyst. A good specimen of this mineral presents by daylight almost the same tint as that of the flower of the violet, but at night, illuminated by lamp or candlelight, it loses much of its blueness, and acquires so distinct a reddish hue that it might be mistaken for a red garnet or carbuncle. This change is due to the deficiency of blue in the artificial light, while ordinarily the red of these stones is annulled partially by the greenish-blue element of daylight. A similar instance of a change in colour has been observed with some sapphires. The *saphir merveilleux* in the Hope Collection, South Kensington Museum, presents a clear blue tint by daylight, but by candlelight it appears violet. Certain flowers show a still more curious property. The flowers of the viper's bugloss (*Echium vulgare*) and of the marsh forget-me-not (*Myosotis palustris*) are rose-coloured in the bud and when they begin to open, but, afterwards, on fully expanding, become blue as viewed by daylight. By artificial light, however, the change appears not to have taken place, at all events, to any great extent, since a spray of one of these plants thus seen by candlelight shows its buds red or rose-coloured indeed, but its fully-opened flowers are not blue, but only pink or a pale purplish-red. The difference between red and a blue verging on purple is thus partially annulled. So also, as regards blues and greens; the ordinary green and blue pigments, with very few exceptions (*e.g.*, aniline green), are hard to distinguish by candlelight. Those blues which verge on green do so, of course, by the special absorptive power which they possess for the yellow, orange, and red rays, and their power of reflecting the green, the blue, and the violet. Now, as candlelight is deficient in blue and violet, the green of these blue pigments then comes out in unusual force. Such serious changes are experienced by some blues under artificial illumination that it is often advisable to substitute green for blue in colour-combinations which are to be viewed at night by gas or candles. The triad—*red—yellow—green* becomes under

such circumstances superior in effect to the triads *red—yellow—ultramarine blue*, and *crimson—yellow—Prussian blue*. So yellow, to be seen well and effectively by candlelight, must incline towards orange or a golden hue; but white, on the other hand, if it be meant to appear white, must by no means be tinted with a shade of blue, with the intention of purifying it, and neutralising the yellowness of the illumination on the material. This plan in daylight is effective, but by candlelight dulls the brilliancy of the white, by the absorption of certain rays of light which it causes.

§ 4. A double illumination, where the lights are of different quality, produces some striking effects of contrast. Such effects are often seized upon and reproduced, with varying degrees of fidelity, by those artists who delight in painting forges, candlelight scenes, and conflagrations. In order to study the conditions and effects of double illuminations, the following experiment may be made. Place a sheet of pure white paper in such a position that it may be illuminated at the same time by diffused daylight and by the light of a candle. Now arrange an opaque rod vertically, so that it may throw two shadows upon the paper. The shadow thrown by the daylight will be tinged with yellow, while that produced by the candle will be bluish; the doubly illuminated surface being itself white. Now we have before pointed out (see § 3,) that candlelight possesses a superabundance of yellow rays, and is therefore more yellow than the light of day. In consequence of this, the shadow of the rod, as cast by the light of diffused daylight, and illuminated therefore only by candlelight, appears yellow. Conversely, as the light of day is bluish compared with that of a candle, the shadow of the rod as cast by the light of the candle, and illuminated therefore only by daylight, appears blue. Of course the contrast between the colours of the two shadows is enhanced in accordance with the laws of contrast, as previously pointed out in Chapters V. and VI. Similar results are met with every day in the case of objects illuminated at the same time by a natural and by an artificial light. The lamps of a church may illuminate some parts of the furniture and floor with a yellowish light, overpowered and contrasted in other

parts by the apparently purplish light of day. A remarkable effect of this kind is seen when strong sunlight illuminates a room through a window partly screened by a yellow or buff-coloured blind. Here the contrast and relativeness of the colours seen become very distinct. The light transmitted through the material in common use for blinds of this sort is of an orange tint, and it will be seen that the direct rays escaping filtration through this medium, are of a beautiful reddish-purple colour. More complicated effects of the same nature may be observed in the case of stained glass windows. The simplest case of this kind that we can recall just now is, perhaps, that of windows glazed with a pale greenish glass, but bordered with strips of white glass, when the latter will appear pinkish under some conditions of natural illumination. The effect here is, of course, not wholly due to the proper or intrinsic colour of the daylight, but to the effect of complementary contrast between the white glass which admits the natural rays almost unaltered, and the greenish glass which very materially affects them. But the most magnificent and beautiful effects of this order are to be watched in the phenomena of sunrise and sunset. When a range of distant mountains is seen against the sky about the time of sunset, the effects produced may be readily explained. If the sun be sinking behind the mountains, the shadows which it casts will be illuminated moderately by scattered and reflected lights of a blue or bluish-violet hue, produced by the minute particles disseminated throughout the atmosphere. These hues will be to a certain extent real and objective, derived from the peculiarity of the light itself, and the colours of the objects and surfaces which it discloses. If these objects be grey, as many rocks, or white, as snow, then the blue or violet hue will be distinct, but it may be modified by the local colouring of the rocks or trees of the landscape. Still further, it will be changed or intensified by subjective contrast with the colour of the sky, for the light from the sky will reach an observer modified by its passage through a turbid medium, the air, and it will thus be yellow, orange, or red, according to the amount of blue, or more refrangible rays, which it cuts off. So the sky near the western horizon will often be of an apple-green colour, with clouds

