SOCIETY FOR THE ENCOURAGEMENT

OF

ARTS, MANUFACTURES, AND COMMERCE.

CANTOR LECTURES

ON

PHOTOGRAPHY AND THE SPECTROSCOPE.

BY

CAPT. ABNEY, F.R.S.

DELIVERED BEFORE THE SOCIETY OF ARTS, APRIL 20TH AND 27TH, 1885.

PHOTOGRAPHY AND THE SPECTROSCOPE.

BY

CAPT. ABNEY, F.R.S.

LECTURE I.—DELIVERED APRIL 20, 1885.

Every lecturer, when he begins, must have a text of some description, and I propose to make my text for the lectures a plate exposed to the spectrum. You see before you a spectroscope comprising a collimator, two prisms, and a camera, with a lens of 13-inch focal length, and in this slide is a sensitive collodion plate.

The spectrum of the hot carbons of the electric light is upon the focussing screen which you see before you, and I will simply expose this plate, and refer to it from time to time as my lecture continues.

The plate is given six seconds' exposure to the light of that spectrum, and now in the subdued light coming from this lantern, whose sides are covered with translucent orange paper, I see the picture is coming out under the action of the ferrous oxalate developer. After fixing, we see that we have the photographed spectrum on the plate.

This is the text on which I have to hang my lectures. We have three things to consider. First of all, we have got the light, then we have the apparatus, and then the sensitive material on which the spectrum is taken. The white light from the carbon poles, in passing through the apparatus, is spread out into a coloured band, which we call the spectrum; and the spectrum has effected a change in the sensitive salt of silver, as is shown by the blackening on the application of what is called a developer. The cause of the change in the sensitive material is what I first address myself to.

To conceive a right notion of photographic action we must first of all conceive, in the most elementary manner, the structure of matter. The structure is beyond our actual visual acquaintance, but we may be able to visualise it from the way it behaves; we have to draw our conclusion about it from evidence of an experimental nature. What we want to get is a mental picture of matter.

Physicists have come to the conclusion that homogeneous matter is composed of molecules, or small masses which are altogether similar one to another, *i.e.*, they have the same composition. In different matter these molecules, have different weights. Further, it is believed that the molecules, or the small particles of matter, are themselves composed of atoms, which we take to be the fundamental unit of matter. Now, from experimental data, Sir William Thomson and others have come to conclusions as to the limits of the size of these molecules, and also as to their distribution in space. From the kinetic theory of gases, it is concluded that the diameter of a molecule lies somewhere between one twenty-five millionth part of an inch and one two hundred and fifty millionth part of an inch. Further, in gases it is conceived that the molecules are free to move in straight lines in any direction, the direction being altered only when the molecules collide; that is to say, when they strike one against another. In a liquid, the particles are bonded much more closely together, and the free path of the molecules is very much shorter. That is to say, that they cannot go

from one place to another without very much more frequently coming into contact with other molecules ; and the molecules pass from place to place at a very much slower rate than they do in gases. A solid, such as is our silver salt, is conceived to be such that the molecule has no free path, but is confined in a limited space in which it can oscillate, moving round a mean centre. As to the distribution of these molecules in liquids and solids, Sir William Thomson has arrived at very definite conclusions also. In a lecture at the Royal Institution, he said that he concludes that in every ordinary liquid, or transparent solid, or seemingly opaque solid, the mean distances between contiguous particles is less than one twelve millionth of an inch, and more than one two thousand five hundred millionth part of an inch. Those are big figures, but still the distance apart is very small. " To form a conception of this," he says, " imagine a globe of water as large as an ordinary football to be magnified to the size of the earth, each constituent molecule being similarly magnified. The magnified structure would be more coarse grained than a heap of small shot, but probably less coarse grained than a heap of footballs." So you see that, by magnifying to this extent, you have a coarse-grainedness which, of course, is only relatively coarse grained after such an enormous magnification. Or you may put it in a different sense. If you magnify eight thousand diameters by an ordinary microscope—and that is about the limit to which a microscope will magnify ; and if you magnify that eight thousand diameters again eight thousand times, you would be able to see the molecular structure of water. So much, then, for molecules.

We will now turn to the atoms. These will not bear such a very large disproportion of size to the molecules as do the molecules to the smallest visible particles. We must, however, I think, conceive that every atom (and this is an important point) is charged with energy very much in the same way that the magnet is charged ; only, instead of two poles, as a magnet has, each atom has only one pole. It is unipolar.

Now, suppose that this energy is something like electrical energy. We know that positive repels positive, and that negative repels negative. And further, we know that the positive energy will attract what is called negative energy ; and if the two be exactly equal when they combine, of course there will be a neutral state. But in the case of the atoms of

matter, circumstantial evidence tells us that the amount of electrical energy which is upon a given atom of matter—if you like to put it in that way—is never the same as it is upon another atom of matter ; that is to say, there is always a surplus of one over the other. Thus we may have an atom charged with what we may call *plus* 2 of energy, and another one charged with *minus* 1 of energy. Those two atoms, on coming together, give you a result of energy of plus 1, and this would again be capable of attracting another atom of matter which was charged with a negative energy, and so on. From chemical considerations, it would appear that plus and minus energies of different atoms, as I have said before, are never exact multiples of one another, and that when they are bonded together there is always an excess one over the other. A good example of the energy of the combination of atoms together may be shown by the combination between a gas, chlorine, which we have here, and the metal antimony, and you will see that when the latter, as powder, is thrown into the former, the two combine with an evolution of heat, showing that a vast amount of energy is given out. The chlorine and the antimony form chloride of antimony ; that is to say, five atoms of chlorine and one of antimony. [A small quantity of finely powdered antimony was dropped into a jar of chlorine.] You see the evolution of heat between those two ; so much, in fact, that the chloride of antimony, as it was formed, was at a perfectly bright white heat. The case immediately before us is the silver salt. Let us experiment with that in a similar way. Into the chlorine I will throw some powdered silver, and I wish you to notice the difference between the results in the two cases. [A small quantity of the powdered silver was dropped into a jar of chlorine.] You see that the combination between the silver and the chlorine only produces a red heat, whereas antimony produced a white heat. In other words, the combination between antimony and chlorine is much more vigorous than the combination between silver and chlorine. If you had to separate the atoms of chlorine from those of the antimony, you would have to use very much greater force than if you had to separate the atoms of silver from the atoms of chlorine.

When two electrified bodies attract one another, they attract one another inversely as to the square of the distance. That is to say, if there is a distance of one foot between them, they attract one another with a force of say—

1. If they are two feet from one another, they only attract one another with a quarter that amount. Supposing atoms attracted one another according to the same law, then of course they being so very close to one another, the attraction would be considerably greater than if they were visibly apart.

But besides this attraction between atoms comprised in the molecules, there also seems to be a repulsive action, into which I will not enter more fully now, because that would be almost beside my subject ; but I may say that besides the atoms attracting one another (we will take chloride of silver for instance) when they get within a certain distance of one another, they repel one another, and so there is a continual oscillation between the atoms composing those molecules.

I will try to show you on the screen how we can picture the motion to ourselves. It is only a mental picture, but still it will give us a sort of idea of what happens. [An image was thrown on the screen by means of reflection].

In this circular glass trough of water is floating a little magnet, the magnet being held at the surface of the water by a cork. Passing round this coil, which is large enough to surround the trough, is an electric current from three Grove cells, and if I place it round the cell which contains the little magnet, and not quite on a level with the water, you will find that the single magnet goes into the centre of the water. It is repelled from the sides by the current that is floating round that wire. Well, now, we have here one magnet. Suppose I put another magnet in. The ends attached to the cork have poles of the same name. They repel one another to a certain extent, and yet the force from outside makes them go as near one another as possible. By moving this coil vertically we can make them separate and oscillate, and we can picture to ourselves the way in which two atoms in a molecule may oscillate, and be attracted, and yet repelled one from another. I put another little magnet in, so now there are three; and here perhaps we have a picture of chloride of silver, which I say is composed of one atom of silver and two atoms of chlorine. We can still make them vibrate and oscillate. Here we have a mental picture —at least it is a mental picture to me—of the way in which the atoms of chloride of silver may be made to oscillate. Again I take four, and we repeat the same thing. Here we have a picture of ammonia—three atoms of hydrogen and one of nitrogen oscillating. And so

I might go on. I might put five or six or a dozen in, and we might get some idea of the way in which they would all oscillate.

Here, then, we have endeavoured to draw from visible phenomena a mental picture of the way in which atoms of a molecule are vibrating.

I must, however, call to your mind that those magnets are vibrating only in one plane, whereas of course the atoms of a molecule are vibrating, not in one plane, but in space of three dimensions ; but anyhow, I hope that you have got into your mind at all events the same kind of mental picture regarding the oscillations or vibrations of the atoms which I have in mine. I think that the case of the magnets is a particularly happy one, because from all the evidence which we have at present we are led to the conclusion that all atoms of matter are really charged with electricity, or what answers to electricity of either one name or the other; that is, either positive or negative.

Now, we will throw a spectrum on the screen. I will call to your recollection what it is. I am now going to send the light of the lamp through this bisulphide of carbon prism, and I need scarcely say that the prism has to play an important part in spectrum photography. The wave length of the red is about one forty-thousandth of an inch, and the wave length of the violet, which is on the left of the screen, is about one fifty-seven - thousandth of an inch. Each ray of light is transmitted in air at the rate of about 190,000 miles in a second. Thus the number of vibrations of the red rays is 500 million millions, and 700 million millions in the case of the violet rays, and this rapid succession of blows batters against anything upon which they fall. The mean violet, I may say, is the photographic light *par excellence*, and we shall recollect that such rays might beat upon the sensitive salt which we expose to it 700 million million times in a second. Therefore, you see, if you give an exposure of the 100th of a second you still have seven million millions of vibrations beating on the sensitive plate, so there is ample vibration to effect any change on the molecule of silver chloride, supposing always the amplitude (or distance of swing) is sufficient. Instantaneous photography will not be complete, I suppose, until you can reduce by a million times.

We may take it that an atom vibrates somewhat in the same way that a pendulum vibrates. Here I have a very rough contriv-

ance to show what I mean. I set the pendulum swinging. Now picture to yourself that the bob is an atom, and picture to yourself, also, a wave of light falling upon that pendulum ; if the wave of light be synchronous with the pendulum, it will increase the swing, or, in other words, it will increase the amplitude of the swing of the pendulum. For a rude illustration, suppose I take puffs of my breath as illustrating the beating of the wave of light, and suppose the atom to be at rest ; I begin, and I blow ; every time I give a well-timed puff to that pendulum, the pendulum increases in amplitude, or swing. But if my breath does not come in unison with that pendulum [blowing irregularly], you see that very soon I should bring that pendulum to rest ; in other words, unless the wave of light beats in unison with the atom, the amplitude cannot be much increased. It is true that as long as the breath strikes the bob as it is going away from me the amplitude is increased, but if the puffs are regular and slightly more rapid or slower than the pendulum oscillation, the amplitude must eventually be diminished.

Here we are met with a difficulty, and a very great difficulty. I exposed the plate to the spectrum, and you see the blackening not only was where one wave of light synchronised with that atomic motion, but that there were a great many waves of light, extending from the ultra-violet as far as the blue which affected it. How are we to get over that ? That is a difficulty which has puzzled a great many people. I would ask you again to form a mental picture of how that could possibly arise. I do not say that it is the correct way, but all I say is that you can form a picture in your own mind, can conceive of how it could be done. Here, I have another pendulum, but in this case the bob is attached to an elastic band. The time of the vibration of a pendulum depends upon the length of the pendulum. Therefore, if during the time of the oscillation of the pendulum I alter the length, I also alter the rate at which the pendulum vibrates during any instant. I pull down the weight of the pendulum, and at the same time set it swinging, and you will see that during every part of this motion the length of the pendulum is altered so that a great many differently timed puffs of breath might be synchronous with the pendulum. It is not like this other rigid one, where it is of a definite length, but here the length of the pendulum keeps altering. I only ask you to form a mental picture of the way in which such

a thing might happen. In this way you can picture to yourself how a molecule might vibrate, and still be synchronous with more than one vibration of light.

Proceeding another step, I may say at once that, to my mind, the theory of the photographic image is well established. I know that there are some people who differ, but in my own mind the formation of the photographic image is not a working hypothesis, but it is a theory. The difference between a working hypothesis and a theory is this—that you adopt a certain idea and say, "I will work upon that idea, and see whether every experiment fits with the idea I have conceived. If it does not fit, then that working hypothesis is no use. I must give it up, I must take some other working hypothesis." As regards the idea of the formation of the photographic image, I think that it has passed from the stage of the working hypothesis into one of a really acceptable theory. It does not follow that everybody will accept it, but still it is an acceptable theory, accepted by most people. I am not going to enter into that very strongly to-night. At the next meeting of the Photographic Society, I propose to deal with it more fully ; but, at the same time, I just wish to state publicly, to perhaps a more extended audience than I shall see at the Photographic Society in about three weeks' time, that this photographic image theory—that is to say, the theory as to the action of light upon molecules of silver—is as well established as, at all events, the wave theory of light itself. Now, I am going to show you an experiment which, perhaps, will help to illustrate what I mean by the vibrations of atoms. In this slide I have got a gelatine plate, and I have a little flat iron which has been made warm. It is rather too warm to be borne comfortably. Here I have a phosphorescent plate, which I propose to illuminate with magnesium wire, in order to give an even source of light ; I press this flat iron against the back of the plate which is in this slide for a short time. I shall not let the plate cool, but while it is warm I will expose it to the phosphorescent light for about fifteen seconds. The plate is now allowed to become cold, and is developed. If everything has gone right, we ought to have something which shows us that the oscillations of the atoms of bromide of silver (which is the silver salt on this plate) have been given extra amplitude by the action of the heated iron to the back of the plate. I am afraid that I cannot show you the development in the light. [When the develop-

ment had been carried out the plate was shown.]

You now see we have a picture of this flat iron produced by the deeper blackening of the heated part, though the whole plate was given but a short exposure to the light from the phosphorescent plate. I will impress this further upon you. I have here a collodio-bromide emulsion plate. But in this case, instead of heating it by a flat iron, we will heat it by immersion in hot water. Of course a collodion plate is not so sensitive as a gelatine plate. I put it into cold water for a short time to moisten it, and then dip half of it into some nearly boiling water; on withdrawing it, I expose it to this candle, and develop it when it gets cool, which we effect by placing it a short time in cold water. It will be seen that the part immersed in hot water is much blacker than that which was exposed cool. If I heat the plate and allow it to cool and then expose, there will be no effect. The plate will develop normally, for the increased amplitude of vibration will have ceased, and the light will have to perform the same work on each part of the plate. Now, in whatever manner increased amplitude is given, when the cause of the increased amplitude is withdrawn, the amplitude will cease in the same manner. The case before us next was the cause, and it will cease after a very short period, in other words, when the plate gets cold. One of the chief reasons against what we may call the "vibration theory" of the photographic image, namely, that the molecule is unaltered by the action of light, is this—that the increased amplitude would cease with the same rapidity with which it would cease when the hot iron was applied to the back ; that is to say, after five or ten minutes the amplitude of the vibrations would come back to the normal extent, a condition which is not fulfilled in the photographic image.

I can illustrate this in a very visible manner. I think you can all see this phosphorescent plate. Now, what is the reason of that phosphorescence taking place? It is that the atoms of the molecules which comprise this phosphorescent material are swinging in a certain rhythm, which gives us the sensation of light. Now, if I apply a hot iron to the back of this plate, I think at once you will see that the image of the hot iron is present. Here is the same kind of action taking place in the one case as in the other.

Now we come to another point, which is a slightly different one, and that is the energy of radiation. I may say that the energy of radiation is a subject on which I could discourse for a good many hours, but here I can devote but two minutes to it. I must try to make it as clear as I can. I hold in my hand a little instrument which is called a thermopile, which you see has a narrow slit which could be narrowed to any degree of fineness ; attached to it is a screw motion, which will make that slit travel along the base of the instrument ; beneath that slit are some thermo-electric couples. It is not my business to enter into how they are made, but still we know that, when thermo-electric couples are heated, an electric current is generated sufficiently strong to cause the needle of a galvanometer to deviate ; and the amount of energy of radiation which falls upon the face of the pile can be measured by the deviation of the galvanometer needle, from the energy heating the lampblack at the junction of the couples. In a great many experiments which were made, this thermopile was caused to travel along the spectrum by the screw motion, and at every part of the spectrum at distances of, say, a quarter of a turn or half a turn of the screw, the amount of deviation which was given to the galvanometer needle was read off. By that means we are able to compare the energy existent at different parts of the spectrum. The spectrum used was that of the electric light, the comparative energies at different parts of its spectrum I have in the diagram—at five turns of the screw we have the end of the red, and at different turns we have the yellow, the green, the blue, and the violet ; whilst from five to twenty we have the dark rays which lie below the red, and with which we are not to deal to-night at all events. The energy, I may say, being measured by taking the amount of the deflection of the galvanometer needle, you will see that the dotted line divides the energy area into two parts.

On measuring this area of the curve in which lie all dark rays, and the area of the curve for the visible rays, it will be found that, roughly speaking, the energy of the latter rays are about half that of the former. But for photographic action we do not have anything like that amount. The red rays for ordinary photographic work are useless ; and why that is we shall see by and by. We will say that the photographic action stops at the blue, and we find that the total energy of radiation which is used for photographic purposes in

the electric light, is only about one-hundredth part of the whole energy of radiation. The remaining ninety-nine parts are wasted as far as photography is concerned, except in so far as they heat up the molecules in the same way as the flat iron heated up the molecules on the photographic plates. The other curves show the energy of incandescent lamps. You will see that they have very little of what is called actinic power; that is to say, they have very little blue ray at all compared with the arc light. In the lowest curve we have a lamp at only a yellow heat, the middle curve being that at a white heat, and you will notice the enormous difference there is in the energy between the two. The energy of the middle curve, which measures the total energy of radiation from the incandescent light, is about twelve times that of the visible power. Yet, when you have to measure the photographic part of the spectrum, you will see that it is only about eighty. That is to say, supposing you have a filament of an incandescent lamp which is one-hundredth of an inch wide and half-an-inch long, then if you take an arc electric light and cut off from the glowing positive pole the same area, the photographic value of the one, area for area, is about eighty times that of the other. [A spectrum was thrown on the screen.]

I will ask my assistant to put in front of the slit something which I showed you at my last Cantor Lectures, and which I dare say you have forgotten all about. That something is a film of the same silver salt with which I photographed the spectrum at the commencement of the lecture. You see that it cuts off all the violet, and well down into the blue. I want to show you that the colour of the photographic spectrum is perfectly different from that which the human eye can see. I wish to show you a little device by which, perhaps, I shall be able to give you an idea of the integrated colour. A tolerably bright spectrum is on the screen of the camera; I raise the screen so that the spectrum falls on a lens placed a little beyond it; and if we had time, I dare say that we should be able to get a screen placed in the focus of the second lens, so that the recombined colours would form a white patch, without the slightest tinge of colour. We have got a white circle, however, which is sufficient for our purpose, though at one margin there is a very narrow red fringe to it. [A white patch about 6 inches in diameter was formed on a transparent screen about 6 feet away from the camera.] In the place where the

coloured spectrum is in focus, I place a horizontal aperture, about ¼-inch wide, and by a little arrangement I can, by strips of card, cut off any colour I like from falling on the collecting lens, so that it recombines only the remaining colours.

You remember that the photographic spectrum does not extend as far as the green, ordinarily speaking, so now I cut off all rays as far as where the photographic spectrum begins, and you can see the colour of the light, which is really useful for photography. It is a sort of sea-green colour. If I were to take that light, and pass it through a slit and a prism, you would soon find that the whole of that spectrum would be photographically active, because all the light which is not photographically active has been cut off. I shall have to revert to this in my next lecture.

I will show you one more method of recombining the photographically effective colour disc; that is by taking the ordinary disc, and cutting out the red and orange. We have, then, only the green, the blue, and the violet; and those, when they are combined together, ought to give you pretty nearly the integration of the colours which are ordinarily photographically active. I will ask my assistant to spin it in front of the lantern. [The instrument was rotated.] I do not know whether you can all see the colour-chart which I hold in my hand, but those who can will see that the colours, when placed in the blue-green light, appear totally different from what they did in the whiter light. The yellows are much deepened, and the reds are much blacker.

I will ask now to have the spectrum thrown upon the screen once more, and we will again pass this colour-chart through the spectrum. The colours are very pure for pigments. I think that it is the finest colour chart of the spectrum which I have ever seen. It is one prepared by Professor Piazzi Smyth, and appears in his Madeira spectroscopic observations. Notice that the blue appears perfectly black when the chart is in the red, the red at the left hand being brilliant. Passing it into the yellow, the yellow is vigorous; the blue is black, and the red undimmed. Upon my passing it still farther on in the green, you will see that the red is blacker, and the orange is blacker, whilst the yellow still keeps its colour, and the blue begins begins to get more bright. Passing it still farther on into the violet, we see that the yellow is now perfectly black, the red has gone, and the blue begins to shine out.

Passing still further, you will see that the blue still shines out, but is less intense, all the other rays appearing black. Upon my passing it again rapidly through, you will now be prepared for the changes that take place. In this lantern, which has been used to form the spectrum, the light passes through a slit. The slit, you see, is perfectly straight, with parallel edges. Now comes the question, "Is it necessary that light, in order to be decomposed into a spectrum, should be passed through a slit of this description, or what shapes may it be allowed to take?"

I propose to try to answer this query in an experimental manner a little. First of all, we will see what the effect will be if we use no slit at all. You see that the colours are not pure. I replace the slit, and you will see at once that we now have, not the various colours light overlapping, but a tolerably pure spectrum. Now let us take a slit of another shape—a zig-zag slit; and here we have another form of spectrum delineation of the rays. Placing a metal in the arc, the bright lines due to the vapour flash, and, it will be seen, take the zig-zag form of the slit. There is, then, no particular reason for using a straight slit, except convenience. Then, again, I may take a ring slit, and to test its value we will put a little silver in the arc to show you. I am not simply showing this as a pretty experiment, but I want to show you that such a slit is absolutely useful in photography, the spectrum of silver now on the screen shows rings of different coloured rays. It is a very pretty spectrum. This form of slit is extremely useful in one branch of spectrum analysis.

You are perfectly aware that, during a total eclipse, the body of the moon covers the sun; but that there are seen beyond the dark moon certain red protuberances which belong to the sun, and are known as "prominences." It has been the work of astronomers to determine the composition of those protuberances, and also to form a definite idea of the corona of light which surrounds the body of the sun, and can only be properly seen during a total eclipse. The picture on the screen is a representation of the total eclipse of the sun which took place in Egypt in 1882. It is a negative picture, and of course the dark halo which you see around was seen as a bright halo, and the white disc is the black moon. On the left-hand bottom corner you may notice the comet which was discovered during the eclipse, and which received the name of Tewfik, after the Khedive of Egypt. Round the disc of the moon are little prominences. Those prominences are vastly more bright than the corona itself, which is the halo extending some distance round the sun. Thus we have a bright ring of light round the moon surrounded by a feeble light. The former, when viewed by means of a lens in front of which a prism is placed, shows rings of colour composing these prominences, and of course these rings can be photographed.

I now show a transparency of a photograph taken in Egypt by means of the slitless camera, from which much valuable information has been derived.

The ring slit was used by an Italian astronomer about 1870; but the eclipse in Egypt was the first time it was entirely successful for photography.

LECTURE II.—Delivered April 27, 1885.

In my last lecture, I left off with the use of the slit in the spectroscope, and I showed you, I think, that under certain circumstances the slit which had the form of a ring was useful, having previously demonstrated that it was not necessary that the slit should be straight, but that it was most convenient that it should be so. I will next deal with the subject of the prism. We know that prisms are employed to separate the different coloured rays, as each colour is differently refracted as it passes through the prism, and it is this difference in the index of refraction between the red ray and the violet ray which gives the amount of dispersion in forming the visible spectrum. Of course, if we go beyond the violet, there are invisible rays, while again below the red there are also dark rays, which also have their indices of refraction, but I wish to show you the influence that the material of the prism itself has on the dispersion of the visible spectrum.

I have here a prism of 60° built up of six or seven different triangles of glass. It is apparently homogeneous, but when we pass light through it we shall find that it is anything but homogeneous; in other words, the different portions are differently refractive. The different portions of the prism are all glass, as I have said, but of different densities, and the denser the glass, the more are rays refracted, and the greater dispersion between the red and violet there is. [A slice of light was passed through this built-up prism, and the different spectra thrown on the screen.] You will notice, by the spectra on the screen, that the length of the top spectrum between the red and violet is much smaller than that of the bottom spectrum. The glass which gives the dispersion to the latter is much denser glass than that which gives it to the former. Practically speaking, therefore, we may say the denser the glass the greater refraction, and the greater dispersion there is. For most purposes in spectroscopy, it is as well to use as dense a glass as possible in order to get the maximum amount of dispersion. I will now combine three prisms together, two of a light glass, and one of a denser, and we get a combination, in which,

although the main beam will pass straight on to the screen, yet the presence of dispersion is also shown by the formation of a spectrum. This is an example of what is called a direct vision prism. The spectrum is given by the differences of the refractive indices for each ray in the two kinds of glass. For some purposes this kind of compound prism is very useful, and particularly for lecture experiments, but, as a rule, for photographic purposes I should not recommend it, on account of the internal reflections which take place between the different surfaces of the glass, though they are cemented together. You must recollect, wherever there is a difference in density between two media, in other words, a difference in the refractive indices, there is always a certain amount of reflection, and those reflections, being white light, are rather apt to fog the plate, and give you false notions of what you get in the photograph.

We come now to a much more important point with regard to the spectrum, and that is, what is the best material to use. In those prisms which I have already shown you, the material was glass. Now glass is, comparatively speaking, a mixture of materials, and has no definite chemical formula; but when we come to a material which has some definite chemical formula, we find that, as a rule, it has certain properties which are invaluable in certain forms of spectroscopy, more particularly when the photographic plate has to be brought into requisition. Quartz is an example of this; it is a definite compound of silicon and oxygen, and we find that it has certain definite advantages which are not to be found in glass prisms. The dispersion is not quite so great as it is with glass, but, on the other hand, it lets through rays which are cut off completely by glass, as I hope to show you on the screen. This quartz prism has very well-worked faces, and we will send a beam of light through it, and then proceed to investigate its behaviour. [Spectrum thrown on screen.]

I may further say, in reference to this, that the condenser in that lamp is quartz, the lens

is quartz, and the prism itself is quartz, so that we are dealing with nothing but quartz. Now, the question comes, is there any advantage to photographers in using such a material as quartz. Let us first see the extent of the spectrum. By placing a card which has been washed over with quinine in the ultra-violet part of the spectrum, you are able to see these ultra-violet rays glowing with a pale blue light, and you will notice to what a great length these rays reach beyond the ordinary visible point of the spectrum. Now, by placing a piece of glass in front of the slit, you will see that the ultra-violet spectrum is very much shortened; in other words, the glass has absorbed these rays. I may repeat the experiment with a card which has been brushed over with paraffin oil, and the same result holds good.

I have here a photograph of the electric arc taken in another manner, to which I shall have to direct your attention presently. The light in this case has to pass through no glass whatever. The spectrum was taken by a diffraction apparatus; for the top part of the spectrum a glass was interposed in front of the slit, and we see the difference there is in the spectra, owing to the use of glass in one case, and not in the other. The glass apparently cuts off many useful rays; but I will now draw your attention to the solar spectrum taken in the same way, in which there has been a glass placed in front of the slit for one spectrum, and not in the other. Both spectra, practically, reach the same limits. We now can answer as to whether it would be advisable for photographers to use quartz lenses for ordinary photographic purposes or not. Recollect that every ray of light you saw fluoresce on the screen is useful for photographers when they are using a light such as we have in the electric light. You will see, then, from that, if the electric arc light was usually employed, all those rays which are cut off by the glass could not be utilised by them, and, therefore, there would be so much power wasted. Now photographers, as a rule, do not work with the electric light, but with sunlight; we have seen that in the solar spectrum taken under similar conditions, the glass practically cuts off none of the ultra-violet rays; the atmosphere of the earth, or of the sun, or both, cuts off the extreme ultra-violet rays before the light reaches us. We therefore come to the conclusion that, so far as photographic work with sunlight is concerned, there would be no advantage in using a quartz lens over the ordinary photographic lens.

Some years ago, Mr. Claudet made an agate lens, which he considered would give him greater advantages over the ordinary photographic lens, simply because he could utilise the ultra-violet rays, but I think you will see from this there is no advantage in using such a lens. Remember, however, if you are photographing the spectrum of the electric light, or using it for illuminating a sitter, there is a very great advantage in using quartz. We may use another definite chemical compound in the shape of Iceland spar. I have here a very beautifully worked prism of Iceland spar, which has a definite composition of calcium and carbon, and I dare say that we shall reach very nearly to the same ray limit as we did in the quartz experiment. Iceland spar holds an intermediate position between quartz and glass. It was with such a prism as that that Dr. Huggins took his famous star spectra, and I thought it might interest you to throw one or two of these on the screen. They are very small, but the definition is very beautiful. Many of the black lines in these spectra indicate, probably, hydrogen. It remains to be seen whether Dr. Huggins has attained any advantage in using Iceland spar instead of glass, for if the ultra-violet stellar light is absorbed, as with sunlight, no advantage would be gained. I may mention that he gives the composition of the stars by reference to the spectral lines of well-known elements.

One more point is this: Would it be advantageous to use a mirror instead of a lens? There is a great deal to be said about this, particularly in spectroscopy, where we have to examine everything minutely. The material we utilise most easily in the case of a mirror is silver; that is to say, we get a glass mirror, and silver it on the front surface. Now, the question is, does the silver reflect every ray in the same way that quartz would transmit it? Here I have a photograph which should give an answer to that question. The bottom half of the spectrum was taken as reflected from a quartz surface, the top half of the spectrum was reflected from a silver surface, and you will see that at one certain part of the latter the rays are very nearly absent, though beyond that again they are present. Where those rays are wanting is just at the end of the solar spectrum, and therefore, when using sunlight, it is no great advantage to use a quartz reflector over a silver reflector. In spectroscopy it is necessary to know exactly the

qualities of all the substances with which you are dealing.

One question in photography and in spectroscopy is, what width of slit you would use—what slice of light would you allow to pass through? Here let me give you a demonstration. In the centre of this black disc there is a fine line of light, and there is a micrometer screw by which we can tell how many thousandths of an inch wide it is. As a rule, about $\frac{1}{800}$ of an inch is the dimension used for ordinary work.

I have been referring to the photographs to two spectra on the same plate, and I must show you how it is managed. For this purpose, it is necessary to have an adjunct to the slit, and that is a shutter, which is able to cut off half the slit at one time, and afterwards leave that part open and close the other half already used. By this means we can get one spectrum adjacent to another. In comparing spectra of different metals with each other, we are able to tell whether we have any two lines coincident one with the other.

Photographic spectroscopy is the easiest thing in the world when you know how to do it, but it requires a deal of patience to learn every dodge. As a rule, a photographer is a patient man; indeed, there ought to be no class of men who have more patience than photographers; hence spectroscopy should not be difficult to them.

Here is another piece of apparatus which is very useful in the spectroscope. It is an apparatus by which you can take a great many spectra on one plate. I need not enter into its details, it is simply a dark slide, which by a rack and pinion motion can be raised, so that the plate gives a fresh surface at each exposure. The only light accessible to the plate comes through an opening of about three-quarters of an inch wide cut longitudinally in the shade. By this method we can get about sixteen different spectra of different materials on the same plate.

