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BY

The President

CAPTAIN ABNEY, C.B., D.C.L., F.R.S.

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LONDON
SAMPSON LOW, MARSTON & COMPANY
Limited.
1897.

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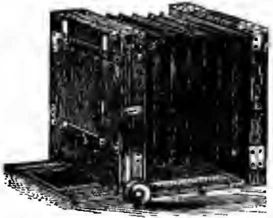

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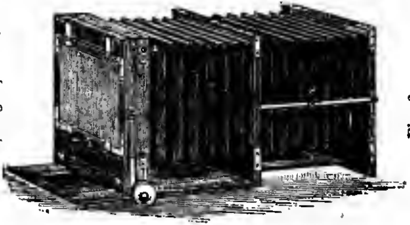

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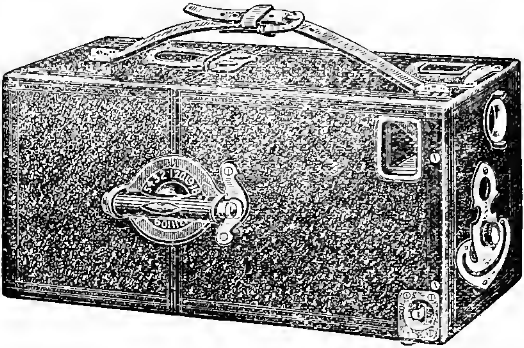

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CARTER AND CO., PRINTERS, 5, FURNIVAL STREET, HOLBORN, E.C.

PREFACE.

IN the autumn of the year 1895 I was requested by the Committee of the Camera Club to give some evening talks on "The Action of Light in Photography." They were given from notes, and illustrated by experiments, and I am led to believe they created a certain amount of interest.

At the request of several members of the Camera Club I have in the first chapters endeavoured to put into a shape for publication what I believe I said, or, at all events, what I intended to say.

It seemed, however, that the work would be incomplete unless it included an account of the experiments I had made on the action of feeble and intense light on a photographic plate.

These, except in one case, had formed the subject of papers read before the Camera Club on different Thursday evenings, and so have been added to the more informal talks, with the hope that they will prove suggestive to the reader of further experiments.

The photographer, as a rule, is not too fond of the theoretical considerations that underlie his craft. My aim always has been, and I hope always will be, to try and arouse an interest in the scientific side of it, as it is from it chiefly that future advances in photography can be built up.

That there are many faults in the treatment of the subject no one is more aware than myself, but I have thought it better to keep to the original line I took in my evening talks than to travel in another.

W. DE W. ABNEY.

South Kensington, October, 1896.

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APPENDIX.

THE ACTION
OF
LIGHT IN PHOTOGRAPHY.

CHAPTER I.

Motions of Molecules and Atoms.

When we have to study a subject, it is well to start with first principles, so far as we know them, and to call in analogy to aid us in making our conceptions. For instance, when we begin to consider the reason why light can act upon matter, it is not sufficient to know that the ultimate subdivision of matter is a molecule or an atom. We must take into account all we have good grounds for believing about such atoms or molecules, and endeavour to form a picture in our minds as to what is taking place, and what they are doing when light is causing a change.

We have the best of evidence, which we need not enter into here, for believing that every atom and molecule at ordinary temperatures is in a state of unrest, or movement. If we are dealing with a gas, we know from experiment that the molecules move about in paths of their own, darting away in one direction till they come into collision with another molecule, and then darting off in a different direction, only to collide once more. By applying fairly simple mathematics to the result of experiments made on the densities of gases, the average velocity with which they move has been calculated. We thus find that at atmospheric pressure the molecules of hydrogen travel at a mean rate of 1,842 metres a second. When the number of molecules in a given space is very much larger, as they are in liquids or solids, they are not free to move to the same extent. As the mutual attractions hold them comparatively close together, the paths in which they move are very much shorter, and they come into collision with other molecules almost as soon as they start on their journeys, and have to return whence they started, and that thus they may take up a rhythmic motion of some kind. As the temperature rises, the body, as a rule, expands and becomes larger, and thus the small enclosed space in which the motion of each individual molecule takes place becomes enlarged, which means that the length of path which it can follow is increased. A molecule, however, is composed of elementary atoms. For instance, a molecule of silver chloride, we have excellent reason for believing, is composed of, at least, two atoms of silver and two atoms of chlorine. If we place silver chloride in a crucible, and mix carbonate of soda with it, we find that on applying moderate heat both swell; but that if we increase the heat, the mass liquefies, and the atoms of chlorine leave the chloride of silver and combine with the soda salt, leaving the silver atoms free to coalesce with one another, to form, on cooling, a solid silver mass. This indicates that, though when at a low temperature the molecules of the soda and silver salts are separated, yet when the temperature is increased the molecular motion is so great that the atoms themselves take larger swings. For we must conceive in our minds that these atoms, though kept together to form the molecule by a central attraction, are also in motion among themselves, oscillating backwards and forwards towards one another, or revolving round one another, such motions being probably more rhythmical than those of the molecules themselves. We can readily account for the atoms of silver and chlorine, which make up the silver chloride, leaving one another, if we suppose that the increased space caused by the increased temperature, in which the molecules are free to move, gives more room—very minute though it be—in which the atoms can swing, and that the increased energy of the impacts of the molecules against each other are sufficient to set up the longer swings. The attractive force which, at an ordinary temperature, and without other influences at work, compels the atoms to cling together, will be so diminished by the increased distance which they travel from the centre of attraction, that some of them (in this case the chlorine) may come under the influence of some other external and greater attraction existing in the molecules of the carbonate of soda, and that therefore they will leave the silver atoms and cause a decomposition of an original molecule of silver chloride. If this occur, the molecule, before it is actually decomposed, will occupy a larger space, which, added to their increased distance apart, may cause an increase in the volume of the heated substance. We have now pictured to ourselves both the molecules, and the atoms composing them, in a state of increased motion when the temperature of the body is raised.

As to the sizes of these molecules or atoms, and the space which separates them one from another, we need not enter into; suffice it to say that both the molecules and their distances apart are ultra-microscopic; they have never been seen, and probably never will be. Their approximate dimensions and distances apart are known within limits from circumstantial evidence of a most convincing kind, but for our purpose it is quite unnecessary to enter into the evidence or the arguments founded upon it. All we wish to impress is that both atoms and molecules in solids have vibratory motions, and that probably the oscillations of the former are more regular and rhythmic than those of the latter, the one being what might be termed free vibration, and the other vibration due to collisions.

But we have further to conceive that atoms and molecules are imbedded in a medium which is infinitely elastic, and yet somewhat jelly-like. Let us take a jelly made with ordinary gelatine, moulded into a cylinder, and let several small weights suspended by strings press against its sides. Now let us remove one weight from the side, still keeping it suspended from the string, and allow it to swing against the jelly. We shall see that all the other weights spring away from the jelly, showing that the blow by the one sets the others in motion, the jelly being the medium of communication, owing to its elasticity. If we continued to give a series of rhythmic blows by the one weight, the others (if the strings were of the same length) would take up the same motion. We can apply this example to the motion of the molecules and atoms in the jelly-like ether which surrounds them. Let them vibrate or oscillate as they will, the ether will carry the blows it receives as impulses through it, and may set in motion (or increase the motion of) other atoms or molecules. These carried impulses we call radiation, for they radiate from the source of molecular motion.

We have, owing to the transmission of these effects of motion, a means of gauging to some extent—we may say to a very large extent—the amount and character of the original motion. Suppose we have a certain rhythmic motion in the molecule, we should have the same kind of impulses conveyed through the ether, and an atom or molecule whose swing can keep time with these impulses would be impressed with the same kind of motion as that which started it. For purposes of illustration we may take away any intervening conductor of motion, and communicate such motion almost direct. For instance, let us have a pendulum constructed as follows:—

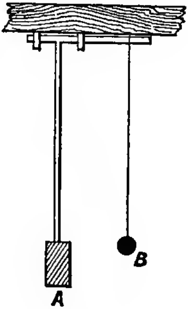


Fig. 1.

Fig. 1 is a double pendulum arranged as shown. The pendulum A is heavily weighted, whilst B is light, being only a string with a small weight attached. This difference in weight is made to prevent any great effect of the movement on B being shown on A. Set A in motion. If the lengths of the pendulum are the same A will begin to swing, and soon it will take up a violent oscillation. If B be longer or shorter than A, B will still swing, but as the times of their oscillations will be different, the two swings will be eventually in opposite directions, B's swing will then diminish, and gradually cease, but will start anew.

Fig. 2.

Fig. 2 shows graphically the motion of the pendulum B, it being made on the same principles that Lissagou's figures are made. Pendulum B, with a pen attached to its top, was started by a pendulum corresponding to A, which had a different period, and the amplitude of the former registered itself on paper, moved by clockwork round the axis of suspension. It will be noticed that the amplitude or length of swing increased rapidly at first, and then very gradually attained a maximum. It then diminished very slowly, and then came rather rapidly to a zero, and the pendulum was for an instant at rest.

Now let us apply this: If instead of the small pendulum we have a molecule oscillating at a distance from another molecule, and find that the latter assumes a more energetic motion, we can but suppose that the ether has been the means of conveying it. The increased violence of motion may be known by a rise in temperature of the body to which the molecule belongs. But we can also conceive that the vibrations conveyed by the ether are so timed that they may be capable of increasing the motion of the atoms of a molecule in preference to that of the molecule itself. As already stated, the increase in the extent of the vibrations of the latter may be such that they can swing out of the molecule of which they originally formed a part; and we may take it that whenever their swing oversteps some fixed amount this must surely happen, more especially if there be some other molecules present which can annex them. The breaking away of an atom and its transfer to some neighbouring molecule is a destruction of the original molecule and the formation of a new one, and this we call photographic action or chemical decomposition caused by radiation.

In the experiments conducted with the pendulum we have seen that the lighter pendulum need by no means be exactly in tune with the large pendulum for the swing of the former to reach a large maximum value before it begins to diminish. Reasoning from this, we may take it that a vibratory motion, though it may not be in exact synchronism with the motion of the atom, may still be sufficient to cause it to swing beyond the sphere of attraction of the molecule of which it forms a part, and so to be the cause of chemical decomposition. We must also bear in mind that there is no reason why the ether should only transmit one set of rhythmic motions or vibrations, any more than that air should do so as in the case of sound.

The latter will transmit an apparently unlimited number at the same time. Thus in a similar way an unlimited number of series of vibrations in the ether may be transmitted, all starting at the same time from the same point. If a great number of series be started, not only those vibrations which are in absolute tune with those of the atoms, but also those which are not quite in agreement will be effective in causing chemical decomposition to take place.

Looking at the subject in the light of what we have stated, it can scarcely be conceived that any series of vibrations, which are in accord with those of the molecule as a whole, can be effective in causing a chemical change in its constituents except in extreme cases, but that vibrations which most nearly approach in period those of the atoms may do so.

Increasing the motion of a molecule only means an increase in the temperature of the body of which it forms a part. Unless the radiation be so powerful that the temperature of the body on which it falls becomes extremely high (as was the case when we considered the decomposition of chloride of silver), thus giving the molecules greater freedom of movement through the liquid or gaseous state being assumed, the vibrations necessary to loose the atoms will be absent.

The atom being smaller than the molecule — a collection of atoms being naturally smaller than the single atom—it is quite conceivable that the mean period of vibration of the first will be smaller than that of the last. Consequently we may reason that those vibrations which induce chemical action will be, as a rule, of shorter period than those which induce a rise in temperature.

CHAPTER II.

LENGTHS OF WAVES IN THE SPECTRUM.

WE must now picture to ourselves that the motion of a vibrating molecule may give rise to an almost infinite series of vibrations. Suppose we have a pea moving with uniform velocity inside a hollow shell with a rough boundary. By some artifice we may imagine that it never stops. It will first dart from one side, to strike the opposite, then glance off perhaps on a short path up, then on a longer path down, striking at some time or another every part of the inside surface of the shell.* It may finally come on its original path and follow the same course as before. The *length* of the paths will be a measure of the time between each of the collisions that take place. Now if we take a sufficient time during which the collisions are happening, we can sort out, as it were, the paths which are all equal in length, the shorter perhaps first, and then those increasing in length, and so on. For the pea let us substitute a molecule in

---

* If it were a smooth shell the paths would be all equal, and would be made in a great circle of the sphere; but it might be arranged that every part of the circumference would be struck within limits. This would only account of a single series of waves.

its enclosure. If we consider only the motion in the ether due to one length of path, we should arrive at vibrations of one period, that due to another length of path to another, and so on. The numerous varying lengths of paths could thus give rise to an orderly series of vibrations of varying periods. In some such way we can imagine that the motions of molecules in their confined space give rise to a very large number of series of vibrations in the ether.

We have so far refrained from using the word "light," for light is really an *effect* of radiation, and not radiation itself. It happens that certain radiations or rhythmic motions of the ether are of such a character that they affect some matter in the eye, not by causing a rise in its temperature, but probably by a chemical decomposition. The sentient being has thus a knowledge of the existence of these particular radiations through the medium of the eye. The existence of other series may be known by the sensation of warmth or rise in temperature which they produce. For our purpose, however, we may adopt the word "light" as synonymous with radiation, being careful to remember that in its strict sense it is an *effect* of radiation, and not the thing itself. Bearing this in mind, we shall use either word indifferently.

Can we sort out these different series of vibrations and present them to ourselves in any recognisable manner? We can in several ways. Let us take that one which is the most common. When a series of vibrations travel across free space, and come in contact with a transparent body, they will travel through the latter apparently unaffected if it happen that the surfaces of ingress and egress are parallel to one another, as they are in a pane of glass. If, however, the series fall on a surface inclined at an angle to its path, its character is altered, and the greater the number of vibrations in a given time (which is the same as saying the shorter the length of the vibrations, or waves), the more they are deflected. The ether which is in the transparent body (for it permeates everything) is in a different state; it is more condensed, to put it in a popular way, and the shorter the waves the slower they must travel through it. Thus long waves will travel more rapidly through it than shorter waves, and when they fall at an angle on a denser transparent body the latter series will be less bent away from the perpendicular to the surface of the dense medium than the former. On emergence they will again take their usual velocities. This might be shown by means of a diagram, which can be found in most text books, and need not be repeated here. These different retardations, and consequent different amounts of bending in a transparent medium, and the subsequent recovery of the speed on quitting it, make it possible, by means of a prism, to sort out the different series of radiations. They spread out in a fan-like form if we only allow a thin slice of ordinary light to fall upon the surface at an angle. The diagram shows what we mean.