of greyish-purple edged with scarlet, all these variations being produced by the decomposition of solar light by its passage through a medium which is not perfectly transparent, and the consequent conveyance to the eye, in varying proportions, of lights of higher refrangibility which have been reflected, and of lights of lower refrangibility, which, escaping complete absorption, have been transmitted.

Hitherto we have regarded the colours of objects as they are modified by the quality of the light which falls upon them. We have to study in the next place the influence of the structure, surface, and material of the objects themselves upon their apparent colours.

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## CHAPTER XI.

SURFACE AND STRUCTURE MODIFY COLOUR—COLOURS OF METALS—DAMASCENING AND PLATING—ENAMELLING ON GOLD AND SILVER—LACQUERING—COLOURS OF GEMS—COLOURED MARBLES.

THE colour of objects is influenced not only by the nature of the light by which they are illuminated, but also by their own peculiarities of texture, structure, and surface. The coloured light reflected from satin is different from that of velvet, though the silk used in the manufacture of these fabrics may have been dyed in the same bath. In explaining modifications of colour produced by texture, etc., we shall select a series of illustrative examples from the mineral, vegetable, and animal kingdoms. We shall then proceed to explain their colour-peculiarities, and the manner in which these may be utilised, in decorative art more particularly.

Metallic colours first claim our attention. Polished metals are distinguished for their intense power of reflecting light, and for an almost complete opacity. An intense reflection of light is also observed with other than metallic surfaces, such, for instance, as the neck feathers of the peacock, and that beautiful chemical salt, the magnesium platinocyanide. But there are some points in which these



lustrous colours differ from those of the true metals. We have alluded to this subject in Chapter I., and may here proceed to apply the principles of absorption and reflection of colour there laid down to the special case of metallic colours. Now it will be allowed that, under ordinary circumstances, metals do not appear highly coloured, though their brilliancy is often intense. The angle of incidence of the light has much to do with this. When we take a polished and level plate of gold or copper, and look along its surface, we shall see it appear very brilliant, but nearly white. In such a case, the rays of light which illuminate it almost graze the surface, making an angle of nearly  $180^\circ$  with the reflected rays that reach the eye. But let this angle be reduced to one of a few degrees only, then the proper colour of the metal will be conspicuous. It may be still further developed and enriched by repeated reflections at a small angle of incidence. Fig. 34

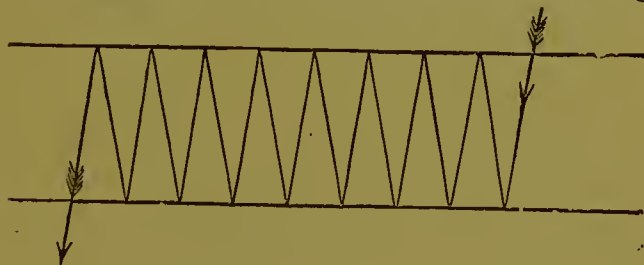


Fig. 34.

illustrates the mode in which a beam of light may become in this way more highly saturated with colour by numerous reflections from two polished surfaces of metal. From this cause chased gold and "granulated" gold appear of a far richer colour than burnished gold. And by so shaping the grooves or lines of chasing upon any piece of coloured metal, that repeated reflections at small angles of incidence occur in them, very rich colour-effects may be produced. The splendid colours inside gold or gilt goblets arise from this cause. Many metals which lack distinctive colour under common conditions may thus be made to develop it. Yet the colour thus produced not only changes in tone or saturation as it becomes enriched, but its quality

is also modified. Thus copper may be made to yield ultimately a nearly pure or monochromatic red light by repeated reflections. The colour is more distinct, it is purer ; but there is less light.