Here is another piece of apparatus which is also useful in investigations with photography. It is, a slide in which you can expose plates in different gases or liquids, that is to say in water, in alcohol, in nitrogen, and so on. It is essentially a glass cell which slips into a dark slide especially adapted for it; on the top there is an air-tight junction which is screwed down, and there are two little tubes through which you can fill the cell with gas or water, or whatever other material you wish to use. This is very useful in investigating the behaviour of different sensitive salts under different conditions of moisture, pressure, &c. This cell has been used in a great many hundred experiments, and I hope it will be used in a great many more. Those who are going in for spectroscopy should not be without such an apparatus as this, for I do not believe much real investigation can be done without something of the kind. The sensitive salt of silver acts differently when isolated from its atmospheric surroundings, and the only way to ascertain how it does so is to expose it with other surroundings, and to differentiate the results one from another. There is no such thing as a perfect vacuum; you cannot say you expose a plate in vacuo, and, for this reason, I say you have to differentiate between the different media in which you expose a plate, in order to get at the true result which would happen supposing you could expose the plate in vacuo.

You saw last time how you could recombine a spectrum by means of a lens, to form white light.

Now, I want to show you that it is not impossible to develop a plate in white light. I expose a plate behind a negative to the electric light, and in the cell which is placed in the patch of white light is some developing solution (which is quite colourless). The plate is dipped into it. The image comes out into it, although exposed to white light, without fog, which was supposed to be an impossibility. I have another plate placed behind the same negative. I expose half of that plate for half a minute to the white light on the screen, and the other half to apparent darkness, but in the same position on the screen, for a couple of minutes. The plate on development shows that the half which was exposed to what was presumably white light gives no image, while the half exposed in the dark shows a perfect picture. I dare say many of you have guessed my trick, for it is merely a trick, but for those who have not, I will show you how it is done. It is perfectly easy, by mixing two elements of light of different refrangibility, to produce a colour which, at all events, to our eyes is a white light. But you must not take it for granted that wherever you can see white light you can photograph with it, because it is quite possible you may not. It is only a trick, but some of these tricks bear fruit in a very practical manner. I will re-form white light again, and we will examine it by means of the colour-chart I showed you

last time. You will see that when the red is placed in the white light there is blackness— no colour whatever—the yellow looks bright, as does the blue, all the other colours are gone except some few which are of a non-descript colour. The meaning of it is this, we have simply a combination of yellow and blue, which gives us the appearance of white light. [The blue and yellow rays were shown to be coming through two slits placed at the focusing screen of the camera.] The blue has no power of acting on the iodide or chloride of silver, neither has the yellow, and, therefore, the white light which is made by the combination of those two colours is powerless to act on films made of such materials as those. We can also produce a white light, practically, by a red and green, and if we examine this (which is a very good imitation of white light) in the same way, you will not see the whole series of colours in the colour chart any better than you did before. The red comes out perfectly, but the blue is no longer visible ; the blue becomes green, and the violet becomes red ; the yellow is also not intense. This is because we have only two colours present, viz., the red and the green. The apparent darkness to which we exposed the one-half of the plate was in reality the dark ultra-violet light, and I need say no more regarding that.

I told you last time that this was a very interesting way of studying the spectrum. You see how, by combining two lights together, you may have a light which is perfectly safe for certain salts of silver. On the screen is the spectrum taken on the three ordinary salts of silver—chloride, iodide, and bromide. The iodide stops exactly at the violet. Below that light we have no action whatever, and we, therefore, may expose an iodide plate with impunity to any rays below the violet. A bromide plate, you see, is sensitive down as far as the yellow, and, therefore, it would be impossible to develop a bromide plate in such a light as I showed you just now, whereas iodide is perfectly capable of being developed in such white light; the chloride again stopped very nearly with the limits of violet, so that it would be safe to develop a chloride plate in such a light.

[The lecturer concluded with a brief explanation of the diffraction spectrum.]

———————————

CANTOR LECTURES

ON

LIGHT AND COLOUR.

BY

CAPTAIN W. DE W. ABNEY, C.B., R.E., F.R.S.

———————————

Delivered before the Society of Arts November 26, and December 3, 10, and 17, 1888.

———————————

SYLLABUS.

LECTURE I.

The production of colour and its dependence on the kind of illuminant.—The spectrum and its recombination.—Simple colours.—The characteristics of colour.—Colours of pigments.
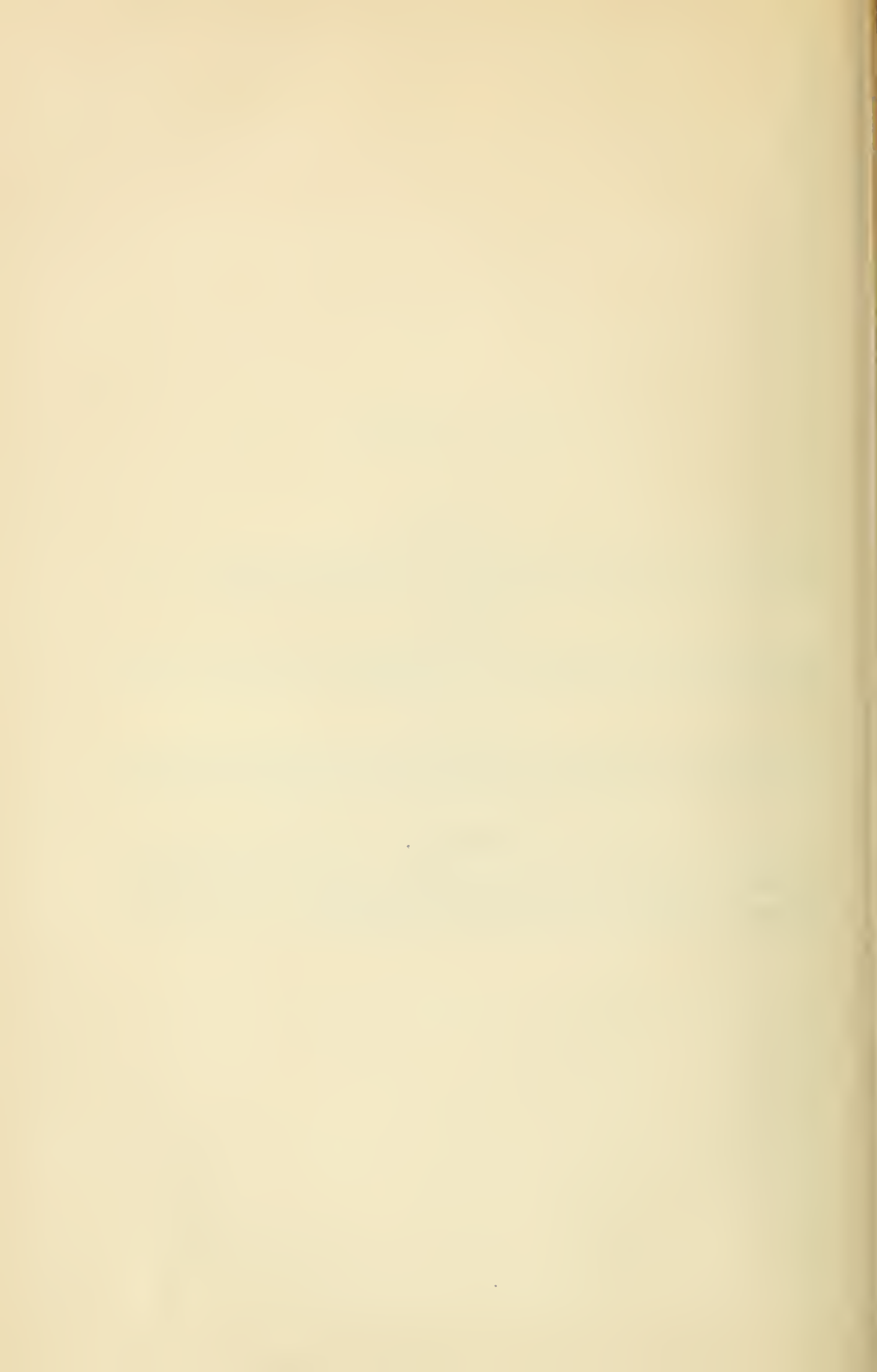
LECTURE II.

Interference colours.—Production of colour by absorption ; by fluorescence.—The measurement of the luminosity of colours.—Colour contrast.—Colour-blindness.

LECTURE III.

The effect of the dilution of colours.—Mixtures of colours.—Impure colours.—The measurement of colours in terms of a standard.—The reproduction of the colours of a pigment.

LECTURE IV.

The action of light on pigments.—The cause of change.—The effect of sunlight, sky-light, and artificial light.—Rays effective in causing change.—Moisture and oxygen necessary to cause change.— Work done by the absorption of light.—Chemical effect, heating effect.

LIGHT AND COLOUR.

BY

CAPTAIN W. DE W. ABNEY, C.B., R.E., F.R.S.

LECTURE I.—DELIVERED NOVEMBER 26, 1888.

I hold in my hand a series of colours of various hues and depths, some of them are fugitive and others are fast colours, and it is the object of the lectures I have been called upon to deliver to show how we can measure and mix colours, and what causes the fading of some by light. In four lectures this subject can by no means be treated exhaustively, and I can only endeavour to explain, in as familiar language as I can command, and by some plain experiments, what I desire to enforce upon your minds. A great deal has been written in the last two years on the subject of the fading of water-colours, and from what I have gathered from the newspaper correspondence, it is not quite unnecessary that a few familiar discourses on the subject should be given, to prevent a repetition at all events of some of the blunders that have been made in physical phenomena. It may be known to some who are present here to-night that Dr. Russell and myself have carried on a series of experiments during two years on the subject of the fading of water-colours, and as our report to the Science and Art Department, which was presented to Parliament, pleases neither the party who cry out that water-colours are stable, nor yet the party who proclaim the contrary, we may presume that our results are not altogether wrong. To these experiments I shall refer later in the course of lectures.

Now, to commence with the elements of colour from the physicist's point of view. I wish to show you that the colour of an object depends on the composition of the light falling on it, on the material on which such light falls, and on the eye of the person. The screen which I have here is what we call white, when viewed by ordinary daylight or artificial light, and such a screen not only will reflect white light, but also all coloured lights with the greatest brilliancy possible.

Let me throw a spectrum on the screen to serve as a text. If a brilliant spectrum be looked at, we see that it is really divided into three colours, blue, green, and red, with shades of other colours blending these colours into one another. I am not going into the theory of the matter, but I would ask you to remember that the mean red light has a wave length of about 38,000 to the inch, the waves being in the luminiferous ether of whose existence we only know by circumstantial evidence, the green of about 50,000 to the inch, and the violet of about 64,000 to the inch. The other colours have intermediate wave lengths.

I would remind you of the old experiment that red, green, and blue, when combined together by means of rotation, give a grey light which can be matched by a combination of black and white. Here we have such a combination forming a grey in the electric light. The reason assigned for this is, that in the eye there are three sets of nerves, one which responds to the red, one to the green, and the other set to the blue. When the disc is at rest, an image of these three coloured sectors is formed on the retina, and the nerves lying at the parts of the retina on which the image falls respond to these colours, and we see the sectors coloured. If there is astigmatism, or defects in the optical apparatus of the eye, the image is not sharp, then we have an image of part of the two colours adjacent blended into one another, or again if the discs rotate rapidly, so that the same part of the retina receives the coloured images in quick succession, all three sets of nerves are brought into use, and we have an impression of white, or rather grey, produced. But this subject I shall allude to again in one of my subsequent lectures.

We can recombine also the pure colours of the spectrum by several plans, the simplest to

my prejudiced mind being that which I introduced. I take away the lens of long focus, and put one of shorter focus in its place attached to a camera, for reasons which I will shortly explain (Fig. 1).

On a collimator, G, to which is attached the usual slit, is thrown, by means of a condensing lens, a beam of light, which emanates from the intensely white-hot carbon positive pole of the electric light. The collimating lens, L_2, is filled by this beam, and the rays issue parallel to one another and fall on the prisms, P_1 and P_2, which disperses them. The dispersed beam falls on an ordinary camera lens, L_3, of slightly larger diameter than the height of the prisms, and a spectrum is formed on the focussing-

FIG. I.
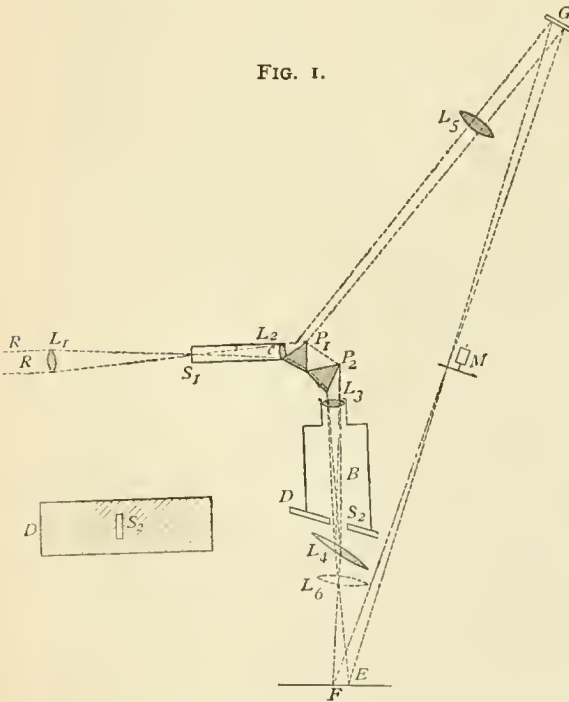
screen, D, of a camera. When the focussing-screen is withdrawn, the rays would form a confused patch of parti-coloured light on a white screen, F, placed some four feet off the camera. The rays, however, can be collected by a lens, L_4, of about two feet focus, placed near the position of the focussing-screen, and slightly askew. This forms an image on the screen of the near surface of the last prism, P_2; and if correctly adjusted, the patch of light should be pure and without any fringes of colour. The card, D , is a strip which fits into the aperture left for the focussing-screen in the camera. In it will be seen a slit, S_2, the utility of which will be explained later on.

It often happens that a second patch of white light, comparable to that formed, is required. Advantage is taken of the fact that from the first surface of the first prism P_1, a certain amount of light is reflected. Placing a lens. L_5, in the path of this reflected beam, and a mirror, G, another square patch of light can be thrown on the same screen as that on which the first is thrown, and this second patch may be made of the same size as the first patch if the lens, L_5, be of suitable focus, and it can be superposed over the first patch if required.

We have now a square white patch upon the screen, from the re-combination of the spectrum. If I wish to diminish the brightness of this patch, there are at least two ways in which I can accomplish it. First, by closing the slit of the collimator, and, second, by the introduction of rotating sectors, M, which can be opened and closed at pleasure during rotation in the path of the beam.

The annexed figure (Fig. 2, p. 3) is a bird's-eye view of the instrument. A A are two sectors, one of which is capable of closing the open aperture by means of a lever arrangement, C, which moves a sleeve in which is fixed a pin working in a screw groove ; D is an electro-motor causing the sectors to rotate, and the aperture in the sectors can be opened and closed at pleasure during their revolution. To show you its efficiency, if I place two strips of paper, one black and the other white, on the screen, and cast a shadow from a rod, by the direct white light on the white strip, and a shadow from the same rod by the reflected light on the black strip of paper, and interpose the rotating sectors in the path of the reflected light, the aperture of the sectors can be closed till the white paper appears absolutely blacker than the black paper. White thus becomes darker than lamp-black, owing to want of illumination on the former.

We all talk about white light ; we say that the electric light is white and that gas light is white. I wish to show you that the whiteness is a mere matter of judgment.

I throw the shadow, by the electric light, of a thick rod on white paper, and another shadow by gas light, on the same paper, and we at once see that the shadow illuminated by the electric light seems blue, whilst that illuminated by the gas light appears orange, yet we speak of both gas light and the electric light as white lights. Evidently, if these two differ so much in colour, pigments will take different hues when illuminated by them. Putting

paper coloured with red, blue, and green pigments in the shadows, the change in hue is at once apparent. Placing in the shadow illuminated by the electric light a strip of paper coloured orange (Fig. 3), by orange chrome and aureolin, we see that now the electric light reflected from it appears of very nearly the same hue as the light from the gas reflected from white paper. Gas light, we may say then, is orange rather than white, if we take the electric light as the standard.

We have seen that colours appear of different hue in the electric light to that which they appear in gas light, and I wish to enforce this more strongly upon you by an experiment which I introduced a year ago. In front of the condenser of the electric light lamp I place a circular aperture some inch in diameter, and by means of a lens throw an image of it on a white screen. We may suppose this to represent the sun, the colour of the light being very much the same as that which it has in England about midday in the middle of May. In front of the aperture I place a trough containing a solution of hyposulphite of soda, and then drop into it dilute hydro-

FIG. 2.
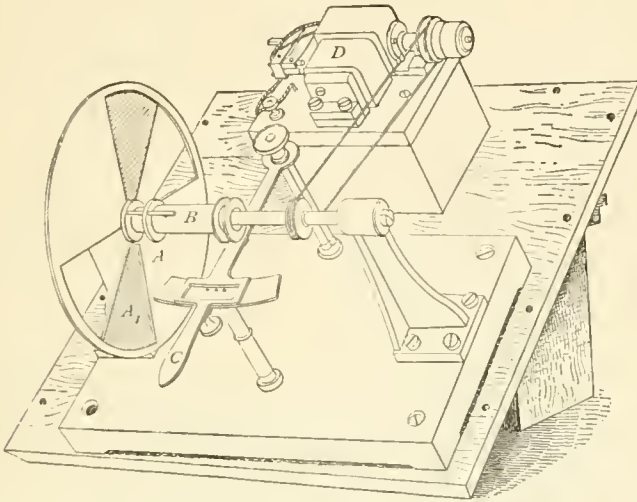
chloric acid, and stirring up the two together very fine particles of sulphur slowly separate, and the white light, owing to the law of scattering by small particles, loses some of its components, and we have a gradual reddening of the sun—first yellow, then orange, and finally a red—the series forming a very exact representation of the colours of a setting sun. If we place coloured pigments in this changing light, we see how, towards sunset, the blues become darker whilst the reds change but little in hue. It may have been remarked that in an evening the last colours in a picture to disappear are the reds. The colour of sunset

FIG. 3.

light now imitated before you gives a clue to the reason of this.

We may as well trace the cause of this change in colour. Placing a cell containing hyposulphite of soda in front of the slit of the spectroscope, and throwing the spectrum on the screen, and then adding the dilute hydrochloric acid, we find that as the light from the reflected beam (which we throw just above the spectrum) becomes yellow, orange, and then red, so the spectrum loses the violet, then the blue, then the green, till finally the red alone remain.

Let me further exemplify that you cannot know what effect the colour of the light has upon a colour unless you know its composition.

The slit s_2 in the card D (Fig. 1) can be passed through the spectrum, and as it cuts off all the colours of the spectrum, except that passing through the slit, we have different coloured square patches of light thrown by—

what I will now call—our patch-forming apparatus, the colour of the patch being that of he colour issuing through the slit.

Now sodium, when ignited, gives a peculiar yellow light, due to a line in the orange. If I send the light from this sodium line through the slit S_2, we have a square patch of sodium light on the screen. The rod casts a shadow as before, but instead of casting a second shadow by the reflected beam, I cast a shadow from gas light, when it will be seen that the two illuminated shadows have almost the same colour.

I now shall perform a common Christmas experiment, and ignite some spirits of wine in which salt has been dissolved, and illuminate with that light cards on which various blue, red, green, and yellow pigments have been placed, and we see that all the pigments partake of various shades of orange, instead of the colours seen by gas light. The reason of this is apparent; in gas light we have all rays present, in the sodium light there is only orange present. We shall see that as the colour of a blue pigment depends principally on the reflection of blue rays, that of a green of the green rays, and so on, it is only to be expected that the colours of pigments, when illuminated by pure orange light alone, will only give different shades of orange.

This shows also that light or colour may to the eye appear to be the same and yet be very different in optical composition. I cast two shadows of the rod in the patch-forming apparatus, one by the recombined spectrum and the other by the reflected beam, and pass the card, D, with the slit, S^2. in it along the spectrum. One shadow will be illuminated by the white light and the other by the light from the parts of the spectrum coming through the slit S_2. If I place emerald green in the shadow illuminated by white light, I find that there is one point in the green of the spectrum which matches it in hue, and I can make them of the same depth of colour by the introduction of the rotating sectors. Evidently, then, the coloured light of this part of the spectrum and that of the emerald green might be mistaken for one another, and so with other colours. There are some pigments, however, which cannot be matched by the spectrum colours.

That emerald green is a combination of colours I will at once show you. A strip of card is placed in the spectrum, on one half of which is this pigment. Half of the breadth of the spectrum falls on the white card and half on the pigmented card. It will be

FIG. 4.
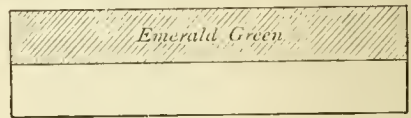
seen that the emerald green reflects other colours of the spectrum besides that which it matched in the colour patch-forming apparatus. The combination of all these other colours in the proportions reflected from the pigment, form the colour which, in the simple colour of the spectrum, we should call emerald green. So if we pass other pigments through the spectrum we get similar results, though not all pigments can be so matched.

LECTURE II.—Delivered December 3, 1888.

In the last lecture I finished the matching of the colour of pigments with parts of the spectrum, and to-night I will endeavour to show you that colourless bodies can be made coloured, under certain conditions, although the light that falls upon them is colourless. I told you last time that the waves of red light are such that if you put 38,000 end to end they make up an inch. If in the sea we have two sets of waves, one set of which is exactly half a wave behind the other, then the crest of the one wave will exactly fill the trough of the other, and instead of motion we shall have rest. Suppose I have a colourless body, whose thickness is comparable with a wave of red light, and that a wave of red light when reflected from the back surface is half a wave length behind that reflected from the front surface, we get darkness instead of light. The easiest way to obtain a colourless body answering to the above conditions is to use a soap film stretched across a vertical aperture. Its thickness is found to be comparable with a wave of light, and as it gradually thins by gravity, some part of the film becomes of the thickness that the reflection from the back surface is half a wave length behind that reflected from the front surface, the red is annihilated at such place. There will be another thickness of film in which the green light would be similarly absent, and yet another in which the blue is absent, and so on. The light reflected from the first locality would be the components of white less the red, in the second the same less the green, and in the third the same less the blue.

I can show you the kind of colour that is seen by the suppression of one small part of the spectrum, by using our patch-forming apparatus and passing a thin rod along the spectrum, which cuts out the part required. It will be seen that the patch is no longer white, but coloured. These colours, remember, are not simple colours, but white light, with some colour abstracted.

Putting a soap film on a ring in the beam of the electric light, at an angle of about 45° with it, the light is reflected on the screen, and a lens in the beam forms an image of the ring. At first the film appars white, but after a short intervals of time coloured bars appear horizontally across it. Putting a piece of red glass in front of the beam, we have a succession of red and black bars, the red glass cutting off all the remaining colours. A piece of green glass placed in the beam shows green bars, and so on.

The bars are brighter at the bottom of the image, which is in reality the top of the film, for the reason that the film is of a thickness of $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, $4\frac{1}{2}$, $5\frac{1}{2}$, &c., wave lengths of the different coloured lights as we go from the top to the bottom of it. The bars gradually widen out and become very far apart, until we see only 3. I now cause a gentle current of gas to play on the film, and the coloured glass being withdrawn, we get a magnificent series of colours whirling one around the other. Peacock green, golden yellow, azure blue, succeed one another, and give a most brilliant effect. All these colours are due to white light falling on a colourless body.

The next experiment is to throw a small image of the film upon the slit of the spectroscope. We see the spectrum traversed by black lines curving down from red to blue, and rapidly shifting in position. These lines show the colours which are absent in the horizontal bars of coloured light reflected from the film, a section of which passes through the slit.

In this case we have a demonstration that the colours reflected from the film are not produced by any conversion of white light into coloured light, but by the abstraction of certain colours from the components of white light.

In the opal we have an example of interference colours, caused by a thin layer of material of different thicknesses, which abstract a certain component of white light in exactly the same manner as does the soap film. When we have the light from the varying thicknesses close together, as we have in the reflected beam in the patch-forming apparatus, they have very much the same appearance as has the opal.

But one more example of interferences,

which is very beautiful, as time will not allow me to go into the theory of the matter; suffice it to say that if parallel lines be ruled on a surface very close together, and the beam of light be thrown on them, the "interferences" are such that pure colours are produced, and we have a spectrum.

Next let me show you that the colour of transparent bodies is also due to the abstraction of colour or colours from the white light.

In a cell I have a liquid which appears green. A spectrum is formed on the screen and in front of the slit of the spectroscope the cell is placed. You will see that the blue and most of the red is cut off, and that we only have the green and a small band in the red left of the spectrum. Recombining the remainder of the spectrum to form a patch as before, we have a square of green light, and side by side with it is the patch formed by the reflected beam, which is coloured by the light which has not passed through the prisms, but only through the cell and the collimator. They are both absolutely of the same hue, showing that the recombined spectrum gives the same colour as the light after passing through the cell. Repeat the same with a red liquid or a blue liquid, and we obtain the same results.

A paper is coloured with the green dye which I had in the cell, and I allow the patch of white light to play on it, and you see the light reflected from it is green. In the path of the *reflected* beam I place a cell containing the green liquid, and throw the patch on *white* paper. The two patches, viz., the white light on the green paper, and the green light on the white paper, are the same colour. The white light which penetrates colouring matter is the same in the two cases, though when on the paper itself it traverses the colouring matter twice. This leads to an important axiom, viz., that the effect is the same whether the colouring matter is in contact with the paper or at a distance from it, so long as the eye receives the light which has traversed such colouring matter. I shall immediately take advantage of this, for I wish to show you that the depth of colour depends on the thickness of colouring matter through which the light passes. Of a double wedge-shaped trough, half is filled with pure water, and the other half with coloured water. Different thicknesses of the blue colouring matter are passed in front of the slit, and as the thickness is increased so the spectrum gets fainter in the blue than in the red.

The patch of white light is next formed, and the wedge of coloured liquid is again passed across the slit, and you will see that the colour deepens as it passes through different thicknesses. As this is true when the colouring matter is in front of the light, so must it be true when the colouring matter is in contact with the papers.

There is another feature which I must not pass over, i.e., what is known as fluorescence, and though it does not enter into the effect of pigments used in water colours, yet it has much to say to the coloured materials of every-day wear. One of the most beautiful examples of this fluorescence is fluorescene. In the beam of the electric light a jar of water is placed, and in it is dropped a concentrated solution of the fluorescene. We have a fine example of fluorescence; the fine threads of liquid as they stretch towards the bottom appear of a brilliant green. I take another jar and repeat the same with quinine sulphate, and we have a gorgeous blue.

We will endeavour to trace this fluorescence to its source. I take a piece of card and brush it over with the solution of fluorescene, and place it in our colour patch; the different colours of the spectrum illuminate one after the other; we now can readily see the light which causes this fluorescence. It is the green and the blue, but the light reflected from the fluorescene is of a totally different hue from the rest of the colour patch. So with the quinine. We see that when the colour patch is apparently dark, the paper covered with quinine shines out with peculiar lustre. The rays which excite fluorescence in this case are the invisible rays in the ultra violet. Common machine oil is fluorescent in the same part of the spectrum, but shines with a greenish light, and not blue.

We now come to the point when we must ascertain the second constant of colour, viz., its luminosity or brightness. Before showing how this is done for pigments, it will be necessary to show you how we can ascertain the luminosity of the spectrum itself. The luminosity of the spectrum varies greatly in different parts, the maximum luminosity of the prismatic spectrum derived from bright lights, such as the electric light, being in the yellow, and there is a degradation of brightness as we go towards each end of the spectrum. Now suppose we find that the reflected beam of white light, when the rotating sectors are as widely open as possible, is slightly brighter than a yellow patch formed from the yellow of the spectrum

—it is manifest that other parts of the spectrum will be dimmer than that. If, now, in the reflected beam, I rotate the sectors at less than full aperture, less light will reach the screen, and it is evident that there are two parts of the spectrum, one on each side of the yellow, which will match the brightness of this degraded white.

In order to make this match, we place the rod as before in front of the colour patch. One shadow is thrown on the white screen by the spectrum colour, and another shadow is thrown alongside it from the reflected beam. The white light and the coloured light, each light up one of the shadows. The slit in the card is moved across the spectrum till we find (say) that when in the blue the illuminated shadow is too dark, and when the slit is in the green the green illuminated shadow is too light. It is evident that at some intermediate place in the spectrum the coloured shadow is neither too light nor too dark. This place in the spectrum is found by moving the slit rapidly, making the coloured shadow first too light and then too dark, diminishing the extent of the oscillations till equality of brightness is seen to the eye. The same procedure is carried on on the red side of the yellow. The angular aperture of the sectors is again altered, and a fresh determination made. Now the card in which the slit is cut carries a scale, and by means of a pointer the scale is read off, which tells us the exact part of the spectrum where the different equalities of brightness are established. We then use the apertures used as giving the relative luminosities of the different parts of the spectrum as measured, and make such a curve as we have below.

FIG. 5.
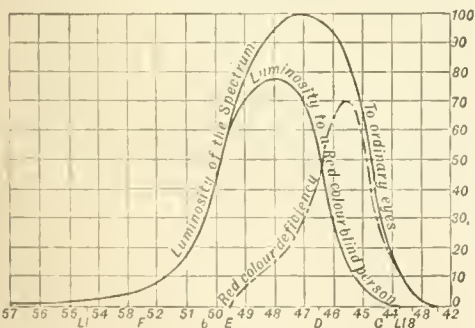
The method, then, of ascertaining the luminosity of a colour depends on the rapid oscillation of either the white or coloured patch between " too light " and " too dark."

This gives us a clue by which we can measure the luminosity of a coloured surface in a direct manner. The rotating sectors in Fig. 2 give us the means of doing this in an easy manner. Suppose the luminosity of a vermilion-coloured surface had to be compared with a white surface when both were illuminated, say, by gas light, the following procedure is adopted :—A square space of such a size is cut out of black paper so that its side is rather less than twice the breadth of the rod used to cast a shadow. One half of the aperture is

FIG. 6.

filled with a white surface, and the other half with the vermilion-coloured surface. The light, L, illuminates the whole, and the rod, R, is placed in such a position that it casts a shadow on the white surface, the edge of the shadow being placed accurately at the junction of the vermilion and white surface. A flat silvered mirror, M, is placed at such a distance and at such an angle that the light it reflects casts a second shadow on the vermilion surface. Between R and L is placed the rotating sectors, A. The white strip is caused to be evidently too dark and then too light by altering the aperture of

FIG. 7.
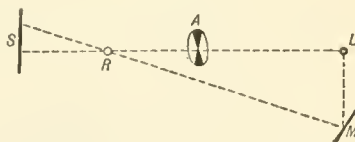
the sectors, and an oscillation of diminishing extent is rapidly made till the two shadows appeared equally luminous. A white screen is next substituted for the vermilion, and again a comparison made. The mean of the two sets of readings of angular apertures give the relative value of the two luminosities. It must be stated, however, that

if the screen remained unshaded, as represented, the values would not be correct, since any diffused light which might be in the room would relatively illuminate the white surface more than the coloured one. To obviate this the receiving screen is placed in a box, in the front of which a narrow aperture is cut just wide enough to allow the two beams to reach the screen. An aperture is also cut at the front angle of the box through which the observer can see the screen. When this apparatus is adopted, its efficiency is seen from the fact that when the apertures of the rotating sectors are closed the shadow on the white surface appears quite black, which it would not have done had there been diffused light in any quantity present within the box. The box, it may be stated, is blackened inside, and is used in a darkened chamber. The mirror arrangement is useful, as any variation in the direct light also shows itself in the reflected light. Instead of gas light, reflected skylight, the electric light, or sun light can be employed by very obvious artifices, in some cases a gas light taking the place of the reflected beam.