The narrow beam of white light, which can be secured by passing a beam of light through a narrow slit, falls upon the surface A B of the transparent prism, and is split up into the different series of radiations, and emerges from B C as a band of colour, three being most distinct —viz., red, green, and violet—but these three gradually fade into one another, so that we have a large assortment of different colours. The violet ray is most bent, from the perpendicular to the surface B C, and the red

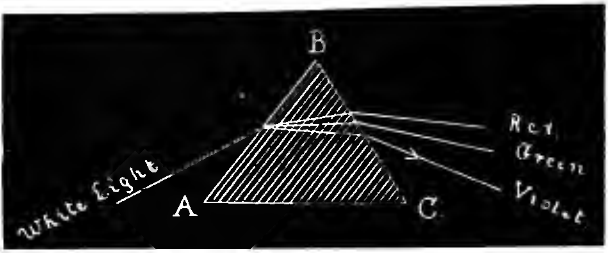


Fig. 3.

the least, the others being intermediately bent. This tells us that the oscillations which produce violet are more rapid than the rest, and those that produce red the least rapid, and as we know, from experiment, that all the component rays of white light travel in space at the same speed, it follows that the wave-length of the violet is the shortest, and of the red the longest. Unless the air be thick with motes, these rays would travel on in space unperceived, but directly we place a white screen in their path they become distinct and visible to the eye; or if the eye itself be placed in their paths, as many as fall on the small pupil will be recognised as existent. By placing a lens in the path of the rays, and bringing the screen to such a distance that an image of the slit would be in focus with white light, we have successive images of it in varying colours, slightly overlapping one another. If the source of light be the white-hot carbon points of an electric light there will be found no break in the succession of colours, and one can scarcely realise that the band is truly an infinite series of images of the slit; but if instead of this white-hot solid being used as a source, we vaporise in the arc of the same source some body such as lithium, we at once see that such is the case; for, instead of a continuous band, we shall have a few fine coloured lines placed apparently irregularly along the space previously occupied by the continuous band. Each of these lines is a coloured image of the slit. In this case there are evidently but a few series of waves given out by the vibrating molecules of the metallic vapour, and not an almost infinite number, as in the case of the white solid. This coloured band, into which white light is decomposed, is called the spectrum, and the lines are the spectrum of the material turned into vapour in the arc. As stated before, the path of a molecule in a gas (or vapour) is comparatively free from collisions, but the atoms still vibrate, and it is the less complicated vibration of the atoms which give rise to the coloured lines which are thus sorted out.

It is not at all necessary to have an elaborate apparatus to see a spectrum. If we block up a window, and place a slit (say) $\frac{1}{10}$th of an inch in it, and look at the sky through a prism, we shall see the line of white light expanded into the spectrum, showing every colour; and further, we shall notice a certain number of black lines, parallel to the slit, crossing the rainbow colours, and if a more elaborate apparatus were used we should increase the number manifold. These black lines, known as Fraunhofer lines, occupy fixed positions in the spectrum, and the most conspicuous are useful, amongst other things, as colour reference points, much in the same way that we use milestones along a road.

It must not be imagined that the spectrum is confined to the length we see with the eyes. The eye takes cognisance of those rays only which can do work on the retina. There are other rays which play an important part in nature, and none more so than those which lie beyond the red. As the red are the least bent of the visible rays, because they are the longest, these dark rays must be still longer if they lie beyond the red. Being longer, the vibrations must take place at longer intervals than the waves which give rise to the visible spectrum, and, as said before, are more likely to affect the molecules than the atoms of which they are made. They are thus more likely to be efficient in causing a rise in temperature than a chemical decomposition in the matter on which they fall. This is experimentally found to be the case, and for this reason they have been mis-named heat rays. No ray can be called a heat ray. It depends entirely on the kind of body on which a ray falls as to what its action will be,

Fig. 4.

whether as heat or as chemical decomposition. If the vibrations of atoms are nearly in tune with these wave oscillations, chemical decomposition may take place if they be not bound together too strongly. On the other hand, if they synchronise better with the molecule, we may expect a heating effect. In proof of this we can show a photograph taken with the dark rays of the solar spectrum (Fig. 4). All to the right of the line marked A are impressions due to these dark rays, and they cover a length equal to that of the visible spectrum. Again we have a facsimile of a photograph of the carbon points of the arc light taken through a sheet of ebonite. The ebonite only transmitted dark rays below the red of the spectrum, yet we have an image as well defined as it would be if taken with visible rays.

Fig. 5.

These photographs were taken on a form of silver bromide discovered by the writer, and it is sensitive to a far larger range of the spectrum than is the ordinary silver bromide. These dark rays were first discovered by Sir W. Herschel by their heating effect. He obtained a spectrum from an image of the sun, and placed thermometers in the different parts of it. He found that the heating effect was greater as the red was approached from the blue, and that when he placed one beyond the red it was still higher, and that it continued to rise for some considerable distance beyond the visible limit, till it attained a maximum, when it fell as the distance from red was further increased. It finally reached a distance where the temperature was no higher than the surrounding air.

Lamansky measured the heating effect of the solar spectrum on lampblack with a thermopile, and found that when graphically represented it exhibited peaks of increased temperature beyond the extreme limit of the visible red. His diagram is shown in Fig. 6.

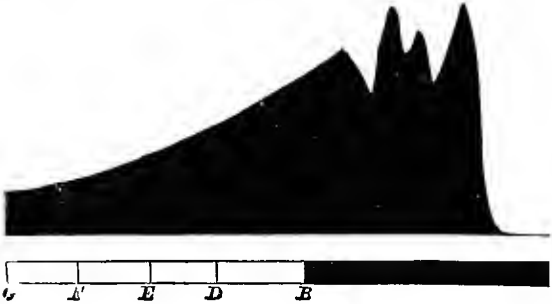


Fig. 6.

Herschel's and Lamansky's curves and the photographs thus not only indicate the existence of these dark rays, but also the two-fold effect they may produce.

We can also show their existence to the eye by an artifice. If we take a phosphorescent plate (a glass painted with Balmain's paint will do), and expose it to white light till it glows brilliantly, and then place it in a short bright spectrum for some seconds, we shall, on withdrawing it, see that the visible part of the spectrum, from the violet to the yellow, is very brilliant, but that the yellow, red, green, and dark rays below the red have apparently destroyed the phosphorescence, the background being of the intermediate brightness due to the gradual fall in phosphorescence caused by lapse of time when in darkness.

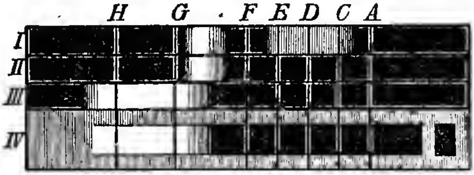


Fig. 7.

The band III. shows the rays that excite the phosphorescence, and these naturally excited the plate when placed in the spectrum, and the bottom band (IV.) shows the destruction of the phosphorescence, the background being shown as grey, to indicate the feeble light which was not extinguished. It will be noted that there is one small band in the dark part of the spectrum which does not destroy the phosphorescence. The bands I. and II. are the visual and photographic spectra of the phosphorescent light.

We have now to deal with another part of the spectrum, which is also invisible, but lies beyond the violet. And here we can call to our aid the beautiful discovery of Sir George Stokes, who found that waves of shorter length than those which are visible could be made apparent by their effect on other matter. Thus, to take the commonest example, if when a spectrum is on the screen we place a strip of white paper on which quinine dissolved in slightly acidulated water has been brushed, light which was before invisible springs out into visibility, and we can see the extent to which the spectrum extends beyond the violet. We may diversify the experiment by placing in the spectrum paper oiled with ordinary machine oil. In this case the light emitted will be yellowish instead of the pale lavender which is so distinctive of quinine.

Though we are photographers, we must ask ourselves why invisible rays can thus be made visible. At first sight it looks as if the light itself had been altered so as to reduce it to waves of such a length that they could affect the eye; this is, however, not quite the case. If we remember that the light which caused our phosphorescent plate to glow was not of the same colour as the phosphorescent light itself, we can understand that invisible rays of light may excite a substance to emit rays which are visible. It is not the original light which affects the eye; it is the light which the invisible rays call forth in the quinine or oil which is active. The incident light shakes up the molecules of these bodies and makes them vibrate, but in a different period to the waves which fall upon them. A substance which acts in this way is called a fluorescent substance, the word being coined from fluor-spar, which exhibits this phenomenon.

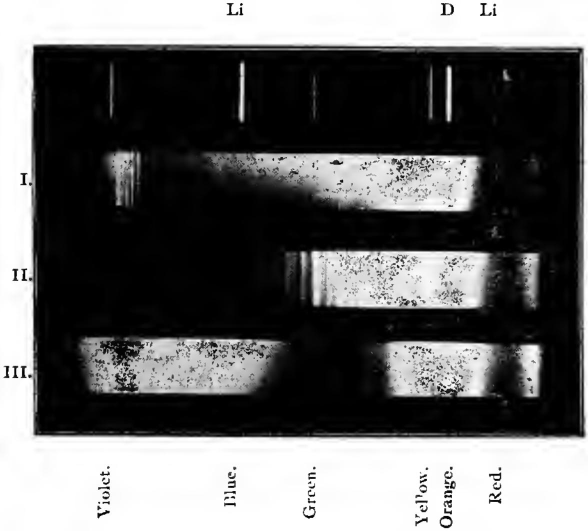
The most ordinary way of showing the existence of these ultra-violet rays is by means of a photograph. If we expose a plate or sensitive paper or film to the action of the spectrum, we at once recognise them as being present by the action they have on the sensitive salt, an action which is in no ways different from that caused by the visible rays which are effective (see Fig. 9, p. 25).

When the substance of this chapter was communicated as a lecture to the Camera Club, a very pertinent question was asked as to whether the invisible rays beyond the violet, when made visible by fluorescence, were more photographically active than when acting unchanged. This question was answered by throwing in a darkened room a bright spectrum on a card, half of which had been brushed over with quinine. The division between the two parts was made to divide the width of the spectrum, so that in half its width the ultra-violet rays were invisible, and in the other half they were shown as fluorescent rays. The spectrum thus cast was photographed by a camera and lens in the ordinary way, when it was found that the fluorescing rays gave a less dense image than the invisible rays reflected from the card, indicating that no advantage was gained by causing them to become fluorescent.

CHAPTER III.

ABSORPTION.

WE have now to deal with radiation when it traverses a body. What can we suppose should happen when radiation traverses a gas, for instance? Let us argue the matter, and then see if our reasoning is correct. Its molecules are free to move in any direction, and their path must be so long that we can scarcely expect that, unless the thickness traversed be great, these should take up much of the radiation transmitted. On the other hand, in a gas which is a compound, the atoms which compose the molecules may be caused to take increased amplitude, or swing, and in this case we should expect that the radiation transmitted would lose something by the transfer of the energy required to give such increased amplitude. Let us put this to the test. We place some flake crystals of iodine, which, though thin, are to all appearance perfectly opaque, in a test-tube. The test-tube we plunge into boiling water, and almost immediately a purple vapour begins to rise, and by degrees fills the whole of it. On allowing the test-tube and its contents to cool, we find dark spangles of solid iodine on the sides of the glass. We re-vaporise these crystals, and allow the beam of light to pass through the vapour, and this filtered light is now decomposed by a slit and couple of prisms, and the spectrum is examined on the screen. We find two phenomena: first, there is slight general absorption or cutting-off of the light in the green; and second, the orange, yellow, and remains of the green are traversed by fine black lines close to one another (III., Fig. 8). The wave-lengths of light represented by these black lines are in tune with the vibrations of the iodine atoms, and are therefore absent after they traverse



Photographs of absorption taken on a Cadett spectrum plate.

Fig. 8.

the test-tube, as they have been taken up by the vapour. There are a great many lines appearing rhythmical, and this rhythm forces us to believe that these atoms have rhythmic swings. The slight general absorption in the green is probably due to the greediness with which these vibrations are absorbed, for when the vapour is attenuated, lines appear in this part also, though it is quite possible that the atomic swings not only take up the waves which are exactly in tune with them, but those which are very nearly in tune as well, exactly as our pendulum behaved; or it may be also that the paths of the molecules are curtailed, and that it is due to a certain want of freedom of their swings.

The colour of the iodine is due to the absence of these vibrations, for, by placing a lens behind the spectrum to collect the rays, and to form an image of the prism on the screen, we find the colour of the iodine vapour reproduced. We may repeat this with nitric oxide. We shall find that the pattern of the lines in the different parts of the spectrum is more complicated than with the iodine, as it consists of broad bands as well as of lines (II., Fig. 8). Arguing from first principles, we may gather that, as the nitric oxide is a gas in which more than one atom probably swing together, the complication is to be expected.

When we dissolve iodine in bisulphide of carbon, or in water in which a little iodide of potassium has been dissolved, we see that the spectrum no longer is split up into lines, but that a large part is blotted out. In the case of the bisulphide solution the green disappears (III., Fig. 8), and in the aqueous solution the blue and the violet also go. Without entering into any discussion as to the reason of the different behaviour of the iodine molecules in the two cases, we will turn our attention simply to the fact that there are bands of absorption, and no lines. In this case we have bands due to the confinement of the molecules. They can no longer traverse distances measurable by ordinary means, but their motions are restricted, and give rise to waves of periods which are more or less in tune with a great deal of the visible spectrum, and, for aught we can tell with the eye, with some of the invisible portions also. This being so, the molecules of the iodine are set in increased motion by the radiation whose energy they take up, and so only the remainder of the rays pass through them in sufficient quantity to act upon the apparatus in the eye. In those parts of the spectrum whose waves are completely taken up by the molecular motion, of course total darkness ensues.

If we turn our attention to transparent solids we find the same thing occurs. For instance, yellow glass cuts off all the blue and violet, but allows a great deal of the green to pass, and all, or nearly all, of the yellow and red. The molecules of the yellow colouring matter are in tune with the violet and blue, but not with the green, yellow, and red. The former rays, therefore, are stopped, whilst the latter are allowed to pass, and, when recombined, these latter give the yellow of the glass. And here attention may be called to the fact that the rays which the fluorescing bodies emit have nearly always a greater wave-length than the rays which excite them. If we place a yellow glass *in front of the slit* of a spectroscope, and examine the spectrum thrown on a screen on which has been brushed sulphate of quinine, we can see no trace of the invisible rays, for they have been stopped by the yellow glass before they reach the screen. If, however, we throw the spectrum on the same screen without the intervention of the yellow glass, but *examine it through the yellow glass* by simply holding the glass in front of the eye, we find that the spectrum is the same in both cases, as far as the exhibition of the series of colours is concerned, towards the red end of the spectrum, but that it differs at the ultra-violet end. At that part the fluorescence caused by the invisible rays will be seen through yellow glass, showing that these latter contain, at all events, some rays which belong to the green, yellow, or red of the spectrum. Perhaps no better proof of Stokes's law—which enunciates that the wave-lengths of the rays emitted from the fluorescent bodies are greater than of those which excite the fluorescence—can be given, and it is commended to the reader's notice.

We may now return to the behaviour in the spectrum of some other solid bodies which are very interesting to the photographer. For instance, we have solid chloride of silver melted into a slab. It looks colourless, and when we make the white light pass through it before the spectrum is formed, we see no appreciable alteration in the range of colours from the ordinary spectrum. But if we place a card over which sulphate of quinine has been brushed, in the position where the invisible rays should flash out, we find that they are altogether absent. We can remove the slab of chloride from before the slit, and they immediately appear. From this we gather that the chloride of silver has taken up the vibrations of the invisible rays. From what we have said before, we can picture that these rays cause the atoms of the chlorine to vibrate with greater vigour than before, and the result should be that photographic action would take place in this region of the spectrum, some of the atoms of chlorine swinging off from the grouped atoms of silver and chlorine. This we can at once prove by placing

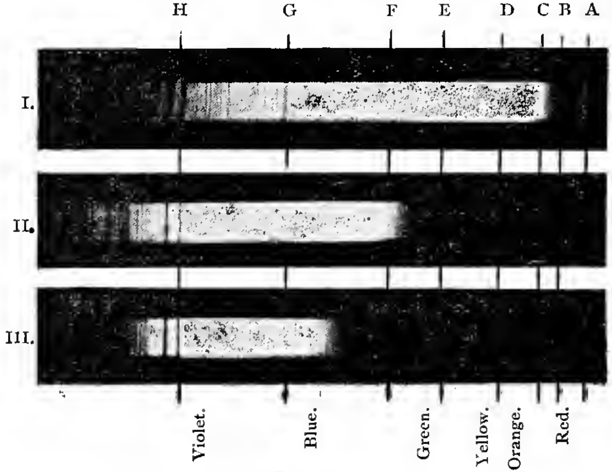


Fig. 9.

a plate prepared with ordinary silver chloride in the spectrum, and we find that its action is principally confined to these invisible rays, for it is in that part of the plate on which they fall where the greatest chemical decomposition is found, as shown on development (III., Fig. 9). We shall allude to I., Fig. 9, later.