The colour of a pure metal may be greatly altered by alloying it, even slightly, with another. Thus, gold 22 parts, with 2 parts of silver, produces a metal of a greenish colour, which may be rendered still more decided by a small further addition of silver. Copper on the other hand, to the extent of 10 or 12 per cent., reddens gold ; while a small admixture of both copper and silver does not materially affect its colour, though it makes it rather paler. A large proportion of silver, varying from 20 to 50 per cent., produces *electrum*, some specimens of which, where the silver exists in nearly equal proportion with the gold, are almost white. Ancient and modern coins, as well as jewellery, furnish interesting examples of the variations in the colour of gold produced by alloy. The old Roman gold coins, with less than 1 per cent. of alloy, show the rich characteristic orange tint of the pure metal ; while in a handful of modern sovereigns the yellowish-orange ones indicate the presence in the alloy of copper and silver ; the greenish ones indicate silver alone, and the reddish ones copper alone. Slight as these differences of colour would appear did they belong to ordinary pigments, yet, in the case of the metals, the intensity of their reflection enables us to use with effect coloured varieties of gold in ornamental jewellery. Gold, if not alloyed very much (not more than 9 parts in 24), may be made to assume its proper colour by a process of "pickling" or "colouring." Gold articles plunged when warm into nitric acid lose a portion of their superficial alloy, be it copper or silver, the pure metal being left with a somewhat *matt*, or dead surface, and a rich orange colour. Or a mixture of equal parts of borax, nitre, and sal-ammoniac may be made, ground into fine powder, mixed with a little water, and applied as a thin coating to the metal. The metallic object is then heated till a faint discolouration appears on the coating ; afterwards, the paste being washed off, the pure gold film will appear beneath. With a film thus prepared, and with some of those films which are obtained by electro-metallurgical processes, the bril-

liancy of the metallic reflection is much impaired, though its characteristic colour may remain. This alteration arises from the loss of continuity of the metallic surface. Silver, in fact, may be so precipitated from a solution as to present a surface almost indistinguishable from a sheet of cream-wove white paper; and gold may be obtained by similar processes in a state which presents a close resemblance to yellow ochre. Some of the most beautiful effects in the decorative employment of metals may be secured by the partial polishing or burnishing, with an agate or steel tool, of such matt or dead surfaces as these. When silver is deposited by Liebig's silvering liquid on glass, it may be made to assume a most perfect or "black," lustre, and is then applicable for use in mirrors or in the reflectors of telescopes. Here the continuity of surface is practically perfect.

The delicate and subtle contrasts between metallic colours has led to the association of two or more metals in several kinds of decorative work. We have already referred to the varieties of coloured gold. In jewellery red gold may be used for flowers, with white gold or electrum; green gold may be employed for leaves; while the ornamental spray itself may be laid upon a chased or granulated surface of pure orange-coloured gold. By the process of parcel-gilding on silver, a more decided difference of colour may be secured; while the methods of metallic inlaying and damascening enable us to obtain the more marked contrasts between iron and gold and iron and silver. In these latter cases we have not only a considerable difference of colour between the two metals, but a very distinct difference in reflecting power. Iron or steel covered, by an easy chemical method, with a film of platinum, is preserved from corrosion, and still furnishes an excellent combination with silver or gold, or with both of these metals, as inlays.

Before giving a list of the colours of a few metals in their pure and unalloyed state, we may remark that other metals besides gold are remarkably modified in hue by the presence of alloy. Perhaps copper shows this effect more commonly and more distinctly than any other. An alloy of 85 parts of copper with 15 parts of tin, or with 15 parts of a mixture of tin and zinc, constitutes a mixed

metal of a rich yellow colour, the pink colour of the copper being then much altered. So 5 parts of the bluish-white metal aluminium will similarly modify the colour of 95 parts of copper, an effect seen in the so-called aluminium gold, or aluminium bronze, which is thus constituted. If the copper be mixed with tin in the proportion of 70 of the former metal to 30 of the latter, then the alloy is no longer yellow, but greyish-white, forming what is known as *speculum metal*.