It will be in your recollection that I said that the colour of an object depended on the eye of the observer. Vision, I have told you, depends on the fact that three colour sensations are necessary for the normal eye to see white light. There are in fact, as I have said, three sets of nerves, one responding to the blue, one to the green, and one to the red.

FIG. 8.
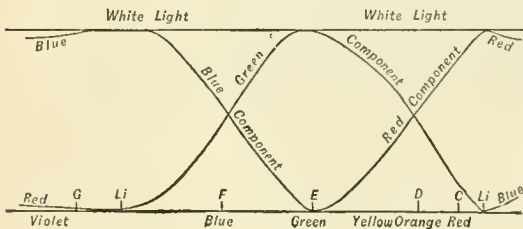
If one of these sensations be absent, then the eye does not see white light as we know it, but as—what would to us be—coloured light. The above diagram shows the three sensations derived from Clerk Maxwell's measures. The top line is supposed to be the spectrum as the eye sees it, all colours being of equal value. It will be noticed that at only three places in the spectrum is the colour due to single colour sensations, and all intermediate colours are made up by mixtures of two sensations, the height of the curves added together giving the height of the straight line parallel to the base of the curve.

Now, in order to test the eye for colour-blindness, it is only necessary to get a person so afflicted, to measure the luminosity of the spectrum. For evidently, if deficient (say) in red sensation, the spectrum would begin where the green colour sensation commences, and even then the luminosity would be much smaller, owing to the absence of such red sensation. Such a luminosity curve is seen in Fig. 5 (p. 7), and in the same figure is shown the colour deficiency. It is comparatively easy to show the colour of the light which colour-blind people see. If a certain proportion of the light near the position which the blue lithium line occupies in spectrum be mixed with a certain proportion of the green light of the spectrum near E, and the two be combined in a patch, the colour of the patch will be that seen by a red colour-blind person. [This was shown on the screen, and the vermilion, emerald green, ultramarine and gamboge were placed in the mixed light, and the alteration in colour of the pigments noted.] In the same way the white light which, blue and green colour-blind see, can be shown.

In measuring the luminosity of the spectrum you cannot but have noticed that the shadow illuminated by the white light never appeared as white, but always coloured. Thus, when placed in juxtaposition with the yellow, the shadow illuminated by the white light appeared bluish; when with the green, reddish; and when with the blue, yellowish. The colour given to the shadows illuminated by the white light is merely the effect of contrast, and is due to error of judgment by the eye. The tendency of white in proximity to a colour is to make it to appear of the hue of the complementary colour, to which I shall draw attention in my next lecture.

LECTURE III.—Delivered December 10, 1888.

My first business to-night is to show you the third constant of colour. You will recollect I told you that the hue is one constant, the luminosity of colour the second, and that the third is the purity of colour. The purity of colour is that which is perhaps the most difficult to measure, but not so difficult to describe. No colour is pure unless it is unmixed with white light. I propose to show you how you can get colour so impure that eventually the colour will entirely disappear and will leave to your eyes only the impression of white. I think my first experiment will very likely demonstate this.

The apparatus is exactly that which you saw before, viz., the colour-patch apparatus. I am only allowing a small beam of light to come through the prisms, to get a small round patch on the screen, instead of the big white patch square to which you are accustomed. Now, supposing I pass the slit in the card through the spectrum, that patch becomes coloured with any of the colours with which I wish to experiment. The reflected beam gives us a large square of white light, which I superpose over the small coloured patch. Let us see whether we can extinguish that coloured light or not. I may take red, green, or blue, and then if I place the rotating sectors in front of the coloured beam you will see that by making the coloured patch fainter it will entirely disappear. This is the case whether we have a blue, red, or a green patch. That the colour is still present I can demonstrate by cutting off the white light, when you see the colour on the screen.

The lesson I wish to inculcate is this—that the blue, green, and red which you saw disappear, and which were mixed with more and more white light, are essentially impure colours, and most impure where the white light is strongest. It was by this method that originally the luminosity of the spectrum was measured. It was seen how much white light it took to extinguish a colour on a screen, and according to the white light it took, so the luminosity was supposed to be proportional to it. To my mind it is not a very satisfactory way of testing luminosity, and I think the way I showed you in the last lecture is far preferable.

There is another deduction I want to point out with reference to this, which is of importance to artists. In water-colour painting it is well known that in order to get what artists call a certain amount of warmth in the picture, a wash of yellow ochre is very often given to the white paper before it is worked upon. Those of you who are water-colour painters know very well that, although you may appear to have a wash of colour on the paper when it is moist, yet when it is very dry apparently there is nothing but white left behind. The colour is so diluted with white that it does not appear to the eye, but the colour is there all the same, and if you increase but slightly the amount of pigment the colour may be visible. All the colours you place on that apparently white paper mix with the yellow ochre. Remember, then, that if you have a wash of water-colour on a sheet of white paper, and it does not appear to the eye, yet subsequent washes of any colour will bring out that colour, and in the case of yellow ochre will give that warmth which artists so often desire to have upon their sketches.

Now, then, as to the question of diluting one colour with another. We have, so far, only diluted a pure colour with white light; but in diluting one colour with another we enter into a region which has been traversed by a great many experimenters, amongst others by Clerk Maxwell and Lord Rayleigh, and there is an immense amount of interest in the results which have been obtained. Some of them I hope to show you in as simple a manner as I possibly can. But I want you to recollect that one can only touch on the fringe of the subject, as it were, in an hour's lecture.

Let me pass some slits through the spectrum of this patch-forming apparatus. First we have a patch of white light, and by a simple means I propose to show you what colours come through the slits placed in the spectrum. If I put another lens L_6, Fig. 1, in front of the big lens, which condenses the spectrum to form the white patch, you will find I can get the

spectrum itself fairly defined upon the same screen as that on which the patch was formed. The second lens in reality produces an image of the first spectrum which was formed in the plane usually occupied by the focussing screen. Now suppose I pass a series of slits through the spectrum you will see the kind of light I am going to use. I have here two colours, and I will show you what is the effect of blending those two—green and red—together; I have only to remove this lens, and we see an orange patch, I will allow another colour to come through a third slit (the card has several), and replacing the small lens we see the three colours. If I blend those three I get a green, and so I may go on blending the colours by passing more slits through the spectrum. Here I have four, and I daresay we shall get a different result again—still it is a green. Perhaps one of the most interesting ways of showing colour mixtures is to take away both lenses, and let different parts of the spectrum pass through the slits, and paint themselves upon the screen. We begin with the red, and here we have a red patch. Then I add yellow which forms orange, and then I shall add a third patch, and pink is formed, then green and blue by adding others until we get nearly a white light in the centre; so I can keep passing these slits through the spectrum, and get many varieties of colour.

Thus we see it is not necessary to have the whole spectrum in order to get certain coloured lights. All we have to do is to take certain portions of the spectrum, and if properly chosen their combination gives us what we call a white light. For example, I wish to show a crucial experiment. I believe every artist will tell you that the combination of blue and yellow gives a green. Now I want to demonstrate that blue and yellow do not give you a green in accordance with the artist's notion, but something totally different. I form my white patch on the screen, as before, and by means of the small lens put a big spectrum on the screen. Passing through the small spectrum two slits, cutting off in the one case all the spectrum except the yellow, and in the other all except the blue, which you see on the screen, and then removing the small lens, instead of getting green we get white. Thus it requires only two parts of the spectrum to be combined in order to get white. So we see blue and yellow give white, not green. This is a crucial experiment, because on this is based a great deal of the theory of colour mixtures, and I want you to bear that in mind.

I would once more ask you to remember that the eye only appreciates three colour sensations, viz., red, green, blue, and that all the other colours which are seen by the eye are composed of two or more of these three colour sensations. I told you the luminosity of the spectrum was greatest in the green. In the diagram
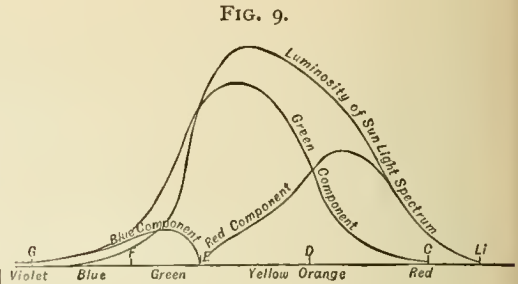

FIG. 9.

(Fig. 9) we have the luminosity curve on a normal or wave length scale; the maximum luminosity is therefore a little bit more towards the violet end of the spectrum than in the prismatic spectrum; the red component, the green component, and the blue component of the luminosity of white light, are shown in the diagram. These three luminosities together make up the luminosity of the spectrum of white light. The blue, you will notice, has but little luminosity compared with the green and the red. The luminosity in the green is far greater than any of the other two sensations. This I wish to get firmly impressed in your minds, noting that the blue is a much less important colour than green or red; in other words, it is far preferable to be colour-blind to blue light than to green or to red light. This, of course, is founded on Clerk Maxwell's theory, though the curves are derived from our own measurements. I think the researches which General Festing and I have made bear out in a very great measure, although they differ in some respects in detail, the results which Clerk Maxwell himself got.

It may be said that we have been dealing with spectrum colours, and not the colours of every-day life. Is it possible that if you are not dealing with spectrum colours that yet you get the same result? The answer to this question I will give by experiment in a very simple manner, and we shall see that we do get the same result whether we are using the colours of pigments or the pure colours of the spectrum. Recollect there were only two rays combined to form white in the

experiment I showed, whereas in the colour of a pigment you may have a great many colours combined, although they give the sensation of one colour to the eye.

The electric light illuminates a circular aperture, behind which is ground glass, and by a lens I can throw an image of this aperture upon the screen. Instead of a simple lens I have here a lens which is divided into two halves. The centre of one half lens is raised slightly above the other. Now every portion

FIG. 10.
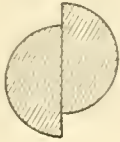
of the lens will give an image by itself, and therefore each half of the lens will give a separate image, one overlapping the other. Thus on the screen we now have two images of the aperture which is in front of the lantern. If I put a piece of yellow glass in front of one half of this lens, I form a yellow disc, and if I put a piece of blue glass in front of the other I form a blue disc, and where the two overlap you have the real colour which a mixture of the blue and yellow lights will give. You can see that yellow and blue do not make green, but white.

But the artist, after all said and done, is not wrong in one way, because he more often than not mixes his pigments together and not the colours reflected from them. Supposing I put the yellow glass in front of the aperture, I then get two yellow discs ; if the blue glass be placed in front of the yellow glass, however, I get two green discs.

Now let us see why this is the case. I must come back to my spectrum, to which we have always to refer when we are dealing with colour. I will put the two pieces of glass successively in front of the light passing into the slit, and ask you to notice what happens. With the blue glass a great deal of red is cut off, and a good deal of yellow ; the blue is nearly as bright as it was before, and the green is fairly bright. If I substitute a piece of yellow glass for the blue, the blue is cut off, and the green left almost as bright as it was before, and the yellow and red are also left. In the one case, recollect, we had the blue and the green left, and the red and yellow cut off. In the

other case we had the blue cut off, and the green and the red left. If we take one from the other we get the green left, so that if I put these two glasses together in front we ought to get only the green left, which is the case. Now if I take away the small lens from the front of the big lens, and form a patch, we have that patch of the same green which you saw in our previous experiment. Here, then, we have the combination of blue and yellow making up the green. Now for one more experiment in relation to this. If a blue sector and a yellow sector be rotated together, and, if what I have said be true, instead of forming green they ought to form grey, i.e., degraded white. Let us see whether it does so. The two discs are now rotating, and we get what is not, at all events, far from grey. Thus we get a blue or a yellow forming a grey or white, when the blue and the yellow are each presented to the eye separately.

Now, I shall have to show you why it is that when they are not presented to the eye separately they form the green. This is a yellow chromate solution in a cell. I place the chromate solution in front of the lantern ; the yellow light falls on the blue sector, which is now at rest, and we have a green. The yellow is almost unaffected, but there is no doubt about the blue becoming green. Prussian blue used in a similar manner leaves the blue sector nearly unaltered, but the yellow has now become green. If I take a still darker blue, the green becomes more pronounced than it was before. You recollect I proved to you, or tried to do so, that it did not matter whether a pigment was next to the paper, or away from the paper, so long as it was in front of the source of light. Now in the case before you, when you mix yellow and blue together, as an artist mixes pigments, you have one particle of yellow, say, in front of a particle of blue, and, therefore, the light which passes through the yellow is that which reaches the blue particle, and that they both absorbed I showed you in the spectrum. The yellow absorbed in the blue alone, and the blue absorbed in the yellow and red, green rays would, therefore, only come through the two.

For the same reason, when I held the yellow glass in front of the beam of light, the blue became green, simply because the yellow glass blocked out the blue, and the blue particles on the paper only allowed the green to pass through. This exemplifies

again what I told you, that it does not matter where you have your colouring matter, whether it is miles away from the paper or absolutely in contact with it, so long as it is between the source of light and the paper itself. But artists, whether they do so knowingly or not, employ the method of mixing the light reflected from the pigments, as well as mixing the pigments themselves, of mixture of colour. We know perfectly well that gamboge and cyanine blue are a very favourite mixture for greens; but, on the other hand, you will find that in some of the most beautiful works of art broad washes, to obtain light and shadow, are not adhered to, but, as in the execution of portraits, stippling is resorted to. Now stippling means that different colours in fine dots are placed close to one another, so close that the eye cannot separate them, and the colours blend one into the other. Thus, if you have, for instance, a great many yellow (gamboge) dots distributed amongst a great many blue (cyanine) dots, the result is exactly the same as you saw on the screen, viz., instead of getting a green the general effect is a grey. This is the whole principle on which stippling depends, viz., the juxtaposition of very different colours to give an effect which otherwise cannot be obtained. Now, the explanation may be new or it may be old, but from having examined a large number of stippled water-colour drawings, one can only come to the conclusion that many of the tender greys which are often seen in stippled works are simply due to the fact that you have two or more colours in dots and fine lines in juxtaposition one to another, which colours, when combined in a rotating apparatus such as you have seen, give the effect of grey to the eye.

I must now repeat the experiment with which I began my series of lectures, viz., that the three colours, vermilion, emerald green, and ultramarine blue, will give you white; and I think that this will be a proof—at all events, a minor proof—that the three sensations which the eye distinguishes are green, blue, and red, and not yellow, blue, and red, as used to be held. Here we have three colours rapidly rotating, and those three brilliant colours give the sensation of white. What proof is there in this that the three primary colours are red, blue, and green? Recollect that I showed you just now that blue and yellow made white, therefore red and green must make yellow. Is that the case? If that be the case, I think the point is proved. Let us see whether such is the case. We will go back to our apparatus consisting of the half-lenses. There is a reddish glass in front of one half-lens, green in front of the other half, the part of the discs which overlap is yellow; hence red and green make yellow. We have already seen that blue and yellow make white, but it takes red, green, and blue to make white; therefore yellow is equal to red *plus* green.

Let me further show this. I have a lens in front of the lantern which forms a slightly larger image of the aperture than before. Cemented alongside one another I have three coloured glasses—green, red, and blue. These, when placed in front of the lens, and in close contact with it, will, with a little manipulation, show a disc of light, something approaching white. The three colours combine to give this result.

I am next going to show you how we can get complementary colours. A patch of white light is now upon the screen by means of our much used apparatus. I have a card in which is cut a wide slot to allow the whole spectrum to pass through, and suspended from it is a little prism, which will cut off a certain amount of the spectrum. The part so cut off will be reflected on to a mirror, and by means of a lens will form a patch on the screen. The rest of the spectrum will go through to the usual lens, and form another patch of white minus the colour reflected. The two patches when superposed give white, but a rod placed in the front give two complementary colours side by side. The complementary colour is that which with the colour itself will give white. I will cut off the different parts of the spectrum, and you will see the real complementary colour. On cutting out the different colours you will notice I get almost every variety of hue, and the colours complementary to them. This seems a very simple way of getting complementary colours, and I think it is instructive, as at the same time it is seen that the background, where the two overlap, is white.

The next point we come to is one that is very germane to our subject, and that is how are we to measure the intensity of pigments in any satisfactory way? As far as I know, a paper which General Festing and I recently read before the Royal Society explains the only method which has been satisfactory, so far, and I hope to show you how that is done.

The desideratum is to compare the intensity of any colour of the spectrum which is reflected from any pigment with that which is reflected

from a surface of white paper. When you get that you know exactly the colour value of the pigment, and by certain methods which I shall show you bye-and-bye, you can at any time make upon the screen by the spectrum alone the exact colour of the pigment you have measured. In order to take these measurements it is necessary to have two similar spectra one above the other, and this we get in the following manner. Upon the screen a lens forms an image of an aperture placed in front of the lantern. Where the rays passing through the lens cross, I put what is known as a double-image prism, and by it we get two discs of light, which will rotate round a centre as the prism is turned round its axis. This double-image prism is of Iceland spar, made by Mr.

FIG. 11.
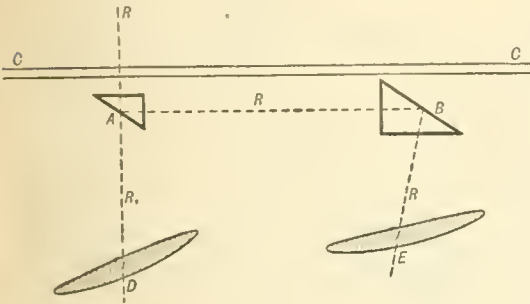
Hilger with his usual ability. It gives us the means of at once getting two spectra one above the other having exactly the same quality of light.

In contact with the lens of the collimator, as it is called (which makes the rays which strike the prism parallel), is placed the double image prism; we thus get two sets of parallel rays, one set inclined at a slight angle to the other. Two spectra by this artifice are formed by the prisms, one above the other, and separated by a breadth of about one-eighth of an inch. Passing a slit through those two spectra, the same colour is cut off from each when the double image prism is properly in adjustment. To the card, C, in which the slit is cut, two right-angle prisms are attached, as shown, and so adjusted that the beam, R, from the top spectrum is reflected first by the prism A, and then by the prism B, on to the screen. A lens, F, of about two feet focus, in front of B, makes a coloured patch on the screen, over-lapping a patch of the same colour formed by the lens D, which comes from the bottom spectrum. By this means we get a parallax of lights of exactly the same colour, one from

the bottom spectrum, and the other from the top spectrum. A rod placed in front of the patch will cast two shadows, one illuminated by one spectrum, and the other by the other. The colour, orange, which I propose to measure, is on one half of this card; the other half is left white, the coloured and the white adjacent rectangles surrounded by a black mask. In the left hand shadow is the white card, and on the right hand is the colour which we wish to measure. In front of the beam which illuminates the shadow cast on the white surface are placed the rotating sectors, and by altering their aperture I can make the two coloured shadows of exactly the same intensity. Stopping the motor, the angular aperture is read off. With another part of the spectrum exactly the same thing is done; by that means we are able to compare the amount of light which is reflected for the pigment, and from the white card.

It is on this principle that these particular colours were measured. To graphically show their reflective power for different parts of the spectrum, the following plan was adopted. Suppose, for instance, that for one spectrum to match the other in intensity throughout its length required an angular aperture of 100, and if for emerald green at a wave length of (say) 5,500, it required an angular aperture of 45, then in forming this curve we set off the wave lengths as a base line, and at 5,500 set up this angular aperture, which gives us a point on the curve, whilst the light reflected from the white surface is represented by 100. Thus, at this point, emerald green reflects only $\frac{45}{100}$ths of this particular light. By taking numerous other parts of the spectrum you are able to build up a curve, which is an absolute measure of the light reflected from the pigment, as compared with that reflected from the white surface. I want you to notice how very peculiar are the curves of the yellow pigments. There seems to be very little difference in the intensity of light reflected from them, but to the eye they appear of decidedly different hues. It is just these little differences in the curves which make up the difference in the hues which are so noticeable. Again, I want you to notice cobalt. You see what a large proportion of red there is in cobalt, and what a little red there is in Prussian blue, Antwerp blue, indigo, or French ultramarine. If we take a line tangential to the bottom of these curves, and parallel to the base line, the height of this tangent shows the amount of white light which
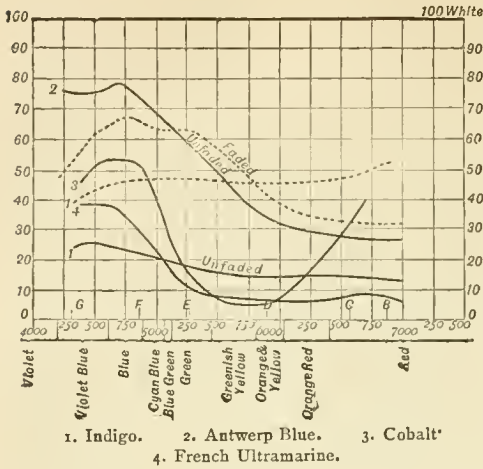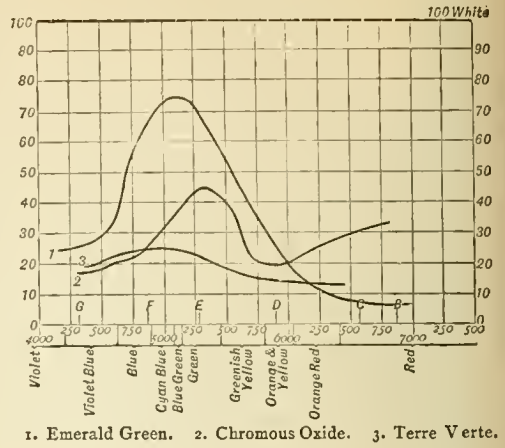
FIG. 12.

1. Indigo. 2. Antwerp Blue. 3. Cobalt·
4. French Ultramarine.

FIG. 13.

1. Emerald Green. 2. Chromous Oxide. 3. Terre Verte.

FIG. 14.

1. Vermilion. 2. Carmine. 3. Mercuric Iodide.
4. Indian Red.

FIG. 15.

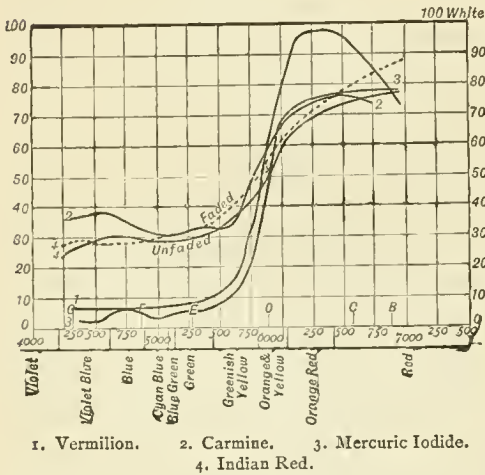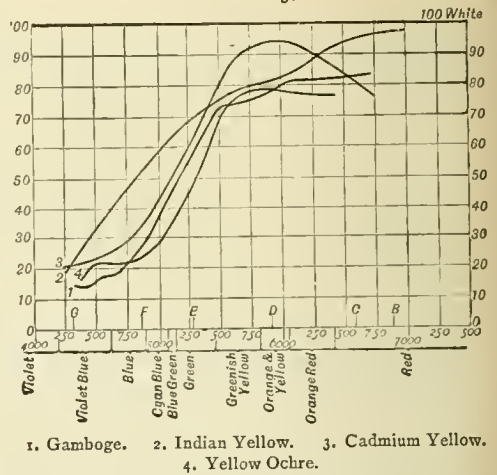1. Gamboge. 2. Indian Yellow. 3. Cadmium Yellow.
4. Yellow Ochre.

is reflected from the pigment, and is a measure of its impurity. For instance, if you take the curve of cobalt, you will see it has about 3 per cent. of white light mixed with it; whilst in the tint measured of Antwerp blue there is about 23 per cent. of white light mixed with the true colour of that pigment. You will notice that, in all cases, a certain amount of white light is reflected from the pigments, and therefore not one is really a pure colour.

Now I want to show you another method, and one which has never been exhibited before, by which we can obtain the intensity of colours in a very simple way. I use for convenience sake a rather short focussed lens in the camera, as I want to form rather bigger patches of mono-chromatic light. Behind those black discs of the motor is a disc of white card, and I am going to measure the intensity of spectrum colour re-flected from a coloured disc by a novel method.

I can put any coloured disc I like in front of the sectors, and in contact with them. I rotate the sectors in the coloured patch, and I can alter the amount of white on the larger disc until I get it to match the luminosity of the colour in the centre. Knowing how much black has to be mixed with white, in order to bring the tint reflected from the colour in the centre to the same value as that reflected from the rotating black and white, I can readily determine the intensity of the light reflected. (Several colours were measured in succession, in the manner described.)

Next on my programme is the method of producing on the screen the exact colour of any pigment. The researches of Dr. Russell and myself on various pigments which have faded in light would be of little value, unless in, say, a thousand years' time those colours could be reproduced with the same accuracy

with which they were measured. We have a means by which we can, without having the pigment itself, absolutely reproduce that colour from a card such as this. I will show you on the screen how it is done.

FIG. 16.

^{D} *Prussian Blue*
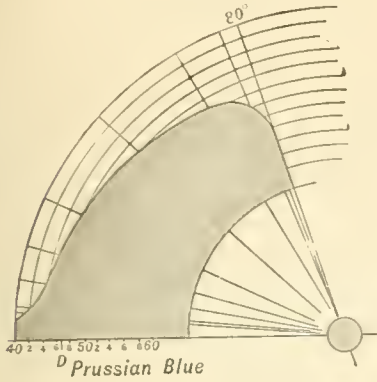
If we mark off the scale of the spectrum along the radius of a circle, and draw circles at the various points of the scale from its centre, and from the same centre draw lines corresponding to the various angular apertures of the sectors required at the various points of the scale to measure the light reflected from a pigment, the point where one of these lines cuts the circle drawn through the particular point of of the scale to which the aperture has reference, gives us a point on a curved figure. Such a figure, when rotated in front of the spectrum in the proper position, will cut off exactly the right amount of the spectrum at each part of it to give the colour required. I will show you one or two of these colours, and by that means you will see that we have literally templates by which our successors in science will be able to reproduce the colours which we have measured in our experiments, and to see whether any alteration has taken place in those particular pigments we have used, and which we propose to leave, either at the South Kensington Museum or elsewhere, for the benefit of those who come after us. (The colours of various pigments of blue sky, gold, and gaslight, were reproduced on the screen.)

By cutting out templates like these, and in your laboratory carefully making the necessary adjustments, you can always reproduce on the screen any colour you may have measured, and if you use the light in which the colour has to be viewed, be it sunlight, gaslight, starlight — whatever light it is—to form the spectrum, you will get on the screen the colour as it would be seen in that light.

LECTURE IV.—DELIVERED DECEMBER 17, 1888.

We have, in the three preceding lectures, seen how colour is produced, and how it depends on three factors—the kind of light falling on to the substance, the kind of substance itself, and also the eye of the observer.

To-night I have to endeavour to explain in one hour what ought to take many more hours, how light acts in altering the colour of pigments through what I may call mechanical means. A water-colour picture (I shall deal only with such) is exposed in the ordinary atmosphere of a room. Sometimes that room is without a fire ; consequently the atmosphere becomes more or less damp, and all absorbent objects, such as paper, take up moisture. At other times, when there is a certain amount of warmth, the moisture which it would take from the air is less ; so that a picture is exposed to alternations of damp and dryness. Dr. Russell and myself concluded that it would be quite fair for testing the stability of water-colour pigments if we exposed them to the ordinary outside atmosphere, and then traced the amount of fading which took place, remembering this, that a picture inside a room would certainly be more stable, supposing moisture had anything to do with fading.

We prepared tubes, as in Fig. 17, perfectly

FIG. 17.

open at each end, but with a small cork in the unbent end, the cork being pierced with a large hole. A current of air could pass throughout the tube when hung on a bar by the bend and exposed to the sunlight. Inside

each tube were strips of paper, covered with a pigment which had been tinted by hand in graduated tints (such as you see here). There were eight tints in all. One such strip was placed in one end of the tube and another in the other. The lower half of the tube was covered with an opaque covering so as to protect it entirely from the light, and the other was left free to the sunlight and the light from the sky. By-and-by I shall show you why it was we deliberately chose sunlight to which to expose our water colours. From theoretical considerations we arrived at the conclusion that fading would take place in a shorter time in sunlight than it would do if we exposed it to the open sky alone.

In such a series of tubes, containing in all somewhere about 100 colours—39 being simple colours, the others being mixed colours—were exposed. The first reading of the amount of fading was taken in August, 1886, or after four months' exposure, and we found that in many of the colours fading had taken place to a certain extent, although perhaps not to so large an extent as might have been anticipated. From time to time after that date the tubes were examined, and the amount of fading noted, our notes showing the deepest tint which was visibly acted upon. Finally, we were obliged to conclude our experiments, owing to the impatience of certain gentlemen who were anxious to get the results we had obtained, apparently for their own advantage rather than for that of the public. We thus stopped our first series of experiments in March of this year, or after these tubes had been exposed about one year and nine months outside my laboratory at South Kensington.

In these tubes, then, we had the ordinary atmosphere, to which moisture and air had free access. If the tube got the least bit heated a current passed through it, much in the same way as would be the case in a chimney. The great point to settle was whether the fading which we knew must take place,

Sprengel pump to work, and made a vacuum, and then when the vacuum was very complete, sealed off the top and exposed them.

TABLE III.

Name of Colour.	Vacuum.
Carmine	No change.
Crimson lake	No change.
Scarlet lake	No change.
Vermilion	Gone black.
Rose madder	No change.
Madder lake	No change.
Indian red	No change.
Venetian red	No change.
Brown madder	No change.
Burnt sienna	No change.
Gamboge	No change.
Aureolin	No change.
Chrome yellow	No change.
Cadmium yellow	No change.
Yellow ochre	No change.
Lemon yellow	No change.
Naples yellow	No change.
Indian yellow	No change.
Raw sienna	Sl. darkened.
Emerald green	No change.
Terre verte	No change.
Chrom. oxide	No change.
Olive green	No change.
Antwerp blue	No change.
Prussian blue	V. sl. faded.
Indigo blue	No change.
Cobalt blue	No change.
French blue	No change.
Ultramarine ash	No change.
Leitches blue	No change.
Permanent blue	No change.
Payne's grey	No change.
Violet carmine	Sl. darkened.
Purple carmine	Sl. darkened.
Purple madder	V. sl. gone.
Sepia	Sl. faded to 6.
Vandyke brown	No change.
Burnt umber	No change.
Brown pink	No change.
Indian yellow and rose madder	No change.
Rose madder and raw sienna	No change.
Raw sienna and Venetian red	No change.
Vermilion and chrome yellow	More yellow.
Burnt sienna and Naples yellow	V. sl. faded.
Indigo, Indian yellow, raw and burnt sienna	No change.
Indigo and gamboge	Gone blue.
Prussian blue and gamboge	Gone green.
Burnt sienna and Antwerp blue	Gone red.
Raw sienna and Antwerp blue	Gone brown.
Prussian blue, raw and burnt sienna, and Indian yellow	Gone brown.
Prussian blue and burnt sienna	Gone brown.
Indigo and Vandyke brown	Faded.
Prussian blue and burnt sienna	Gone brown.
Prussian blue and raw sienna	Gone red.
Indigo and raw sienna	No change.
Indigo and burnt sienna	No change.
Indigo, raw and burnt sienna	No change.
Prussian blue and Vandyke brown	Gone brown.
Indigo and Venetian red	No change.
Prussian blue and Indian red	Gone red.
Indigo and Indian red	No change.
Prussian blue and crimson lake	Gone pink.
Antwerp blue and crimson lake	Gone pink.
Indigo, Venetian red, yellow ochre	No change.
Prussian blue, yellow ochre, Venetian red	Gone red.