Again, we have a slab of fused bromide of silver, and examine it in the same way. To the eye, when examined by white light, it possesses a yellow colour, which is not unlike that of the yellow glass we previously examined, and the rays it cuts off are very closely the same. Here we have, then, the invisible rays, the violet, the blue, and part of the green, cut off or absorbed by this material, and the energy which they carry is taken up by the molecules of bromide, and in this case the swings of the atoms are increased, indicating a possible photographic action. We can test the matter, as before, by placing a plate prepared with bromide of silver in the spectrum, and noticing at what parts photographic action is induced (II., Fig. 8).

Now we must not run away with the idea that, because action takes place at this region, it therefore follows, if we were to use this for a screen over a light during developing operations, we should not run any danger of fogging a plate prepared with the same substance. We might use it if *all* the wave motion were taken up at every part where photographic action takes place. As a matter of fact, there is such a large portion of the rays of the spectrum whose waves are not altogether in tune with the vibrations of the atoms of the bromide molecule, that a good proportion pass through, and would be available to affect a bromide plate exposed to such light. We can lay a slab of fused bromide on a dry plate, and expose to light through it, and we shall find that a certain proportion of those rays which are active in producing the photographic image do pass through. The wiping-out of the wave motion—or, as it is more usually called, the *absorption*—is not by any means complete in some parts.

The appearance of the absorption by coloured substances is now familiar to you, but we wish to show that colourless bodies likewise absorb. By means of the particular form of bromide of silver to which we

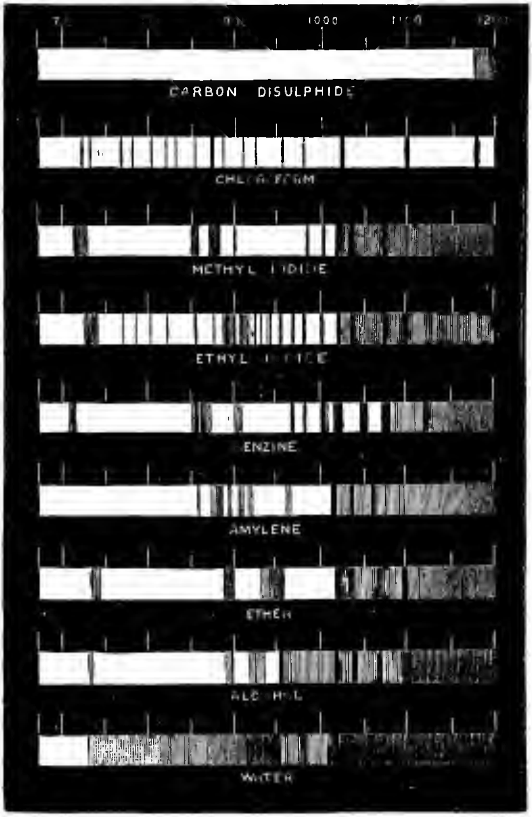


Fig. 10.

have already referred, this can be demonstrated. In the figure we have copies of the absorptions in the infra-red of the spectrum of various colourless liquids. The character of the absorptions is very different, but it is beyond our scope to endeavour to attempt to explain the reasons for the difference.

It may not be without interest, however, to show that by heat measurement and photographs of the absorption of water we gain a knowledge of the condition of the atmosphere of which we might otherwise be uncertain, and that the thermopile measures and photographs confirm one another.

In Fig. 11 we have in the outside curve a diagram of the heating effect on lampblack, as measured by a thermopile, of the arc electric light. In the inside curve II. of the same shape, we have the diagram of the heating radiation after passing through a glass cell. Curves II., III., IV., and V., show the heating power of the radiation after it has passed through various thicknesses of water. The dotted curves show the same when free from the absorption due to the glass cell. Beneath are representations of the water spectrum and the solar spectrum. The spectra shown below are from photographs. All to the right of the A line are invisible radiations. The scale of the spectrum is the same as that of the base of the thermogram. In this last the height of each part of the curves is a measure of the current produced by the heating of the junctions on the narrow face of the thermopile when placed in the different parts of the spectrum. The current is a measure of the various temperatures produced by the different rays in the lampblack with which the surface of the thermopile was coated. (The curves were illustrations to a paper read before the Royal Society by the writer and General Festing.) The scale is given in "turns of the screw." The meaning

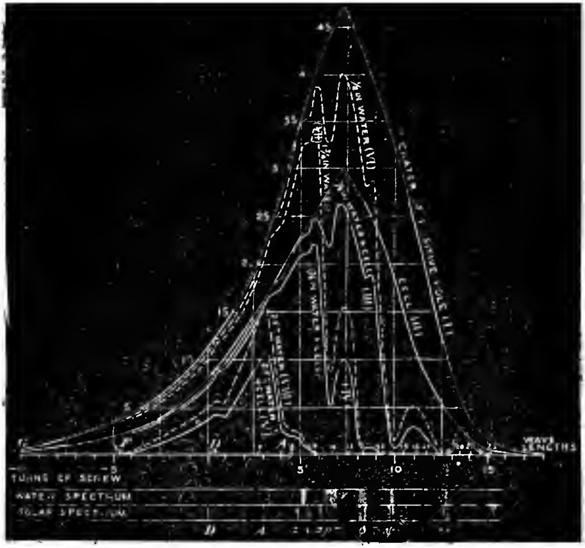


Fig. 11.

of this is, that the thermopile was caused to traverse the spectrum by a screw motion, and the distance traversed was therefore conveniently given by a reference to the screw thread.

A comparison of this with the next figure, the scale of which is the same as Fig. 11, will show that all the dips due to water in the heat curves made with the arc light are to be found in the dips in the solar spectrum, whence we deduce that the absorption by the water in the atmosphere has a marked influence on the radiation reaching the earth. The curves in this figure are two curves made from thermopile measures with sunlight on

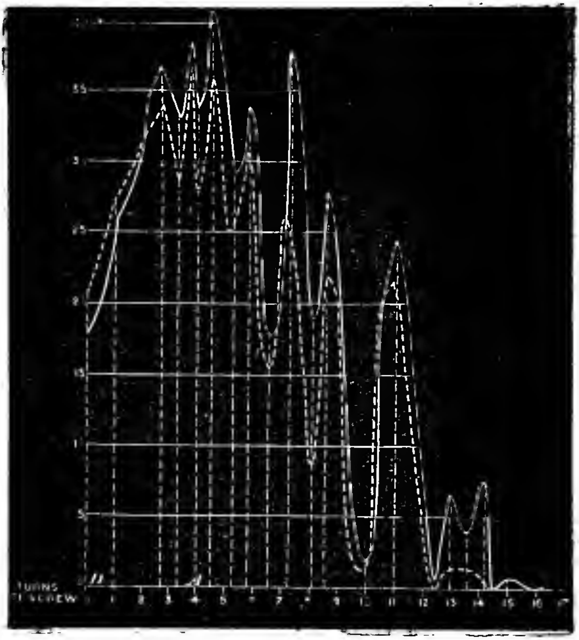


Fig. 12.

separate days by the writer. This figure should also be compared with (Fig. 6) Lamansky's curve.

There are certain substances used in photography to, as it is called, orthochromatise plates—that is, to render them sensitive to colours to which they are ordinarily insensitive. Amongst others, we have derivatives of fluorescin, which, as its very name implies, is highly fluorescent. The kind of fluorescence it gives is very beautifully illustrated by throwing a beam of light on a jar of water in which a solution of this substance is allowed to drop. The water appears quite colourless, but where the drops penetrate we have a burst of beautiful greenish-yellow light reflected from them, though looking through them we see that they are of a dark muddy colour.

Let us examine one of the derivatives of this substance, eosin, which is very generally employed in photography. Placing a cell containing a solution of it in front of the slit of the spectroscope, we find that there is a great gap in the green part of the spectrum; but if we throw the spectrum upon a piece of paper brushed over with the solution, instead of upon the white screen, we find that at the very part where the absorption takes place in the spectrum when the light is transmitted through the solution, the dyed paper shines with a peculiar olive green lustre. Looking through ruby glass at the spectrum thus cast on the coloured surface, we can again verify the truth of Stokes's law, for we find that the green part of the spectrum is visible (which it would not be without the fluorescence), but shines with a ruddy tint. The ruby glass practically cuts off all rays except the red and a little bit of the yellow. The fluorescent rays must therefore consist partially of red rays which are of greater wave length than the green, which excite the fluorescence.

Now let us consider once more the subject of fluorescence. If the wave-lengths of the exciting rays were themselves merely altered, they should be reflected from a surface coated with the fluorescent substance, as are the other rays. If, however, they are extinguished, and simply excite new radiation in the fluorescent body, that body practically becomes a source of light, and it is evident they cannot be reflected, but will radiate in all directions. We can put this to a practical test. Let us coat a thick glass plate with collodion to which a certain amount of this dye has been added. We can receive an ordinary spectrum on this film through the glass, and reflect it upwards on to a white screen; we shall find that we have two spectra reflected—one from the uncoated, and the other from the coated surface of the plate. The first spectrum will contain all the rays, enfeebled, of course, by the fact that only a small proportion can suffer reflection. The second spectrum will be the reflection almost wholly from the colouring matter, since most, if not all, of the ordinary reflection from the glass surface is done away with by its contact with the solid or viscous collodion. This spectrum shows a complete absence of all the green fluorescent rays, showing that these rays are not reflected; they will be seen, however, shining brightly on the film. It is only those rays which are not fluorescent which are reflected. This is a very instructive experiment, and worthy of repetition, as the requisite appliances are so very simple. It is also in those very parts where the fluorescence occurs that the spectrum colours are made sensitive. The rays where this fluorescence is excited are, as a rule, those which have no photographic action; but when the fluorescent body is in contact with the silver compound, it becomes sensitive to this ray.

Whilst perusing these pages it will have become devient that we simply regard the ether waves as energy carriers, the energy carried being that of the molecules which set the ether in motion. Energy we may look upon as the capacity of doing work. If we have a ship riding near shore at anchor, and waves roll in towards the shore, these last will raise the ship, and do work. As a consequence, we shall find that the height of the waves on the shore side is much diminished; that is to say, the work done by the waves in raising the vessel reduces their amplitude, or height. Let us see what the amount of work depends upon. Throw a stone in a pond, and we shall see ripples circling out, growing less and less in height, till they are lost in the calm of the main surface. We may take it that, apart from friction of the water, the volume of each circle of wave is the same, for there is no reason why it should change. If such be the case, then the section of the wave will be inversely as the diameter of the circle, and if the wave-length of the wave remains the same, the height of the wave will approximately vary also inversely as the diameter or distance from the centre of disturbance. In a similar way we may argue about waves of radiation, but we have a practical experimental proof of this in another way. If we illuminate a screen with a candle at 1 ft. distance, then at 2 ft., then at 3 ft., &c., we find that if the illumination be unity at 1 ft., then at 2 ft. it is $\frac{1}{4}$, or $(\frac{1}{2})^2$, at 3 ft. $\frac{1}{9}$, or $(\frac{1}{3})^2$, and so on; that is, the energy diminishes inversely as the square of the distance, and we know that the energy is proportional to the square of the amplitude or extent of swing of the wave. That brings us to the same fact, that the amplitude of a wave diminishes inversely as the distance from the source of radiation.

CHAPTER IV.

EFFECT OF SMALL PARTICLES IN THE PATH OF LIGHT.

WE must next dwell on another phenomenon connected with radiation when it falls on matter. What we have to consider is the effect on the waves when the matter consists of very small, almost ultra-microscopic particles. We can form some opinion as to what will happen if we again take water waves as an analogy of radiation.

Suppose there is a very small piece of rock standing above the surface of the water: waves which are long from crest to crest, however shallow they may be, will pass it, and the existence of such an obstacle will be scarcely felt, except close to the rock. If, however, instead of the waves being long, they are merely ripples, and that the same rock lies in their path, a very different state of things will occur: the ripples will be diverted by the obstacle, a comparative calm being behind it. The new direction taken by the ripples will be partly at right angles to that of the original direction. With waves of intermediate length they will be more or less scattered by the rock. Thus we may take it that the longer the wave, the less it will be deflected.

We may apply the same reasoning to waves of light, and may presume that the smaller the wave-length, the greater will be the proportion that can be deflected at right angles to the path. We should thus come to the conclusion that the component rays of a beam of white light, meeting small particles, would be differently affected; the loss of intensity they would suffer in the direction in which the beam was travelling would vary inversely to some function of the wave-length; thus the blue would lose more than the green, the green than the yellow, and the yellow than the red. The outcome of this varying loss would be to make white light, after passing through a number of fine particles, yellow or even red, and the light scattered at right angles bluish. This we can prove for ourselves by a very simple experiment. Let us have a glass trough, say six inches in length, and in it pour turbid water prepared by allowing a weak spirituous solution of ordinary negative varnish to fall, drop by drop, into a large jar of water, with plentiful stirring. If we now allow a narrow beam of light from the electric lamp to traverse this turbid medium, and receive it on a white screen, we shall see that it has a yellow colour, indicating the truth of our first assertion. We shall also notice that the turbid medium is itself rendered luminous with a bluish light where the beam enters, but that it gradually becomes yellower as the end is approached where the beam makes its exit. This change in colour is a necessity. The first small length of the turbid medium encountered by the beam robs it of some of the violet rays, rather less of the blue, and so on. Consequently, when the beam arrives at the next small length of the medium, there is only a smaller portion of the violet and blue, and so on, to be deflected. At the next small length this diminution occurs again, till finally the violet and blue may be so diminished that there is but little to deflect, and we then have a yellowish light illuminating the far end of the cell. In a beautiful mathematical investigation on the subject of this scattering of light from small particles, Lord Rayleigh has shown that the co-efficient of the light penetrating is inversely proportional to the fourth power of the wave-length. ($I^1 = I_e{}^{k x \lambda^{-4}}$ where I and I^1 are the original and transmitted intensities, k a constant, and x the thickness of the medium, and λ the wave-lengths.) If, therefore, one wave-length is double that of the other, the exponential co-efficient of the latter is sixteen times greater than of the former; if it were three times that of the other, it would be eighty-one times. The wave-length of the extreme red is about twice that of the extreme violet, therefore it will be seen that if only $\frac{1}{10}$th of the red is cut off by fine particles, the intensity of the violet will be diminished to less than $\frac{1}{6}$th of its original brightness, and for the intermediate colours the intensities transmitted will vary between these two limits.

Lord Rayleigh found mathematically that the light deflected at right angles to the direction of the beam should have another remarkable property—viz., that it should be "polarised," as it is called, in a certain direction, a fact which Tyndall had already proved experimentally. If we have a pendulum, O A, oscillating in a circular path, A C B D, it can be conceived as made up of two motions, one along A B, and the other along C D, which, combined together, make up the circular motion along A C B D. If this be so in theory, we ought, if we can quench the motion along C D, to get only the motion along A B. In somewhat the same way we can conceive a wave of light as it travels in space to have an up and down motion, and also a right and left motion at right angles to the direction it is taking, and if one of these motions is annihilated whilst the other is continued, we have the ray of light polarised. The simplest way of showing that this can be effected is with two plates of tourmaline cut out of the same slab. When one is placed in a beam of light, it tells us nothing except that a certain percentage of light is abstracted by absorption; if we place the second piece over it, the two lengths coinciding, a little more light is cut off by absorption; if, however, we turn the two at right angles to one another, we find that the beam of light is quenched. Only one side of what we may call the two-sidedness of the waves of light can pass through the crystals placed in one direction, and having quenched one side by the first tourmaline, we quench the other

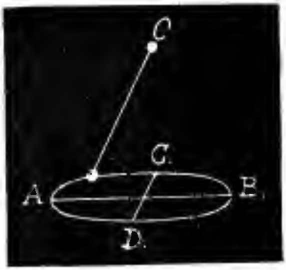


Fig. 13.

by turning the second crystal at right angles to the first. It is more convenient to use what is known as a Nicol prism to effect this reduction of light to one-sidedness. We need not describe this "Nicol," as it is called for short, but may simply use one for our purpose. Let the beam of light pass through the trough as before, but let it pass first of all through a Nicol, turned in such a direction that the full blue light is seen through the side of the trough (Fig. 14). Now, keeping the eye steady, if we turn the Nicol a quarter round we find that the bluish light has disappeared—that is, the track of the beam of light alone, without its halo, is seen (Fig. 15).