The colours of some of the metals, in a few cases ascertained and determined by two or more reflections, are here given :—

Copper . . .	<i>red.</i>	Silver . . .	<i>orange-yellow.</i>
Gold . . .	<i>orange.</i>	Sodium . . .	<i>rosy-pink.</i>
Lead . . .	<i>bluish-grey.</i>	Steel . . .	<i>neutral-grey.</i>
Mercury . . .	<i>slaty-grey.</i>	Tin . . .	<i>greyish-yellow.</i>
Potassium . . .	<i>lavender-grey.</i>	Zinc . . .	<i>bluish-white.</i>

There is one remarkable and important property enjoyed by metals, and particularly by gold, of at once harmonising with and setting off ordinary coloured materials. Two instances of such a use of gold will occur to every one—the gilt frame of a picture, and the gold threads in embroidery. Gold, in fact, is removed from the series of ordinary paints and dyes by the intensity of its metallic lustre, and so combines into agreeable assortments with all colours, even with those with which yellow and orange pigments do not associate well. In a picture-frame this peculiarity of its metallic lustre prevents its yellow colour from interfering with the similar hues of the picture, while its colour being luminous and “near,” gives the idea of some degree of distance to the picture itself. We seem to look through an opening into the scene represented.

Gold, and other metals as well, may have their lustre made use of as a brilliant background for the development of colour. A transparent film of some sort is often placed upon metals, and when this film is coloured, such part of the light as escapes reflection at its surface passes through it, is reflected from the metal behind, and again passes outwards, leaving the film strongly tinted with its colour. Films of this kind are of two sorts, one kind

belonging to the vitreous or glassy series of materials, and the other being resinous, that is, essentially similar to a varnish. These transparent films are applied to metals for three purposes—to protect the surface, to cause an inferior metal to assume the aspect of a more precious one, and to produce certain colour-effects not otherwise attainable. Silver, when varnished with white lac, loses some of its brilliancy, but is no longer liable to tarnish. Iron and brass may be protected from corrosion, and improved in appearance, by a lacquer in which the red resin known as *dragons' blood* is an ingredient. With this preparation, silver assumes something of the rich aspect of gold, and iron resembles bronze. Resinous substances may be applied to metals either in the form of varnishes—that is, of solutions which dry and leave a continuous film or coating of the resins they contain—or by means of fusion. In the latter case the finely-powdered resin may be introduced in a pasty form mixed with a little water into the grooves, etc., prepared to receive it, and then heated to the temperature necessary to produce fusion. True translucent enamels of the vitreous class, on the other hand, require a much higher temperature than the resin, and yield far superior and more varied results. They consist essentially of different kinds of glass, coloured suitably with metallic oxides. Blue enamels thus contain cobalt; puce and violet enamels are furnished by manganese; grass green by chromium sesqui-oxide, and so forth. Such enamels appear on silver of their proper colour, but on gold the hue of the metallic background produces a change of colour, sometimes advantageous, sometimes the contrary. But as the colour of gold may be greatly modified by a little alloy, it is easy to select or prepare a quality of gold suitable for the several coloured enamels in use. The following list gives the most appropriate metals for a few colours :—

*Green.*—Gold of 20 carats with 4 carats of silver alloy.

*Red.*—Gold of 22 with 2 carats copper, or a mixed alloy.

*Violet, rose, white, yellow.*—Silver, or, less suitably, white electrum.

*Puce.*—Electrum of 16 carats gold, 6 carats silver, 2 carats copper, or gold 20 carats fine.

*Brown.*—Gold of 20 to 22 carats.

The subject of translucent enamels naturally leads us to the consideration of gems and glass. It ought scarcely to be necessary to vindicate for the natural precious stones a very high position amongst decorative coloured materials. Besides the hardness of the more esteemed sorts of jewels, they present beauties and singularities of colour and optical effect which are, to a great extent, quite inimitable by artificial methods. Yet amongst a certain clique of artists and amateurs it has become the fashion to depreciate their excellence, and, further, to insist upon their being cut, if used at all, in a way which is usually fatal to the development of those qualities upon which the beauty of precious stones depends. This method is known as the cutting *en cabochon* or "tallow-topped," and is applicable or appropriate, as a rule, only to those stones which are not perfectly transparent—opals, cats'-eyes, chrysoptases, etc. When applied to transparent gems, it prevents the full play of light and colour proper to them, internal reflection is imperfect, and the marvellous dispersive power often present does not show its effect in producing the so-called *fire* of the stone. Analysed with a prism, the colour of gems is often found to differ from that of the nearest approach in artificial "paste"—that is, glass—that can be manufactured to represent them. Then, too, gems often exhibit peculiar optical properties which no fused artificial substances can possess. The minute internal fissures, to which the splendid play of colours in the precious opal of Hungary and Mexico is due, cannot be imitated, though there is another mineral, *sphene*, which possesses this remarkable quality in a high degree. The opal is seen best upon a black or dark-blue background of enamel, and is still further enhanced in beauty by a border of small diamonds, which form a delicate yet effective contrast, through their perfect transparency and purity, and their almost metallic lustre, with the milkiness and variegation of the opal. The stones known as star-stones have also optical peculiarities, which are quite inimitable. These gems are essentially crystallised alumina, and are known as star or asterias rubies or sapphires, according to their colour: they are translucent only, and owe their beauty to a peculiarity of their minute crystalline structure. This is