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

We here arrived at the very interesting fact that out of thirty-nine simple colours which were exposed, only five were acted upon in the very least, and the amount of change was so slight that you might almost say every colour remained perfectly unchanged in vacuo. The five that were changed were vermilion (which went black to a very slight extent), raw sienna, Prussian blue, purple madder, and sepia. We are apt to look on sepia as one of the most permanent pigments; as a matter of fact it is fugitive in ordinary air, and those who have examined sepia drawings made in the early part of the century will see there has been certainly a distinct fading of those drawings. By the process of exhaustion, we arrived at the fact that it requires both moisture and air to cause the fading of these pigments.

Now the question arose—Would heat without light cause the fading of pigments? Where they were exposed to sunlight it might be surmised, perhaps fairly, that in the sunlight, which we know has a heating effect, the fading might be due to this cause in the open tubes.

This could not be the case in the closed tubes, as in them the colours did not fade. To test the action of heat alone, we took tubes in which the papers were sealed up with moist air, and exposed them for three or four weeks, at the temperature of boiling water, in the dark. There was a certain amount of fading in these colours, but I need scarcely say that the fading was small, and also that the temperature to which they were exposed was something far beyond that to which colours in our open tubes were subjected. If you put a thermometer up one of the open tubes when it is in full sunshine, the difference between the temperature of the air inside it and the air outside only varied between

three and four degrees. That was simply due to the fact that there was a draft created up the tube, as already pointed out.

But another point, and a very fair point for the critics to take hold of, is this. It is all very well to say light alone causes fading, but how about light and heat together, would not the heat aid the light ? This possible criticism was combated, I hope, in a successful way. A certain series of pigments, washed on paper, were taken and exposed on a vessel containing boiling water ; similar papers were exposed to the sunlight free, that is to say, without the presence of the boiling water. In some few cases the fading was rather more rapid, in others less, and you will very readily see why, in some cases it was rather less rapid. You require moisture *plus* air in order to cause fading, and if you heat the paper of course you take away part of the moisture—one of the agencies which are conducive to fading. But the difference between those exposed on boiling water, and those exposed without, was so small that you might take the action of light *plus* heat as equivalent to the action of light alone.

There was another experiment we had to try, and that was as to the rays which caused the fading. I have shown you in my previous lectures that beautiful band of colour we call the spectrum. I daresay you noticed that the beam of light which passes through the slit to form the spectrum is uncommonly narrow ; for accurate experiments we should not use it more than $1\text{-}1000$th inch wide, and that has to be spread out into that band of colours, so that really the light which strikes upon the screen is very feeble indeed. If we had attempted to expose some of these pigments in the spectrum, we should have had to expose them for some thousands of years, and as life is shorter than this, we thought it was better to take some other means of arriving at the conclusion as to what coloured rays were the active agents ; so we adopted a method which, perhaps, may be called crude, but I do not think it is crude when you know how you are going to work. We exposed slips of paper beneath coloured glass—red, blue, and green, and also white. Here are some of the pigments which were actually exposed. We got the results as shown in Table IV. (p. 20).

We exposed 39 or 40 simple colours besides compound colours, and I want you to notice how very few faded in the green, in the red less than the green, but a very great many more

under the blue glass than under either of the other two. You will see that the blue and the white were almost equally effective. Had a certain proportion of the blue rays in the white light been cut off by the glass, practically those two columns, white and blue, would have been identical. Under the red and green glasses the fading of the few pigments which succumbed was so small that it required a practised eye to distinguish it.

Now I will read you some conclusions we came to with regard to the fading of water colours :—" Mineral colours are far more stable than vegetable colours, and amongst those colours which have remained unaltered, or have very slightly changed after an exposure to light of extreme severity, a good gamut is available to the water - colour artist. The presence of moisture and oxygen are in most cases essential for a change to be effected, even in the vegetable colours. The exclusion of moisture and oxygen, particularly when the latter is in its active condition, as experiments to be described in our next report show, would give a much longer life even to these than they enjoy when freely exposed to the atmosphere of a room. It may be said that every pigment is permanent when exposed to light in *vacuo*, and this indicates the direction in which experiments should be made for the preservation of water - colour drawings. The effect of light on a mixture of colours which have no direct chemical action on one another is that the unstable colour disappears, and leaves the stable colour unaltered appreciably. Our experiments also show that the rays which produce by far the greatest change in a pigment are the blue and violet components of white light, and that these, for equal illumination, predominate in light from the sky, whilst they are less in sunlight and in diffused cloud light, and are present in comparatively small proportion in the artificial lights usually employed in lighting a room or gallery."

Now, it has been said that moisture and oxygen are essential for the fading of water-colour pigments. Is it possible that they can fade without light ? I have here a stream of oxygen passing through this tube in which are some papers coated with pigments ; half of each paper has been damped and the other half is dry. In connection with this tube is an ozone generator, and a Ruhmkorff coil produces ozone, or the active state of oxygen, which is said to be particularly present near the sea. In this

TABLE IV.

	White.	Blue.	Green.	Red.
Purple Madder......	Faded to 2	Faded to 1	—	—
Antwerp Blue	No experiment	Faded	—	—
Leitches Blue	Sl. faded	Sl. faded	Darkened ..	Darkened
Violet Carmine......	Faded to 1	Faded to 1	—	—
Payne's Grey	Faded to 1	Bluer	Blue	—
Indigo	No experiment	Faded to 1	—	Sl. faded.
Prussian Blue	No experiment	Sl. faded	—	V. sl. faded.
Rose Madder ...... (2 experiments.)	Sl. bleached	Sl. faded	—	—
Brown Pink	No experiment	Faded to 3	—	—
Crimson Lake	No experiment	Faded	Sl. faded ..	Sl. faded.
Vandyke Brown	No experiment	Faded to 1	Sl. faded ..	—
Vermilion	Darkened	V. sl. darkened	—	—
Carmine	No experiment	Faded to 3	Sl. faded ..	—
Gamboge	No experiment	Faded to 1	—	—
Indian Yellow	No experiment	No change	—	—
Sepia	Become lighter	Become lighter	—	—
Burnt Sienna	No change	No change	—	—

COLOURS MIXED WITH CHINESE WHITE.

	White.	Blue.	Green.	Red.
Antwerp Blue	No experiment	Bleached	—	—
Prussian Blue	No experiment	Bleached	—	—
Purple Madder......	Bleached	Bleached	—	—
Burnt Sienna........	No change	No change	—	—
Gamboge	No experiment	Sl. bleached	—	—
Indian Yellow	No experiment	Sl. bleached	—	—
Vandyke Brown	No experiment	Bleached	—	—
Brown Pink	No experiment	Bleached to 3	—	—
Crimson Lake	No experiment	Bleached to 3	—	Sl. faded.
Carmine	No experiment	Bleached to 3	—	—
Vermilion	Blackened	Blackened under 1 and 2	—	—
Rose Madder	Sl. bleached	V. sl. bleached	—	—
Violet Carmine......	Bleached to No. 1 and darkened to 2 and 3	Same as under white glass	—	—
Payne's Grey	Bleached to 1	Become bluer	Become bluer	—
Sepia	Lighter............	Lighter............	—	—

NOTE.—Sl. means slightly; V. sl. means very slightly; No. 1 is the faintest tint.

frame [shown] you have a series of colours which have been exposed to moist ozone. A great many are bleached entirely, thus proving, if you have ozone and moisture together, you get a bleaching without the presence of light at all. Here are some papers which were exposed, I think for about ten minutes, to moist ozone before the lecture, and you will be able to see the amount of fading that has taken place. In the example of indigo the bottom part was damped and the top part left dry; the first half has faded, the other has not. In carmine, too, you will see that where it has been damped the colour has entirely gone; the dry part is much less changed. We come then to the conclusion that oxygen and moisture are sufficient for the fading of water-colour pigments, and that it is not absolutely necessary that there should be light present in order tha this fading may take place. Now, as before said, you are supposed to have more ozone at the seaside than inland. It is therefore a matter for consideration whether it may not be the fact that water-colour drawings fade more rapidly near the sea, where there is more ozone present, than they would do inland. That is a question I am not going to touch upon now, but when we make a subsequent report no doubt that will be brought forward prominently.

We have seen the results of light, and I wish to show you how it is that light acts upon matter. Matter is formed by molecules, or very minute particles, far beyond the vision of the best microscope that was ever made; you can only reason and argue about them from the circumstantial evidence which nature from time to time puts before us. The molecules themselves are composed of atoms. Thus, in the molecule of water it is supposed there are two atoms of hydrogen and one of oxygen. Each molecule is presumably of identical shape, and size, and composition. There has been a certain amount of evidence brought forward that perhaps some molecules of the same kind of matter are rather bigger than others, but to my mind such evidence is incomplete, and I cannot accept it. At any rate, as a rule, we may take it that the size of the molecule is the same for the same species of matter; that, for instance, all water molecules are the same size and composition, as are those which go to form the molecules of these pigments we are considering.

I want to give you a homely notion of what a molecule is like, and how we may suppose the atoms vibrate. I have here a little cell of water, through which a vertical beam of light can be thrown, and again be deflected to the screen. A lens forms an image of the surface of the water on the screen. Around this cell of water I can cause a current of electricity to pass through a coil of wire. When you have a current passing there is a certain amount of magnetism produced which repels magnetism of the like kind. I have here some little needles which are magnetised, and inserted in small bits of cork by one end, the same poles being in the corks. The corks will float on the surface of the water, thus supporting the needles. Now, if we float some of these little magnets in the water, they will repel each other and tend to go farther apart, the reason being that magnetism of the same kind repels. Now if I turn on the current in the wire passing round the cell you will see that they are found to approach one another, and as I move the wire up and down, they alternately approach to and recede from one another.

You must recollect that at the same time that these atoms are vibrating one towards the other, the molecules themselves are vibrating to and fro from one another, so that we have vibrations of the molecule and vibrations of the atom. Now I have told you that the waves of light vary in length; the red waves are the longest, and the blue waves are the shortest, and as they all travel at the same speed, the time of oscillation of the red wave is longer than the time of oscillation of the blue wave. We may take it that the oscillation of a molecule is slower than that of an atom, and it is much more likely to be isochronous with a wave of red light than it would be with one of blue light. Similarly, the waves of blue light are much more likely to be isochronous with the time of oscillation of the atoms than the molecules, and, as a matter of fact, such we find to be the case.

Now let me give you another homely example of what we mean by oscillation on the part of an atom or a molecule. You can quite understand, I think, that if you have a body oscillating to and fro from another body, both of which attract one another, if you increase the oscillation, a time comes when the attraction between the two is so small that there is a great tendency for them to fall apart. If there is another body at hand which is willing to take up one of those atoms—which has a great affection for such atom—it will take hold of it, and bring it to itself. The bob of this pen-

dulum, which is of iron, is supposed to be an atom swinging to and from another atom, and some three inches behind it is fixed a magnet. By puffing with my breath at the same rate as the pendulum vibrates I can increase the amplitude of that oscillation to such an extent that, eventually, the attraction of the magnet for the bob of the pendulum is greater than the force of gravity, and it reaches the magnet and is held by it. This very simple experiment teaches us a lesson. Here we have an atom swinging away, we will suppose, from another atom of something. My breath timing itself with the swing may be taken as the oscillation of the waves of a ray of light. The waves of light perpetually beating on the atom will increase the amplitude of swing of that atom so greatly that if there is another body near it which will take up the atom, it leaves the original atom for it. When such a re-arrangement of atoms takes place, we say that a chemical action has taken place, that is, that light is able to decompose a molecule by robbing it of some of its atoms, and giving them to another body. We get, then, by the decomposition new molecules formed, and consequently new matter, and such a new body may be in the shape of a faded pigment.

Throwing a spectrum on the screen, I put a layer of pigment in front of the slit, the light passes through it, and we get, as you saw by previous experiments, some colour taken away from the white light, and other colours left behind. In the case before us the red and the green and the blue are left, but most of the green is cut off. I will put another substance (permanganate of potash) in front, which gives a beautiful absorption spectrum, and there are a number of dark bands in it. If I take the iron salt which I used in the experiment in measuring the quantity of light which came to galleries of South Kensington, you see that it cuts off the blue almost entirely. You can see, then, that these various solutions cut off a certain amount of colour from the spectrum. Now the question is this, what becomes of the rays that are cut off? The whole principle of the chemical action, and the heating effect of light upon pigments, is answered by the answer to that question. It is this. Where you have an absorption of light, there you have work done upon the body on which it falls. In that permanganate of potash, for instance, which you saw gave a fine spectrum—the rays missing, which gave the black spaces, were doing work on it. They were heating up the permanganate of potash, or chemically changing it into something else. You cannot have work done on any body unless there is absorption by that body. You understand what I mean by absorption—the cutting off the light by the body. When there is chemical action taking place, the work done is the swinging the atoms away from each other, when heating effect takes place the molecules are swung further apart from one another. I hope I have made clear to you that my view is that when you have chemical action taking place, the absorption takes place in the atoms; when it is a heating effect which takes place, it is the molecules which are acted upon, and made to jostle each other more vigorously. As far as chemical action is concerned we have a very familiar example in photography. I am going to develop a spectrum for you. This has been done before in this room by myself, but as there are many here who have not seen the experiment, I think it might be as well to repeat it. [The photograph of the spectrum was developed.] The paper was covered with bromide of silver, and if I place a slab of bromide of silver in front of the slit, you will see that the absorption exactly agrees with the locality where chemical action has taken place.

Now I have another experiment to show you, and that is the heating effect of radiation. I have here a little instrument called a thermopile which consists of strips of two metals soldered together at one end. If the junction be heated, a current of electricity will pass through wires attached to the other ends when joined; and if a galvanometer is in the circuit the galvanometer needle will be deflected. By means of a mirror attached to the needle, which will reflect the light from a lamp on to a scale behind, I can show you the deflection. I now form a very small spectrum, and cause different parts of the spectrum to fall on the junction of the metals. The needle deflects very slightly with the blue, showing that the heating effect is small; as it gets towards the green and travels into the yellow the deflection is greater, and when we get into the red portion it is again more. At the very limit of the red the deflection is greater still, and outside this colour and in apparent darkness we see that the light on the scale travels further still, showing an increased heating effect. Thus an invisible part of the spectrum which lies beyond the red heats this junction of the two metals more than any part of the visible spectrum. We have here a proof that not only the rays which cause the sensation

why we made experiments with light *plus* heat. I told you we exposed the pigments on paper against a vessel of boiling water to see whether the decomposition was accelerated. It was possible that these dark rays might

FIG. 18.
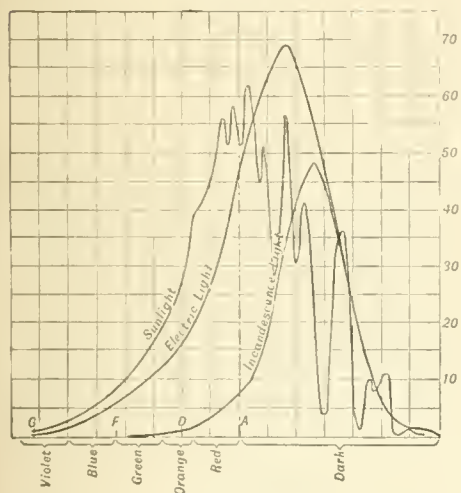
have heated up the paper to such an extent that the heating action aided chemical decomposition by the blue rays which we found most effective.

Now I want to call your attention for a minute to this diagram (Fig. 18), which represents the heating effect of different sources of light. The height of the curve is a measure of the heating effect. The curves on the right hand of the dotted line show the energy of the dark rays, whilst on the left the heating effect of the visible spectrum is shown. The heating effect (which is a measure of the energy) of the dark rays is very much greater than the heating effect of the rays which lie in the visible part of the spectrum. I want to call attention to the solar curve; you see what a peculiar jagged curve it has. The jagged in-

in the visible spectrum, and a very large effect in the dark part of the spectrum. The same applies to gas-light and candle-light.

In estimating the chemical action of radiation on a body, there are two factors to be considered, the intensity of the radiation acting, and the time during which it acts. This is very important. Thus if a certain coloured surface be exposed to a radiation whose intensity we may call 100, which bleaches it in one hour, then if a similar coloured surface be exposed to intensity 1, it will require 100 hours' exposure to effect the same amount of bleaching. There is an idea abroad that if the light be very feeble, no matter what length of exposure be given, it will not affect a bleaching; this, however, is not the case. The same proportion of the total energy absorbed by the body which, with intense radiation, effects chemical decomposition, on exposure to feeble radiation is doing the same kind of work. We may say, briefly, that the deductions from scientific experiments lead us to believe that if strong light causes fading, a feeble light will do the same, if the exposure to it be prolonged. The pendulum experiment, I think, fully illustrates what I mean. I will give you a rather fuller illustration, however. The amount of increased swing that light can give to the atom means an increase in the amplitude of a wave, and the amplitude of a wave in the sea is the height from the crest to the trough. Suppose we have a heavy church bell hung without friction on its supports, and without any resistance to its motion, and suppose it to make a complete swing once a second. Suppose also that at the end of the bell-rope there was a small horizontal plate, and at intervals of a second a thousand grains of water fell from a fixed height on the plate. The bell would gradually oscillate; the bell would be like this pendulum, and finally it would oscillate so greatly that the bell would ring. Now, if instead of 1,000 grains falling from the same height, we had

but one grain falling every second, it would take 1,000 times longer before the bell rung; or if the weight were 1-1000th of a grain, it would take one million times as long before it rung. The work done by the dropping water may be looked upon as the work done by the amplitude of the wave of light on the atom, as it, too, moves without friction and without resistance.

As to the light which pigments in water-colour drawings are ordinarily exposed, a few remarks may be made. There is no doubt that pictures as a rule are carefully protected from direct sunlight, but it is nevertheless true that the greater portion of the light they receive is reflected sunlight. On a bright day the clouds reflect sunlight, and on a dull day

FIG. 19.
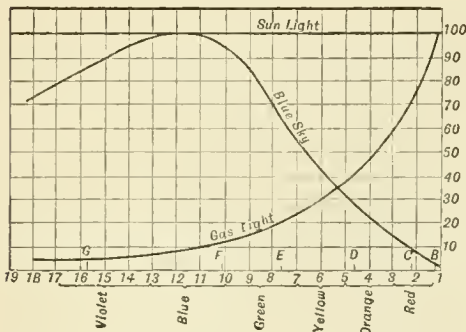
the diffused light is also sunlight, which is reflected according to the laws of geometrical optics, and a large per-centage reaches the earth from the clouds. There is also a fair proportion of light from the sky; this is bluer than that reflected or diffused from the weakened sunlight. In cases where the windows of a gallery are in vertical walls, which is the most ordinary case, and have an interrupted view of the horizon, the blue light reflected is comparatively small, the light near the horizon being distinctly more like sunlight than that nearer to the zenith. In galleries lighted like those at South Kensington the light comes from above. The artificial lights to which water-colours are exposed are gas-light, electric arc and incandescent lights. The first and last are very deficient in blue rays (see Fig. 19). You see, for instance, how deficient gas-light is in blue rays compared with sunlight or blue sky. Blue sky, you will notice, possesses hardly any red light whatever.

Now I think you will see why we were justified in exposing our pigments to sunlight

instead of skylight. If you know the amount of blue rays that are in any particular light, and the amount of work such rays are capable of performing, it is quite fair to translate the action which one source of light has upon a pigment into the amount of effect from a different source of light. That is to say, if I know what action sunlight will have upon a pigment, then from diagrams such as the above, we can calculate the amount of action which skylight will have, and also the gas-light, whether the intensities of the total light are the same or different.

It is now necessary to explain to you how it was that we came to use three kinds of glasses for our experiments to see which part of the spectrum was most effective. As a preliminary, I should like to show you that a pigment may be very rapidly acted upon, although apparently perfectly inappreciably to the eye. I have here two transparent films which were treated with two dyes. Those two films were exposed behind a transparent cross to the electric light for ten seconds, and were then floated over with a silver salt and a developer. From previous experiments we knew that where these particular dyes had been acted upon by light there silver would be deposited on them, and I think you will see that these two show that such is the case. The first film was dyed blue originally, and you will see where the light has acted the silver has deposited upon it. Here is another film, originally red, on which the same thing occurs. I want you to lay this thing to heart. Do not think that because an object does not visibly fade in a year that, therefore, it has not begun to fade at all. A year to one pigment may be the same as 30 seconds to another pigment, and if you expose pigments for a year, which will only fade as much as that particular pigment faded in 30 seconds, then, applying this silver salt, you will probably get exactly the same action after a year's exposure as you did with that shorter exposure on the more fugitive colour.

One more experiment. Here I have a piece of paper which has been impregnated with a silver salt, and has been also dyed with a colour. I want to show you that the smallest action of light on this particular colour will cause the reduction of silver salt. I am going to expose the paper to the spectrum for 10 seconds. [The paper here was developed.] You see in this case that we have a black band corresponding to the absorption spectrum of the dye with which it was dyed. This band is absent where the silver alone without the dye

is acted upon. The dye has been acted upon, and thus caused a reduction of silver to take place where it has been altered, although such alteration is perfectly invisible to the eye.

Now I can show you why we chose red, blue, and green glasses for our experiments. I want you to notice the different parts of the spectrum that these particular glasses absorb. Passing the glasses through the spectrum, the red glass allows the red, and a little bit of yellow and green, to pass (see Fig. 20). With the green glass a great deal of the red is cut off, and all of the violet. With the blue glass you will see that a great deal of the red is cut off. Thus, in the case of the blue glass, we have the blue principally left, in the case of the green the green principally left, and in the case of the red glass we have the red principally left. Now, suppose I put the red glass and the blue glass together, what would happen? We only ought to have a bit of the red of the spectrum left, and if I put the green glass with these

FIG. 20.
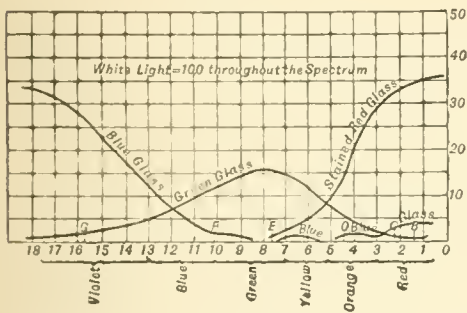
we ought to have nothing left, which is the case. In other words, the rays transmitted by those three glasses make up the whole spectrum, so that when using those we are utilising the rays of every part of the visible spectrum. It was for this reason we choose those particular glasses through which to expose our pigments. Fig. 21 shows the heating effect of the light after passing through the different glasses. Notice the dark rays. They are nearly entirely transmitted through the red glass, very slightly through the blue and green glasses. Had the fading of the colours we have examined been due to the dark rays, it ought to have been shown beneath the red glass far more than under the green or the blue glass. This was not the case, as a reference to Table IV. will show. We may, therefore say that the blue, violet, and ultra violet rays are those which are by far the most

active in producing a change in the pigments with which we have experimented.

I may say a word or two about the exposures we gave, and the results deduced. We exposed between May, 1886, and the middle of August, and we found that during that time these pigments had 705 hours of bright sunshine. That bright sunshine we reduced to so much sky light, and the total amount of effective sky light received in that time was 1,700 hours. Allowing for overcast skies, and for blue sky light and sun light, we find that these pigments had an average of 2,225 hours of average of blue sky—or, roughly speaking, 2,500. We may now go a step further, and calculate the amount of illumination which a

FIG. 21.
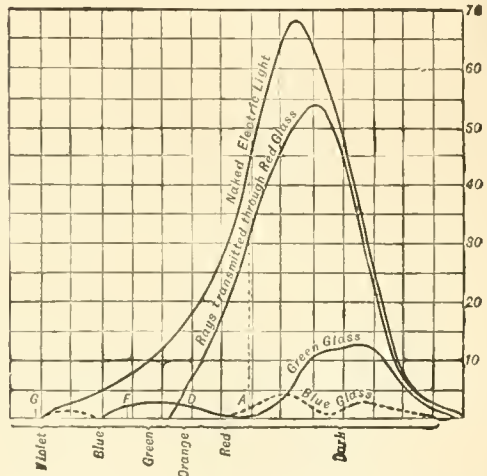
picture shown in a gallery such as those at South Kensington would have during the same period. There is no direct sunlight, and making calculations from photometric observations, and seeing how much light came into the gallery, compared with that outside, we came to the conclusion that to have the effect on these pigments in the galleries which took place in the sunlight, 32 years would have to elapse, supposing the light was always equally bright to that between May and August. But we know it is not equally bright, and we came to the conclusion that it would take 100 years to get the very little fading such as we got outside the laboratory in four months.

Now let us see what would happen to a pigment supposing it were exposed to gas light. Calculating the amount of blue light in such light, and also the total illumination in the

gallery in question, we found it would require at least 2,000 years of continuous exposure for the same amount of effect to take place as occurred in the four months of sunlight exposure. After an exposure of one year and nine months, we have the astonishing result that to obtain fading of the same amount in the colours exposed, it would have taken 485 years of average daylight in the galleries to have got that amount of bleaching. If we had exposed it continuously to gas light, the time required is almost incredible to believe, viz., 9,600 years. With these facts before us I think you will say it is not at all surprising that we chose to use sunlight instead of any other source of light for our experiments. I am afraid that neither Dr. Russell nor myself are good for 480 years, and therefore we preferred to use the shorter time of one year and nine months in order to arrive at the conclusions we did.

The methods of measurement that I have brought before you are for the most part new, but I believe they can escape any very serious criticism. The details of many of the experiments, from which our calculations have been derived, have been published in various papers laid before the Royal Society and the Physical Society. I may say we have the greatest reliance on the accuracy of them.

I have now finished my course of lectures, and I have only to thank you for the great attention which you have paid to me.

CANTOR LECTURES

ON

PHOTOMETRY.

BY

CAPTAIN W. DE W. ABNEY,

C.B., F.R.S.

Delivered before the Society, April 2nd, 9th, and 16th, 1894.

PHOTOMETRY.

The lectures on photometry are not given with the idea that they will be of practical value for the measurement of gas light. There is excellent literature on the subject, part of which I shall have to refer to during my course. What I have undertaken in these lectures is to endeavour to give an idea of the general principles of photometry, almost restricting myself to the scientific aspect of the question. Photometry, in its broadest sense, is the measurement of light, at least, so we must think, from its derivation. Now, the light measured may be light coming from an object, or from a self-luminous body, such as a candle or the sun, or it may be the light transmitted through objects. In the second case, if an appropriate screen be used to receive the light, we are in reality measuring the illuminating power of the source of light, rather than of the light itself. Hence, almost as much depends upon the screen on which the light is received as on the light itself. A screen is usually what is called white, and by white is meant a screen which reflects every colour equally well ; but, I would remark that in London the white may become imperceptibly brown, and such colour may interfere materially with accurate results. But the photometry that I am alluding to not only includes the measurement of the illuminating power of light, but the measurement of the light transmitted through bodies of various kinds, when they are transparent, like plain glass, or translucent, like ground glass or paper. The requirements of the candle-power of gas I shall not enter into, as it is a subject which others than myself are much better fitted to deal with.

We may take it, I think, that the first matter we have to consider is the light we have to use as a standard. Parliament, in its wisdom, in 1860, pronounced its standard of light to be the light of a candle 6 candles to the pound, each burning 120 grains of sperm per hour, and this is at present the only legal standard known in England, though why, in the name of common sense, such a definition has been continued our legislators alone can guess, when it has been proved to be so faulty. The standard of light for France is the Carcel lamp, which is equal to about 9·5 candles. Now, a light from a candle is a very pretty thing theoretically, but practically it is anything but practical, as it has the unhappy knack of burning inaccurately, particularly when one is anxious to shield it from draughts. Heat affects the rapidity of combustion, and if it be confined, and no proper access of air be given it, its light may be most irregular. We have to remember that part of the energy of combustion is taken up by melting the sperm, or wax, or whatever it may be, and if the surrounding air be heated the wax is at a temperature nearer its melting point than it should be when at a normal temperature. When the melting point is attained the liquid is decomposed and the flame results, and there is more liquid to be vapourised and vapour to be improperly consumed than in the normal state.

I show you a trace made by photography of the light from a candle burning under normal conditions. The light was admitted through a slit to sensitive paper, and a fresh portion of paper was continually being exposed. You will now see the irregularity of the burning. Of course, by taking several candles the variation is not so great, but even then you have to be sure that the proximity of the candles to one another does not alter the rate of burning.

An Argand burner, however small, will not, during a long series of experiments, differ 1 per cent. in light value. Here we have a proof of this. This small paraffin lamp was allowed to burn for three hours, and you will see that the band it makes is perfectly uniform in appearance, and when the measurement is

made of the blackness produced by it on the photographic paper, it proves my statement is correct.

The apparatus by which these diagrams were made is a very simple one. It consists of a clockwork arrangement drawing a pulley, which pulley is in connection with a drum, which can rotate on its axis. Round this drum is placed sensitive paper, and a box, with a long slit in it, covers the drum. The light is placed opposite the slit, which is covered by a moveable lathe, in which is an aperture of a convenient width. As the drum moves, this aperture moves across the slit, and so we have a corkscrew band of exposure produced. With some clockwork the motion is regular in its irregularity, and every tooth of the train can be counted on it, by noting the bands of varying exposure, and for this reason the clock was at one time abandoned, and the smooth motion of the sinking of the height in subsiding water was substituted. This gave very good results, but for my purpose the clockwork was sufficient.

The sources of light I have mentioned are what may be called feeble sources of light, and cannot be used when a body is fairly absorptive, if the transmitted light is to be measured. We want in such a case a stronger source of light, and one which is practically constant. Such a source of light we have in the electric arc light. If we project upon the screen an image of the points where the positive pole is slightly behind the negative pole, with a fairly long arc, we become aware that there is a central part, which is higher than any other [shown]. It comes from a depression in the positive pole, and for the last eight years I have been in the habit of using this as a source of light of uniform intensity, and many hundreds of measures have proved it to be so. This, as several years ago I pointed out, was due to the fact that the temperature of this spot was that of the volatilisation of carbon. It is an intense light, and may be taken as 50,000 A.L. per inch of surface, and very useful for a great many purposes, as we shall see as we proceed. Now we call all these lights which I have mentioned white, but it is quite evident that there is white and white if all these be white. I believe myself that Mr. Lovibond's definition of white is a good one, which is the light which is seen in a white fog about midday, and if we compare this light with any other we shall, I think, come back to it as being a very practical white light. Now the electric light is not far

from this quality of light, and as such is very useful in comparing the transparency of objects by what is approximately daylight. We can measure the light of each part of the crater passing through a small hole.