Fig. 14.

Turning the Nicol slowly round another quarter turn, we find that the halo gradually returns till it attains its full brightness. By this simple experiment we fully prove that the light is polarised. Figs. 14 and 15 being from photographs, the blue light is alone impressed, and the main track is almost invisible owing to its yellower colour. If we were to look at the trough from a direction not at right angles to the direction of the beam of light passing through it, we should find that the illumination of the trough was not completely,

Fig. 15.

but only partially quenched. Lord Rayleigh tells us that this is in accordance with mathematical theory, the polarisation being only complete in a direction at right angles to the direction of the beam.

Whilst we are discussing the question of the action of fine particles on light, it may be of interest to give a telling proof that the luminous part of an ordinary candle flame is made up of fine incandescent particles. This is usually supposed to be the case, one of the most cogent reasons being that its spectrum exhibits no breaks. But we may further confirm the presumption by the very test we have used with the turbid medium. We can project a very intense beam of the electric light as a small point on a candle or gas flame, and examine it through a Nicol, from a standpoint at right angles to the beam. We shall be able to trace the path of this comparatively blue light when we look at it with the Nicol turned in one direction, but it will disappear when it is turned a quarter turn. This is in itself evidence of the presence

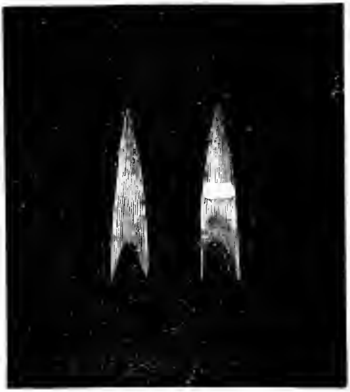


Fig. 16.

of fine particles in the flame. Figs. 16 and 17 show photographs taken of a candle flame and of a gas jet, with the Nicol turned in the two directions. As the light from a flame is polarised in every direction, it is probable that the light given from, say, a batswing gas burner, will be found to be more photographic in one direction than in the other, though the difference must be small.

To test the quality or colour of the light which we get after its passage through increasing turbidity, we can make a very pretty experiment which anyone can repeat for himself. We throw on to a screen an image of a small hole placed in front of a cell containing hyposulphite of soda, and through which a concentrated beam of the electric light passes. The round patch of light we may suppose to be an image of the sun. Into the cell of hyposulphite we may now drop a small quantity of a dilute solution of hydrochloric acid in water. The effect of this acid solution is to *gradually* decompose the hyposulphite with a liberation of very fine particles of sulphur. The particles are few in number at first, and so scarcely alter the colour of the light. As they increase in number the light gets scattered, as already shown, and we have a yellowing of the image, and when the decomposition of the hyposulphite is still further complete, the image becomes cherry-coloured,

Fig. 17.

and finally dusky red. Our mock sun has passed through every phase of colour which the real sun appears to take, from the mid-day to sunset, and if fine particles are suspended in our atmosphere, we need not seek any further cause for these changes in colour with which we are so familiar. We shall learn more of the cause of these alterations in colour if we throw the image of this mock sun upon the slit of the spectroscope, and watch the alteration in the spectrum that takes place. We shall find that the violet and blue fade away most rapidly, then the green, till finally, at sunset, when the sun is really red, only a red band of the spectrum is left. Now we can apply this to photography. Towards sunset a landscape may be brilliantly illuminated with sunlight, more or less ruddy or orange, and yet, on taking a photograph of the same, we shall find that there is not a trace of sunlight effect on the negative. The brilliantly illuminated high-lights have had no effect at all. The reason of this will now be apparent. The molecules composing the sensitive substance of a photographic plate, as we have found, respond chiefly to the violet, blue, and green of the spectrum, and these very rays are nearly totally absent in the light from such an evening sun. The effective illumination for the photograph under these circumstances is practically due to light from the sky which is reflected on to the landscape.

Perhaps we have rather delayed what should have been said earlier. The scattered rays from a beam of sunlight must go somewhere. They are scattered in all directions upwards and downwards, and they reach other particles, and come to the eye as blue light, which we call sky. We now see why we have a sky at all. When looking through a Nicol prism at the sky at places at right angles to the direction of the beams which reach us from the sun, we find that at those parts the light is most polarised, indicating that a portion of the light from the sky is due to light scattered by fine particles. We could scarcely expect it to be entirely polarised, as not only are rays which are incompletely polarised reflected, but there are coarser particles which scatter all colours alike, so that we have a mixture of polarised and unpolarised light.

The writer has beside him a small instrument with which he has been able to measure very accurately the polarisation of light from the sky in any direction. It consists of a couple of square tubes placed side by side; at one end of each tube is a lens so arranged that they each throw an image on a screen inclined at 45° to their axis. These images can be observed through an eye-piece. In front of both these lenses are aluminium shutters, one of which can be closed to any desired amount by slow motion screws. Behind the other is a Nicol prism, which can be rotated on its axis. An arrangement is adopted by which the axis of the lens can be accurately pointed to the sky at right angles to the direction of the sun. When the Nicol is turned in one direction, the shutter in front of the other lens is closed until the image of the same piece of sky appears of the same brightness. The Nicol is then turned at right angles to its former position, when equality of brightness is again established. The ratio between the two apertures employed gives the ratio of light polarised to that unpolarised.

If we look at a white cloud through this apparatus we find that very little, if any, change in the brightness of the image occurs, in whatever direction the Nicol is turned; whereas the neighbouring sky, if it is at all near the plane at right angles to the direction of the sun, appears dark when the Nicol is turned in one direction. We thus see that for rendering cloud and sky the use of a Nicol prism, combined with a lens as advocated by Messrs. Dibdin and Wellington, must be advantageous.

Now do not let us have the idea that the sky is only above us. It is around us, and we see it in that blue haze of the distance which almost entirely eliminates local colouring. Distant mountains appear blue, and differing but little from the sky near them. They appear slightly darker, with perhaps just a faint trace of local colour to differentiate them from it. Who is there that has tried to photograph such distant hills, and has succeeded in rendering them as he wished? We prophesy that, in all probability, not one in a hundred, if he used the ordinary photographic apparatus. Let a Nicol prism be used, however, combined with the lens, and we shall see that success is by no means impossible, or perhaps we should say, impracticable. The Nicol can be turned till the blue sky is cut off, and the local colouring will appear, and be "photographable." A yellow glass may also be used, for the same purpose, but not so successfully. The sky between us and the distance is caused by the presence of the innumerable small particles which exist in the atmosphere, and they are most numerous near the earth's surface. As a result of several years of careful measurement, the writer has found that the number of particles varies at any altitude as the height of the barometer. If the barometer stands at any place, say at twenty-five inches, and at another at thirty inches, the number of particles in a thin layer at these two places are as 25 to 30. A few miles along the earth's surface are thus equal to a good many atmospheres in thickness. In fact, at the horizon a horizontal beam of light has to traverse what is equivalent to about thirty-five thicknesses of atmosphere, so far as the number of particles is concerned.

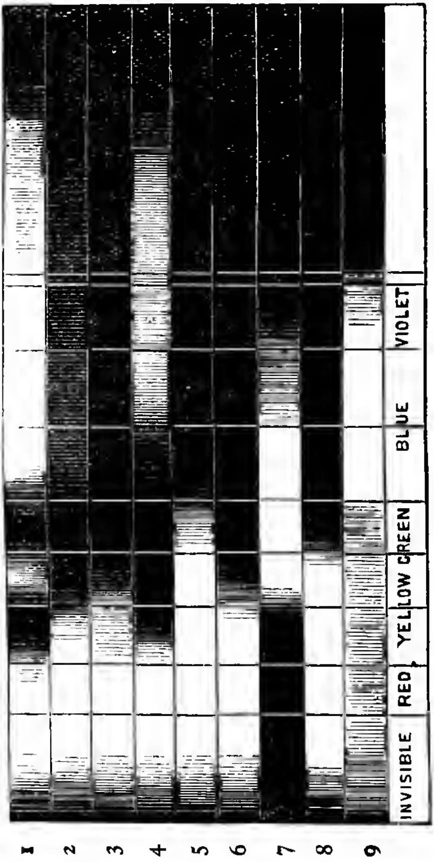
CHAPTER V.

LIGHT IN THE DARK-ROOM.

ONE reverts to the question of light in the dark-room with very mingled feelings, for the suggestion naturally forces itself upon one that everything that can be possibly said about it has been written, and the author acknowledges that he has been a considerable offender on the subject from time to time. It is a subject, however, of such importance to the photographer that in articles on "Light in Photography" it must not be passed over. It has been shown in a previous chapter the extent in the spectrum to which ordinary bromide of silver is sensitive, and reasons have further been given why the light coming through bromide of silver would not be safe to use in developing. Fused bromide of silver, as stated, possesses a yellow colour, whilst in photographic plates it appears to vary between red and blue, and in the case of that specimen sensitive to the infra-red, to sap green. The question as to whether these are really the colours of the bromide is a difficult one to answer. When bromide is precipitated as an emulsion the particles are evidently built up by innumerable infinitesimally smaller particles, and these, though brought together and made into the large particles, are yet separated, and light struggling through them must be subjected very largely to the same scattering that takes place when sunlight traverses the atmosphere. When the particles are first precipitated they would have what may be called a certain looseness about them. In such a case we should expect white light to appear ruddy after passing through them, the blue and green rays being most scattered at right angles to the beam of light. Now those who have watched the effect on light transmitted through a turbid medium will have seen that the liquid becomes opalescent throughout, and that the more fine particles there are, the more pronounced does this blue opalescence become. Finally, when the turbid medium becomes so dense that a strong beam of white light fails to penetrate it, or to penetrate it very slightly, the opalescence becomes whiter. At this last phase of the phenomenon no doubt the small particles become very thickly intermingled one with the other, and they form larger aggregations through the smaller ones coalescing, but they may still be separate one from the other. The light which, after issuing through the film, would be ruddy under ordinary circumstances, is cut off and reflected internally by these larger aggregations, and mix with the scattered light. By repeated reflections it may get absorbed to a large extent, so that the colour of the film may appear to be green, or even blue, owing to their absence. We can take a plate coated with gelatine in which some alkaline sulphate has been dissolved, and when dry immerse it in, say, chloride of barium. The film may be so dense in the moist state that white light fails to penetrate it as a beam, but it appears white; on the other hand, when dry, a gaslight examined through it will appear ruddy or orange. These two states represent the same amount of suspended matter in the gelatine, but they are not suspended under the same conditions. The bearing of this experiment will be apparent. Again, when bromide of silver is heated in gelatine it passes from the red stage to the blue stage, but in either stage, if the film be thin, and the plate be laid on a piece of white paper with writing on it, no trace of the red or blue colour will be visible, showing that we have not the true colour of the bromide in the light transmitted through it. The colour of a bromide film under these conditions must not, therefore, be assumed as showing any molecular change of the bromide itself, but rather as a change in the structure or aggregation of the particles.

But what has this to do with light admitted to the dark-room? A good deal. It must not be assumed that because we have a difference in colour of the two films when examined by transmitted light, that therefore they have different spectrum sensitiveness. That there is a difference in sensitiveness to the spectrum cannot be gainsaid, but it is probably due to the fact that, as the *general sensitiveness* to white light is increased, so the range of the spectrum which is capable of increasing the amplitude of the atom's motions to the extent necessary to break up the molecule is larger than it was before. This readily accounts for the fact that whilst only some plates are sensitive as far as the blue-green, others prepared with the same silver salt are sensitive as far as the yellow. To judge of the suitability of a light in which to manipulate any plates, it is safe to reckon with the spectrum sensitiveness of those whose range goes furthest towards the red. We have, however, another consideration to bear in mind, and that is the physiological peculiarity of the human eye. The eye is less sensitive to feeble red light than to any other. Red light does not "carry" far. A red light may properly illuminate a plate close to it, but remove it a couple of feet, and almost all the image on a developing plate will become indistinct. Orange light, on the other hand, has much more "carrying" power, and a light of this colour, and of an equal luminosity or brightness as a red light, will enable a plate to be examined at a distance considerably further than can be done by the last-named light. When we come to a green light we find this still more true. Evidently, then, the light that most nearly approaches a green light is far better than any other. A green glass, however, as a rule, admits a large amount of blue with it, and hence we are bound to fall back on a yellow or orange glass, as the light transmitted through it allows but little, if any, blue to be carried with it.

Now we may go a step further, and show to what extent we may overstep theoretical perfection in practice. If the most sensitive plate in the market at the present time be exposed to the light of a candle at forty feet distance for ten seconds, no action of such light can be traced on the plate. If a yellow glass be placed in front of the candle, this time may be increased at least twenty-five times, or the ten seconds, or be increased to four minutes and more. It is quite evident, then, that we may place a candle shaded with this screen at eight feet from a plate without any ill-effect resulting from its employment during ten seconds at least. The best practical way, then, to test what light may be used, is to place different pieces of glass, paper, or other material, which it is proposed to employ, in contact with a plate in a dark slide, and expose the plate through these coloured media to the white light, which would come in through the window, for a time which should allow developing action to commence. Probably half a minute would be ample. All media should be rejected which showed any but a very slight action on developing the plate. That medium amongst those selected which gave evidence of passing the most yellow light should be accepted on physiological grounds. This is a practical way of carrying out a test. One of the safest media is a solution of iodine in alcohol, or iodine dissolved in an aqueous solution of iodide of potassium. When concentrated, it cuts off all colour except the extreme red, whilst when more dilute it allows orange as well to be transmitted. A liquid screen is somewhat awkward to deal with, but it can be managed with a little care. We may, however, for ordinary plates which are non-orthochromatic, use with safety a coloured screen which consists of stained red, and an orange paper to diffuse the light entering into the room. We cannot do better than reproduce a diagram (Fig. 18), which is to be found in "Instruction in Photography," to show what are the absorptions of different media. Fig. 19 will give an idea of the loss of illumination caused by using stained orange and ruby glass. The outside curve shows the relative brightness of each spectrum ray in good white light. The two inner curves show the



1, Cobalt glass; 2, ruby glass; 3, chysoidine; 4, magenta; 5, flashed orange; 6, stained red glass; 7, bottle-green glass; 8, aurine; 9, quinine.

Fig. 18.

amount of the different rays that are cut off. A feeble white light outside the window glazed with either of these media means almost darkness within the room. If we could find a medium which would admit all the rays to the light of the scale No. 45½, we should have a luxurious light at all times.

Changing plates is often a difficulty to some amateurs who are on tour if they have forgotten their lantern. There need be none at night. If we recollect that a candle when at forty feet off from a sensitive plate has no effect in ten seconds, the way to utilize such a light at night is easy. Place the candle beneath a table in a room, and change the plates on the top of the table. This can be effected in a few seconds, and no evil effect need be feared, particularly if the walls are of a yellowish colour.