revealed when one of these crystals is cut across its principal axis, and left with its top *en cabochon*. Then a six-rayed star makes its appearance, best seen in sunlight, or by the light of a small brilliant flame, or in the focus of a condensing lens. It is due to the symmetrically disposed *layers* of which the crystal is built up. The less transparent varieties of red garnet, when cut as carbuncles, occasionally show a star, but it has only four rays, owing to the simpler crystalline structure of the stone in this case. Among other *chatoyant* stones with a play of light upon or in them, the moonstone, a species of nearly colourless and transparent felspar, is one of the most familiar. Its light is more diffused than that of the star-stones, and has a pearly whiteness. Moonstones may be very effectively combined with dark-coloured clear amethysts, the contrast being one not only of colour but of lustre. The stones called cats'-eyes are of two species: one of them, the more precious, is yellow or yellowish-green, hard, and shows a pale bluish line of light when properly cut; this is due wholly to the optical structure of the crystal itself. But in the commoner variety we merely have quartz penetrated with fine fibres of asbestos, which catch and reflect the light. There is one peculiarity of precious stones which we cannot pass over, a property known as *dichroism*. A crystal which is greenish in one direction may appear rose-pink when seen in another. A ray of light is affected differently according to the direction in which it passes through the crystal. The tourmaline is an excellent example of this, a grass-green specimen of this stone appearing dark brown or even black when viewed along the principal axis of the crystal instead of across it. The emerald, also, shows two hues of green: one, verging on yellow-green, is seen when a crystal is viewed along the principal axis, the other hue is more bluish and is observed in directions at right angles to that just named. This, again, is a quality of some natural gems which cannot be imitated exactly in artificial mixtures.

We may here find occasion to introduce a word or two concerning the commoner sorts of ornamental and coloured minerals, ranging from agates down to tinted building stones. There are two points of special importance con-

nected with such materials. One of these points is the undesirability of mixing natural with artificial materials in walls and pavements. It is very difficult to combine satisfactorily tiles and marbles. There is a faint approach to translucency in many marbles, with which the dull, dry, opaque surface of unglazed tiles contrasts unpleasantly; and glazed tiles are coarsely artificial in their gloss. Then, again, we have, in the second place, to remind our readers that marbles with natural veinings and mottlings of colour do not allow of sculptured ornament. Your surface decoration in relief will interfere with Nature's prior decoration in colour. The wildness and almost infinite variations of the natural tones of brown in a piece of Derbyshire alabaster are broken up when its surface is diapered with a conventional carved ornament—the natural picturesqueness and the artificial are incongruous. A surface in a tessera of mottled or veined marble, or a pillar, displays its beauties, but in a sculptured capital of the same material they are disfigured, while the light and shade of the ornamental design do not come out properly in the variegated material.

There still remain for study among mineral products glass, porcelain, and pottery. Opalescence and iridescence, as well as several other peculiarities influencing their colour-effect, are common in a measure to some kinds of all these artificial products, and we may, therefore, group them together for consideration in the next chapter.

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## CHAPTER XII.

COLOURED GLASS—COLOURS OF POTTERY AND PORCELAIN — MINERAL PIGMENTS — COLOURS OF PLANTS, FLOWERS, WOODS, AND VEGETABLE FIBRES—COLOURS OF ANIMALS AND ANIMAL PRODUCTS.

WE have now to consider the peculiarities of coloured glass. Glass, being a vitreous and not a crystallised substance, does not present that extensive variety of optical properties which characterises many natural gems. It is



probably on this account that the most perfect and uniform coloured glass is not by any means satisfactory or interesting from an artistic point of view. Very instructive examples of the bad effect of such glass are to be seen in many painted glass windows, especially in those which belong to the earlier period of the recent revival of Gothic art in this country. The blue and other glass is deep enough in colour, but lacks real richness; it is thin and flat, though staring. There is no fluctuation of colour, no breaking up and scattering of the transmitted beams of light. The glass to accomplish this must be less perfect as a mechanical product of manufacture. If the colour be uniformly diffused throughout the glass, the glass must vary in thickness, its surfaces must be uneven; and striæ and blebs only improve the effect. A glass which is absolutely perfect as glass may be rightly devoted to the construction of optical instruments, but is incapable of completely realising the poetry of colour.