We can at once see the difference between all the ordinary lights by a simple experiment. This box is divided into partitions with tissue in front, and in each partition we have a different source of light — a partial gas jet, an Argand gas - burner, a candle, and a paraffin lamp. It will be noticed that the light enclosed in a chimney is much whiter than those burned in free air, but you will also see that all these lights have various depths of yellowness when compared with the electric light. It is quite evident that even supposing they gave the same illumination, that they are not all fit for standard lights. I take it that a standard light in photometry must always have the same quality of light as well as the same quantity of light. Now we can, by appropriate means, make the electric glow-lamp light of the same visual intervals as a gas jet. The one before us is so, but it is evidently not of the same quality. One of the very best tests that we can make of ascertaining whether any difference in quality exists is to see if, when they are equally strong visually, they give the same photographic results. [An experiment was made with an electric light and an amyl acetate lamp, in which both were made of the same visual intensity, but photographically they differed materially.] You see that the amyl acetate lamp is decidedly the worse photographically.

Perhaps I can show you why this is. I take an incandescent lamp, and cause it to glow : it goes red, to begin with ; then I increase the current, it gets yellow, then whiter, and so on, till it is nearly white. I cannot make it as white as the arc light, for the reason that, as the temperature increases, the fusing point of carbon is reached, and that, as I pointed out, is the temperature of the crater of the arc light. These temperatures, however, are subject to different amounts of energy expended upon them ; and here I have a diagram, showing how, with an increased energy expenditure on the same filament—that is, with an increased temperature—the different rays of the spectrum are altered in proportion. These diagrams are taken from measures made with a linear thermopile, moved through the spectrum. You will see that the higher the temperature, much more rapidly do the rays of high refrangibility increase.
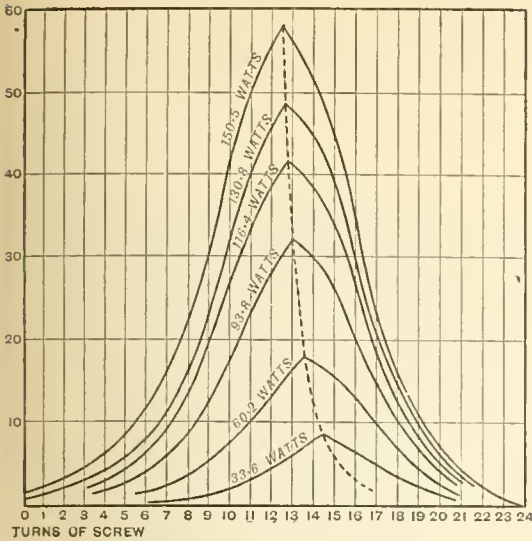
FIG. 1.

FIG. 2.

The value of the abscissæ in Fig. 1 (in wave lengths) is as follows :—

	λ			λ
1·25	 5,900		13	 14,650
5	 7,250		17	 20,750
9	 9,900		21	 27,500

These numbers apply to both diagrams, and in Fig. 2 the numbers attached to the different curves, are those which are attached to the abscissæ in Fig. 1.

Let me show an experiment. I will balance an electric light against the amyl acetate lamp, and expose a piece of paper to its action. I will increase the temperature and balance again, and expose another portion of the same paper to its influence for the same time. Notice, please, the difference in the two. You will find that the highest temperature filament is much more " photographic." By this means all lights, which are due to the incandescence of solid particles of carbon, can be tested as to quality. Make them visually equal, and then see if they are photographically equal. For my own part, I believe that a knowledge of the photographic value of light is essential in the near future ; for I cannot help thinking that there will have to be a registration of photometric values for record, independent of the eye, and this must be by photography.

For this purpose the photographic value, and the visual value of every light used, will have to be known and carefully recorded. We shall see soon how these records can be
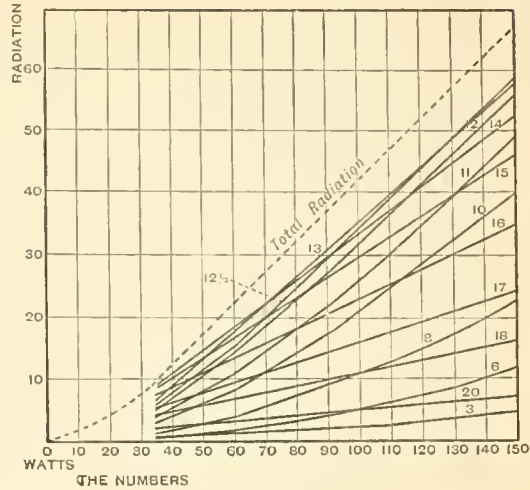
utilised, and become of permanent value in themselves, being capable of being measured at any date after being made, and remeasured if required. I throw on the screen the photographic values of a candle, an amyl acetate lamp, a gas jet, a paraffin lamp, and an arc light—all made of the same value as a candle visually [shown]. You will see that they vary enormously, and the scale of opacity below, which was made by exposing different parts of a plate to a steady light for different times, gives us a means of comparing one with the other.

I have said that all lights which are due to solid particles of incandescent carbon can be tested by means of photography, and I have shown you the deposits which certain lights cause on a photographic plate. There can now be but little doubt that a luminous candle flame is as much due to solid incandescent particles as the glow-lamp we have been using. The final proof has been long in abeyance, but I think no doubt now can exist regarding it. First of all, if we examine the spectrum of the luminous part of the flame, we find that it is continuous, though occasionally a bright line of sodium in the orange puts in an appearance, but it is of no account. Now any light which emits a continuous spectrum must be due to a solid or liquid body in a state of incandescence, or to a gas in similar state, but under great pressure. The flame is certainly not liquid, nor is it gaseous under pressure. It seems, therefore, the light must be due to solids, and those solids must be so small

that even a microscope of low power will fail to distinguish them. This fact (if it be a fact) enables us to put the matter to a good test. If we project a beam of light against a cloud of small particles, the rays which are most refracted (the violet and the blue) are violently scattered in all directions, as Lord Rayleigh has shown should be the case theoretically, and the greater the number the more yellow is the light coming through them. There is one peculiarity, however, about these scattered rays, viz., that those which are scattered at right angles to the beam are what are termed polarised in one direction—that is, that if they pass through a Nicol's prism turned in one direction, they become quenched, whilst they will pass through readily if the Nicol be turned in the direction at right angles. You will see what I mean by the scattering by an experiment which I now make.
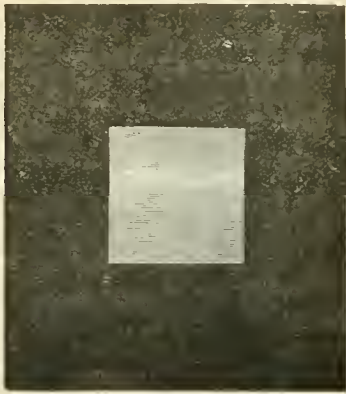
the solution, the path of the beam is clearly visible, but if I turned it in a direction at right angles it is at once quenched. Its existence, in the first case, and its absence, in the second, shows that the light, coming at right angles to the beam, is polarised. This you can see for yourselves, at least most of you who sit in the proper direction; but for the sake of those who do not I take two photographs, one with the Nicol turned, so that the polarised light passed, and the other when it was turned, so as to present the beam. You see the result.

Now let us apply this to the small carbon particles. If a beam of intense light, such as that coming from a small image of the sun, be thrown on the flame of a candle, a white beam of sunlight should be seen on the flame, and a beam of white light passing through the flame. Unfortunately, I have not the sun at

Fig. 3.

Fig. 4.

If to this clear solution of hyposulphite I add a few drops of hydrochloric acid, it becomes cloudy, owing to precipitation of fine particles of sulphur. I allow a beam of light to pass through the solution before I make the addition to the screen, and then add the HCl. The light becomes yellowish and then reddish, as the number of fine particles increase; that is, the more particles the redder it becomes, and the more light is scattered, as a look at the cell testifies.

By precipitating mastic in water we get the same results. Here is some which has stood two years or more, and while it is turbid the beam of light passes freely through it, but scatters light on each side. Now, if I pass that broad beam of light first through a Nicol's prism, turned in one direction, and then through

my command here to-night, so I cannot show it, but you may take my word for it that such is so. Sir G. Stokes examined this white beam in a position at right angles to its direction, and found, by means of a Nicol's prism, that it was completely polarised; that is, that when the Nicol was turned in one direction, the streak of white light in the flame disappeared altogether. This establishes the fact that the luminous part of the flame is due to small particles, independently of any other proof. It appears to me, therefore, that one is correct in stating that the bright flames are due to measurement carbon. Into the theory of flames I will not further enter at the present time; this is enough for my purpose.

In case there be any doubt amongst you, I will show you some photographs of the phenomena I have taken.

Fig. 5 is a photograph of an Argand gas-flame, on which the rays of the sun, collected by a lens of about 8-inch focus, were concentrated so as to pass along part of the circumference of the cylinder. The Nicol prism was turned in such a direction that the scattered rays would be unaffected in the left-hand

FIG. 5.

photograph, whilst it was turned at right angles to the first direction for the right-hand photograph. In the left-hand figure the track of the beam is readily seen, whereas any trace of it is absent in the right-hand figure. Fig. 6 is the same, but the electric arc light was used in place of the sun. The results are the same.
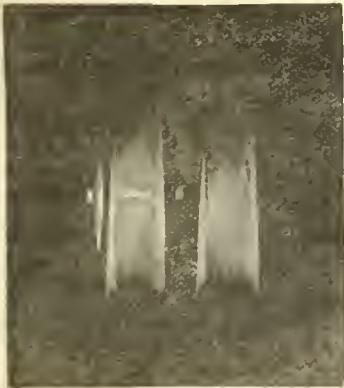
FIG. 6.

Fig. 7 shows the results when the beam from the electric light is passed through a candle flame. In the one figure a broadish white band is seen, whilst in the other it is absent.

We are now in a position to see why it is some flames are whiter than others. When a chimney is used with gas, for instance, we find that the illumination is whiter—bluer, if you like the word better. The function of a chimney is to supply air to the flame, ample room being found through interstices to allow as much air as is needed to be drawn up into the chimney. In the case of hollow flames, such as an Argand burner, not only is the air admitted to the outside shell of the flame, but also to the inside. The consequence is that the small particles of carbon are heated to a higher temperature, as they are in the blacksmith's forge by the bellows, and they then emit a whiter heat before they are converted into carbonic acid. When one has a smoky lamp, there is one of two things happening—either the supply of air is insufficient to the chimney, or else the flame is too high and the sudden access of cold air chills down the incandescent carbon particles till they become black, and smoke results. One of the
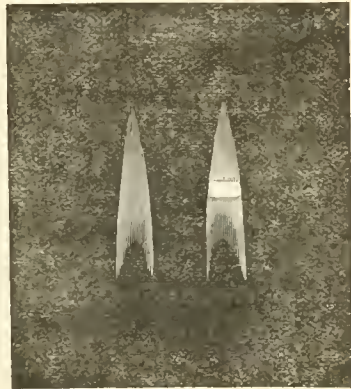
FIG. 7.

most instructive experiments as to the need of air and warmed air to a flame is shown by lighting a paraffin lamp. It is an orange smoky flame, but directly you place the chimney on it the light whitens and the smoke ceases.

I should here like to correct a very common notion which exists regarding the blackening of ceilings by gas flames. As a matter of fact, the carbon in a gas flame ordinarily is totally converted into carbonic acid. It is the ascending current of heated air that catches up the floating motes in the room and dashes them against the ceiling, to which some cling tenaciously, and gradually the blackening is encountered. A friend of mine lately put up the electric light in his house, and placed the glow-lamps close to his ceiling. He was astonished to find that the ceiling above them blackened to an extent which reminded him of gas. It was the current of warm air which

caused the blackening. Similarly, hot-water pipes will do exactly the same thing. Heated air will ascend, and when it ascends it carries the motes and particles with them. In South Kensington Museum, ceilings which adjoin hot-water pipes blacken quicker than where there is gas, the reason being that the volume of heated air is so large.

LECTURE II.—DELIVERED APRIL 9, 1894.

I omitted, from want of space, to say in my last lecture that the fact that a flame viewed end on is from 10 to 35 per cent. less luminous than when viewed sideways. Fig. 8 gives a measurement if taken with a flame at different angles to the screen according to Mr. Dibdin. The variations in the light of a burning candle

FIG. 8.

minant. I put the amylacetate lamp first not because of its superiority, but because it requires such little manipulation. This is a lamp which is a great favourite of mine because it is so accordant in its results. It consists of a tube of German silver, 8 mm. in diameter, and 25 mm. high. The flame is 40 millimetres high, and when it has been burnt

FIG. 9.
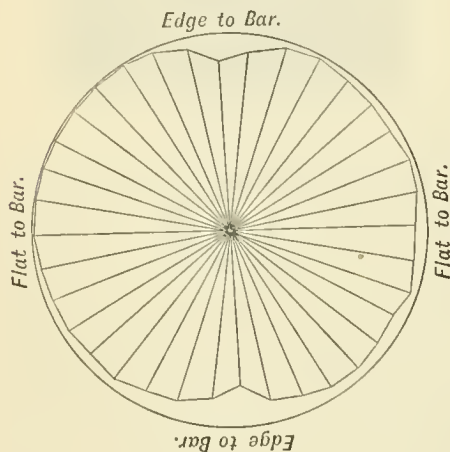
has been shown you, and I think that for scientific working it must be dismissed as unworthy of serious consideration. There are only three what I may call feeble light standards which I shall refer to, viz., the amylacetate lamp, due to Hefner Alteneck; the pentane illuminant, and the ether illu-

for five minutes the flame remains of a constant height. It burns amylacetate, but it is not necessary to use this compound, as any similar one will consume as well. Hefner Alteneck gives a Table of the results of the different compounds and their comparative luminosities :—

	Constitution.	Per cent. of carbon.	Boiling point.	Intensity of light.	Time for the combustion of 1 gramme of the substance	Carbon consumed in 100 seconds.
			C.			
Valerate of Amyl...............	$C_{10}\ H_{20}\ O_2$	69·7	195°	1·03	430	0·162
Acetate of Amyl	$C_7\ H_{14}\ O_2$	64 6	138°	1·00	388	0·166
Formiate of Amyl...............	$C_6\ H_{12}\ O_2$	62·1	122°	1·01	372	0·163
Acetate of Isobutyl	$C_6\ H_{12}\ O_2$	62·1	116°	0·99	373	0·163
Formiate of Isobutyl	$C_5\ H_{10}\ O_2$	58·8	98°	0·97	355	0·166

The drawback to this lamp, as originally constructed, is that the metal takes a green deposit, which is tiresome ; if it be plated with silver, this disappears.

Dibdin's pentane Argand, which burns pentane, is the next one to refer to, and is the lamp which appears to me most perfectly to utilise the pentane, employed as an illuminant, in a simple method. Pentane is a hydrocarbon of the paraffin series, but is not perfectly pure at all times. The illuminant is air passed over a carburetter containing the pentane. The height of the flame is 3 inches, $\frac{7}{10}$ths of which are cut off by a screen at the top. By these means a standard flame is obtained, which is equal to 10 candles. The great point in this is that the height of the flame does not affect the result, at least it does not to the eye. Temperature has no effect on the result, as Mr. Dibdin has thoroughly tried.
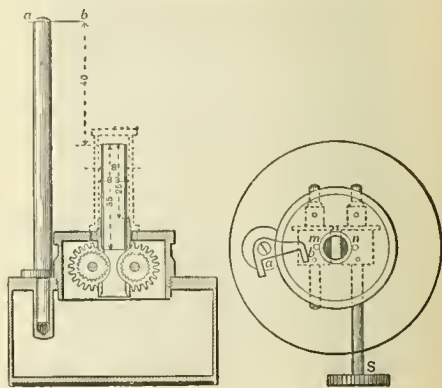
The next standard is a very simple one, introduced by Mr. Dibdin more especially for photographic purposes ; ether, instead of pentane, is burnt in a pentane lamp, and gives a very fine light. Photographs taken with these two lights at different heights of flame, but of the same visual intensity, do not give quite the same photographic effect, so that there is a deviation from the definition of perfect standard.

We have seen what kind of a light we must use for photometry as to quality and quantity. Now we come to photometers. The photometry we will first consider is the comparison of two lights together. How are we to compare two lights ? There is one evident way, and that is to place side by side two white surfaces which are illuminated by the two lights. This is the principle of Rumford's photometer and nothing else. We are usually told that it is the method of shadows—the comparison of shadows one with the other. Now it is nothing of the kind, it is really the illumination of a surface by two distinct lights,

the one illumination being not interfered with by the other, and this is secured by making one light cast a shadow of a rod on the screen, which is illuminated by the other, and this last light to cast a shadow of the same rod at a different place, which is illuminated by the first light. These two illuminated surfaces can be made to touch by moving the rod or the angle of the light, and by various plans these can be equalised in brightness. No less a distinguished authority on photometry than Mr. Dibdin, in an excellent book he has written, says, although this method has certain advantages, "the method is one which few practical photometrists of the present day would venture to adopt." Well, I am a tolerably practical photometrist myself, and I must confess I prefer it to any other kind of photometry, as it is simple, and very few errors can creep in if one is ordinarily careful, which is more than can be said of some others, as we shall see. One error that may be met with is that if the lights make a great angle with each other, and if the screen is not placed at right angles to the line bisecting the angle, an error may creep in.

Let me show you this experimentally, and this experiment really demonstrates another mode of photometry.

This white cube is placed between two lights, one of the right angles of the cube being towards you. I place a square aperture in front, so that it is bisected by the edge. The cube is rotated round that edge as a centre, till the two sides appear equally illuminated. The reason of the equality of illumination is quite plain. It is because the side nearest the light is skewed at a greater angle than the other to it. If we have a diagram, we shall see why this is. In Fig. 10 (p. 8) A B and B A are the two sides of the cube illuminated by rays R and R. It is evident that the side A B will not receive so many rays as B C, in fact, the amounts are measured by $p\ q$ and $m\ n$. If the lights are unequal, of course when the

intensity of the one multiplied by $p\,q$ is equal to the intensity of the other multiplied by $m\,n$ the two will equal. The intensities, where a balance is struck, is found by taking the cosines of the angles through which the cube is turned.
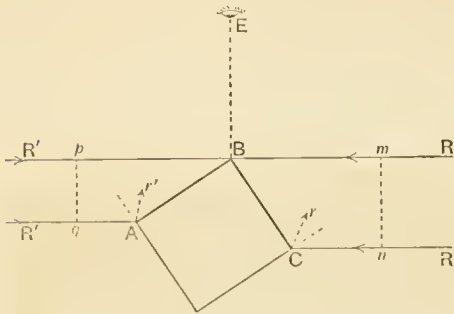

FIG. 10.

We now see that light illuminating a surface varies as the cosine of the angle through which it is turned. If it be turned 5° more towards one light than the other it is evident that we shall get a variation. The amount would be as 1 to ·996, or an error of $\frac{4}{1000}$, or $\frac{1}{250}$. If it were 10° it would be 1 to ·984, or $\frac{16}{1000}$ or $\frac{1}{62}$ part, which would be appreciable.

There is still one more error which might be felt, and that is that the eye receives more light when the angle which the screen makes with the eye and the source of light is greater than a right angle (see r and r' in Fig. 10). This must always be the case, but what may be called the difference in the specular reflection is so small for ordinary angles, that it is of the same order as that given for the wrong placing of the screen, and becomes practically negligible.

For great accuracy the illuminated shadows should touch, and if the lights be not too broad, there is no difficulty in causing this to be done; sometimes, however, a white line or a black line will separate the two owing to the penumbra of the shadows, and then making the illuminations of the two strips equal becomes more difficult. As the black line has greater contrast to the two illumined surfaces than the white line has; the former is the worst kind of line to put up with.

The next method that is adopted is what is known as the Bunsen method. It consists of equalising the brightness of a greased spot in the centre of a paper disc, or its total disappearance. The principle on which this is based is the translucence of the spot. If as much light goes through the spot (if perfectly made) from one light as goes through from the other, the spot is equally illuminated throughout its thickness, and appears the same whiteness as the paper. If it be greater on one side it will appear dark on one side, and lighter on the other. It is evident that with such a method every suspicion of stray light must be rigidly excluded, unless it be exactly the same on both sides of the disc, and only that coming directly from the sources of light utilised. Light reflected from the sides or bars will give fatal results as far as accuracy is concerned. I have met with some instruments in which reflections seem to have been encouraged rather than allayed. To my mind the method should not be accepted except in the hands of those who are thoroughly practical and scientific. I show the design of a Letheby photometer, kindly lent me by Mr. Sugg. [The instrument itself was in the lecture-room, through Mr. Sugg's goodwill.] The grease spot is viewed on both sides by inclined mirrors, and when the grease spot disappears on both sides, or at all events appears to equally dim on each side, the light illuminating the spot may be said to be equal.

There is one thing to be noted, and that is that very much depends upon the kind and amount of grease, and the kind of paper, employed. I have made a good many grease spots in my day, and I have found the sensitiveness of the method vary considerably according to the attention paid to these details, but I have abandoned the method in my laboratory, except under special circumstances, in favour of the old Rumford method.

Mr. Dibdin, in his work, says:—

"When first setting up a disc for use, special experimental readings should be taken; and if any material difference is found between the indications when one side or the other is turned towards the standard flame, it should unhesitatingly be rejected, as no amount of after allowance can compensate for the trouble and doubt arising from contradictory results. The disc should be clean and perfectly free from scratches or other markings of any kind; it is but sorry economy to work with a defective instrument. The Gas Referees went so far, a short time back, as to run a new disc, to be used every week. As, however, a good disc, when taken care of, will last much longer than that period, the point has not been insisted upon; but that is no excuse for the continued use of a defective one, which should be instantly destroyed as soon as detected."

We see from this that a disc photometer is open to a very grave objection, and it is for this, if for no other reason, that I prefer the

Rumford system, where there is no liability to err on this matter. A modification of the Rumford method of shadows is that employed by Prof. V. Harcourt. He casts his shadows on ordinary printing paper, rendered partially translucent by a wash of spermacetti dissolved in petroleum. Instead of a rod, and about three-quarters of an inch from the paper, he places a brass screen, having two rectangular apertures cut in it exactly their own breadth apart. The two lights are placed at equal angles on each side of the line perpendicular to the screen, and the illuminated shadows are caused to just touch one another. It will be noticed
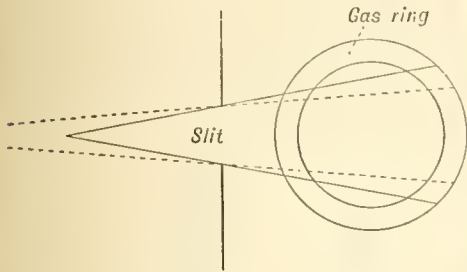
FIG. 11.

that really there are four shadows illuminated, one from one light being touched by the other two, and the fourth falling on an opaque or black space. A great advantage of this plan is that they are looked at from the back of the screen, no rod being between the eye and the screen. If two lights of approximately the same colour are looked at, the fact that the light has to traverse the paper is of no moment, though, when coloured lights have to be compressed, there is a danger of absorption slightly altering the values that should be obtained.

Before quitting the subject of the Bunsen method, I ought to mention that in photometry, for the grease spot is sometimes substituted a star of thin paper, sandwiched between thicker paper; that is known as a Leeson disc, and has been much improved by Mr. Dibdin.

Methven proposed to use a slit placed in front of an Argand gas-jet as a regulator, if I may call it so, of the quantity of light issuing
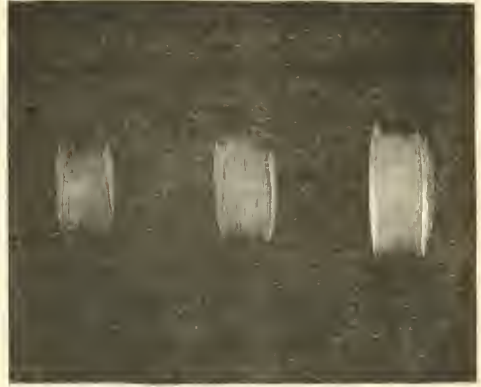
FIG. 12.

on to the grease spot. This appears at first sight an admirable arrangement, and it would answer well if the grease spot were always kept at the same distance from the source of light, but when it is moved, an error, though it may be very small, must be introduced. An Argand flame is practically a hollow cylinder of light, of a certain thickness (Fig. 11). As you approach the light the section of the cylinder varies,
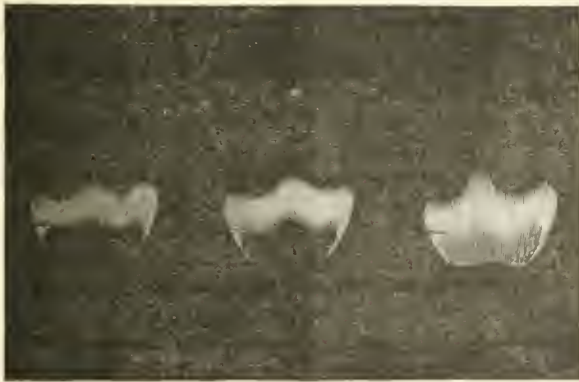
FIG. 13.

and consequently the quantity of light falling on the spot must vary beyond what it should do. It may be remarked that putting aside this error the measurements are made from the slit and not from the source of light, which is a decided advantage. Messrs. Hurter and

Driffield have to a large extent got rid of this light and employ a flat flame, of large size, as the source of light, and use a small square aperture in front of the flat side. As the section of such a flame appears to be uniform, the inaccuracy of measurement introduced is done away with. In reference to this, it may be interesting to show that in an ordinary flame the light varies in intensity at different points. This can be done well by means of photography, reducing the exposure each time. Fig. 12 (p. 9) is an Argand burner flame, Fig. 13 (p. 9) a batswing, and Fig. 14 an ordinary candle.

It will be seen that in the candle flame we have an almost expected result. The Argand gas is more surprising. The batswing gas is perhaps the best, as it shows that in the wing used the intensity remains almost constant. I think these photographs will demonstrate to

appreciate about the $\frac{1}{50}$th part in the intensity of light, or, say, 2 per cent. There is a story told of a celebrated witness who, when asked whether such and such a thing was the case, said :—" Yes and No." Now if I were asked the question as to whether the above limit was true, I could safely answer in the same terms. First of all let me show you an experiment, which will prove that this limit is both understated and also overstated. I have on this screen a variety of greys between black and white. We can now see them all, and the difference between them. If I turn down the light, a great many of these appear the same tint. If I turn on to them a very strong electric light, those not nearly white, when looked from where I am, appear white, and it is only when there is considerable black in the shade of tint that they appear grey.

FIG. 14.

FIG. 15.

you that if the quantity of light to be admitted to a screen is to be determined by an aperture, the burner should be of the batswing type.

Before quitting the subject of photometers, I must introduce to your notice the radial photometer of Dibdin (Fig. 15). The diagram almost explains itself. The object of the photometer is to measure the illumination of a flame in all directions. It will be seen that the arm which carries the light to be tried remains always at the same distance from the screen. The screen itself is so arranged that its surface bisects the angles between the lines joining the two lights and itself — a most necessary thing, when Fig. 10 is taken into consideration.

We have now to turn to the method of judging the equality of light; that is, how the eye can best appreciate the light.

We are told very frequently that the eye can

As a matter of fact, there is an intensity of light, in which much smaller differences than the $\frac{1}{50}$th can be perceived. I believe, for my own part, that, when the light is suitable, a difference of nearly $\frac{1}{200}$ is recognisable. But it is not necessary that the eye should be so sensitive as the above, so long as proper precautions are taken in balancing the light. If we balance from "too light" and then from "too dark," the mean will be fairly exact, and probably not be far off the truth by a good deal less than 1 per cent. But there is another plan, which is better still, and that is by rapid oscillations in intensity on each side of the true point. This is difficult with many photometers, but not with all. When this plan is adopted, supposing we are using the shadow method, the two shadows appear to *wink*, and, when exactly balanced, this winking stops. It is curious how, without this artifice, readings,

which can be proved to be palpably wrong, are made. For instance, when one shadow is intensely darker than another, the eye of the observer will fail to see it, when the alteration is made slowly. If the eye, however, has a rest, by looking away at some black object, the inequality of the shadows will at once be seen. This cannot happen when the method of rapid oscillation is adopted.

What the cause of this may be is not absolutely proved. When the eyes look at two objects (spots or shadows) the images of the two are projected on different parts of the eye, these portions get fatigued, and the longer they are looked at the greater the fatigue. The brightness of the two gets lowered and they gradually approach one another. When the system of oscillation is adopted, though both images are lowered in tone, yet there is a constant brightening and dimning in both, not sufficient rapid to make each of them practically uniform in a tone midway between the two, but scintillation is produced. We can see how the eyes can be fatigued by a very simple experiment. I will throw a bright patch from the electric light upon the screen, which is also partially illuminated by gas-light. If the audience look at it for a few seconds, and keep their eyes fixed on the screen when I cut off the electric light, they will see a dark spot where the bright patch was, and it will appear to travel about as the eye wanders over the screen. This shows that the part of the retina on which the white patch was received is fatigued, and is less sensitive to the feeble gas-light illumination with which the screen is illuminated.

Some very instructive measures of the sensitiveness of the eye to different shades of light can be made by a sector arrangement. Black dots of any size required (in the case in point they have one-eighth of an inch in diameter) can be placed on a white disc, as shown. This disc is cut radially from the centre, and a black disc is marked out in the figure. The proportion of black and white can be altered at pleasure, and a further slight alteration in the grey produced is made by the dots ; the

FIG. 16.

smallest alteration, of course, being when the dot subtends the smallest angle. By this plan the sensitiveness of the eye to any small change in light can at once be found. The sector may be varied between all white to nearly all black. Similarly white dots may be placed on a black disc, a white disc overlapping, and unique measures made. It must be remembered that in all cases the black itself reflects a certain amount (in this case about 4 per cent.) of white light.

LECTURE III.—DELIVERED APRIL 16, 1891.

The sensitiveness of the eye to changes in intensity, I have shown you, varies according to the intensity of light from which the variation takes place. As my time is short, I must omit some other theoretical considerations which it was my intention to show you. I will first of all commence by showing how it can be ascertained whether a light is up to the standard temperature, such standard temperature being required for visual and photographic comparisons.

It is well known that by mixing two properly chosen spectrum colours white light can be formed, and when I say white light, I mean the

colour of the light under trial. Now, for lecture purposes, it is useless for me to try and use the light of a candle to form a spectrum. It would be invisible to you all; but I can use the electric light just as well for the object I have in view, viz., the demonstration of the principles involved. Now the whiter the light, the more blue and violet there is in its spectrum. There is, therefore, a large quantity of blue and violet in the electric light. I will form a spectrum, and place a slit in the orange and another slit in the blue, so that I can have a slice of each coloured light. By means of a lens I can cause these two slices of spectrum colours to expand and overlap and form an image of the face of one of the prisms used, and I can then cause a beam of the original light to illuminate a white surface alongside of it. The two slits can now be opened till they form by their mixture exactly the same colour as the original beam. Let us see if we use another source of light whether we shall get exactly the same result, keeping the slits as they are. I tone down the electric light by a very pale yellow glass: the light imitates very closely gas-light. If we place it in front of the slit of the spectroscope, so that the spectrum is the spectrum of the yellower light, and the incident beam is the yellow light, you will see at once that the mixture of the two colours no longer gives the same colour as the yellow light. Making the light the same as the amylacetate lamp light, you will see again that the balance is upset, the two patches of light on the two white surfaces are no longer the same.