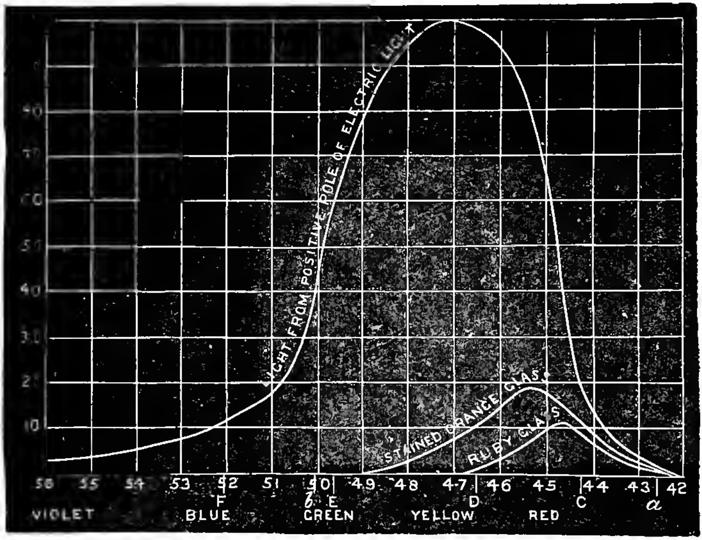


Fig. 19.

CHAPTER VI.

LIGHT SCATTERED BY LARGE PARTICLES.

IN Chapter IV. we have called attention to the scattering of light by fine particles, and we shall now devote ourselves to the consideration of the scattering of light by larger particles—particles which are not ultra-microscopic, but which can be seen. It has already been stated that we may have the scattered light from both kinds of particles existing together, as is found in the sky, for example. There are some effects in photography which are entirely due to the light falling on these coarser particles. If a vertical beam of light falls on a bright spherical ball placed on a sheet of paper, the rays will be reflected differently from each part of the surface on which it falls; the most intense ring of light which reaches the paper will be that just grazing it; the light reflected from the other circles of the sphere will form less bright rings, since the reflected beam will reach the flat surface at an angle, and thus the quantity of light reflected from such circle will be spread over a larger surface.

For a spherical ball let us substitute a particle of sensitive salt, and for the white paper a sheet of glass. The rays specularly reflected from the small particle will reach the first surface of the glass plate, and instead of all being again reflected, will only be partially reflected, as some will pass through the glass and reach the bottom surface of the plate. When they reach this polished surface they may all be reflected back, or some may again pass through, and only a portion be reflected. The case where the reflection from the bottom surface of the plate is complete is that which is peculiarly interesting.

Common optics tell us that when a beam of light is incident on a surface which divides a light from a dense medium, no part of it will pass out of the latter if it fall on such surface at a certain angle, and that for this, and for all greater angles, the beam will be wholly reflected. The angle at which this total reflection takes place is called the critical angle, and is dependent on the indices of refraction of the two media.

When a beam of light in air falls at an angle θ (measured from the vertical) on the surface bounding two media, the sine of that angle multiplied by a constant number gives the sine of the angle which the beam will make with the vertical when it enters the denser medium (if we call the last angle θ^1, we express it mathematically as $\mu \sin \theta^1 = \sin \theta$, 1 and μ being the constants or indices of refraction, as they are called). If the beam of light falls in a dense medium into air, the reverse takes place: the angle at which it emerges is greater than that at which it strikes the surface, and the sine of the angle of the former has to be multiplied by the same constant. In the case of glass, when the index of refraction of air is taken as unity, μ is about 1·5. If, then, the angle at which a beam in the glass strikes the surface is rather less than 42°, the sine of the angle which the beam would make would be 1, or 90°, or it would graze the surface, and a beam striking at any angle greater than that (since the sine of an angle can never be greater than 1) would fail to get through at all, but would be wholly reflected back, and at the same angle as that at which it struck the surface.

Now we may apply this to the light scattered by our particle. Of the scattered rays which enter the glass those which struck the bottom surface at a greater angle than about 42° would be reflected back to the first surface, where they would, if it were a bare surface, be again reflected back to the second surface, and so on. In a photographic plate, however, the first surface is not bare, but is covered with gelatine or collodion containing sensitive salts. The fact that the density of the gelatine is comparable with that of the glass allows the first reflected beam from the back surface to pass into the gelatine, and to strike the particles in its path. If, then, we have a small beam of light (such as that which is obtained through a pinhole in a piece of foil placed in contact with film) striking a few particles, we should expect to find on development not only an image of the hole, but also a ring having a radius of nearly twice the thickness of the plate (due to the total reflection of the light at the critical angle) surrounding it. Outside this ring the density would shade off gradually, as the totally reflected light would be spread over a larger area, but inside it the shading towards the hole would be much more abrupt, as a large portion of the light would pass through the plate, the remainder only being reflected back. We have here an explanation of "halation."

An experiment proves the worth of this reasoning in a very convincing way. Punch out a small hole in the foil, and at a small distance from it cut a line, and place the foil in contact with a plate, and expose. No. 1, of Fig. 20, gives the result. On development the image of the hole is surrounded by a ring, as described, and the deposit round the line can readily be seen to be made up of a series of rings due to each small part of the line. If the glass had been thicker, the ring round the dot would have been larger, as would have been the boundary of the halation round the line. If the glass were thin, or if a celloidin film had been employed, it is evident that the ring would be practically coincident with the point, and the line would show no practical extension of breadth. This accounts for the fact that with plates

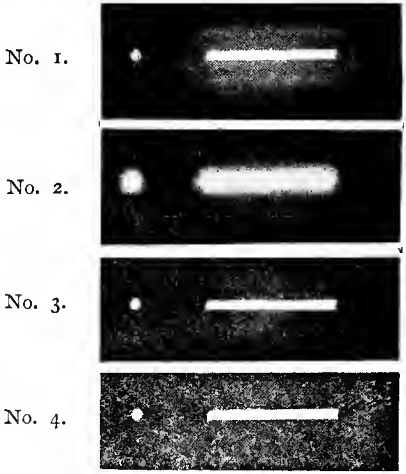


Fig. 20.

we have halation, whilst with films it is practically absent.

It is rather an instructive experiment to place the foil in contact with one plate, and behind the first plate to place a second, separated from it by the thickness of a sheet of paper, so as to prevent contact between the two. The top plate will show by its rings the light reflected from its back surface, and the second the amount of light which passes through the first. Of course, by very prolonged exposure, a ring of halation may be traced in the second plate. No. 2 in Fig. 20 shows what is obtained, and if " applied " to No. 1 would fill up the darker spaces within the lighter boundaries.

We now come to another phase of the question. Suppose we coat the *back* of the plate with some substance such as asphaltum whose index of refraction is not far off that of the glass. All, or very nearly all, rays which come into the glass plate from the film side will penetrate into the asphaltum, and will not be reflected from the back of the glass, but would have to be reflected from the back of the asphaltum. But in passing through the asphaltum they are absorbed, and there are practically none which find their way to the surface; hence no halation should take place. No. 4, Fig. 20, is an example of this; the halation is completely absent. With a *very strong* light a very small halation would be visible, owing to the fact that the asphaltum is not quite so dense as the glass, and a very small percentage of light would be reflected from the surface bounding the two. If the back of the plate be coated with a film of collodion, halation will be found of a similar strength as if it were bare—the diameter of the circle will be very slightly different; but if the collodion be mixed with an orange dye, the halation will be absent with ordinary plates, though with an orthochromatic plate it will be plainly visible. Halation may be *mitigated* by brushing over the plate gum mixed with a pigment, such as sienna or chrome yellow, but the writer has not found that it is so effective as if the colouring matter were soluble. The light can struggle to the back of the layer, and be reflected back, a certain portion reaching the glass (see No. 3, Fig. 20).

In backing plates, the great point to attend to is that the two surfaces are in absolute optical contact—that is, that no film of air is between them at any part, and that the material absorbs the photographically active rays. Carbon tissue, pitch plaster, and other adhesive materials will be found effective for this reason.

The absence of halation when a sensitive surface is used for the measurement of "photographic" light is a point that should be attended to, otherwise a slightly erroneous result may be anticipated.

If, instead of studying halation by means of a photograph, it be desired to study it with the eye, there is nothing simpler than to place the tinfoil in contact with the film on a plate, and, having illuminated it with a strong light, to examine the plate from the back. The ring and the shadings of light will be distinctly seen. If the back of the plate be cemented by Canada balsam, or even by a film of water, to a thick plate, the same phenomena will be observed, but the rings will be of greater diameter, since it is dependent on the thickness of the glass, and the two plates become one to all intents and purposes.

CHAPTER VII.

INTERFERENCE AND DIFFRACTION.

WE are now leaving the effects of light, with which photographers usually have to deal, and are entering on a somewhat more difficult part of the subject, but as it leads to the explanation of the formation of spectra by diffraction, and of pinhole images, we shall not scruple to discuss it. We have all along treated light as being due to wave motion, and in the explanation of interference and diffraction this treatment is absolutely necessary. We may once more go to a water wave as an example of wave motion, since the waves which cause the sensation of light are supposed to be transverse waves with vibrations at right angles to the direction of the beam. If two stones be thrown in a pond at the same instant and far apart, the two separate sets of waves will move in circles, and at some point these circles will intersect. At that particular part where the crest of one wavelet meets the crest of another, the water will be raised higher than before, and where the trough of one wave meets the trough of the other the water will be more depressed, but where the trough of one wave meets the crest of the other the water will remain at the ordinary level, and stillness result. Yet, though the waves may disappear at the spot where this stillness is seen, the wave motion is only masked, for each wave will reappear and go on its way as before. It must not for a moment be conceived that the wave carries with it the water of which it was first formed. There are successive motions of each part of the water. A cork on the surface, for instance, is not carried on with a wave; it simply rises and falls as the successive waves reach it and pass away from it. Waves merely carry the energy which is generated by the fall of the stones. Light waves act in somewhat the same way, but with a small difference. With these the two sets of waves of the same length must start from the same point, but by different routes. When one arrives at some point exactly a wave-length behind the other, the effect will be to increase the distance through which the wave oscillates, or, as we have called it before, the amplitude. If the original amplitudes are equal, the

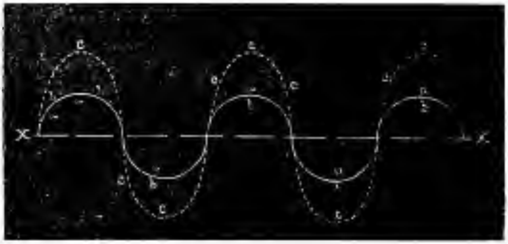


Fig. 21.

amplitude of the compound wave will be doubled. Fig. 21 shows this: *a a a* and *b b b* are two sets of waves starting from the same point. Separately they have the amplitudes shown by the continuous lines, but when compounded they have the double amplitude shown by the dotted line. Suppose, however, one set of waves arrives only slightly behind the other, as in Fig. 22, the two will be compounded in the following way: Take any point of the path X^1. At this point one wave has

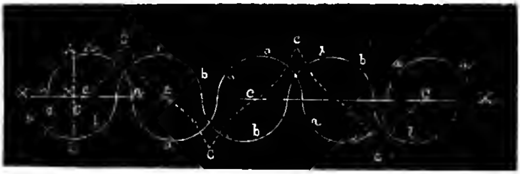


Fig. 22.

a positive amplitude X^1 A, and the other a negative one X^1 B. The difference between the two is X C, and this will be a point in the motion of the combined motions. By this plan of combination the wave motion will assume the form shown in the dotted line *c c c c*.

If the one set of waves was exactly half a wave-length behind the other, the positive (above the line X X) motion and the negative motion (below X X) would exactly neutralise one another, and no motion would be seen along X X; one wave amplitude would destroy the other, and there would be no light. Such waves are said to interfere with one another. Now, suppose two series of waves of the same length start from the same source; these sets will be in the same phase—that is, their crests and hollows will occur at the same instant—when they have travelled through the same distance in the same medium. Now it is perfectly possible that both sets of waves may be compelled by circumstances to arrive at the same point on a screen, but by different routes. If it happen that at this point the difference in length of the paths makes one series of waves arrive exactly half a wave-length behind the other, then at this point there will be interference, and darkness will result. For instance, a point of light will radiate waves which will be spherical—that is, all the crests and hollows will be in concentric spheres, and if it be far enough off from an obstacle lying in the path of the waves we may consider that the surface of the sphere close to it is a plane. Now a wave at any part of its path may be considered to be made up of a large number of very small waves, each spreading out in a hemispherical form, and this we may take to be the case where the wave meets the obstacle. This being granted, we may reason that all the small waves that pass by the obstacle will spread out in every direction, and that those which graze the obstacle, or are near to it, will spread round the edge of the obstacle, and instead of a sharp shadow resulting, as there would be if there were no waves having a tranverse motion, we ought to have light shown on a screen within the geometrical shadow of the obstacle. Experiment shows this is absolutely true. When we have light issuing from a small point, such as from the image of the sun formed by a lens of short focus passing over an edge of an opaque object, the edge is not defined on the screen, but is shaded off. But we also find that there are alternate bands of *partial* darkness and light on the *bright part of the screen* near where the shadow of the edge falls. These alternations of light and darkness are called fringes. The darker bands are due to the fact that at these parts of the screen the wavelets near the edge are exactly half a wave-length behind the waves which are proceeding direct to these points, and this causes the partial darkening on the screen. As many wavelets which pass unimpeded to the screen combine together to give the illumination, and but a few near the edge of the obstacle are half a wave-length behind, it follows that the interference can be by no means complete, but only partial. A little reflection will show that there will be an unlimited number of these darkened bands, but that as they recede from the edge they will become fainter and fainter, till they finally are lost to the cognisance of the eye, for the further away they are from the geometrical shadow the less will be the reduction of the amplitude. The

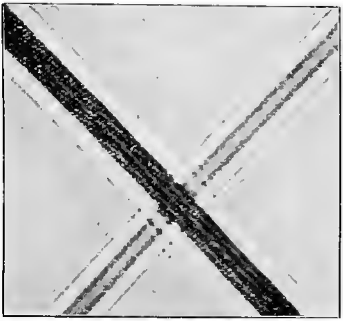


Fig. 23.

light bands are accounted for in exactly the same way. On the shadow side of the edge the light of the wavelets spreads outwards, and each contributes something to the illumination; but, as will be seen, the effect of the combination must rapidly die out. Fig. 23 shows the fringes due to an obstacle. The obstacle is a thick wire crossed at right angles with a thinner wire. The light lines shown in the centre of the wires are due to the "interference" (a turn which will be explained directly) of the light passing from each edge into the geometrical shadow.

We now come to a more interesting phenomenon based on the same principles, and that is the diffraction of light coming from a point after it has passed through a slit. Let us consider we are dealing with monochromatic light. The light reaches the slit S S in the same phase from a distant point of light, and the question comes, what will be seen on a screen, A B, placed some little distance from it? We may consider what will happen at

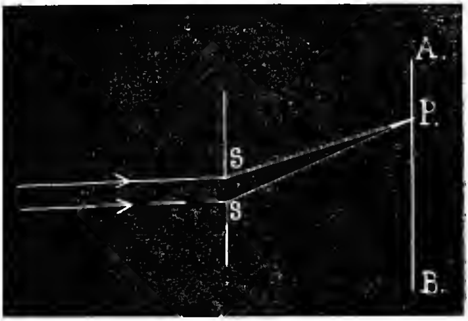


Fig. 24.

a point P on the screen A B. The light arrives at every part of the slit S S in the same phase—that is, the crests and hollows arrive severally at the same time at S S. We can divide S S into small strips, so that the light travelling to P from each subdivision is just half a wave-length behind that travelling from the next one to it. If the number of these divisions be an even number, it is manifest that each of these small wavelets will interfere with one another, and there will be darkness at P. On the other hand, if it be an odd number, the point P will be illuminated. At other points in the screen we shall find darkness or brightness from the same cause. We shall thus have stripes of light divided by darkness, since we are using monochromatic light. If, however, we were using white light, we should have no bands of absolute darkness, but the screen would show bands of different colours, for the positions of the dark bands depend upon the wave-length of the light employed, and as in white light the wave-lengths are numerous, evidently the light band due to some one wave-length will overlap the dark band due to some other, and so we get the coloured bands. When monochromatic light is used, the distance apart of the dark bands evidently depends on the width of the slit. For let us suppose the breadth of the slit can be divided into strips giving six half wave-lengths of difference on arriving at P; then P will be in darkness. If we halve the slit there will be only three such strips, and being an odd number it will be in brightness. By calculating in this way we shall find that the narrower the slit the further apart are the bright and dark bands. There is, of course, a central image as well as these bright and dark bands outside it, and if the screen be sufficiently far off it will be a uniformly bright stripe, but if it be so close to the point of light that the fringes formed in the way we have already mentioned, by each edge falling within the image, it will be traversed by dark lines.