The colours of glass may arise from several causes. A fine white powder—say oxide of tin—diffused through clear glass gives it the opalescence of a cloudy medium; a bluish colour being produced by reflected light, and a yellow or red colour by transmitted light. Opal glass may vary from a faint cloudiness to milky and nearly opaque white. Another glass, owing its peculiarity to solid matter, is known as aventurine glass; it contains glistening crystals of copper. But the colours of most transparent glasses are due to the presence of metallic silicates, such as those of iron, copper, cobalt, and manganese. These metals give to glass various tints of green, orange, blue, and violet. One metal, uranium, imparts not only a distinct yellow colour, but the interesting property called fluorescence. The common "canary" glass is a glass of this kind. Viewed by transmitted light it is yellow; but when the solar beams fall upon a piece of this glass, the actinic rays are modified, and are reflected back to the eye as green light.

The method of using coloured glass in windows should be limited very strictly by the nature of the material, as well as by the office of a window. The glass must not pretend to be a picture, nor must it contain large shaded or obscured portions, opaque or nearly so to light. Minute

lines and details of drawing are out of place and useless. A mosaic work of small pieces of glass, separated by bold and firm lead lines, is most effective. If the window is required to let in unmodified daylight, the glass may be decorated with firmly-drawn outlines in dark maroon or brown upon a white or grey ground, the pattern extending through a large number of quarries. Here and there a medallion of richer colour may be symmetrically introduced. Where highly-coloured windows are considered desirable, some of the richest and happiest effects are to be obtained by the use of blue glass in preponderating quantity, as in the ancient glass of Canterbury Cathedral, or of ruby-red with blue and a golden yellow, as in the windows of La Sainte Chapelle, at Paris. Some portions of the latter glass may be studied at South Kensington. Where the pieces of glass are small, the effect of the contiguous beams of red and blue light is to produce a result similar to that of violet glass, but infinitely richer, more brilliant, and more "bloomy;" while the lead lines prevent a confused mingling of the colours when seen more closely. Mosaic work in coloured glass is most appropriate and effective. Painting in *chiaro-oscuro*, especially in monochrome, is radically bad in theory, and unpleasant, to say the least, in result.

The peculiarity of the colours of porcelain and pottery consists mainly in the mode in which they are applied to the wares. In the case of delft, faience, and majolica ware, the colours are painted, as enamel colours, upon an opaque white or nearly white stanniferous enamel. Transparent or translucent colours on this opaque ground come out with great force; while opaque colours appear less characteristic than they do upon porcelain, and upon translucent bodies generally. Upon earthenware and porcelain, designs may be either printed or painted, either under or over the glaze. Colours printed or painted over the glaze are generally better defined and more brilliant than those which are below it. In the decoration of pottery and porcelain, besides the use of enamel colours, other decorative effects may be produced by means of preparations of gold and platinum, and by means of colours mixed with the body of the ware or the glaze. Some of the most remarkable effects of the latter sort are to be

seen upon the old Italian lustre-ware plates, and upon the modern porcelain of M. Brianchon, imitated at Worcester and Belleek, in which recent instances the iridescent glaze contains a considerable amount of bismuth in its composition.

A very important series of coloured materials is produced directly or indirectly from minerals. Most of the native mineral pigments are of a useful and permanent character. The compounds of iron, chiefly oxides and hydrates, have always been largely employed in the arts, and afford a wide range of useful colours—yellows, reds, browns, maroons, etc. The colours derived from copper, such as verdigris and malachite, are more liable to change by conversion into the black oxide and dark brown sulphide of this metal. Pigments made out of coloured glass or frit—such pigments, for instance, as smalt and ultramarine—are commonly difficult to manipulate and mix, but yet are endowed with considerable fixity. Preparations of lead, such as the carbonate and the chromate, white lead and chrome yellow respectively, are subject to one great drawback. This is their sensitiveness to sulphuretted hydrogen, which darkens and destroys all the more delicately-coloured preparations containing this metal with considerable rapidity. The protection of these materials from change is partially affected by covering the particles of which they consist by a film of oil-varnish, wax, paraffin, or gum, as in the ordinary methods of painting in oil, encaustic, or water. In fresco and distemper painting, where lime or size serves to bind or cover the pigmentary granules, the action of injurious substances upon sensitive materials is more rapid. In stereochromy, and other methods of silicious painting, the colours are liable to change. But then the range of colours is rather limited, owing to another consideration, namely this, that water-glass, and the alkaline silicates in general, which constitute the medium with which the pigments are mixed in stereochromy, or with which they are fixed, alter and destroy many mineral colours, such as emerald green, Prussian blue, and chrome yellow. If we exclude such alterable pigments, including most preparations of lead and copper, and then further eliminate, for the same reason, some of the most beautiful vegetable and animal