Here, then, we have an indication of the method to pursue in ascertaining if lights are of the same quality. By having two adjustable slits in the spectrum, which will with a standard light exactly match the colour of such a standard, we can at once see if any other light is of the same value; if it is not, the two illuminated surfaces will be of a different hue. Another plan is to use proper coloured glasses in front of a lens, and allow light to pass through them in such proportions that they cast an image of a beam of exactly the same colour as that of the standard light itself. When another light is used, equality of colour no longer exists.

There is one method of altering the intensity of a light, if it be a glow-lamp which may interest some. In the first lecture I showed how the visible rays increase in intensity in a parabolic curve. This was further investigated by General Festing and myself. If each ray goes up parabolically, it is probable that the sum of them does the same. In a paper read at the Royal Society on December 8, 1887, we showed that our surmise was correct, and that if a constant was deducted from the current multiplied by the volts the result was the square root of the light multiplied by a constant—$(w - m = n \sqrt{y,})$ which is a parabolic. By altering the resistance in the lamp, and reading an amperemeter, and a voltmeter, the result is obtained, though it is sufficient if the amperes alone be read, for then $c^2 - s = t \sqrt{y}$, very nearly when c is current and y the light, s and t being constants.

As to the use of the sectors, it has been brought to my notice that Mr. Ferry has called in question the accuracy of the sectors when comparing lights of different colours with one another, such as lime-light and a glow-lamp. He states that for light of the same colour, and for monochromatic light, no error can be found in its use. I may refer, however, in opposition to this, to some experiments which were carried out by General Festing and myself, in which the luminosity of the spectrum was measured without the intervention of the sectors, comparison having been made with a glow-lamp. It was found, as published, that the two methods gave identical results. There are many other experiments which show that no error in the results obtained with the sector have been found by us. That this is the case, we may take to be the fact by direct and by indirect measures.

There is, in my opinion, no method so good in photometry as that of using properly moving rotating sectors, whose open apertures can be altered at will. It allows both lights to remain stationary, as, also, the screen. This method of diminishing the intensity of the light was, I believe, first introduced by Fox Talbot more than fifty years ago, though he had not the advantage of using moveable apertures. This principle of altering the aperture during rotation I first saw exhibited by Mr. Kempe, Q.C., at a *soirée* of the Royal Society. It was applied to a colour top. Without entering into the history of the matter, however, let me show you the exactitude with which such sectors can be employed.

In doing this, I wish to introduce to your notice a photometric method which I brought out, and is, I believe, very fairly successful. I am not saying it is the very best for comparing ordinary lights, but it fills a gap for measuring light transmitted through

bodies, which is very convenient. The principle of the screen, you will at once see, is different from almost any other. It consists of a square aperture cut in a thin disc, and over this is stretched a white piece of paper of such a nature that the light from an illuminant is only scattered, and no direct image can be seen under any circumstances. On the other side is cut a mark in black paper or black retint, which is exactly double the size of the cut-out square, and this is filled up by the white paper stretched over the aperture, so

FIG. 17.

Back View.

that we have a rectangle of paper half of which is translucent and the other half opaque. If now we place a light behind the aperture, the half is illuminated by transmitted light, and if a light is placed on the other side, the whole rectangle is illuminated. By placing a rod in the path of this last beam, we may cast a shadow which prevents the last illuminating the half through which the transmitted beam comes, and then we have half the paper rectangle illuminated by transmitted light, and the other half by incident light. If the paper be of good quality, the light will

Front View.

FIG. 18.

appear of the same colour. By placing the rotating sectors in the path of the front beam, and altering the apertures, we may cause the two to appear of equal brightness.

Now suppose I want to examine the amount of light transmitted through this piece of ground glass, I can readily do it. If I place it near the candle, and use an ordinary Bunsen or Rumford photometer, I shall find that it varies according as I place it close to the source of light, or half way, or close to the screen. It is quite evident that the closer I

place it to the screen, the truer will be the measure of the total amount of light transmitted. With this photometer I can get the ground glass close to the screen, and we then get a measure of the transmission of light through it. An objection has been made that light has been reflected back from the surface of the white paper to the glass, and back from that surface again. This may be true to a very limited extent. If I take a piece of ordinary glass, and hold it close to the lamp, I can balance the two lights, bringing it closer and closer, till it in fact almost touches the aperture, you will see that the balance is undisturbed. A variety of experiments has shown that any error caused by this is negligible. We can take a piece of a photographic negative, and test it in the same way, and balance it, and move it at different distances towards the screen; we find that if we strike a balance when it is near the light it becomes apparently darker as it approaches the light, then gets lighter and lighter, till it appears lightest of all as it approaches the screen. Another point is this, that it need not be used in a totally dark room, where provision is made that any light there is must pass through the body under measurement; a small amount of diffused light is of no very great moment anywhere, since it illuminates the front of the rectangle, and has no effect on the measures of the light transmitted. We can also use it for coloured objects, such as coloured glass. For ordinary purposes it suffices if the glass be placed against the aperture, or in the path of the beam somewhere, so long as the aperture is only illuminated by the light transmitted through the glass. This makes one half coloured; but it is easy to balance the illuminations by the oscillations of the sector [This was experimentally demonstrated.] The light passed through is then very easily found. Again I may use coloured paper and do the same. To myself it is more easy to balance a coloured light against a white one than a white one against the white. I need scarcely say that, first of all, the illuminations of the white surfaces are balanced, and the sector opening read before the light coming through any coloured or other body is measured. If the white surface require a sector opening of 80°, and only 40° when a body is against the aperture in the screen, half the light is transmitted.

We may often want to know the amount of light reflected from a body, and the next photometer I shall show you is used by me

for that purpose. It is very similar in principle to the last. The aperture is cut as before, but instead of being covered up, it is left open to allow the coloured object to be placed in it, alongside a white square. Instead of two lights one light may be used for this photometer, a reflection being used instead of the second light. This avoids any alteration in the relative intensities of the two lights used, for they both are from the same source. A rod casts shadows, one on the aperture and the other on the white square. The aperture is fitted with (say) a grey square, and the sectors in the direct beam altered till the two appear of the same colour; or I may introduce a coloured object and repeat the process. In this case, of course, first of all the aperture should be fitted with a white surface and a measure taken, and the aperture of the two measures of the sectors gives the relative brightness of the two objects.

There are often cases where we may wish to measure bodies which only allow but very little light to pass, though they are transparent. In such a case we have to use a very powerful light, and it may be that the body varies greatly in absorption at different parts. For this reason I use the electric arc light as the source, and concentrate it so as to give a brilliant beam. There are, however, variations in the electric (arc) light from time to time, and unless the comparison light, with which the relative intensities passing through different parts of the wedge are measured, varies at exactly the same time and in the same proportion, the measurements will often be very much out. If we merely wish to measure the white light transmitted, the apparatus to employ is not very extensive, and Fig. 19 will show what it is. E L is the electric light, placed in a lantern or box of some kind, to prevent the room, which should be slightly darkened, from being flooded with light. L_1 is a condenser which throws an image of the crater of the positive pole upon the slit, S, of the collimator, C. The rays issue
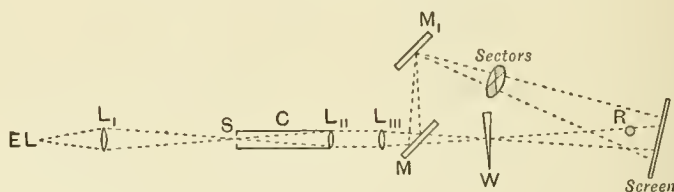
FIG. 19.

parallel, and are caught by a lens L_{111}, which forms an image of the slit upon the surface of the wedge, W, placed in a proper position and in its mountings. The light, after passing through the wedge, forms a circle of light on the screen. It will be noticed that the image of the slit may be as narrow as one wishes by opening or closing S, and that we have a line of light passing through the wedge, such as is required to effect the graduation. Calculation will show that, with a fairly narrow slit, the measured intensity passing through it may be taken as that passing through the mean thickness of that part on which the image falls.

Placed in the path of the beam, and between the wedge and L_{111}, is a plain mirror, M (for which I often substitute a prism of $1\frac{1}{2}°$, and so obtain a single reflection), which reflects the light at right angles, or any convenient angle to its path. It is again reflected from M_1, a silver on glass mirror. An image of the slit is formed in the path,

and a second disc is formed on the screen. The centre of this disc is made to coincide with the centre of the disc formed by the light passing through the wedge. A rod, R, is placed in the path of the two beams, which casts two shadows, one illuminated by one beam and one by the other. The usual black mask is used on the screen, to confine the attention to a small part of the shadows.

It will be seen that, when any variation takes place in the light, it equally affects both the illuminated shadows; hence the measures may be made without fear of error creeping in. Sectors with apertures, moving at will whilst they are rotating, are introduced, as shown in the figure, and sometimes a second set of fixed sectors are introduced between M and W should the light passing through W be too bright. The screen is placed perpendicular to the line bisecting the angle made by the two beams. It should be noted that this plan almost necessitates movable sectors, but

sectors which are fixed at known apertures can be used at a pinch, and the balance made by moving the wedge in its settings.

It should be remarked that though the wedge may not be pure black the readings can be very readily made by the method of oscillating between "too light" and "too dark" for the shadow whose brightness is controlled by the sector. In making a valuation of the wedge, the first thing to do is to compare the lights without the intervention of the wedge, and then to take readings.

For certain purposes it is necessary to know how much of each colour of the spectrum is transmitted through a wedge, and Fig. 20 shows how this is accomplished.

The electric light and the collimator are placed as before, but the parallel emergent rays fall upon a pair of prisms, and the spectrum is brought to a focus by L_{11} on to a screen in which there is a slit against which the wedge in its setting is placed. The slit can be placed in any spectrum ray, and the wedge surface is always kept perpendicular to that ray. A lens, L_{111}, brings the rays to a focus, so that a monochromatic image of the surface of the last prism is formed on the screen. From the surface of the first prism parallel rays are reflected: these are caught by a mirror and fall on a pair of precisely similar prisms, and the remainder of the apparatus is exactly the same as that described above, a second patch of coloured light being formed over the first patch. The slit, S_{111}, is so adjusted in the spectrum that the two patches are of the same colour. The
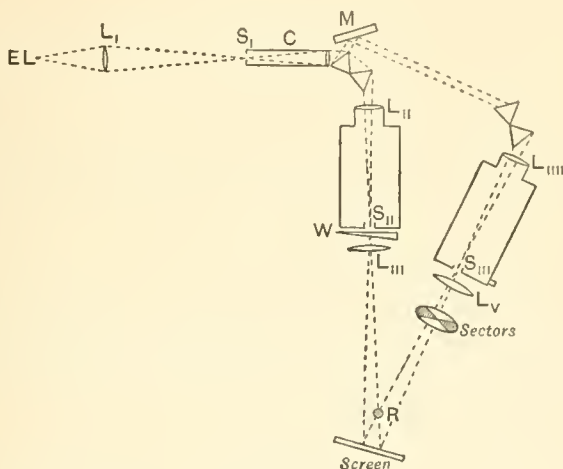
FIG. 20.

sectors are placed as shown in the figure, the rod, R, forming two shadows, as before. The method of procedure is to place the slit, S_{11} in some colour in the spectrum, and S_{111} in the same. The wedge is then graduated for this beam throughout its length, another position is taken up, and the same process gone through. By this means we get the logarithmic factor of transparency for each part of the wedge for the whole of the spectrum colours.

The last point that I shall have to refer to is an apparent failure of the law of inverse squares as regards photometry.

I have upon the screen two patches of spectrum light—a red and a green—of equal intensity, if anything the red is rather the brighter. I place the rotating sectors in front of them and gradually close them. Notice that the red begins to fade away much more rapidly than the green. When very nearly closed the red has disappeared and the green remains not of its light green colour but as a green grey.

Let us argue from this what should result. If when we illuminate a screen with red light we can remove it to such a distance that the screen becomes invisible, though if we have green light, which appeared of equal brightness when close to it, we should be able to remove it much further before the same screen became invisible. The point at which the screen disappeared from view would evidently be the zero point from which the illumination would have to be reckoned for the colour which was used. So with white light, there is a point at which the screen would become invisible.

Evidently then the law of inverse squares for illumination appears to fail for low intenseness of light, and this is owing to the insensitiveness of the eye. Theoretically, of course, the screen may be moved to an infinite distance and still be visible. The law is obeyed practically of course. It may be thought that this limit of vision is of no practical account. But I must say that it is. For instance, in the photographic room we use red light, and we find that the corners of a fairly-sized room are invisible. If we use canary medium the corners will be well illuminated. This is owing to what I may call the superior space penetrating power of illumination of the yellow-greenish light over the red.

I have not been able to show all I wished owing to want of time, but I trust that what I have shown may not be lacking in instructiveness.

SYLLABUS.

LECTURE I.

White light—Sources of light—Standard light—Quality of lights from different sources.

LECTURE II.

Principles of measurement—Different methods of Photometry—Oscillation and scintillation in light measurement—Colour no bar to measurement.

LECTURE III.

Applications of Photometry to various scientific purposes.

SOCIETY FOR THE ENCOURAGEMENT

ARTS, MANUFACTURES, AND COMMERCE.

CANTOR LECTURES

ON SOME CONSIDERATIONS CONCERNING

COLOUR AND COLOURING.

DELIVERED BEFORE THE SOCIETY OF ARTS, MARCH, 1890,

BY

PROF. A. H. CHURCH, M.A., F.R.S.

SOME CONSIDERTIONS CONCERNING COLOUR AND COLOURING.

By PROFESSOR A. H. CHURCH, M.A., F.R.S.

LECTURE I.—Delivered March 17, 1890.

Syllabus.—Definition of terms—Constants of Colour—Primary Colour Sensations—Classification and Nomenclature of Colours—Luminosity of Pigments—Translation of Colours into White, Greys, and Black—Effects of Varying Illumination—Dichroism—The Chromatic Circle—Chromatic Equivalents.

It was after considerable hesitation that I accepted the honour of addressing the Society of Arts on the subject which is to engage our attention to-night, and on the two remaining Monday evenings of the present month. I was doubtful as to the freshness of my material and as to my ability in presenting my opinions to your notice. Then, too, I remembered that Captain Abney had handled some parts of this subject so ably and so recently, in the course of lectures which he delivered in this room in 1888. I felt, however, that if I could but succeed in developing your interest in the connection between the science of colour and the art of colouring, I might perhaps be justified in acceding to the request of your Council.

The syllabus of the course indicates the limited range of these lectures, and shows that they make no pretension to an exhaustive treatment of the subject of colour. To my "Manual of Colour," published in 1887 by Messrs. Cassell and Co., I must refer my auditors for a systematic exposition; in this place I purpose developing some only of the topics discussed in my book, especially in relation to our everyday surroundings. But I cannot refrain from expressing the great debt I owe to the "Modern Chromatics" of Professor Ogden Rood, published just eleven years ago. You will notice how often I have to cite his authority and to quote his results.

Definition of Terms.—The sense given to certain terms, which will be freely used in these lectures, ought to be explained at the outset.

The essential difference between tones lies in their brightness or luminosity, that is the amount of optical sensation caused by a given area. Tints contain differing amounts of white, shades contain differing amounts of black, broken tints contain differing amounts of grey—all these are tones; the particular descriptions I have given being so framed as to apply to coloured and uncoloured substances rather than to lights. When a series of tones is said to constitute a scale, it is formed by the addition of equal increments of the modifying element. Each hue admits of three scales—the reduced scale, made up of tints; the darkened scale, made up of shades; the dulled scale, made up of broken tints. Theoretically, each possible scale starts from the pure normal colour; practically, when we deal with pigments and other coloured bodies and not with lights, such a perfect starting-point is unattainable. It should be added that the tints of black and the shades of white are the greys, and that passage-tones are distinguished from the tones which constitute the above-named scales in one respect only; they pass by imperceptible gradations from the beginning to the end, and not by definite steps of ascertainable value.

Constants of Colour.—Of these there are three, namely, hue, purity, brightness. The hue of a colour appeals at once to the eye; we endeavour to identify it, perhaps to name it, calling it red, orange, yellow, green, &c., and so on. The purity of a colour refers, in the accepted language of chromatics, to its freedom from white; in this sense no pigmentary colour is pure. In the spectrum, under certain conditions, we have pure colours. The brightness or luminosity of a colour is measured by the total amount of light sent to and perceived by the eye, and is independent of hue and of purity. Colours which do not sensibly differ from white, are therefore far removed from purity, are bright because the white light freely reflected from them produces more optical sensation than any positive colour. On the other hand, a pure colour is not necessarily a bright colour, for not only is the absence of white light the exclusion of the cause of the highest luminosity, but a pure colour may be so low in tone as to be barely recognisable.

When a colour is at once as bright and as pure as possible, it is called saturated; such a colour may be called "full" in speaking of pigments and other coloured materials. Its less pure tones are, as I have mentioned before, called tints, and are more or less "pale." Its less luminous tones or shades are more or less "dark." Such of its tones as are at once less pure than its shades and less luminous than its tints, are more or less "dull."

Of all the above terms there are two only which are applied in a manner somewhat different from that belonging to ordinary parlance. These two terms are shades of colour and purity of colour.

Primary Colour-Sensations.—Colour is, we know, an internal sensation, and has no external and objective existence. It originates, in all the cases which we purpose discussing in the present course of lectures, in the impact on the optic nerve of that energy or mode of motion which we call light. Certain waves or vibrations which affect the nerve-fibrils of the eye are translated by the brain into colour. I do not intend to place before you the various theories which have been propounded as to the method and mechanism of this translation; they involve numerous intricate and obscure physical, chemical, physiological, and psychological problems. But I ask you to accept, as the best of all working hypotheses, the view of the subject taken by Dr. Thomas Young in 1802, and since developed by Helmholtz, Maxwell, and Rood. The idea that there are three primary colours must be abandoned, but that of three primary colour-sensations may be very conveniently accepted, at least provisionally. What selection shall be made has been debated on various grounds. Several triads have been chosen, but a certain red, a certain green, and a certain blue have been accepted by some of the most distinguished investigators of the subject. I venture to add my own testimony as to the superiority of the triad of red, green, blue, over that of red, green, violet. With lights which provoke these three colour-sensations we can obtain all the colours of the spectrum as well as the purples which do not exist therein. Equivalents—I say, equivalents, not equal quantities—of the standard or normal red and green produce the normal yellow; of the standard or normal green and blue produce the normal sea-green; of the standard or normal blue and red, the normal purple. Intermediate colours are produced when the quantities of the two lights, which are together received by the eye, are not equivalent. Thus with red and green an excess of red produces orange; with green, and blue, an excess of green produces a greenish sea-green; with blue and red, an excess of blue produces a bluish purple or violet. No tertiary colour is possible, the colours called tertiary by artists being broken tints of the three primaries and of the three normal secondaries. In fact, if you mix the three normal coloured lights in their proper equivalents together, you get nothing but white, or grey if the brightness of the lights be small; and if you mix these three normal lights together in any other than equivalent proportions, you get tints of the primary or secondary colours—that is, these colours mixed with white. By using the initial letters of the various normal colours to represent their equivalents, we may place the above results in the form of equations, which we will give after the manner adopted by chemists :—

$$R + G = Y, \text{ or yellow.}$$
$$2 R + G = O, \text{ or orange.}$$
$$G + B = S, \text{ or sea green.}$$
$$2 G + B = \text{greenish sea green.}$$
$$B + R = P, \text{ or purple.}$$
$$2 B + R = V, \text{ or violet.}$$
$$R + G + B = W, \text{ or white.}$$
$$2 R + G + B = W + R, \text{ or pale red.}$$
$$2 R + 2 G + B = W + Y, \text{ or pale yellow.}$$
$$R + 2 G + 2 B = W + S, \text{ or pale sea green.}$$
$$2 R + G + 2 B = W + P, \text{ or pale purple.}$$

An essential difference between the colours produced by mixing lights and those produced by mixing pigments consists in this, that the addition or commixture of lights produces increase of brightness, while the commixture of pigments diminishes brightness. This difference of result is caused by the fact that the mixture of two lights possesses the added brightness of each of its elements, while the colour resulting from the mixture of two pigments possesses merely the residual brightness left after a twofold or manifold absorption of light. For when blue and red lights are mingled on the retina, the eye receives the combined brightness of both; but when the blue and red pigments are mingled, the eye receives only that portion of the light which has escaped the absorptive action of both the blue and the red pigments. In this and similar cases the dulness arising from absorption is very marked, and an artist who wishes to secure the greatest possible brilliancy in his work avoids, wherever he can, the commixture of pigments, rather placing touches of

colour side by side, so that the colours they severally reflect shall mingle on the retina; the works of Samuel Palmer, William Hunt, and J. F. Lewis may be named as illustrating this method.

But there is a second difference between the colours produced by mingling lights and those produced by mingling pigments. This difference is not one of brightness or of purity; it is a difference of hue. You know the effect of mingling yellow and blue pigments together on the palette is the production of a green, more or less decided and bright, according to the chromatic constitution of the two pigments employed. But the commixture of yellow and blue lights in equivalent proportions results in the production of white more or less bright— that is, either white or a shade of grey— according to the brightness of its constituents. If there be an excess of yellow light the colour produced is pale yellow; if an excess of blue, pale blue. You may prove this point by the use of Maxwell's rotating sectors. Take the same two pigments, chrome yellow and ultramarine blue, which mingled on the palette produce green—rather a dull green — and mingle the lights they reflect, by the method of rotation, on the retina, and you get a white of low luminosity, that is, a grey. But, as in this case, there is not the double absorption produced by the commixture of pigments, the grey is brighter than the green made by such commixture, and you will have to add much black to it (by means of a third sector of black) to obtain the same low degree of luminosity by rotation. I have purposely selected for citation this case of the mingling of blue and yellow, because it is the crucial instance by means of which is most strikingly shown the difference in hue above-named, and it also serves to demonstrate the fallacy of the still prevalent notion that blue and yellow lights produce green. When green is formed by the mingling of two pigments, one yellow, the other blue, this result is attained by the suppression of the yellow and blue and the survival of the green which was present in both. So when white light, transmitted through a yellow and a blue glass, appears green, it is the residual green which has escaped absorption by both glasses which colours the emergent light. We know that the simple yellow of the spectrum, and the compound yellow produced by the mixture of red and green lights, affect the red and green nerve-fibrils of the retina in exactly the same way, and it is for this reason that we affirm that yellow is a compound colour-

sensation, and not one of the three primaries I do not now dwell further on this point, as I I have dealt with it at length in chapter vii. of my "Elementary Manual of Colour," to which I beg to refer you for a fuller treatment of the differences between mixtures of lights and mixtures of pigments. I ought, perhaps, to mention here that the advocates of the red-green-blue theory of three primary colour-sensations, while denying the truth of the explanations afforded by the red-yellow-blue theory of Brewster, do not contest the occurrence of the chromatic phenomena presented by the admixture of pigments, or by the transmission of light through coloured media, which Brewster's theory incorrectly interprets.

Classification and Nomenclature of Colours. — The simplest arrangement of colours must include white, a balanced or neutralised compound of two or more hues; black, the negative correlative of light and colour; and the positive hues, with their tints, shades, and broken tints. In bare outline it may be given thus:—

DARKNESS ....,....... Black.

LIGHT.. { Colourless.. { White. Greys, or shades of white. } Coloured .. { Hues. Tints, shades, and broken tints of hues. }

But directly we endeavour to enter into further details, to give quantitative values and appropriate names to our many materials, we are confronted by serious difficulties. Whites and greys must have their brightness determined; all other tones require the determination of the three constants of colour, namely, hue, purity, and brightness. The fixed lines of the pure normal solar spectrum enable us, it is true, to locate all pure and saturated hues save the purples. Prismatic analysis reveals the chromatic elements of any colour; the methods of shadow photometry enable us to ascertain relative luminosities, but the intelligible expression of our results in reference to definite standards has not yet been attained. The problem is, moreover, greatly complicated by reason of certain modifications of tone or of hue caused by contrast, dilution with white, &c., &c., as well as by the immense number of colours, with their shades and tints, which the human eye is competent to distinguish.

Of the modes of classifying colours, the cone of W. von Bezold and the cube of W. Benson have many merits, but are not free from limitations and even defects. The colour-cube may

be described in a couple of sentences, so far at least as its principle of construction is concerned. At one solid angle of the cube black, or the absence of light is placed, at the opposite solid angle white. At the three solid angles nearest to black, the full red, green, and blue are respectively placed, while at the three corresponding and opposite solid angles nearest to white the three complementary secondaries occur, namely, sea-green, purple, and yellow. The beautiful diagrams in Mr. W. Benson's "Principles of the Science of Colour" will fully explain the position of tints and shades in the cube.

The chromatic arrangement of Chevreul is vitiated by the adoption therein of the erroneous theory of the red-yellow-triad, nor are the hues represented referred to a definite standard. Radde's colour-chart, though nominally based on certain spectrum colours, lacks precision in plan and execution. The scales of Lovibond's tintometer are represented by numbered and named glasses, referred to a certain arbitrarily-fixed pale tint of which the value of one unit is given, and then the true chromatic elements of these glasses have not been determined.

The nomenclature of colours is intimately connected with their classification. It has difficulties all its own owing to (1) the shifting meaning of well-known colour names; (2) the difficulty of coining new names. Purple sometimes means dark blue, sometimes a colour half-way between violet and crimson. The old German verb *bleuen*, to strike or beat, has originated the modern German *bläuen*, and there is no longer a distinction between the procedure of the schoolmaster and the laundress, though *blauen* is given in some dictionaries for to dye blue, *bläuen* to beat blue, but *bläue* is the colour blue. The system, if such it can be called, of the mineralogist Werner (1774) included 92 terms arranged in nine groups. It lacks accuracy and orderly sequence, but is of interest in showing the use of terms for designating colours derived from certain typical, animal, vegetable and mineral substances, the hues of which vary but little. (See "Colour," page 63.)

The long list of colour-names given to silks by the Lyons manufacturers will furnish some expressive terms, but many of the names are quite arbitrary and fanciful. R. Ridgway's "Nomenclature of Colours for Naturalists" (Boston, U.S.A., 1887), is useful in giving at once many colour-names, and actual water-colour washes of pigments representing them. Unfortunately, many of these names are very vague (dahlia, aster, phlox), and they are placed in an order based on no recognisable chromatic system. The 51 degrees of the *cyanometer*, for measuring the blue of the sky, serve to define its tone only, not its hue nor its purity.

We want an international colour conference, in which artists, manufacturers, and scientists shall be represented. We want an agreement upon the names to be assigned to a number of different hues. We want representations of these standard hues reproduced in enamel, preserved like our standards of weight and measure, and distributed to every educational institution in the United Kingdom.

For my own part, I should be content to employ a combination of the systems of name and of number in the nomenclature and classifying of colours. The importance of having a definite nomenclature, of quite intelligible character, at our disposal, when we are talking or writing about the decorative employment of colour, is so important that I venture to make a few suggestions which may tend towards the attainment of this object.

Let, then, equivalents for the full red, the full green, and the full blue (as already described), be represented by the symbols R, G, B, the seagreen, the purple, and the yellow, which are the several complementaries of the above hues, being similarly expressed by the symbols GB, RB, and RG. The capital letter represents the hue; where no number is subscript, 1 equivalent is meant; for lower or higher luminosities decimals are used. If the sea-green, to select one instance, inclines towards green, that is, has more than one equivalent of green in it, we may easily express this modification of blue by a fractional addition to the symbol for green, and a simultaneous fractional subtraction from the symbol for blue. Such a series would result as this :—

$$GB = \text{Seagreen.}$$
$$G_{1 \cdot 1} B_{\cdot 9}$$
$$G_{1 \cdot 2} B_{\cdot 8}$$
$$G_{1 \cdot 3} B_{\cdot 7}$$
$$G_{1 \cdot 4} B_{\cdot 6}$$
$$G_{1 \cdot 5} B_{\cdot 5} = \text{Greenish Seagreen.}$$
$$G_{1 \cdot 6} B_{\cdot 4}$$
$$G_{1 \cdot 7} B_{\cdot 3}$$
$$G_{1 \cdot 8} B_{\cdot 2}$$
$$G_{1 \cdot 9} B_{\cdot 1}$$
$$G = \text{Green.}$$

The corresponding modifications in the five other principal series of colours would be ex-

pressed in a similar manner, the symbols, &c., being used exactly in the same way as in chemical notation. In order to obtain a scale in a concrete form, I would recommend the use of Maxwell's rotation method, by which each step in the gradation could be matched. I would use for the series between sea green and green two discs painted with as near an approach as possible to the full normal green and the full normal blue, and the former should be increased and the latter diminished (in the form of sectors) in accordance with the system I have suggested. The rotation colour produced at each step should be copied, or rather matched, and would then take its place in the series with a definite symbol attached to it. By the introduction of a white sector similarly treated, the tints of any colour could be made to match; with a black sector the shades, with a black and white sector the broken tints. The symbol for black may be conveniently called Z, that for white should be R G B or W, as the case may require. But it is also possible to express the shades of a colour by reducing its luminosity, and the broken tints by at once reducing its luminosity and adding white. Here are the symbolic expressions or formulæ for such changed hues :—

$$S \qquad = GB \qquad = \text{Seagreen.}$$
$$S_{\cdot 9} \qquad = G_{\cdot 9} B_{\cdot 9} \qquad = \text{A shade of, or darkened, Seagreen.}$$
$$SW_{\cdot 1} = GBW_{\cdot 1} = \text{A tint of, or a pale, Seagreen.}$$
$$S_{\cdot 9} W_{\cdot 1} = G_{\cdot 9} B_{\cdot 9} W_{\cdot 1} = \text{A broken tint of, or a dull, Seagreen.}$$

In the case of pigments or other coloured materials the proposed symbols, though quite exact enough for any purpose for which they are employed, will not admit of accurate analysis. This is due to the fact that no pigment reflects a pure coloured light, there is always some white mingled with it, rarely less than 20 per cent. of the whole. And even with coloured lights there are also variable sources of error, for the addition of white light to coloured light, and also the reduction of its luminosity, alters the original hue. To this change, which occurs also with pigments, and often in a very conspicuous manner, I shall invite your attention shortly.

Luminosity of Pigments.—One often hears the remark with reference to a work in black and white, an etching or line-engraving, for example, representing a coloured picture, that it has got good colour in it. Such an expression may be interpreted to mean that the relative tones of the original are preserved in the copy, and suggest the force of the original colours. Now it requires much experience and singular skill thus to value and interpret the relative luminosity of differently coloured portions of a painting. An aid in the work of translation is afforded by making determinations of luminosity or brightness by means of shadow-photometry, or by comparing the brightness of various white and coloured materials with the brightness of greys of known composition. The latter method, though not very easy or very exact, involving the use of black and white sectors in the rotation apparatus, gives results which are, at all events, approximately true. These results

represent the comparative luminosities of the particular specimens of pigments, &c., employed, and vary somewhat with the method of applying the pigment, its thickness, and the medium (if any) used. The following figures were obtained in this way, some by Professor Rood and others by myself :—

Chinese white, dry, in thick layer on pastel paper	100
Plain white paper	90·9
Whatman's paper (not hot-pressed)	88·2
Chrome yellow, pale water-colour wash	73·0
Emerald green, pale, in thick paste	44·2
Cobalt blue, water-colour wash	32·2
Vermilion, in thick paste	23·4
Natural Ultramarine	8·3
Artificial Ultramarine	6·9
Black paper	4·7
Lamp black, dry, in thick layer on pastel paper	·8

I cannot help thinking that a more extended series of comparative luminosities would prove useful to the translators into black and white of works executed in colour.