Fig. 25.

This reproduction of a photograph shows what will be seen when a fairly wide slit is employed. The photograph has been enlarged in order that the alternate bands may be seen more readily. In this case the screen was placed at such a distance that the effect of the fringes is absent, as they lie outside the geometrical image. When we have a large number of equal apertures side by side, and separated by equal opaque intervals, and allow a beam of light coming from a distant point to fall upon them, each separate aperture will have its own bands of light thrown on a screen, and they produce a confused appearance where they are cast; but if a lens be placed in their path, then they can be collected and brought to a focus in the ordinary way, and they form fairly bright lines at regular intervals; *but this depends on the intervals being regular.* (We are, of course, talking of monochromatic light.)

The figure is a photograph of the bands taken from a surface with rather irregularly spaced apertures. Lines were ruled with a point on a glass plate coated with asphaltum dissolved in benzine, to which a little olive oil was added to keep the surface from being brittle whilst it was being ruled. The lines were about $\frac{1}{26}$th of an inch apart. This ruling was reduced by photography, so that the photograph contained about 300 spaces to the inch. Instead of a point of light, a slit parallel to the apertures was employed, through which monochromatic light was sent. An ordinary photographic lens brought the various images to a focus, and the result shown in the figure was obtained. The top line is an image of the slit, whilst the lines below show the central image and the bands. It will be seen that the brightest lines of light are visibly duplicated, owing to a slight irregularity in the ruling.

Fig. 26.

To obtain the next figure a fairly wide slit was employed, and the three sets of bands are due to monochromatic light of different colours coming through the slit and falling on a surface on which some 3,000 lines to the inch were ruled. The figure is an absolute reproduction of a photograph. Successive strips of the plates were used for the exposures to the different coloured bands. The monochromatic rays used were orange, green, and violet. The orange rays, being due to longer waves than the green, are more widely separated, as are the green than the violet, and for a similar cause. If these three monochromatic lights were all sent through the slit at the same time, the plate would have shown all the sets of lines side by side. We have only to imagine a very large number of rays of varying wave-length to come through the slit, and the lines would coalesce, and we should have a complete series of spectra, but only the first on each side of the central image would be pure and unmixed. For, as will be seen, the 3rd of violet bands lies between the 2nd and 3rd orange bands, and would therefore mix with the intermediate colours. The 2nd, 3rd, and other spectra would therefore be impure.

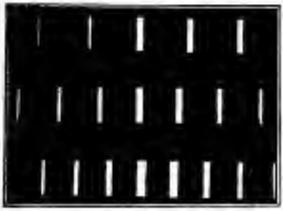


Fig. 27.

Such spectra are diffraction spectra, and white light is decomposed into the same colours by this plan as it is by prisms. The violet is least and the red most diffracted, owing to the fact that the waves of the former are the shortest, and those of the latter the longest, which can give an impression on the eye. The ultra-violet and the infra-red rays are also diffracted. With the former, the wave-lengths being shorter, the bands of light would be closer together; with the latter, further apart.

The wave-lengths of the different colours have been determined with spectra of this kind by measuring the angles which they make with the central image, or by measurements from photographs. If the spacing of the intervals is known accurately, formulæ will enable the wave-lengths to be determined. Conversely, knowing the focal length of the lens, if we measure accurately the distance apart of the images of the lines produced by monochromatic light of some known wave-length, the distance apart of the lines can be determined. This may be useful when very fine ruled surfaces are used for producing typographical half-tone blocks. For instance, if we use a lens of 10 inch focus, and find that the bands produced by a wave-length of ·000016 inch are ·048 inch apart, we know that very approximately the ruled lines are $\frac{\cdot 048}{\cdot 000016}$ or $\frac{1}{333}$ of an inch apart. In practice one would measure the distance apart of the 3rd or 4th band on each side of the central image. Say we measured the distance apart of the 4th bands from each other, and found it to be ·38 inch, then the distance apart of the 1st bands from the central image would be $\frac{\cdot 38}{8}$, or ·475, which would make the lines $\frac{1}{337}$ apart, instead of $\frac{1}{333}$, as above—a difference which would be inconsiderable for the purpose which such lines had to serve.

The following is a table of wave-lengths (in $\frac{1}{10,000,000,000}$ of a metre) of the principal Fraunhofer lines in the solar spectrum, together with the bright lines of lithium. The lithium lines, the D line (due to sodium), the *b* line (due to magnesium), and the H line (due to calcium), are most useful in determining the different parts of the spectrum in the arc electric light. In subsequent chapters these lines will be shown as reference lines for photographs of spectra.

A	7,596	limit of visibility in the red.
B	6,867	dark red.
Lithium	6,705	dark red.
C	6,562	bright red.
D	5,892	orange (centre of pair).
E	5,269	green.
b	5,183	green.
F	4,860	blue green.
Lithium	4,603	blue.
G	4,307	violet.
H	3,968	limit of the violet

CHAPTER VIII.

PINHOLE IMAGES.

WHEN light is treated from a geometrical optical point of view, we can trace in a very simple manner the course in which a beam will travel through any transparent medium; but there are phenomena which cannot be thus accounted for. If we treat it on the wave theory, as we have already done, any difficulty disappears. If, for instance, light from a distant point passes through a minute hole on to a screen, we should conclude we ought (according to geometrical optics) to have an image of such a hole, with a sharp-cut edge. The figure on the screen ought to be a facsimile of such a hole, the dimensions being increased in the ratio of the distance of the point of light from the screen to that of its distance from the hole. Facts—or, what is better, observations—are against this assumption; the image will be found to be confused, and if the hole be one with angles, the sharp corners will be found to be shaded off. The cause of this is explained in a satisfactory manner if we take into account what we have described in Chapter VII.

We may deduce theoretically the image we ought to get, and then see experimentally if it is correct. First of all, we will suppose that we are dealing with light of one wave-length only. Let B C be the hole in a plate A D, and let L G be a straight line passing through the centre in the direction of the beam of light. Then, evidently, as the source may be considered to be very far distant, E F would mark the diameter of the geometrical image on the screen S S. Now let us see what really occurs at the point G. Let us first divide the radius *b* B of the hole into such intervals that the distance from G to each is just a half wave-length (which we will call $\frac{1}{2}\lambda$) greater than it is from the preceding one. Thus G b' will be greater than *b* G by $\frac{1}{2}\lambda$, G b'' will be greater than *b* G by λ, and so on. If we call *a* the distance *b* G, then b' G will equal $\sqrt{a^2+(b'\,b)^2}$, and this is very nearly equal to $a + \frac{(b'\,b)^2}{2a}$, since *r*, the radius of the hole, is supposed to be very small compared with the distance of the screen. But *b* G $= a + \frac{\lambda}{2}$, so that $a + \frac{(b'b)^2}{2a} = a + \frac{\lambda}{2}$, that is, $b'\,b = \sqrt{a\,\lambda}$. In the same way $b\,b'' = \sqrt{2\,a\,\lambda}$, and $b\,b''' = \sqrt{3\,a\,\lambda}$. If we draw circles through these

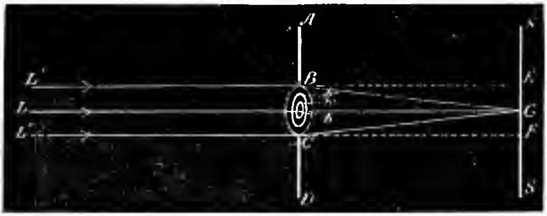


Fig. 28.

points thus found, it will be readily seen that the areas enclosed between them will be each equal to one another—namely $\pi a \lambda$.

This is evidently a somewhat important point, for it means that the light coming through each of these areas is equal in quantity. [It may here be stated that if the point of light be near to the pinhole, and c is the distance between them, that then the points into which the radius of the hole are divided are $b' b = \sqrt{\frac{a c \lambda}{a + c}}$, $b b' = \sqrt{\frac{2 a c \lambda}{a + c}}$, $b b''' = \sqrt{\frac{3 ac}{a + c}}$, &c., and the successive annuli are all equal to $\frac{\pi a c \lambda}{a + c}$]. Leaving mathematical formula, we thus arrive at the conclusion that something which would be unexpected from geometrical considerations will happen. If two sets of waves, each starting from the same point at the same instant, arrive at a point on a screen, but by slightly different paths, they may not be in the same phase, as we already know—that is, the crests of each of the two sets of waves may not strike the screen together. To repeat what we have already said, if the hollow of one wave arrives at the screen when the crest of the other wave arrives there, the one will fill up, as it were, the other, and there will be no motion, and, as light is simply wave motion, there will be darkness. Taking this view of the matter, we come to the conclusion that the light coming through the central area of the pinhole will destroy the light at G coming through the first ring, that of the second will destroy that of the third, the fourth of the fifth, and so on; and if it happens that there is an even number of rings (including, of course, the central area), then there will be a dark spot at G. If there is an odd number, there will be a light spot. If the outside ring be not equal to the others, there will be a grey spot at G, since the motion will not be completely destroyed. It is thus evident that, as we move the screen nearer to, or further from, the pinhole, there will be alternations of bright and dark spots at G, and between these positions partial brightness only. The distance of the screen for these positions is given by $\frac{r^2}{n\lambda}$; when n is odd it gives the position for a bright central spot, and when even for a dark central spot.

We have next to see what will happen round G. Now we shall give an *approximation only.*

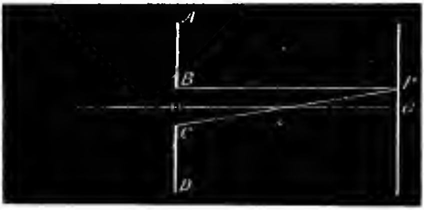


Fig. 29.

What will happen at P, for instance? The circular hole will not appear circular from the position P, but elliptical; but P being not far distant from G, we shall neglect this. But now we must see what difference there is in the lengths P C, P B. Let us call P G x. The distance P G $= \sqrt{a^2 + (x + r)^2}$, or very nearly $a + \frac{(x + r)^2}{2a}$.

The distance P B $= \sqrt{a^2 + (x - r)^2}$, or very nearly

$a + \frac{(x - r)^2}{2a}$. The *difference* in length between P c and P B is therefore $\frac{(x + r)^2 - (x - r)^2}{2a}$—that is, $\frac{2rx}{a}$. If this difference is an odd number of half wave-lengths $(\frac{\lambda}{2})$, P will be a point in a bright ring, and if it be an even number of half wave-lengths $(\frac{\lambda}{2})$, it will be a point in a dark ring.

We can now readily find where the dark and light rays will be found, for we have then $x = \frac{a\lambda}{4r}$, $x = \frac{3a\lambda}{4r}$, $x = \frac{5a\lambda}{4r}$, &c., for the bright rings, and $x = \frac{a\lambda}{2r}$, $x = \frac{2a\lambda}{2r}$, $x = \frac{3a\lambda}{2r}$, &c., for the dark rings. The points of maximum brightness will not be quite at the above intervals, but for our purpose this is near enough. [It will be evident why these formulæ are but approximations, as we have only considered a single vertical section of the hole. If a horizontal section were taken with P, as represented, the joint phases of the waves would not be quite the same as given. The complete solution of the accurate position of the rings is one of extreme difficulty.] If P be a bright point, and situated within what would be the geometrical image of the pinhole, it is evident that it will be very much brighter than if situated beyond it, for most of the light passing through the pinhole would be in that area, and will be condensed into these rings. If P be beyond, only a small proportion of light will be in such a ring. We have only to imagine the hole much larger to see this, for evidently then the direct light would be strong in the geometrical area. The rings outside the geometrical image will not be exactly given by the formula, nor will they be so nearly correct as those inside it. To illustrate the appearance of an image given by a point of light, the accompanying is an enlarged facsimile of pinhole images taken of a point of light ·005 inch diameter, placed at 24 inches from the pinhole, which had a diameter of ·042 inches, monochromatic light of a wave-length of ·0000183 inches being used. No. 8 is the enlarged photograph of the pinhole itself.

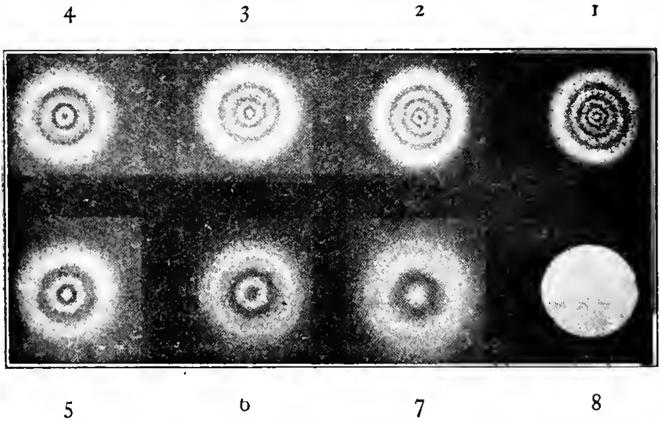


Fig. 30.

No. 1 was taken at 3 inches.
No. 2 ,, ,, 3·5 ,,
No. 3 ,, ,, 4·2 ,,
No. 4 ,, ,, 5·2 ,,
No. 5 ,, ,, 6·8 ,,
No. 6 ,, ,, 9·5 ,,
No. 7 ,, ,, 16·0 ,,

It will be seen that Nos. 1, 3, 5, and 7, have bright centres, and that Nos. 2, 4, and 6, have dark centres. No. 1 has four bright rings enclosing a bright centre, No. 3 has three rings, No. 5 two rings, and No. 7 has one ring. These correspond approximately to the results obtained by the two different formulæ given, as do also the other Nos. with dark centres. No. 7 is where the last bright centre possible is beginning to be formed. It is evident that if the pinhole be so small that at a distance from the screen the aperture cannot be divided into rings, so that one destroys the other, the central image will always remain bright, and that there will be only rings outside the geometric image.