colouring matters, the residue of available pigments is indeed small. The point, however, to which we now wish to draw attention is not the modification of colour by injurious atmospheric or other influences, but the colour-peculiarities caused by the nature of the medium with which the pigments are incorporated, or by the optical qualities of the pigment itself. The most important general characters of pigments reside in their translucency, or opacity, as regards light. A transparent pigment need be much less saturated or intense to produce a given colour-effect than an opaque one. The reason of this will be clear when the statements made in former chapters are recalled. The light reflected from the ground on which a transparent colour is laid has to pass *twice* through that colour; while an opaque colour often reflects, or at least scatters, much unaltered white light. The use of clear colours upon opaque grounds or painted surfaces is often called glazing by artists, and gives a depth, intensity, and richness which cannot be exactly attained in other ways. *Scumbling* is the precise opposite of this, for in it an opaque colour or white, mixed with some oil or other medium, is used to cover partially, and so to modify, the clear or mixed colours which have been previously laid on. It conveys an idea of distance, or mystery, or cloudiness.

The binding material which unites the particles of a pigment together, or which retains them on the painted surface, may be either opaque or transparent. In all ordinary water-colour and oil-colour painting, the binding material is practically transparent; but in fresco painting it would seem that the freshly-covered surface acquires a film of carbonate of lime (calcium carbonate), which gives deadness and opacity to the surface of pictures executed by this method. Something of the same kind of effect is produced in the several methods of silicious painting, of which the only one which is of any importance, and has been practically employed, is the stereochromy of Fuchs. In this process the pigments are bound to the wall, and acquire coherence by the changes which the soluble potassium and sodium silicates used in the process undergo. They appear to enter into direct combination with the zinc oxide or calcium carbonate laid on as a ground or mixed

with the pigment. The silicate must not be saturated with silica, but should be, contrary to the usual opinion, strongly alkaline; otherwise an irremovable silicious bloom will shortly disfigure the mural painting executed by this process. The wall, slate, plaster, or stone to be decorated should be wetted with baryta-water, painted with the previously-tested colours, and then, when dry, syringed with a fine spray of the fixing silicious solution. This syringing is repeated at short intervals, until no trace of colour can be removed with a dry or wet hard brush applied to the painting. If a saline bloom appear after a time, it should be removed by means of sponging with distilled water. If a hard white silicious bloom mar the brilliancy of the colours, no chemical or mechanical method is competent to remove it. But in this case the appearance of the injured fresco or stereochrome picture may be greatly improved by a process which the writer of this volume invented in 1856. It consists in the use of paraffin, driven into the picture by heat, or applied in the form of solution, by a brush or in spray. The solvent used may be either benzole or mineral turpentine. Some fine copal or dammar varnish is a desirable addition. In this way old distemper paintings may be preserved from destruction. The effects of damp and decay are arrested, and the colours may actually acquire more than their pristine beauty. In fact, this process converts the opaque binding materials of the painting into transparent or translucent ones. It is scarcely necessary to say that all colours, oils, and varnishes should be tested before they are used, if their colours and appearances are to remain unchanged. No soluble saline matters should remain in pigments; they ought to be tried alone and mixed with others, to see if they alter or fade when exposed to sunlight. The oils and varnishes must be examined to see whether they darken, or if they irregularly contract on drying, and so forth. But we must not dwell further on the chemistry of pigments, of grounds, and of the media and methods of painting, for this subject requires a volume for its adequate treatment. Yet we must add a word or two on a subject of the utmost importance to artists, and to those who are engaged in copying pictures. As the colours which we see are modified subjectively, it is necessary that they should not be repro-

duced as we see them, but as they actually exist. The high lights of a blue robe may appear yellow or orange to us, and yet could be copied only by the use of a lighter tone of blue. So the high lights of a face may give by way of contrast a greenish hue to its shaded parts, although this effect would not be reproduced, but grossly exaggerated, by mixing some green with the grey of these parts.