Effects of Varying Illumination.—The very considerable alteration of appearance experienced by coloured materials when the hue of the light by which they are rendered visible is changed, is rendered familiar to us by the case of pictures and dresses, seen first by candlelight and then by ordinary daylight. We discover that what we thought was purple is really violet, crimson is purple, green is blue, and so forth. The deficiency of the more refrangible rays of the blue end of the

spectrum, and the superabundance of the less refrangible rays of the red region in the light of burning oil and gas, and even in that emitted by incandescence electric lamps, furnish the explanation of these changes. It is of course more conspicuously evident when we view richly and variously coloured objects in a light which is virtually monochromatic. The pure orange yellow of sodium cannot furnish the vibrations to which the majority of hues are alone capable of responding; only what is yellow can be seen, and even in this case not the yellow compounded of red and green vibrations. But I must not enlarge upon this point, as it has been often treated, and at length, elsewhere; and I want to direct your attention to those changes of hue in coloured objects which are caused by alterations, not in the hue of the incident light, but in its brightness. The observant student of Nature will have learnt that the hues of many-coloured objects are most characteristically brought out by a comparatively moderate illumination. The chief cause of this pheno-menon is often traceable to the large excess of unaltered white light, which such objects reflect or scatter when the illumination is intense, while when the illumination is mode-rate it just suffices to develop properly the particular hue of the material. I recollect a case in point. Wishing one day to show to a connoisseur in precious stones a fine aurora-coloured zircon, which had lately been cut for me, I took the specimen into the sunshine. The colour was so altered and so impoverished that my pride in the recent acquisition was humbled; the stone was distinctly inferior to a similar specimen in the British Museum.

This pallor was not the result of the glittering reflections from the polished facets of the gem, but the coloured light reflected to the eye from the lower facets was greatly reduced in purity by much admixture of white light. Out of the strong light the specimen resumed its rich and beautiful appearance, and showed, moreover, not only a much deeper but a much redder and less yellow hue than when sunlight fell upon it. Painters have long been familiar with such changes of hue. If you examine the works of the great colourists of the Italian schools you will see many striking examples of their appreciation of this natural phe-nomenon; indeed, I may say that these changes of hue with changes in the brightness of the illumination have been not infrequently much accentuated, even greatly exaggerated. At all events, artists have long known that the high lights of a self-coloured drapery cannot be properly represented by merely adding white — that is, by forming tints of the same hne — although it does indeed sometimes happen that the addition of white paint to one having positive and strong colour brings about changes of hue analogous to those we have been considering. Be it remembered that I am not now speaking of those purely accidental modifications of hue which are caused by reflections from coloured objects, and which often cause a white drapery to assume the beautiful orient tints of the pearl.

If increase of light above what we may call a normal standard (one capable of showing in perfection a colour) effects a change in hue, so also does decrease of light, although in an opposite direction. These changes of hue are well brought out in the following Table:—

Decreased Light.	Standard Light.	Increased Light.
Purplish	Red	Scarlet.
Red	Scarlet	Reddish Orange.
Brown	Orange	Yellow.
Olive Green	Yellow	Paler Yellow.
Greener	Yellow-Green	Yellower.
Greener	Blue-Green	Bluer.
Violet-Blue	Blue	Turquoise.
Violet	Violet-Blue	Blue.
Violet-Purple	Violet	Bluer.
Purplish-Violet	Purple	Red-Purple.

Similar changes of hue occur when coloured lights instead of coloured objects are reduced or increased in brightness. Thus by lowering the luminosity of a pure solar spectrum, there will not only be a selective reduction or even extinction of some of the constituent hues, but also a shifting of the position of the hues. The red will invade the orange region, so that the line D, for example, will be bordered by a kind of red-lead colour; the green will extend to-wards the sea-green, and even include the line F, and the pure blue will contract. We should then describe the darkened spectrum as prac-tically consisting of red, green, and violet. By

a further reduction of brightness the red will become brownish, and the green and violet dull. In the next stage the violet disappears, the green is more dim, while the brownish-red acquires a sort of chocolate hue. The last colour to be recognised is a very faint green hue. I ought to mention in this place that when white light is added to coloured light the changes of hue which occur are generally to be explained by the statement that they are such as would be produced by a slight admixture of blue light with the white light.

The bearing of these observations upon pictorial and decorative work in colour are obviously of considerable moment. If we want to be sure of the chromatic effect of a decorative scheme we must arrange and modify its elements in such a way as to adapt it to the usual illumination of the apartments in which it is to be carried out ; and here one curious result may be noted. In a very dimly lighted room, saturated and comparatively pure colours may yield delicate and refined harmonies, while the same colours in a blaze of strong daylight, or direct sunshine, may also lose their garishness because of the large amount of white light which then becomes mingled with the proper hues they reflect. But with a medium illumination these saturated colours, if freely used, become intolerable, just because they are perceived in their original strength. We thus learn how it is that a scheme of colouring, which seems exquisitely choice when occurring in the dimly lighted apartments of a Cairo or Damascus house, may become to the last degree crude when transferred to the full illumination of an English home, where the walls are pierced with large windows of plate-glass admitting floods of light. The employment, under such altered conditions, of colours saddened with black and dulled with grey, has been long recognised and practised as one of the easiest ways of modifying the crude effect of such chromatic arrangements. If saturated colours are still used we reduce their area, or employ them in such small and involved touches that the mingling of their hues produces what Owen Jones called a neutralised bloom.

Before I leave this important subject (of the effects of varying degrees of illumination upon the hues of objects), I wish to direct your attention to a very simple and decisive class of experiments, by means of which some of these changes of hue of which I have spoken may be recognised. You need only take some pieces of richly coloured material, paper, cloth, or silk, of uniform hue, and partially crush and fold them, so as to get various portions illuminated in different degrees. An orange coloured silk will look yellow in its high lights, and brown in its hollows. A blue paper will appear violet in its shaded parts, and of a purer blue, or perhaps of a somewhat greenish blue, in its projecting portions. A crimson cloth will seem scarlet where it catches most light, and crimson where it reflects the least. These changes of hue are in part due to errors of judgment, but they are none the less real.

Our next subject for study is intimately allied with that we have just been considering. I regret that the narrow limits of my available time will permit me to give little more than the barest reference to it. I refer to the alteration of hue caused by the addition of white, of grey, and of black to a pigment. White added to a red pigment does not usually produce just a paler tint of red, but the new tint varies in hue, tending in some cases towards crimson, in others towards scarlet. The dilution of a transparent red pigment with a colourless medium—that is, attenuation of its thickness—produces analogous alterations of hue. Similar changes are caused in pigments of other colours by dilution and by commixture with white substances. Some of the changes produced by adding black are perhaps more striking. Rood found that, on mixing carmine with lamp-black, the mixture on the palette was more purplish in hue than the colours obtained by mingling the pigments optically by the method of rotation. This approach to purple was of course due to addition, with the black, of more blue to the carmine. An analogous observation, also due to Rood, relates to the admixture of black with white. Black pigments as free as possible from any tinge of positive colour are generally observed to yield a bluish-grey when mixed with white pigments. This result has usually been attributed to the fineness of the particles producing a blue by the same action on the light as an opalescent medium exerts. But Rood found that when white and black are mingled optically on a rotating disc, the grey they yield is matched in hue (not in brightness) by a white disc into which much blue (in one case 17 per cent.) has been introduced by means of a sector covered with a strong wash of indigo.

Dichroism is the next topic for our study. This term has been applied to similar phenonema produced in similar ways. A liquid or solid is said to be dichroic when the light

which is transmitted through it differs in hue as well as in tone when the thickness traversed differs. Many liquids, such as solutions of double potassium and chromium oxalate, and potassium permanganate, well illustrate the phenomenon, so do many solids, such as copper sulphate, and several kinds of coloured glass and gelatine films. But there is another kind of dichroism occurring in solids which are not optically homogeneous. Many crystals are dichroic, or even pleiochroic, for when white light is sent through them in different directions it suffers thereby different selective absorptions, and so the emergent beams are differently coloured. The ruby, the emerald, and the tourmaline amongst precious stones are characteristic examples of this group of dichroic phenomena. Even a third class or group may be named, where the light transmitted differs in colour from that reflected and scattered, solutions of chlorophyll and of uranin, and the solids uranium glass and fluor spar belong here.

The first class of dichroic phenomena (depending upon the thickness of the coloured medium) is largely concerned with the production of beautiful quality in colour, as we shall see in the next lecture. It depends upon the increasing absorption of certain of the constituents of white light with increasing thickness of the medium. Thus, a solution of blue vitriol or, better still, a crystal, allows blue, green, and yellow light to pass through it if it be thin, but when thick only blue. Analogous phenomena are shown by purple films of gelatine, and by a solution of chromium potassium oxalate. These are cases of increasing selective absorption where waves of certain coloured lights can pass in some measure through weak solutions or thin layers, but are at last completely stopped or absorbed by layers of increased thickness.

The Chromatic Circle.—I can dwell no longer on this very convenient mode of arranging an orderly sequence of colours than will just suffice to explain the uses which I shall have to make of it in subsequent lectures. The disc of which our chromatic circle is the boundary may be regarded as the base of a colour cone, differing from that of von Bezold in the approximately correct angular positions accorded to the several colours which find place in the circle.

I have followed in the main the construction given by Rood to the chromatic circle, but I have not adopted his nomenclature, except in a few cases, while I have used capital letters to indicate the hues corresponding to the three primary colour-sensations, and have emphasized these and their complementary secondaries by joining them by diameter lines of extra thickness. (See diagram.)*
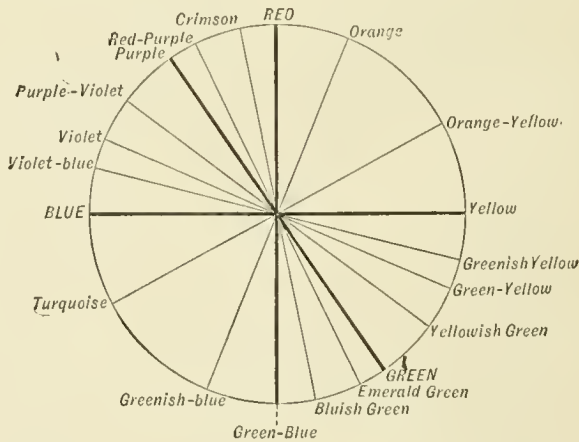
Professor Rood determined the position of his normal red ("spectral red"), in a pure solar normal spectrum, and found it to be at 285, when the space between the fixed lines A and H was divided into 1,000 equal parts. Similarly his normal green is situated at 600, and his natural ultramarine at 785. His normal blue was taken at a point nearer the blue-green side of lapis-lazuli than that which I am able to accept. The three primaries I adopt are approached very closely in hue by the following pigments:—

Crimson Vermilion, for the red.

---

* This diagram is reproduced from "Colour," p. 91 (Cassells.)

Emerald Green with a trace of chrome, for the green.

Pure Natural Ultramarine, for the blue.

Putting aside the questions of purity and of brightness, each one of these three primaries is neutralised, so far as hue is concerned, by one of the three secondaries, thus—Red, by green + blue or seagreen; green, by blue + red or purple; blue, by red + green or yellow. Thus the pairs, red and seagreen, green and purple, and blue and yellow, are what we call complementary colours, and united produce in each instance white. But of course there are an infinite number of complementaries, the pair of colours at each extremity of every diameter of the circle having the right to be so designated. This, however, is a subject to which we must return in the next lecture, and so I wish now to confine our attention to two other matters—the angular intervals which separate the selected colours to which I have assigned names, and the doctrine of chromatic equivalents.

In the earlier attempts at arranging colours in a circle, an inaccurate and quite arbitrary plan was adopted of placing the three primaries at three points equidistant from one another. Supposing, however, that we obtain a normal diffraction spectrum, and merely glance at the position which our three selected fundamental hues occupy, it will be immediately obvious that the green is separated from the blue by a smaller interval than that which divides it from the red. And if we take the numerical differences obtained by comparing the wave-lengths of the three fundamental hues, we shall arrive at the same conclusion. It is by fixing the spectral position of the pigments which most nearly approach these fundamental hues, and consequently learning their corresponding wave-lengths, that we are enabled to assign approximately correct angular positions on our chromatic circle to the pigments in question. For the practical purposes we now have in view, the allocation of proper positions to our most characteristic pigments is the problem which our chromatic circle is intended to aid in solving.

Chromatic Equivalents.—Still dealing with pigments, we may ask—What areas of complementary pigments neutralise one another's hues? and—What are the equivalents of the three fundamentals as represented by the corresponding pigments? We can answer these questions with a sufficient degree of accuracy by means of rotation-experiments with sectors suitably painted, using such areas of the different pigments as shall produce a neutral grey. Here is one set of results thus obtained with a circle divided into 100 equal degrees:—

Red (crimson vermilion) .... $38^\circ 3$
Green (emerald green and chrome) .. $35^\circ 0$
Blue (natural ultramarine).......... $26^\circ 7$

On rotation these sectors produced a grey equal to that derived from 25° white (paper), with 75° black (paper). This large quantity of black shows how great a stride towards darkness is made when pigments (owing their colours to selective absorption) are used. From the above chromatic equivalents, reduced to their simplest expressions, we get the following equations:—

Red = 12.　　Green = 11.　　Blue = 9
Red + Green = Yellow = 23
Green + Blue = Seagreen = 20
Blue + Red = Purple = 21

It will be remembered that Field, by the erroneous method of combined absorption through coloured glasses, found the following equivalents:—

Yellow = 3
Red = 5
Blue = 8

And on these equivalents, widely as they differ from the truth, have been based those calculations generally current amongst colourists as to the proportionate areas of coloured surfaces, by which a chromatic balance and the so-called "neutralised bloom" are to be secured.

I may add here that Rood, employing a red paper of moderate brightness along with emerald green and artificial ultramarine, obtained for these pigments the following values in degrees:—

Red = 50.　Green = 31.　Blue = 19.

The neutral grey these sectors produced on rotation was matched by the rotation mixture of 13 of white (paper) and 87 of black (paper). These values differ, as one expected they would, from those I previously gave, but they lend no support to the figures of Field. On the contrary, they correspond to the ratio—

Yellow, 81 : Red, 50 : Blue, 19;

while Field's figures, multiplied by 10 for the sake of easier comparison, are—

Yellow, 30 : Red, 50 : Blue, 80.

Next Monday I purpose discussing further the subject of complementaries and of contrasts, inviting your attention also to various arrangements of colours in association.

LECTURE II.—DELIVERED MARCH 24, 1890

Complementary Colours.—The chromatic circle, to which I drew your attention in last Monday's lecture, is also, you will have seen, a contrast circle. On its circumference may be arranged a host of colours, limited in number only by the discriminative power of the human eye ; these colours will be united in pairs by the diameters connecting them. Each colour has its complementary in that colour which is 180° off, that is, most remote in position from its own place on the circle ; the pair united in equivalents from white ; in other than equivalents one hue preponderates, but a tint is thus formed, for it is merely the uncombined excess which is perceived mingled with the white produced by the equivalents. Conventionally, we speak of white as present in the centre of the circle ; in truth, it is present at different points on each of all possible diameters, in accordance with the value of each chromatic equivalent. And when we concern ourselves with pigments, we shall soon discover that their positions are variously disturbed by their divergence from normal standards of hue, purity, and brightness.

Besides the numerous complementary pairs which we can place and recognise *on* the circle, there are many corresponding pairs *within* its area situated on its diameters ; these are complementary *tints*. And outside the circle, on the prolonged diameters, will be found complementary *shades*—that is, colours of reduced brightness.

There are several ways of learning the complementary of any hue. In practice we generally desire to ascertain the complementary hues of coloured materials ; to this question we confine ourselves now. As such materials produce their hue by selective absorption, we cannot expect to obtain white from the union of the rays they send to the eye, but must be content with a neutral grey, often with a very dull or dark grey. One method of ascertaining the complementary of, say, a pigment, consists in erecting a sheet of glass in such a way that we can see directly through it the pigment of which we want to ascertain the complementary hue. We then cause an image of each of a series of trial complementaries to be seen by reflection on the glass, so that the direct and the reflected images coincide. When the patch of light thus produced has no positive hue in it, we know that our trial complementary colour is the true one. But this method is troublesome, and so we generally use another, mixing the lights reflected from the pair of colours by rotating coloured sectors. The case of brown paper is generally taken in order to illustrate this method. We prepare a disc of such paper, and associate it with such angular amounts of other discs as shall produce on rotation a neutral grey. In this particular instance Rood found that it required 45 parts of artificial ultramarine and 14 parts of emerald green to produce a greenish blue which should neutralise 41 parts of brown paste-board colour. The grey these complementaries yielded was matched by rotating 24 parts of white and 76 of black paper. Just look a little more closely into the chromatic constituents of this pair of complementaries. The three pigments—vermilion, emerald green, and artificial ultramarine—required in order to yield a grey need to be rotated in the proportions 36 : 34 : 30. But the complementary of our paste-board contained the emerald green and ultramarine in the ratio 14 : 45 or 9·3 : 30 ; consequently the paste-board must have furnished the equivalent of 24·7 parts of emerald green as well as that of 36 parts of vermilion. But these proportions of emerald green and vermilion, when mixed by rotation,

produce an orange - yellow of rather low luminosity—a broken tint of orange-yellow—and it is by this term that we should define the colour of the particular brown paste-board. [It should be noted here that by the successive impressions of colours on the eye, produced in the rotation experiments, we do not get the added luminosities of the pigments, but only their mean luminosity; and that our bright yellow and orange pigments possess a degree of brightness quite out of proportion to that of most of our pigments of other hues.]

If we put aside the questions of brightness and purity, taking into consideration hue only, we may describe all complementary pairs as made up of—

(*a.*) *One Primary and one Secondary*, or of
(*b.*) *Two Secondaries.*

Examples of *a* are furnished by the pairs—

> Red   : Seagreen.
> Green : Purple.
> Blue   : Yellow.

Among the countless instances of *b*, I name—

> Orange   : Greenish-blue.
> Orange-yellow   : Turquoise.
> Greenish-yellow : Violet-blue.
> Yellowish-green : Purple-violet.
> Bluish-green   : Crimson.

There is one characteristic of all true complementary pairs of colours—they do not affect each other's hues. They are already as unlike in hue as possible, and cannot therefore mutually modify this colour-constant. They may, and often do, modify their apparent luminosity and purity. So in the pair "blue : yellow," which affords, next to "black : white," the strongest possible difference of tone, the blue makes the yellow at once brighter and paler, while the yellow makes the blue at once purer and less luminous. The characteristic of the non-alteration of hue when the complementaries are placed in contact affords a criterion of the truly complementary nature of any pair of colours. For instance, in this diagram of true and false complementaries, in the pair "red : green," the red makes the green look bluer than it is, while the green makes the red appear to incline towards purple. So in the pair "yellow : purple," the yellow looks somewhat greenish, the purple somewhat violet ; and in the pair "blue : orange," the blue inclines towards green, and the orange towards yellow. These are examples of the peculiar optical effect known as simultaneous contrast, in which two contiguous surfaces, which differ in one or more of the constants of colour, have such differences mutually enhanced or modified. Of such contrasts of hue, brightness and purity, I shall have something further to say directly, but I want to ask you first which of my columns of supposed complementary pairs commends itself to your judgment and taste as preferable ? I do not say that the strongest possible contrasts of hue, as afforded by our approximations to the complementaries, are necessarily agreeable, but I do feel that the similar series constructed on the false basis of the red-yellow-blue theory is decidedly unpleasant : the angular intervals between the pairs should have been greater or less. Red with seagreen seems to be more agreeable to the eye than red with green ; green with purple looks better than with yellow ; blue with yellow better than blue with orange. That these effects are not wholly due to differences in brightness may be argued from this case of blue with orange, where I have tried to lower the luminosity of the orange so as to make it no brighter than the blue with which it is associated. But the inherent falsity of the red-yellow-blue theory precludes one from giving to these pairs of complementaries their proper share of brightness—assuming for the moment that we could really accomplish such a result with pigments.

Contrasts of Tone and Hue.—Contrasts are of three kinds, namely, contrasts of hue, contrasts of brightness, contrasts of purity. I have already directed your attention to contrasts of hue ; the other two kinds of contrast now demand notice. The best illustration I can give you of contrast of tone will be one in which we shall produce simultaneously a series of greys. By means of this black figure mounted on a white disc we shall produce a series of optical mixtures of black and white, regularly increasing the white by five steps. The outermost ring of grey will be the palest tint of black, the innermost the deepest shade of white. But you will observe another and unexpected appearance produced in this experiment. Each ring seems to be itself tinted and shaded, although it must really be of one uniform grey. Simultaneous tone-contrast is produced, not by optical fatigue but by an error of judgment. The effect is enhanced by the difference of tone on each side of these contiguous rings, for the middle ring is bounded by a darker shade of grey on one side, and is there made lighter by contrast, while on the other side it is in contact with a paler tint of grey, and is there made darker by

contrast. The immense importance of this phenomenon in pictorial and decorative art is well known ; it, of course, takes place with positive colours as well as with negative. If in an engraving or Indian ink drawing a certain dark space seems monotonous and heavy a single touch of a darker shade will at once lighten and vary it, while just in the same way a lighter stroke on a tint which is too pale will enrich and deepen it. In both cases the result of simultaneous contrast will relieve the flatness of the work.

When positive colours come into the arrangement of differing tones the results may be indicated by means of a few diagrammatic figures. Suppose we begin by introducing a kind of brown in the form of a disc. This colour of medium depth is deepened by a smaller half-disc of white near its centre, and lightened by the contiguity of a corresponding half-disc of black. Again, suppose we place a small disc of full blue upon a larger disc half white and half black, the black will make the blue it touches less pure, that is, will lighten it, while the white will affect the blue in an exactly opposite way.

We now proceed a step further, and take two colours instead of one. Using the same reddish-brown colour as before, we place it on a disc of deep blue, and find that it becomes lighter in tone and less pure, while at the same time it acquires a distinctly yellow cast, having thus received a portion of the complement of blue. Similarly on an orange-red (red lead colour) disc, lighter in tone than its own, it appears deeper in tone, and assumes a somewhat greenish-blue cast, though this effect is but slight, owing to the addition of this complementary mainly serving to neutralise some of the red in the brown disc.

A third case may now be considered. We select for apposition two colours which are separated from one another by a comparatively small angular interval in the chromatic circle, and which are both somewhat bright. We find, as we might expect, that their mutual action as to alteration of tone is but slight, while their change of hue is more decided, each tending to recede farther from its companion by acquiring more of the complementary hue. Here visual fatigue and the warping of the judgment both conduce to the same result.

Harmonies of Colour.—I must now ask you to consider what are called chromatic harmonies. Chevreul's classification of harmonies under two headings — harmonies of

analogy and harmonies of contrast—is somewhat arbitrary. All harmonies are in varying degrees harmonies of contrast. In every chromatic harmony there is contrast, contrast of hue, or of brightness, or of purity. Contrast generally, therefore, does not afford a criterion of classification. No fundamental difference really exists between those harmonies where change of tone or of hue is gradual and those where it is abrupt ; it is a matter of degree, and is quantitative rather than qualitative. I do not see my way to improving the arrangement which I proposed in my " Manual of Colour " (pp. 134 to 139). I suggested arranging the various possible harmonies upon the arc of a circle, placing the harmonies of close analogy at one end, the harmonies of strong contrast at the other :—

1. The passage, by insensible differences, of the tints, shades, or broken tints of one hue, from light to dark.

2. The gradation by small but regular, definite, and perceptible steps, of the tints, shades, or broken tints of a single hue, from light to dark.

3. As in 2, but each step separated by a neutral element, as white, grey, or black.

4. The passage, by insensible differences, of one hue, or of its tones, into another related hue or its tones.

5. The gradation by definite steps of one hue, or of its tones, into another related hue or its tones.

6. As in 5, but each step separated by a neutral element.

7. The passage, by insensible differences, of one hue, or its tones, into another chromatically remote hue.

8. The gradation, by definite steps, of one hue into another chromatically remote hue.

9. As in 8, but each step separated by a neutral element.

10. The collocation of different tones.

11. The collocation of chromatically distant hues.

12. The collocation of chromatically distant hues separated by a neutral element.

The idea of seriation or gradation becomes more and more involved with that of decided change as we follow the sequence of these numbers ; analogy gives place to contrast.

This classification may be illustrated by a few examples, but I have no time to develop the subject completely. And it must be noted that such definitions as I have offered are of use in the way of suggestion, but must not be allowed to fetter the imagination of the artist ;

they cannot take the place of experiment, observation, knowledge, and sensitive perception of chromatic beauty.

I take three examples only; they will serve to illustrate Nos. 5, 6, and 7.

The diagram shows the gradation in three steps only, of yellow to orange (No. 5 above); and also the same gradation when the neutral elements, white, grey, or black, are inserted (No. 6). These cases furnish examples of the use of what has been variously termed "the dominant hue" and "the small interval." We may illustrate it by the budding foliage of spring, the changing hues of autumn, and the association of nearly-related hues in many flowers, as in several kinds of daffodil.

My next diagram shows the passage of red to blue (No. 7 above). Really it is only a more extreme case of our No. 4, but there is not here a chromatic element common to the whole series of passage hues, for the red at one end contains no blue, and the blue at the other end no red.

Associated Colours.—Of pairs, or dyads, I must say a few words. These are of three orders, namely, complementary pairs, large-interval pairs, small-interval pairs. Complementary pairs, when their tones differ considerably, as in the case of deep red with bright sea-green; or when they contain much white, or are pale; or when they contain much black, or are of low luminosity; or when they are at once of low luminosity and contain white (that is, are broken with grey), are all, or may be, so adjusted as to be agreeable. Large-interval pairs are usually more difficult of management, and when both possess a full degree of saturation, are often unpleasant. Cases are afforded by red with yellow, orange-red with blue-green, orange with purple, orange-yellow with green, orange with green, and greenish-yellow with turquoise. The dilution of one of the pairs with a neutral element generally improves these combinations, but some of them, though so strong as to require moderation in use, are naturally excellent. Amongst these may be named red with blue, orange-red with blue, orange-yellow with violet, and blue-green with violet. In these cases, however, there is normally a considerable difference in the luminosity of the two colours associated in pairs. By beauty of material and of pattern some of the simplest dyads may yield exquisite effects, as in Italian velvets and brocades of the 16th century. Such dyads are yellow-green with medium violet, pale olive-green with deep indigo, leaf-green with deep blue, and pale leaf-green with deep amber.

The simplest triads contain two colours and a neutral. Suppose we desire to associate violet and blue we may interpose with agreeable effect between them white or a pale grey, but not black. The blacks available have a low degree of luminosity and so do not differ enough from the full blue and full violet we are using; moreover they become tinctured with an unpleasant rusty hue, the complementary of the blue or violet. Generally the poor and bad dyads may be improved by the introduction of a third element, while good dyads are often spoilt thereby. Good triads may frequently be secured by taking three hues rather widely separated from each other on the chromatic circle, and, as a general rule, two of these hues should be pale or bright and one deep or dark, or *vice versâ*. Except in special circumstances it will be easier to manage these triads when two of the members belong to the "warm" side of the circle and one to the "cold." I give a few good triads:—

Amber, Cream, Blue (medium).	Leaf-green, Puce (deep), Rose-grey.	Leaf-green, Violet, Salmon.
Amber, Blue (pale), Crimson.	Terra-cotta, Maroon, Sage-green.	Apricot, Crimson, Gold-brown.
Flesh-red, Blue (normal), Olive-green.	Maroon, Bronze-yellow, Olive-green (dark).	Red (normal), Gold, Blue (normal).
Brick-red, Indigo, Sea-green.	Bluish-green, Violet, Red-ochre.	Lavender, Turquoise, Blue (deep).

Other examples of triads, and of more complex colour-combinations, taken chiefly from historic and national chromatic arrangements, are—

1. Blue (deep), or Lavender (pale)
2. Gold-amber   (Ancient Egyptian)
3. Vermilion-red in fine lines on 2

1. Lavender (pale)
2. White   } on ground of { 5, orange yellow
3. Black   6, ochre-yellow   (Assyrian)
4. Red-brown (medium)

1. Chamois-leather
2. Raw Sienna   } on ground of 4, black   (Greek)
3. Venetian Red

1. Blue (medium)
2. White   } with outlines of 5, black   (Moresque)
3. Red
4. Greenish grey

1. Silver
2. Gold   } with outlines of 3, puce, all on ground of 4, pale emerald green   (Indian)

1. Silver
2. Lavender   } with 4, white in bands
3. Emerald Green (medium)   } and 5, black in lines   (Irish MS.)

1. Silver   (area $= \frac{4}{10}$)
2. Gold   (area $= \frac{4}{10}$)
3. Red edgings   (area $= \frac{1}{10}$)   (Irish MS.)
4. Black ground   (area $= \frac{1}{10}$)

1. Lavender
2. Lemon-yellow
3. Crimson (medium)   } with as lines and ground, 6, black   (Irish MS.)
4. White (in strap work)
5. Green (medium)

1. Bluish-green (full)	4. Blue (full)
2. Yellowish olive (medium)	5. Purple (medium)
3. Orange (pale)	6. Crimson

1. Crimson (medium)	4. Yellow green (medium)
2. Salmon	5. Yellowish olive (medium)
3. Yellow (pale)	6. Maroon

And now I desire to draw your particular attention to one of those characters of good colour which is of supreme importance. You will understand the nature of this " quality " in colour when I have described and analysed illustrative examples. I begin by choosing a few cases in which it is either absent or irrecognisable. A surface of matt paint of one uniform tone and hue, and illuminated by a direct and colourless light, is confessedly prosaic and colourless light, is confessedly prosaic and uninteresting ; so also is a piece of self-coloured " surface " paper or a plain printed cotton cloth. All the materials are flat, and they exhibit no variations of tone or hue, or at least no perceptible variations. Of all the hues that can be chosen as examples of this point, perhaps the full red, the full green, and the full blue are the most telling ; but the full orange and the full violet come very near to them. If the generally accepted theory of the three primary colour-sensations being red, green, and blue be accepted, we shall perhaps be able to suggest a partial explanation of the unpleasant appearance of a considerable surface of any one of the three above-named hues when alone in the visual fatigue of one set of optical nerve-fibrils which they severally cause. Orange and violet are, however, assumed to affect the red and green fibrils and the red and blue fibrils respectively. Yet in the case of these two colours (orange and violet), the stimulation of the two sets of fibrils which they each cause is not equal, for the orange has an excess of red in it, and the violet has an excess of blue. If we select other hues in which the two components are present in

equivalent, if not in equal, proportions, the force of our argument is, I think, increased. Such hues are yellow (red + green), seagreen (green + blue), and purple (blue + red). Now it will be generally conceded that the contemplation of an *unmitigated* yellow is less displeasing to the eye than that of orange or red, seagreen than green or blue, and purple than violet. Such comparisons are, I confess, very difficult to make, and, without special contrivances for excluding all disturbing elements, they are quite inconclusive. With the pigments commonly employed for such comparisons, the varying amount of white light they reflect, and the presence of chromatic elements other than those we desire to compare, do more than imperil the accuracy of the result. And then the presence of backgrounds and surroundings modifies the effects produced; these depend also very much upon the manner in which the coloured substances used are illuminated. Even with the spectrum-colours themselves a just comparison is by no means easy. I am reluctant to illustrate my argument by citing the case of certain sounds, because the analogy between colour and sound has been frequently pushed to unwarrantable lengths; yet I think I may say that an absolutely pure loud note of uniform pitch, without the simultaneous presence of those harmonious constituents which combine to form its *timbre*, would be no more pleasing to the ear than a pure full colour of elementary character is to the eye.