What we have shown as the results of light coming through a pinhole naturally leads to the subject of pinhole photography. What is the best size of pinhole to use ? We can only answer the question by a reference to what has just been said. It will be seen that practically a pinhole forms an image of a point of light of the same size, or a little larger, than itself, when the aperture can be divided into rings, the light coming through which can mutually interfere with one another. The pinhole which is of such a diameter that we have only one bright central disc, and surrounded by a black ring the size of the pinhole, is evidently that which should give better results than any others which give more rings, for then the total area of light will be larger. The question is, why not make the pinhole smaller still ? We can answer the query by calculation and by experiment. Suppose we place a screen at ten inches from a pinhole, and can alter the size of the hole. The radius of the hole which will give the first white centre is $r = \sqrt{10 \times {\cdot}000018}$, or r equals ·0134 inches—that is, the diameter is about

$\frac{1}{40}$ inch, and the dark ring will be at the circumference of the geometrical image. Suppose we make it $\frac{1}{60}$ of an inch in diameter, or ·0083 inch in radius, then the first black ring will be $\frac{a\lambda}{r}$, or $\frac{10 \times \cdot 000018}{\cdot 0083}$, which is ·021 —that is, the image will be larger than when the pinhole is ·0134. The central disc in the latter case would, however, fade off more gently than in the former, so the practical difference would not be so great. For our own part the diameter of pinhole which appears best suited for photography is that which the writer has already given, which is $r = \sqrt{a \times \cdot 000017}$, where a is the distance of the plate from the pinhole, and ·000017 the wave-length of the ray of maximum photographic activity. The accompanying diagram gives an idea of

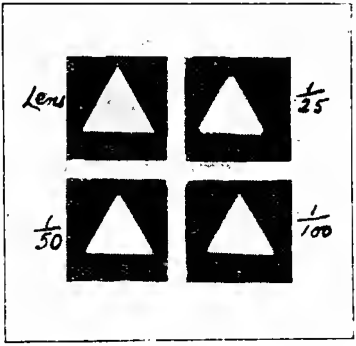


Fig. 31.

the kind of image of a point of light formed by pinholes of $\frac{1}{25}$, $\frac{1}{50}$, and $\frac{1}{100}$ inch in diameters, on a plate ten inches distant. The triangle was photographed at ten feet through these holes, and an image by a lens of nearly the same size is shown with them for comparison.

We have so far only spoken of the effect of a pinhole with monochromatic light. One of the most beautiful phenomena is to examine the light coming through a pinhole by means of an eye-piece or focussing-glass. The eye will see, as the magnifier is gradually drawn further away from the pinhole, a succession of coloured centres. This is due to the fact that at every distance there is one colour which is quenched entirely by interference, and others which are more or less quenched. What is left of the remaining colours is therefore seen blended together. Similarly, the black rings are fringed with colour due to the same cause. If we put a solution of ammonia sulphate of copper in front of the pinhole, we get what should be approximately photographic light, and we can notice the sharpness or otherwise of the rings. They are not so sharp as with monochromatic light.

We next may call attention to a method of increasing the rapidity of a pinhole exposure by an artifice. If we divide a hole into concentric rings in such a way that the path of the rays to the point exactly opposite to the centres of the hole be exactly half a wave-length behind each other, the rays coming through the alternate rings destroy one another. If, however, we block out the alternate rings—say the second, fourth, and sixth, and so on—the rays coming through the remaining rings will arrive at the screen all in the same phase, and will not destroy one another, but will increase the illumination. If we draw rings with a diameter of 1, $\sqrt{2}$, $\sqrt{3}$, $\sqrt{4}$, &c., on a piece of paper, and blot out every alternate ring with black paint, and photograph the target-like drawing, and then make a transparent negative by means of photography, reducing the centre ring to (say) $\frac{1}{20}$ of an inch, and use this photograph instead of the pinhole, we shall get an aperture which will give a brighter image at a distance of ten inches than with the simple pinhole. Such an aperture is called a zone plate, and with it the focus of the red is nearer the screen than the violet, a result exactly the reverse to that obtained with an uncorrected lens. A zone plate, to be properly tested, should be used with monochromatic light, which can be obtained in the way we shall shortly describe.

CHAPTER IX.

THE COLOURS OF THIN FILMS.

WHO of our readers has not in his childhood, and perhaps in his manhood, amused himself by blowing soap bubbles, and found himself delighted at the rainbow hues they exhibit, or in watching the endless variety of colours which rest on the lather floating in a wash-hand basin? We may ask, further, how many have traced the cause of these colours to their source? For the sake of those who have not, we will endeavour to give a simple answer. We have seen if two rays of light of the same wave-length start from the same point, and happen to meet again, one being half a wave-length behind the other, the wave-motion is destroyed where this occurs. This is exactly what happens when a ray of light strikes on a soap film. Part of the ray is reflected from the front surface, the larger portion goes through, and a part of this residue is reflected from the back surface, and follows the track of the first reflected beam; and if, the ray being monochromatic, on striking a screen or the eye, one beam is an even number of half wave-lengths behind the other, there will be darkness. When the number of half wave-lengths is odd, there will be light. Suppose the thickness of the film be such that, say, the waves from the back arrive at a screen nine half wave-lengths behind those reflected from the front, then we shall have brightness. Let us see, however, what would happen to a ray set of whose wave-length was $\frac{9}{10}$, say, that of the other. Evidently, in the thickness of the film there would be $\frac{10}{9}$ of $4\frac{1}{2}$, or ten half waves—that is, the last ray would be annihilated. If there were rays with wave-lengths intermediate between the two, it is also evident that the colours whose rays were short would be dimmed, and those whose rays were approaching the longer set would be increased in intensity. Thus, with white light falling on a soap bubble at each point there would be an intensification of some rays, and a reduction in intensity of others, and the combination of them all would result in a colour which was a mixture in varying proportions of the spectrum colours. What colours were dimmed and what intensified would depend on the thickness of the film. Now let us reason out whether the colours ought to be more distinct with a thick or with a thin film. Suppose, instead of nine half waves, we had ninety-one half waves in the thickness of the film, and we can see, as before, what would happen with the rays that were $\frac{9}{10}$ as long. Evidently, in the thickness we should have 101 (and a small fraction) of half waves within the film, and we should have nearly maximum brightness with both rays. There would be some wave-length intermediate, when complete interference would take place. Hence the thicker the film the closer together would be the parts of the spectrum which would be darkened or intensified. Finally, we should come to such a thickness that the parts would be so close together, and melt so one into the other, that we should fail to distinguish any loss or increase in intensity of the various parts, and we should by their mixture on the screen get white light. Thus, the thinner the film the less mixed with white light the colour would be. This agrees with observation, for a large bubble with a thin film takes more brilliant colours than a smaller bubble with a thick film.

Now a soap film need not be in the form of a bubble to be examined. It is much more amenable to physical observation if it is merely a flat film, and this can readily be secured by dipping a piece of card or metal in the soap solution, and drawing the moistened end across an aperture such as that in a large stop of a lens. The film can be placed in a white or monochromatic beam, and the image of the aperture be then thrown on a white screen or card. What we shall see at first will be an image of a colourless film, for the reasons just stated, as the thickness will be comparatively great. As we will suppose the film to be vertical, the excess of liquid will be found drawing away from the top, and thinning the film from the top downwards; each horizontal section will practically have the same thickness. The thicker part of the film will be downwards. The beam of light will now have to traverse varying thicknesses before reflection from the back surface, with a result that, when using monochromatic light, we shall have bands of blackness close together at the bottom, and gradually getting further apart as the top of the film is approached.

With white light we shall have the same number of coloured fringes as we have black bars. This, as we have just explained, will be due to the fact that for every thickness of film there will be a different mixed colour.

The accompanying figures are photographs of a film illuminated with green monochromatic light. Fig. 32 evidently shows a thicker film than Fig. 33, since the bands of darkness are closer together. It must be noticed the white portions (which were really green in the film) are not of one uniform tint. They shade off gradually towards the dark bands. This simply shows that the varying thickness of the film. This will be evident if we consider what would happen if the rays were only, say, ¼ of a wave-length behind one another. Then the trough of one would not fill up the crest of the other, but would only do so partially. This will be seen

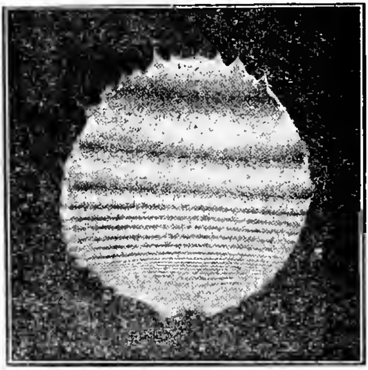


Fig. 32.

by reference to Fig. 22, page 61. These reproduced photographs tell us that the colours reflected by a soap film are not merely visual effects, but act on a sensitive surface like colours produced in other ways.

We can learn more about these colours, however, and make an interesting experiment, by viewing the spectrum of the light reflected from a narrow section of a film, and more still if we secure a permanent record of the spectrum by means of photography. We can throw a beam of sunlight or the electric light on to the soap film, and then, by means of a lens of suitable focal length, form an image of the film on the slit of a spectroscope furnished with a camera. On looking at the focussing screen we shall see a continuous spectrum traversed obliquely in its length by black bands. The slit, it will be remembered, allows only the light from a narrow vertical section of the film to be decomposed into its spectrum colours, the width of the spectrum answering

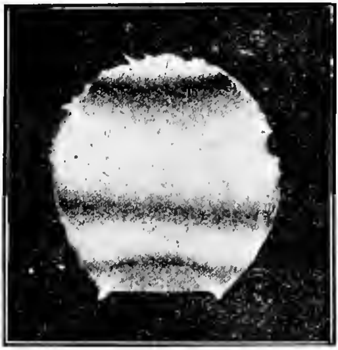


Fig. 33.

to the length of the slit. As through each part of the slit we admit light of different mixed colours, we may expect to see blank bands in the spectrum, which show us what colours are absent, and also what residue is left to form the mixtures. Fig. 34 shows such spectra as photographed on a Cadett orthochromatic spectrum plate. In one part these bands are close to one another, and in another they are separated by wider intervals. This tells us two things—if we take a horizontal line along the spectrum, 1st, we can tell what wave-lengths are absent, and 2nd, knowing this, we can calculate the distance apart of the bands, and the thickness of the film at any part. It is true that there are bands of interference when the waves reflected from the back are just half a wave-length behind those reflected from the front, but owing to the fact that one reflection takes place from the soap solution into air, and the other

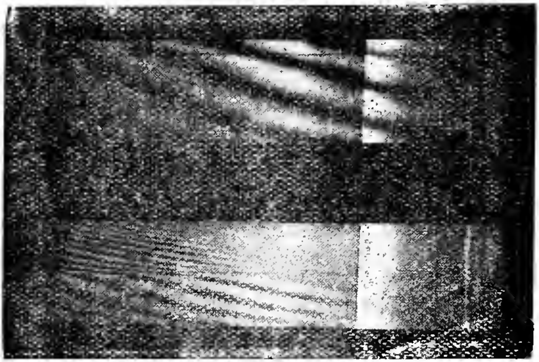


Fig. 34.

from air into soap solution, the phases of the waves are to begin with retarded as regards one another by half a wave-length—that is to say, if the path of the ray through twice the thickness of the film (for it has to traverse it twice) should be so long as to make it an exact multiple of some wave-length, it will be found to differ really by half a wave-length. Unless we knew this from theoretical considerations we should suppose the two beams would reinforce one another, though they will really interfere with one another. (If we call t the thickness of the film, and θ the angle at which the light falls on it, in order to see what the issuing waves will do, we must add half a wave-length to the path; thus the length of path for any beam will be $2t \cos \theta + \frac{1}{2}\lambda$.)

We now measure the distances apart of the bands in a horizontal line, and, knowing the wave-length scale of the photograph, we see what wave-lengths are obliterated. This is useful to know, because the path might be any number of wave-lengths, and these will enable us to calculate the thickness of the film by means of very easy equations. All the wave-lengths of the black bands in a horizontal line must be exactly multiples of the thickness of the film, and thus we can easily see that these bands may be made to tell us what the thickness is.

From the photographs it was found that in one horizontal line the wave-lengths of the black bands were 397, 441, 496, 566. If we call n the number of wave-lengths of the first band, then there will be $n-1$ wave-lengths of the second, and $(n-2)$ of the third, and so on, and as there is interference n must be a whole number. We must first suppose the film to be of air, as the wave-lengths are given in this medium, and subsequently convert this thickness into that of soap solution, and allow for the angle at which the beam strikes the film. Calling this air thickness $2t$ we find that—

$$2t = 397n = 441\,(n-1) = 496\,(n-2) = 566\,(n-3).$$

From this we find that $n = 10$, it being so almost exactly from the first and second wave-lengths, and also from any other combinations. The thickness of the film in the direction in which the light entered it is therefore

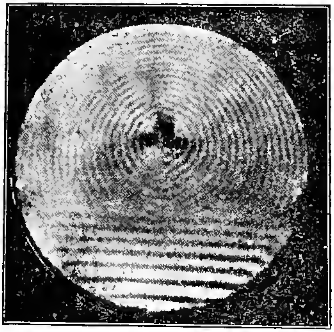


Fig. 35.

five times the wave-length 397 (the unit being 100,000,000 of a centimetre)—that is, ·0000794 of an inch if the film were of air, but as it entered at 45°, and is in water, we must multiply this result by cos 45°, or by about ·7, and divide by μ, the co-efficient of refraction in water, which is about 1·3. The thickness of the film normally is therefore ·000036 inches.

It will be seen now how photography lends itself to the exact measurement of thin films, which it is difficult to carry out by visual observations.

Soap films are so thin that they can be made to show the nodes produced by sound.

When we have sound waves, the vibration will be taken up by metal in which the aperture is cut, and the vibrations set up will also be in the film stretched over the aperture. Now, owing to its rigidity, the metal will not show the vibrations of these waves, but owing to the thinness of the film the vibrations set up in it will be very apparent, and the nodes will be seen in a very beautiful way. Fig. 35 is the note E sounded by a penny whistle. It will be noticed that not only are the circular nodes shown, but also the dark bands of light interference are likewise visible, and apparently undisturbed. This and the next two photographs (Fig. 36

Fig. 36.

and 37) were taken with monochromatic light, one ray of the spectrum of the electric light being spread out to cover the film, and the reflection was received on a lens. The image of the film being focussed, exposure was given to a plate for about the $\frac{1}{20}$th of a second. Fig. 36 is the effect of a shrill whistle sounded some two feet off the film, and Fig. 37 the effect of a shrill note sung by a human voice. In Fig. 36 the film showed one uniform tint, and hence no bands of interference are visible. The fact that the colours of thin films can be photographed shows that a rainbow can also be photographed, and on several occasions the writer has secured a landscape picture in which a rainbow appears most markedly.

Fig. 37.

CHAPTER X.

MODES OF MEASURING GREY SURFACES AND OPACITIES.

HAVING a plate, film, or other sensitive surface which has been exposed, and, where necessary, developed, cases occur in which we ought to be able to measure the transparency or blackness of the different parts of the image, for we can then apply such measurements to the investigation of various problems which present themselves to us, amongst them being the amount of chemical action produced under varying conditions.

The oldest plan of measuring the illuminating value of two lights is by no means the worst. This plan is due to Count Rumford, and is called the Rumford method. It consists essentially in causing two lights to cast two shadows of a rod on a white screen. By altering the distance of the rod from the screen, or by a slight adjustment of the angle which the lights make with the screen, the two shadows (each of which is illuminated by the light not casting such shadow) can be placed side by side so as to touch one another (Fig. 38). One of the two lights can then be drawn away from or advanced towards the screen, till the eye judges that the two shadows are equally bright. The judgment is aided if only a small portion of the shadows can be seen, and this can be secured by covering the screen with black paper or velvet, in which an aperture of, say, one inch square is cut. The shadows are cast on the exposed white surface, and the attention of the eye is then directed entirely to their brightness, and is not distracted by the brighter white light around them. The surface of a white cube against a black velvet screen answers well, and in some cases is more convenient. The comparative illumination of the two lights is found by measuring their distances from the shadows on the screen, squaring these distances, and dividing one square by the other, the illuminating value being *inversely* as the square of the distance. Thus, if one light be 2 feet, and the other 4 feet, from the screen, the latter is $\frac{16}{4}$, or four times more luminous than the former.

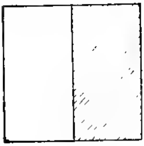


Fig. 38.