The most conspicuous colours belonging to flowers are usually very fleeting, and cannot be utilised for decorative purposes. Generally, too, they are particularly liable to alteration by acids or alkalies—becoming red under the influence of the former agents, and blue or green by the action of the latter. This property has been turned to account in chemical testing; one of the best test-papers being prepared from that beautiful crimson-foliaged plant, the *Coleus Vershaffeltii*. The stems of the plant are bruised and extracted with spirit; then white blotting-paper is soaked in the solution. The lavender-grey of this paper becomes red with acids, and green with soda and other alkalies. In the copper-beech and the dark portions of some zonal geraniums, we have the ordinary green colouring matter of leaves, called chlorophyll, mixed with a crimson colouring matter, the combination producing a kind of deep maroon. The extreme beauty of many flowers depend in part upon their peculiarities of structure. The cell-walls within which the vegetable pigments occur are often extremely thin, and present a soft yet glistening aspect, which enhances and varies the colour-effects of their contents. This aspect, though often called crystalline, in no degree arises from any structure to which this term can be applied. Some very beautiful and yet permanent colouring matters are, however, obtained from plants, though these do not always contain them ready-formed. As instances in point, we may cite indigo and some of the madder colours.

The vegetable fibrous materials used in the manufacture of textile fabrics are generally white or pale yellow, but may be dyed of any colour by suitable processes. In some cases the dyeing material may be made to enter a central cavity in the fibre; but usually colouring substances can be made to adhere permanently to vegetable fibres only by means of a mordant. First of all, a substance such as tin

peroxide, having an attraction for colouring matter, is precipitated upon the fibre, and then it is immersed in a dye-bath. The colouring matter is withdrawn from the liquid, and adheres firmly to the mordanted fibre. The lustre of vegetable fibres is usually not very marked, and is diminished in the process of dyeing them. Linen, the woven fibres of flax, does, however, reflect the light which falls upon it with considerable power, particularly in certain positions. A pattern may thus be made in which the strands which form the warp may be contrasted, not only as regards colour, but as regards lustre, with those of the woof. Under these conditions damasked linen, just like silk damask, may exhibit a curious optical illusion. If a white warp and a red woof be associated, it will be noticed that in certain lights the white parts of the fabric assume a bluish-green tint, acquiring, very distinctly, the tint complementary to the dyed threads, the effect being enhanced by the difference of lustre dependent upon the way which the light falls upon the fabric. Similar but still more decided effects are seen in fabrics where lustrous silk and dull cotton or wool are associated. Nor should we here neglect to allude to the peculiar mingled tones produced by the repeated recurrence at short intervals of similarly coloured strands in a fabric.


The colours of woods are usually subdued, but varied. Much of the beauty of some woods depends, however, rather upon texture and lustre than upon colour. In furniture and the general decorative treatment of wooden construction, much may be made out of the combined use of these two qualities of lustre and colour. One wood dark in colour, and of lustrous texture, may be introduced in the form of bosses, panels, or mouldings into a framework of an opaque and light wood. So woods of distinct patterns may be associated with those which possess a uniform appearance. The colours of woods are, indeed, brought out by varnishing and oiling; but the former of these processes has a tendency to check those alterations of tint which often render old specimens of woodwork far more beautiful than new.

The colours of animal products are usually less changeable than those of vegetable products. In some cases, notably in the case of the humming-birds, the brilliant,

almost metallic colours of the animals are due rather to the optical structure of the coloured substance and surface than to any actual colouring matter. Instances, however, do occur, as in the plantain-eaters, or touracous of Africa, where a colouring matter may be actually extracted from the brilliant plumage of birds. The colouring matter of these birds was discovered by the present writer, and found to resemble the red colouring matter of arterial blood in some respects. It is especially remarkable as containing a fixed per-centage of the metal copper. White feathers, like other animal products, may be dyed without any mordant, silk and wool being also particularly characteristic examples of this fact; ivory, bone, and horn may be noticed in the same connection.

We trust that the principles laid down in this manual will at least serve to furnish a suggestive guide in the arrangement and study of coloured compositions, both pictorial and decorative. Further information may be gained, both as to textile fabrics and paintings, from "The Laws of the Contrast of Colour," by M. Chevreul; while Dr. E. Brücke's treatise on "Colours," which may be read in the French translation of Dr. Schutzenberger, enters more fully into the physical and physiological matters connected with this subject. Besides the papers of the late Dr. George Wilson, of Helmholtz, and of Professor Clerk Maxwell, we have two excellent works from the pen of Mr. W. Benson. These latter are entitled, respectively, the "Principles of the Science of Colour," and a "Manual of Colour," and deserve careful study. Nearly all these works contain something about the singular condition, to which we have been able to allude but cursorily, known as Daltonism, or colour-blindness.

THE END.



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