Hitherto, I have been speaking of full colours, colours, that is, which are intense and saturated, and also pure or unmixed with white. The current theory of colour sensation does, however, assume that there is *some* stimulation of all the three kinds of optical fibrils caused by each colour, however pure. Still the sensation, say, of green is caused by an immensely preponderating stimulation of the green fibrils over that of the blue and red fibrils. A corresponding statement may be made with regard to the sensations of blue and of red. In these instances, the fibrils not necessary to the production of the two sensations in question are even less stimulated than in the case of green, a difference which has been attributed to the median position of the latter hue in the spectrum and therefore to its intermediate wave-length. It is argued that the green nerve-fibrils which respond to the vibrations of green light are capable of responding, to a slight extent, to the vibrations of light on either side of green,

but that the red nerve-fibrils are somewhat less affected by the impact of the vibrations at the other end of the spectrum, and *vice versâ*. In confirmation of this view I may mention the curious observation that the last colour to disappear when a continuous and normal spectrum is gradually reduced in luminosity is the green. That it appears finally as a grey, having but a faint tinge of green, is quite in accordance with theory. And it may not be out of place to observe in this connection that the full, nearly normal green, as represented by the pigment emerald green, is much more luminous than the full red as represented by vermilion, probably in a ratio approaching 2 : 1.

One reason, then, why pure white and the infinite series of tones of grey do not offend the eye as do certain pure, full, and luminous colours, may be traced to the equal stimulation of the three sets of optical fibrils which they cause. Tints of any colour—the full colour lightened with white; shades of any colour—the full colour darkened with black; broken tints of any colour—the full colour dulled with grey, come into the same category; for the stimulations they cause, though not equable like that of white and of grey, either approach equality, or are less energetic and one-sided than those of the full normal hues.

We are now in a position to offer some explanation, inadequate though it be, of the peculiar satisfaction afforded to the eye by one of the characteristics of beautiful colour. We call it "throbbing," "pulsating," "palpitating." This quality may be imparted to it in several ways, by which its dead uniformity is broken, or its *criant* effect is subdued. The fluctuation in question may be caused by—

Light and shade from inequalities of surface or irregular scattering of light.

Varying surface-reflections.

Passage from translucency to opacity.

Varying depth of hue.

Variations of hue limited to the "small-interval."

Several of these causes often conspire to produce throbbing colour in one and the same case, and they will be best illustrated by a few concrete examples.

The case of rough paper which has received a uniform wash of water-colour furnishes us with an illustration of the effect of light and shade as modifying hue. We will assume that the pigment has been so equally distributed that the hollows of the surface have

not retained more than the elevations. Then we shall find, in the case of many pigments of full colour, that the hue in the hollows differs from that in the prominences. For instance, if French ultramarine has been used, the hollows will show a colour tending slightly towards violet, while the pigment on the elevations will exhibit a purer blue. In practice the effect will be augmented by the varying amounts of pigment which have lodged in different parts, the hollows retaining more than the elevations. The same wash of the same pigment on smooth paper will present a different appearance ; and in order that the effect of the pigment on the latter may rival that on the rough, it will be necessary to introduce a second pigment, perhaps even a third. That the difference in question is not one of light and shade only may be proved by comparing the two kinds of coloured surface in a suitable instrument constructed on the principle of Lovibond's tintometer, and admitting of the examination of small isolated points or patches of colour—the chromatic analysis of these points will be found to vary not merely in depth but also in hue.

That the majority of painters in water-colours should prefer a comparatively rough paper for their work to the smooth sameness of Bristol board is not surprising. One admits of happy accidents of hue, and even involves them ; the other demands the introduction of laboured effects, while the result, at best, is inferior.

Our second cause has been called " varying surface-reflections." To illustrate it we will take a piece of porcelain. The glaze may vary in thickness ; parts may be more perfect in gloss than other parts ; it may even exhibit iridescence. A colourless glaze may produce modifications of the hue of the colours beneath it by reflecting from its surface in varying amounts the coloured rays which fall upon it from surrounding objects, or by itself decomposing the white light by which it is seen. In both cases its colour will be variously changed even when that colour was originally flat and uniform. I have in my mind, at the moment, a vase of old Chinese egg-shell porcelain of an amber-yellow. This colour is due to lead antimoniate, a substance which has become partially incorporated with the colourless glaze in the kiln. The surface reflection varies in intensity ; in some places it reflects the incident white light unchanged, in others it shows iridescent colours, chiefly purple and greenish blue. The fluctuation of colour is produced by the mingling of the light which has passed through the yellow pigmentary layer and has then been reflected to the eye from the white subjacent ground with the light directly reflected from the glossy surface. From different portions of the surface we receive light of at least four different hues, namely, the original yellow ; the same colour diluted with white ; pale orange-yellow, where the original yellow hue is modified by commixture with the purple of the iridescence ; and pale greenish yellow, where it is similarly mingled with the greenish blue rays from the glaze. Of course, in some positions, the iridescence alone can be perceived, just as in others the original amber-yellow alone is visible.

When a colour varies in transparency or opacity we get a third case of fluctuation. This variation is generally accompanied by variations in depth and hue, but it alone suffices to bring about the quality we are considering. Let us take an illustration from oil-painting. We shall require two pigments, one transparent, the other opaque. It will be difficult to match them exactly as to hue, but vermilion and a kind of madder red will answer sufficiently well. We spread a very thin layer of the latter upon a white or colourless ground ; some distance off we prepare a similar patch of the vermilion ; between the two we make a gradated mixture of the two pigments, and thus obtain the passage of a transparent colour into an opaque colour ; yet the whole coloured area is a red, and a red which can be represented by one and the same numerical expression when referred to the wave length of the corresponding hue in the spectrum. But instead of employing these two pigments in the diagrammatic fashion, let us use them in pictorial or decorative painting by placing the two pigments side by side, or glazing with the translucent pigment, or scumbling with the opaque upon the same background. Only in some such way is it possible to suggest the throbbing colours seen in many natural objects, feathers, precious stones, marbles, &c. Of course in representing these we are not restricted to the use of a pair of colours of the same hue and depth ; the limitations we imposed upon ourselves were intended merely to simplify the consideration of this third source of pulsating colour. Let me add that the fluctuation here is between two red lights, one of which reaches the eye after passing twice through a translucent red medium, while

the other is produced by selective reflection from the surface of an opaque red solid. I say opaque, although in point of fact the incident light, or rather a part of it, plunges to some depth amongst the red particles of vermilion and passes through them, a chromatic selection being thereby made. And it is really in this manner that the light finally reflected to the eye by this pigment, having lost in selective absorption some of its coloured constituents, is red. I might cite many examples of the fluctuation of colour produced by the passage of an opaque colour into a transparent one or by the juxta-position of two closely related colours, one of which is due to surface-reflection, the other to reflection from an appreciable depth : the sea, for instance, when it shows the local blue colour of the water itself, and, associated with this, the reflected blue of the sky. The effects produced in certain textiles, such as linen and silk, damasks and velvets, partly belong here, but they are also connected with the variations due to inequalities of surface and to differing powers of reflection.

The fourth and fifth causes of the throbbing colour are to be traced to variations in depth of one colour, or to slight variations in hue ; they may be fitly considered together, for in actual examples they are generally associated. Again, we may have recourse to Chinese porcelain for an illustrative example. There is a beautiful ceramic colour known as dragon's blood ; its hue varies much in differeut specimens, and even in the same specimen, but the red element always largely preponderates. The red sometimes approaches a red-purple, that is, has a small proportion of blue in it ; more often it oscillates between a crimson and the colour known in France as *garance dorée*. The crimson varies in depth. Sometimes it is a full and saturated colour, sometimes it passes into a paler tint, a kind of rich rose-pink. The *garance dorée* is a translucent red, which, when diluted, has a somewhat golden-red or orange-red hue. When we examine a good specimen of this kind of porcelain, we may sometimes detect the presence of all the colours I have named, as well as of their intermediate or passage tints. These hues are separated from one another in the chromatic circle by a very small number of degrees ; they illustrate the effect of the collocation of colours differing by what is called " the small interval." If the circle be divided into $100°$, their extreme range will amount to about $10°$. And the most extreme colours are not in juxtaposition, for one

slides into another by imperceptible gradations both of tone and of hue. And a range so extensive as $10°$ is by no means necessary in order that the prosaic flatness of ordinary colour may be avoided ; possibly a range of $2°$ or $3°$ may suffice, even if it be unaccompanied by variation of tone. Coloured glass, of good quality, may be chosen as affording an excellent illustration of the points now under consideration, but I reserve it for fuller consideration later on, although I may observe, in passing, that the fluctuations in colour of the transparent enamels on porcelain, and of glass, arise from the same causes, only that, as we look *at* porcelain and *through* glass, surface iridescence in the latter plays either no part, or a very small part, in the production of the phenomena in question. Of course I exclude from consideration glass intended to be looked at, that is, those vessels of glass, coloured or uncoloured, which owe their beauty of hue to the iridescence of their surface.

I have now shown, I trust, that throbbing colour is produced in more than one way, and that it is agreeable to the eye, even when we are unconscious of the elements that concur in its production, at least in part through physiological causes. I do not think these causes furnish an adequate explanation of the pleasure such colour affords, for its charm is doubtless connected with certain fluctuations of our judgment when any element of contrast in colour or in tone comes in, with the agreeable associations it recalls, and with its complexity and mystery. We do not see it all at once, nor do we instantly grasp its full meaning. Its effect may be likened to that of an intricate architectural vista, or of a range of distant mountains, or of the cadences in the exquisitely chosen language of a beautiful poem. I cannot but think that throbbing colour is as necessary to chromatic decoration as to pictorial art. You are familiar with the numerous and most useful coloured designs which illustrate Owen Jones's " Grammar of Ornament." Translate these flat and terribly prosaic figures from the uniformly coloured paints with which they have been printed into those precious materials—silk, and marble, and glass—which present delicate variations of tone and of hue, and at once the chromatic combinations are ennobled, changed from awkward prose into refined poetry fraught with varied interest. It is just in the same way that the sympathetic painter of landscape treats the clouds and the sky. He is not satisfied with white and grey for

the former, and with blue for the latter. He does not merely gradate his tints, but suffuses his whites and greys with faint suggestions of amber and apricot, and rose ; and varies his azure with hints of lavender and of aquamarine.

LECTURE III.—DELIVERED MARCH 31, 1890.

SYLLABUS.—Balance, Proportion, and Distribution of Colour—Interchange and Counterchange of Colour—Colours of some Natural and Artificial Materials—Decorative and Pictorial Colour—Colour in Relation to Architecture and Sculpture.

Distribution and Balance of Colour.— When the constituents of a set of colours to be associated together have been decided on, it still remains to determine their sequence and the relative areas they shall occupy. Such triads as were given in the last lecture may be made disagreeable or pleasant by altering their distribution or their proportions. The triad *red*, *gold*, *blue*, affords as good an illustration of this fact as we could wish. If we make the red and blue come into contact throughout the design in equal areas, and if we then spread over the surface a spray of gold foliage in such a way as to employ, in masses of considerable extent, just as much gold as red and as blue, the result will be crude and unsatisfactory. But we may develop the varied beauties of which this group is susceptible by modifying the arrangement and proportions of its constituents in scores of different ways. Let us devise one such way, of which the plan shall be—separation of the blue and red by gold, and the use of these three chromatic elements in the ratio 7 : 3 : 1 : so we make our blue ground cover 7-11ths of the area to be decorated ; our arabesque and its curves, or our spray and its foliage, will be of red, 3-11ths, bordered throughout with gold, 1-11th. I need not tell you how much we may modify and improve the result by the beautiful curves of our spray, and by half entangling patches of the ground within its borders. And this end may be reached by many other methods which I cannot stay to describe.

One of the tetrads named in the last lecture will serve to illustrate these matters of arrangement and proportion. The example is taken from an early Irish illuminated missal. The four elements are silver, gold, red, and black. The proportionate areas are 4 : 4 : 1 : 1. Silver and gold quatrefoils alternate. They are bordered by red in the form of a line of uniform breadth ; the residual space is covered with black, but this is broken up into such small portions that it does not look heavy, while the continuous red outline serves at once to bind the whole design together, and to prevent too strong a contrast of tone between the black and the gold or silver. You will be able to think of many an arrangement of these four elements which would prove less felicitous, and, doubtless, of others equally good.

I have before spoken of the principle of the " dominant hue." It will be easy to carry out this principle by modifying the area of the elements in our triads. In this way one of our " cold " triads—such as bluish-green, violet, red ochre, may be made " warm." In such a case we shall have to increase greatly the area occupied by the red ochre, and to proportionately diminish that of the other two elements of the group. We may, for instance, prepare a large design of foliage of red ochre upon a ground of bluish green, separating these two colours by a contour line of violet, adding perhaps some fine veins of violet to our large leaves. But it must be noted that such arrangements often become easier and more pleasing when we are at liberty to introduce a fourth element, even if that element be but white or other neutral. A fine old Rhodian tile in my collection affords a case in point. It has a ground of a red ochre hue occupying 5-10ths of the whole area. Upon this a design of white foliage, highly conventionalised, spreads in a connected and symmetrical fashion, and covers 3-10ths of the surface. The remaining 2-10ths are shared between a full blue and a slightly bluish green in nearly equal proportions. These colours are distributed upon the white portions of the design

chiefly in the form of veinings. There is also a fifth but inconspicuous element in the chromatic scheme, namely, a delicate contour line of deep grey. The effect of the whole arrangement depends upon the dominant red hue of the ground, but this is refined and lightened by the net of white foliage, which, in its turn, gives strength and purity to the graceful curved forms of blue and of green which it encloses. The uses of colour-schemes, in which a dominant hue is present, are frequently of the utmost importance in hangings, papers, and wall-decorations. These have to perform the office of a background, and to set off one or more conspicuous chromatic elements in the room. If you want to display properly some fine pieces of blue and white porcelain, your walls must not be so coloured as to interfere with their effect, but rather to enhance it both as to tone and hue. A flat buff or grey may make your porcelain too conspicuous ; a bright blue and a pure white will clash with it ; a strong red will overpower it. A scheme of colouration, which in its totality produces the effect of a greyish olive green, half way in depth of tone between the white and the blue of your vases, will probably be found to answer well.

When it is not desired to direct attention specially to the colours of the objects in a room, then it is allowable to gather into certain parts of your wall decoration the more telling of the chromatic elements which enter into its composition. You accentuate the design by focussing the more saturated and luminous colours in the more important parts of the design.

From what I have stated thus far, I think it will be evident that, even if we could attain such a chromatic balance as would produce a true " neutralised bloom " on our walls, or in the carpets on our floors, we should still have left out of our scheme the more important chromatic elements belonging to our moveable furniture and ornaments. In fact, the system of contrasts of hue and tone—contrasts more or less subdued—is the only one by which a real unity of effect can be reached ; at the same time that due prominence and relief are secured for those parts or objects where prominence and relief are needed.

Returning once more to our triads, 1 would mention a principle of arrangement often adopted with success, namely, the separation of two nearly related tones by a tone which is darker or lighter. Sometimes this sequence brings together chromatic elements which clash, and, of course, it must then be avoided.

Still, the rivalry of two colours having the same degree of brightness is frequently unpleasant, especially where they are both strong. The triad of full red, gold, full blue, illustrates these observations. The use of a triad of three full colours is rarely successful, and can no more be tolerated than the presence of three trees of equal size and equal prominence in a landscape picture. Where three colours having three decidedly different tones are used in one scheme, we are almost compelled to arrange them in the order of their depth—dark, medium, light.

You will, I think, excuse the elementary and fragmentary character of all these remarks of mine on distribution and balance of colour ; no one can be more conscious of their imperfection and of their commonplace character than 1 am.

Counterchange and Interchange. — In heraldic colouring the principle of counterchange is frequently adopted. Ermine is white spotted with black ; counter-ermine, black spotted with white. Suppose a shield of arms divided diagonally from right to left, and bearing a star. Where the field is azure the star is argent, where the field is argent the other half of the star is azure. In the latter half of the 17th century the same arrangement was adopted in textiles and embroideries, great skill being shown in the passage from a design, say, of red upon a blue ground to the same design in blue upon a red ground. I have noticed that in the more successful of these counterchanged patterns the areas occupied by the pattern and the ground are about equal. When these designs were executed in "cut" work there was no loss of material, for the pattern cut out from one part of the design formed the ground of the next. In the cut-cloth-work of Resht in Persia, a similar mechanical method of procedure was adopted, but the counterchanges were not effected in the same piece.

The principle of interchange may be illustrated by the alteration of a set of tones of greenish yellow with a corresponding set of tones of violet. These tones may be so arranged that the series begins with the deepest tone of each colour alternated, the rest following in regular sequence, or the deepest tone of one colour may be followed by the lightest tone of the other, and so on ; but a satisfactory effect is difficult of attainment.

Colours of Minerals.—1 have time to refer to a very few only of the characteristics of coloured minerals. The colours of some of

the most beautiful precious stones are in a measure dependent upon the phenomena of dichroism which they exhibit. The ruby, sapphire, emerald, and tourmaline may be named in this connection. Quite apart from the prismatic decomposition of light which these gems effect when facetted, they show, with more or less distinctiveness, the twin colours of dichroic bodies. The ruby exhibits in the same stone a pure red and a crimson or carmine-red; the sapphire a straw-yellow and a pure blue; the emerald a bluish-green and a pure green; and the tourmaline broken tints of yellowish-green and reddish-brown. No monochroic substance, such as paste, enamel, or glass, can give rise to the variable fluctuations of colour seen in these dichroic gems. The peculiar chatoyancy of Labrador spar has also not yet been imitated in any artificial material. The beauty of lapis-lazuli and of many agates and jaspers is no doubt partly dependent upon the pulsing of the colours they exhibit, partly upon a certain measure of translucency which they possess. This quality of translucency is also seen in many marbles, especially when they are polished; its absence from some artificial materials (such as terra-cotta) is perhaps one of the reasons why it is difficult to associate the two classes of materials together with satisfactory effect. When both are in small pieces, and especially when they all receive together the same polish, the incongruity in question does not attract notice. The tessel-lated Roman pavements found in this country often afford excellent illustrations of this har-monising of natural with artificial materials— marble and stone, with pottery and even glass.

The picturesque coloured markings and veinings of many marbles are best developed by polishing, and best seen in surfaces of con-siderable size. If these surfaces are not plane, their curvature should not be complicated with flutings or other sculptured treatment. A carved ornament in such marble is a mistake, at least whenever the coloured markings are decided. Man's art in relief spoils nature's decoration in colour. For this reason the carved work in Derbyshire alabaster, for which the late Sir Gilbert Scott showed so much par-tiality (witness many a reredos which he de-signed) is most unsatisfactory. Over and over again a dark veining makes a prominent part of the carving appear to recede, while a bright and pale patch throws a hollow or recessed detail into conspicuous relief.

Colours of Animals.—The most brilliantly coloured of animals—birds—naturally attract our attention. I do not pretend to champion all the chromatic arrangements of nature. Yet two circumstances must be taken into account in considering the colours of animals and plants. These colours and colour-associations must not be considered apart from their natural *entourage* and the conditions of their existence. And, secondly, if we are to follow the leadings of evolutionists, it cannot be maintained that the colouration of plants and animals in a state of nature is connected with the chromatic tastes of man. Of course, under domestication, the hues of both are greatly modified by pro-cesses of artificial selection and of treatment.

Let me direct your attention to the colours of certain humming birds as typical examples of peculiarly powerful colours, many of them belonging, in the intensity of their regular re-flection of light, to the metallic group, but being more strongly coloured. One of these is a Central American species, and is known as the "garnet" *(Lamprolæma Rhami).* It is commonly spoken of as showing a brilliant patch of garnet-red upon its throat and breast. But in reality this hue is not invariable and uniform. In the constant movements of the living bird it must be ever changing with its changes of position. As you examine a mounted specimen you will see at first only a metallic crimson; but when your view-point is altered, all the passage-tints between a rose-madder and a greenish yellow follow in their regular spectral sequence. This sequence, which will be observed, I believe, in all similar cases, is connected with the mode of produc-tion of these metallic colours. They do not arise directly from the presence of actual colouring matters or pigments, but from the minute optical structure of the web. Another humming bird, a "train-bearer" *(Cynanthus forficatus),* has its conspicuous tail-feathers adorned with metallic violet; but this violet passes in some positions and in some parts into a splendid greenish blue, every inter-mediate hue being present. So with one of the "comets" *(Sappho sparganurus),* the tail-feathers sparkle with a golden bronze, ranging from orange to red-orange. Another "comet" *(Sappho phaon),* is similarly decorated, but the colours range from madder-red to red-purple. Another bird, the "ruby and topaz" *(Chrysolampis mosquitus),* has on its head a patch of metallic crimson, passing into orange when viewed from some positions; similarly, the fiery metallic orange of its breast passes into yellowish green in some positions.

I cannot refrain from citing the case of another humming-bird, one of the "sapphires" (*Eucephala cœrulea*). Here the head is decorated with a colour not of the metallic order, but still very rich, almost the colour of French ultramarine blue. But on the breast of this bird a metallic colour re-appears ; it is a fine blue, passing into an equally fine green. I have said nothing of the brownish-black background which shows off all these splendid hues, because I want you to notice more particularly that these dazzling metallic colours are never really uniform and flat, even though their tones may be equivalent, for they show large ranges of hue, not capricious, but following the orderly sequence of wave-lengths in the spectrum. I must omit all reference to the colouring of butterflies and shells, about which I had much to say, in order to pass on to the vegetable kingdom.

Colours of Plants.—The texture and translucency of flowers and leaves greatly modify the hues of the colouring matter they contain, and of the light which they reflect. The peculiar glistening of the cell walls in the coloured tissues of flowers is a case in point ; it is sometimes erroneously spoken of as crystalline. The distribution of the various colouring matters of flowers in the cells, when the coloured tissues are examined under the microscope, is seen to be much less regular than might be imagined, and is doubtless one of the causes of the peculiar chromatic beauty of many flowers. In speaking of the colours of plants some reference must be made to the green of foliage. If the fully developed leaves of a forest tree in summer sometimes tend towards a certain heaviness and monotony of hue, still there is, even in this case, a degree of variety present. Some leaves are in shadow, some transmit the incident light, some reflect the blue of the sky or the grey of clouds, some display in perfection their local colour, and some show in different parts the various hues just indicated. And then, too, it must not be forgotten that the green colour of foliage varies with its age, and that it always possesses a singular characteristic which distinguishes it from other greens ; for if we place a spray of green leaves upon a piece of green cloth or of green paper resembling it in general hue, we shall yet find that the natural pigment differs materially from the artificial in its chromatic constituents. To prove this you need not have recourse to prismatic analysis ; you have only to illuminate both surfaces with red light, or to inspect both through a piece of red glass,

to see a very striking difference, especially noticeable with the yellowish-green foliage of young branches.

I regret that time fails me, or I should have liked to direct your attention to the colours and textures of wood, and of various vegetable fibres.

Colours of Artificial Materials and of Fabrics.—I have already named glass as affording illustrations of the throbbing or vibrating of colour. In the examples of coloured glass which I now show you by means of the electric lantern, we may observe the various causes which conspire to produce the artistic charm of really beautiful glass. They include not merely fluctuations in hue and tone, but the presence of bubbles and blebs, of striæ, and of solid and comparatively opaque particles. All these things serve to prevent the direct emergence of uniformly-coloured beams of light from the material. I have mounted some of these specimens of glass in pairs, putting side by side, for instance, a piece of builders' blue glass and a piece of the beautiful blue glass made by Messrs. Rust and Co., of 353, Battersea-park-road, S.W., to whom, indeed, I am indebted for a series of choice specimens, illustrating the poetry of coloured glass as distinguished from its most ordinary prose. In this connection, it is interesting to observe that the good old stained glass, like these fine samples of Messrs. Rust and Co.'s manufacture, is immediately discriminated from the common-place kinds in a strong light. When the sun or the electric light shines through the former it becomes itself illuminated, but throws no definite coloured images upon a white screen suitably placed ; while the optically perfect but wholly uninteresting flat-coloured modern glass reproduces by transmission its chromatic design. By this test the modern "restorations" in an ancient window may frequently be recognised.

I have no time to tell of the colours of other artificial products, of enamels and of porcelain, for example. But I cannot refrain from directing your attention to the colours and patinas of certain metallic alloys. The Japanese are masters in this particular line. Their *shibuichi*, or grey bronze, consisting of copper alloyed with considerable but varying proportions of silver, gives a series of yellowish greys ; their *shakudo*, copper containing a small per-centage of gold, when heated in suitable pickling baths, is susceptible of receiving a blackish patina, sometimes violet-black, sometimes bluish-black. Their bronzes, into which lead

and antimony, as well as tin, often enter, frequently present very beautiful effects of colour upon their surface. But perhaps the "red copper" of the Japanese metal-worker is as beautiful as any alloy. It is pure copper, the surface of which has become coated with a strongly adherent and coherent film of red sub oxide. This film is tough and strong, and varies in colour in different specimens from a crimson-red to a reddish brown. This patina is often translucent, if not transparent, and shows a fine gloss like that of lacquer. Messrs. Christofle, of Paris, and Messrs. Tiffany, of New York, have achieved a measure of success in their attempts to reproduce some of these beautiful Japanese patinas, but there remains a large field for their employment in artistic metal-work, in the form of flat inlays and reliefs.

I cannot do better, in order to illustrate the tone and colour effects which may be produced by the association of different textile fibres, than show you in the light of the electric lantern a series of Japanese brocades and of Persian embroideries. The "shot" silks, the varying sheen produced by the different directions of the threads, and the association of lustrous with comparatively dull materials—all conduce to the beauty of the effects.

Pictorial and Decorative Art.—It has often been pointed out that colour is an end in decorative art, a means in pictorial. This almost amounts to saying that decorative colour is without meaning; expresses neither the ideal nor the real. I cannot but think that this view is far from being correct. Let us contrast and compare the colouring of a landscape and that of a decorative fabric. In the picture great use is made of gradation of tone and hue, in order to represent atmosphere, the play of light and shade, and different planes; the artist, moreover, is restrained in his use of full and saturated colours, nor does he attempt to represent all he sees, but makes such a selection of the materials at his disposal as, without violating nature, shall best serve to realise his impression of the scene. Form is with him of equal importance with colour, while symmetrical arrangement and repetition of similar elements are never made evidently conspicuous. The designer of a fabric, one, say, for use as a curtain, avoids the use of those contrivances by which the flatness of the surface would be destroyed; gradation of hue and tone, though admissible, plays a quite subordinate part in his work. He is at liberty to use the most saturated and intense colours,

provided only he can so employ them as to produce a pleasing harmony, and at the same time be in accord with the nature of his material and the purpose to which his design is to be put. Moreover, the decorator selects, as does the landscape painter, but he rejects much more than he absorbs. To nature he goes for motives, but individualisation assumes the last place, generalisation the first. Form and colour are not with the decorator of equal moment, sometimes the former being paramount, sometimes the latter. Usually, the less pronounced his colour the more dependence does he place upon his form, although in complex chromatic schemes also he has often to rely greatly upon trenchant contours in order to avoid confusion. The notion that bad or weak drawing is permissible in decorative art ought not to be accepted for one moment. The very fact that the boundaries between two colours in ornamental designs frequently need to be sharply accentuated by means of well-defined outlines should suffice to demonstrate the necessity of thorough draughtsmanship. And, lastly, the decorator makes large and frequent use of symmetrical and repetitive arrangements.

If I am right in this comparison and contrast, then the distinction between decorative and pictorial work is, like many another distinction in the domain of art, one of degree rather than of kind, quantitative rather than qualitative. The same elements are at the disposal of the decorative and of the pictorial artist, but they must be employed in different proportions. And here I am in accord with the view that there are an infinite number of possible transitions between the colouring that is most fully pictorial and picturesque, and the colouring that is most purely decorative or conventional. Much, but by no means all, of Japanese decorative work in colour illustrates some of these transitional forms.

Colour in Relation to Sculpture.—In the very few words on this subject for which I can find time I should wish to draw your attention to these two points, namely, the surroundings of sculpture in relation to its colour, and the material of sculpture in relation to its colour. It seems to me that when sculpture is destined to form an integral part of an architectural scheme, its tone and its hue must not be such as to interfere with the unity of the plan, but rather to enrich and vary it. And it may easily happen that an association of sculpture in marble with an edifice in stone may be harmonious when both marble and stone are

fresh, but may in course of time accord less happily, as the latter darkens with age much more considerably than the former. The same effect is produced when a glaring white marble monument is intruded into a building deeply toned with the rich warm grey of centuries. So, on the other hand, a statue in bronze may be too deep in tone to harmonise with new clean cut stone, but, as years pass, the startling difference between them will abate. The case is different where the building and the sculpture it contains are not intended to fuse into one organic whole. Under such circumstances, the building must be subordinated to and even contrasted with its contents ; it becomes a background so coloured and so arranged as to emphasise the statuary it protects ; and in considering the vexed question of the artificial colouring of works in sculpture, it will be well to glance for a moment at the four chief kinds of material out of which such sculpture is generally wrought. These materials are terra-cotta, bronze, stone, and white marble. It will be owned that the critical eye accepts without hesitation the refined colouring which the exquisite terra-cotta figures from Tanagra still so frequently retain, as well as the varied hues of the patina on statues in bronze. In the latter case, we go so far as to dislike what may be called the natural hue of the metal, unless it appears to a limited extent only in such parts of a figure as *might* be supposed to have lost their artificial or altered surface colour by a process of attrition. But when we leave artificial materials and pass on to those which are natural our attitude as to the problem of colouring differs. While there seems to be an innate congruity between artificial materials and artificial colouring, natural materials lend themselves less readily to chromatic treatment. Perhaps there are here two causes at work, one being our satisfaction with and appreciation of the natural beauty of the tones and hues of native substances, the other

being the difficulty of bringing our added colouration into harmony with that which is natural. This view is supported by the observation that the addition of colour to the rarer and choicer materials, such as statuary marble, is more generally resented than the similar treatment of the commoner and less interesting kinds of stone. But is there not a third and more potent cause ? Does not pure white marble, with its slight translucency and its beautiful crystalline texture, lend itself so perfectly to the presentation of ideal forms that even the faintest suggestion of realistic colour may look like sacrilege, and may only too easily lapse into vulgarity ?

In architecture, too, the poorer and less interesting the material, the more useful does the addition of artificial colour become. Yet it may serve, on the one hand, to emphasise the poverty and weakness of bad contours and mouldings, though, on the other hand, it may be made to accentuate and to ennoble forms which are in themselves beautiful. Its distribution and arrangement are as important as its tone and hue. It may destroy the unity of an architectural scheme, or it may serve to fuse discordant or fragmentary elements into one harmonious whole.

Excuse, ladies and gentlemen, the all too casual and imperfect discourses which I now conclude. Yet I trust my disjointed utterances may not prove to be wholly valueless, for they may serve, if no other end, that of directing your attention and guiding your observation to some of the infinite resources and intricate delights of chromatic combinations. I venture, moreover, to express my confidence that the scientific study of the glorious sheaf of spectral colours which we have been making together will not lead you to agree with the poet Keats when he sang—

> " Do not all charms fly
> At the mere touch of cold philosophy ?
> There was an awful rainbow once in heaven :
> We know her woof, her texture—she is given
> In the dull catalogue of common things."