If, instead of a white square on the screen, we have one half of it grey (such as is produced by a moderate exposure of platinum paper to light), the grey lying on one side of a central vertical line, the other half being white, we can throw one shadow on the grey half, and the other shadow on the white half. By moving the light which illuminates the white, the two shadows can again be made equally bright (say we have to move it six feet away to cause this equality), and if we replace the grey half by a white, we can again make the illumination equal (say we only have to move it four feet away from the screen). The amount of white light which the grey reflects is given by the same rule; as before, it will be inversely as the square of the distances of the one light on the two occasions. In the measurements we have supposed, this would make the grey reflect $\frac{4\times 4}{6\times 6} = \frac{4}{9}$ of the white light, which the white screen would reflect—that is, it would reflect 44·4 per cent. of light.

All extraneous light should be carefully excluded from the shadows when a grey is being measured, for supposing that the grey absolutely reflects, say, 44·4 per cent. of white light, then it will only reflect the same percentage of the stray light, whilst the white half would reflect 100 per cent. A measurement made then in diffused light would make the grey appear darker than it really is. To overcome this difficulty, these measurements should be made in a darkened room, and

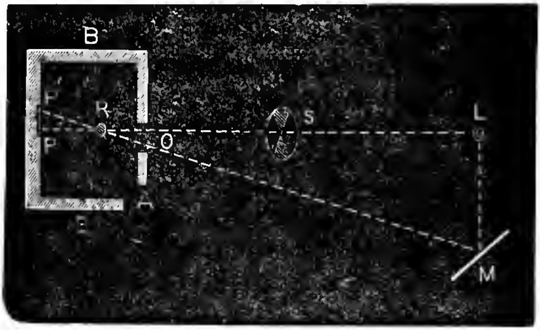


Fig. 39.

the screen should be in a box such as given in the figure below.

The box is B B. In the front towards the light is an opening (*o*) through which the light passes. At one edge is another opening (A) through which the screen P P[1] can be viewed, the rod R being inside the box. By this plan such darkness is secured that the blackest black appears luminous by contrast with the white when the light which illuminates it is entirely shut off. The figure (Fig. 39) shows a slight variation of the method. Both illuminations are due to one source of light, the second being furnished by the reflection of the first light from a silvered mirror M (Fig. 39). In this case the amount of light falling on the screen from either beam can be reduced

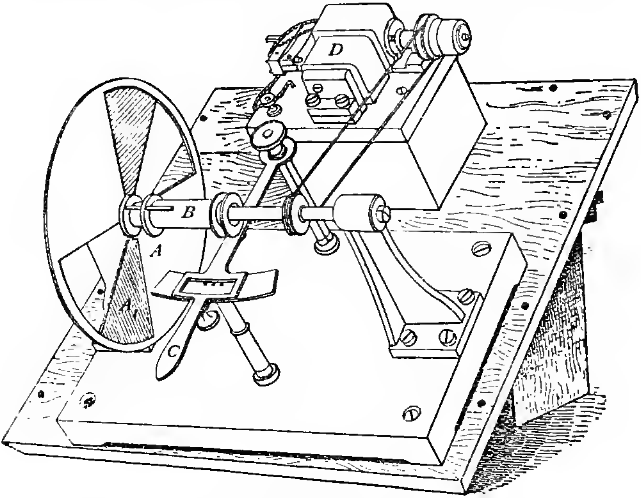


Fig. 40.

by placing in it rapidly rotating sectors (Fig. 40), the apertures in which can be opened or closed at pleasure during rotation. A A_1 are the two sectors which move across one another. B is a sleeve in which is a point that moves in a screw cut in the spindle. The pins, which are fixed to one of the wings in the sector, cause it to turn where B turns. B is moved to and fro in the sectors by the lever C, which has a join worked in the grooved portion of B. D is an electro motor attached by a band to pulley on the spindle. The rim of the sectors is divided into degrees. The shadows can thus be made to be equally illuminated. This is a refinement, and is not absolutely requisite, though it is convenient. The two lights may be used, as before stated, but as each light might vary (particularly if it were that of a candle), the measurements are more liable to error than is the case where one light alone is used, for then any variation in one shadow is equally felt in the other.

In a box such as described, there is an aperture cut out at P P (Fig. 39), which is not shown. This aperture is oblong, the longest side being horizontal. Inside the box it is seen as an open space. Filling half the opening is an oblong of white. If it be desired to measure a piece of grey paper, it is made to fill the remainder of the aperture from the back, and we thus have the grey and white alongside one another. In practice it is well to have the back of very thin metal, so that the junction between a piece of white paper placed in the aperture, and that of the grey alongside, is almost invisible. The two then appear, as in Fig. 38.

This, then, is a plan for measuring the greyness of a surface. But besides this, we may require to know what are the relative transparencies of a deposit produced photographically. Here the circumstances are completely changed. We might, indeed, place such deposit of a negative in the path of one beam, and see how much of the light was cut off by it. A deposit of this kind does not cut off light by absorption, for it is not continuous. It is formed of opaque granules, and the light is really cut off by the interposition of these grains of silver in the path of the beam. Now where we have granulation a certain proportion of the light will not pass through regularly, but will be scattered by reflection in all directions, and thus will not proceed in the path of the beam. This may be readily demonstrated. Let us take a small gas flame, and balance it by the shadow method against another source of light, say an amyl acetate lamp. Now let us take a "whole" plate, which has been exposed to a uniform light, and develop it. It will have approximately a uniform deposit all over it. Next cut out in a blackened card an area somewhat larger than the flame, and place the aperture in the path of the beam to the screen. No alteration in the balance will be seen; the shadows will appear equally illuminated, because each part of the shadow illuminated by it will "see" the whole flame. Now place the negative in front of the black mask, and alter the other light till the shadows again appear equal, and note the distance the moving light is from the screen. Change nothing, but remove the black mask, and at once the shadow illuminated by the light coming through the negative will appear lighter. The only cause of this alteration is the increased area of the plate exposed, and it is from those parts of the plate not in the direct line of the beam that the increased illumination comes. Moreover, we have only now to alter the ***distances of the plate*** from the source of light, and the illumination of the shadow will vary. The place which gives the least illumination will be found about half way between the light and the screen, and when the plate approaches either the source of light or the screen, the illumination will become greater. What we want to know is the percentage of light which absolutely penetrates through the deposit. For this reason the writer has devised a method by which the deposit is almost in contact with the screen, so that not only the rays which come directly through the deposit are measured, but also those rays which are scattered, since they are equally caught by the screen. In this case the size of the plate presented to the light is immaterial. The plan the writer has adopted is as follows :—

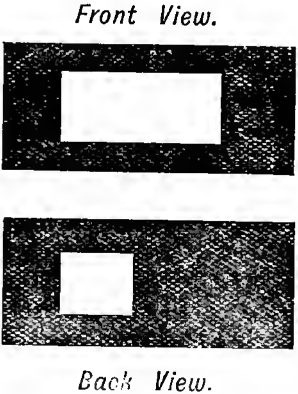


Fig. 41.

Suppose we pierce a small square aperture in a thin (say a ferrotype) plate, or a thin black card, and cover all one side with white paper, and over this place a mask of black paper cut out to a double square (Fig. 41), one half of which is placed over the paper covering the aperture, and the other half an equal square of white paper; then a light from behind the aperture will illuminate the paper covering the aperture, and a light in front will illuminate both the squares of white paper. If we place a rod so as to cast a shadow on the white square illuminated from behind, the *oblong* will have two illuminations, one half by transmitted light, and the other by the direct light from the front. These two illuminations can be equalised (1) by moving the front light, (2) by placing sectors such as have been described in the path of the beam of the front light, or (3) by altering the distance of the screen between the two lights. It is not everyone who has the means of using the second method, and it is best, if possible, not to resort to the first, so the writer will describe the third method, which he has now adopted. Mr. Chapman Jones first described a most complete method of doing this, and he only used one light, the second light being a reflection of the first light. The writer's plan is a modification, which is simpler in some respects, but in which two lights are employed.

D D D′ D′ is a box 2 ft. 6 ins. long by 9 ins. broad and high. D′ D′ is a side of the box left open, but which can be covered by a black cloth. A A is an aperture sufficiently large to allow the whole of the light from the lamp L to illuminate the covered aperture in the screen. S S is another similar aperture for the light of L″ to traverse. Behind S S the negative, N, can be placed over the aperture in the screen. The rod, R, casts a shadow over the paper covering this aperture. M is a silvered mirror in which the double squares can

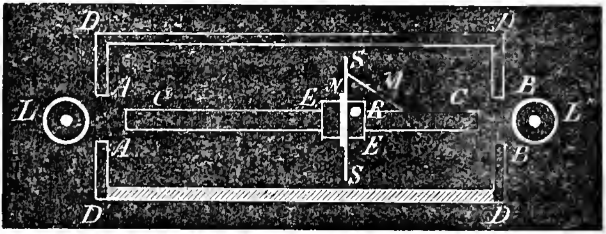


Fig. 42

be viewed. E E is a cradle carrying S S, R, and M, which can move along on a batten, C C. A scale is placed along D′ D′, so that the distance of the screen from each light can be read off.

This scale is conveniently made a logarithmic scale, as first carried out by Messrs. Hurter and Driffield in their measuring box, since it enables the squares of the distances from each light to be readily found by logarithm tables. If this scale, or an ordinary scale, be used, it is convenient that the zero point should either be exactly half-way between the middle of the lights, or else start exactly opposite the centre of the light directly illuminating the white square, in this case L″ The two squares can be made to appear equally illuminated by moving the screen, S S, and the distances (or logarithms of the distances) noted, and then the part of the plate whose transparency is to be measured is placed with a clip over the aperture in the screen, and equality of illumination again arrived at by a further movement of the screen, S S. The distances are again noted, and from these measures the light transmitted through the negative is readily calculated. An objection has been raised to this plan of placing the negative near the screen, as it was supposed that the reflection of the light from the white surface of the paper on to the plate, and back again, made more light appear to penetrate than should do if it were at a distance. That more light passes is true, because the screen takes into account the scattered light, but the reflection is negligible. We may popularly explain it as follows:—We will suppose that a light of one unit falls on the white square, and that three-quarters enters the paper, and gives the illumination at the front surface; then the remaining quarter is reflected back. Of the quarter reflected by the paper, if glass be next it, about 2 per cent. will be again reflected back by the glass, and three-quarters of this will penetrate—that is, ¾ of ½ per cent., or ⅜ per cent.—and ¼ per cent. of ½ per cent.—that is, ⅛ per cent. will again be reflected back. A minute percentage of this will again pass through, and so on, in diminishing terms. If the surface away from the white paper be also bare glass, somewhat of the same amount would penetrate, which would make about 1 per cent. in all due to reflected light. The measurements ought to show a different result if a black deposit be next the paper, and the bare glass away from it, to that which it would show if the bare glass were the surface next the paper. As a matter of fact, the readings are indistinguishable one from the other. Perhaps the readiest plan of ascertaining whether the reflection from the paper causes an error in the true reading, is to place a piece of bare glass behind the aperture, A A, and equalise the illumination of these two squares, and then move the glass towards the light. If the reflection causes any error, it should at once show, for the light reflected from the paper will spread away, and a diminished reflection from the glass would ensue. When the glass is over the aperture, any light that the paper reflects back will be so scattered that it must be negligible.

We have entered into this somewhat lengthily because the reflection has been said to be fatal to correct readings. We may further point out that for printing purposes the screen and the plate are in contact, as they are in the photometer, and thus a correct value is obtained for the uses to which a negative is usually put.

Messrs. Hurter and Driffield had previously constructed a photometer which is very compact, and appears to be capable of measuring very exactly the light that falls upon a screen. Broadly speaking, it is constructed on the same lines as Fig. 42, it being a box containing a movable screen, the screen being furnished with a grease spot, the measurements being made after the manner of a Bunsen photometer. The lights are admitted through two apertures, one at each end of the box, and as the flame more than covers the apertures, the measurements are taken from the apertures to the screen. The density to be measured is placed in contact with one aperture, and the screen shifted till equality of illumination of the grease spot is secured. The position of the opacity to be measured, it will have been gathered, is not that which the writer would choose, for the reasons already given. The great point in choosing a source of light is that the part opposite, and close to the aperture, should be of equal brightness throughout. If not, the screen at differing distances might be illuminated by different quantities of light, irrespective of the amount dependent merely on the distances. Even a flat flame will vary, as the accompanying figure of a lamp flame, photographed with different exposures, shows. The shortest exposure tells us where the flame is brightest. A needle point placed in front of the flame is a guide as to the position of the brightest part.

Fig. 43.

For measuring densities it is sometimes of advantage to use a black wedge or other transparent graduated opacity. There are two plans of measuring such opacities. The first is to measure it by means of the screen described before, using a narrow long vertical aperture, so that when covered by the wedge only a small portion is employed. This gives very accurate readings, the real measure being that of the portion of the wedge next the junction of those parts where the reflected and transmitted lights are used. By adopting this plan, not only can we graduate a wedge, but also can measure the opacity of negatives at different points. This plan has been followed in the measuring of some negatives of the spectrum, which will be alluded to in a subsequent chapter. Another method, however, will be described which is very effective, especially when a very opaque image or negative is to be measured. In the case of a negative, if we measure a scale of opacity in the same way that we measure the opacity of the negative, it is evident we can refer the last to the first, without any appreciable error, and if we subsequently measure the scale of opacity by the first (contact) plan, we can convert one set of measures of the negative into those which would have been given by the same plan.

The accompanying figure will show the arrangement. EL is the arc electric light; L_1 a lens which throws an image of the points on a vertical slit S, placed at one

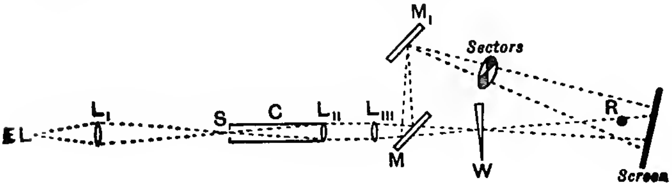


Fig. 44.

end of a tube C. The light passes through S, and strikes the lens L_{11}, which is fixed at the other end of the tube. The rays pass out parallel, and are collected by another lens, L_{III}, which forms an image of the slit on W, which in this case is the wedge. The rays spread out and form a circle of light on the screen, as shown. A narrow vertical slit of light thus passes through the wedge, and a certain proportion is cut off by the opacity of the wedge. If we insert in the path of the beam a plane piece (or very lightly silvered glass), M, part will be reflected and be brought to a focus, where a silvered mirror may be placed, throwing a slightly larger circle of light on the screen than that proceeding directly to it. The two should be thrown concentrically on the screen. This can best be secured by covering up nearly all the lens, L_{II}, leaving only a small central hole in the mask. The circles of light of the screen will be much curtailed in diameters, and the two may be made to overlap exactly. When these precautions are taken, any variation in one circle of light will have a similar variation in the other. A rod, R, when placed in a proper position, will cast two shadows touching one another, due to the direct and reflected beams. In the path of the reflected beam the sectors with movable apertures during rotation may be inserted, and equality of illumination of the shadows secured, or the sectors may be fixed to different apertures, and the wedge moved till the same equality is obtained. The slit at S may be curtailed in length, or any shaped aperture may be given, and for the wedge may be substituted a negative, all parts of which, together with an impressed scale of opacity (see later chapter), may be measured. The different parts of the negatives of the corona taken during an eclipse can be measured by this artifice, and the relative brightness of different parts of the corona be thence deduced. Mr. Warnerke has recently introduced what we may call an annular wedge. It is made by pouring gelatine, mixed with an extremely finely ground black pigment, into a mould. The mould is a flat thick plate of steel, in which is cut a circular chase, which gradually increases in depth. The coloured gelatine is run into the mould, and extracted by its adherence to a flat glass plate, placed in contact with the flat surface of the steel mould. When dried, it presents a very even gradation.

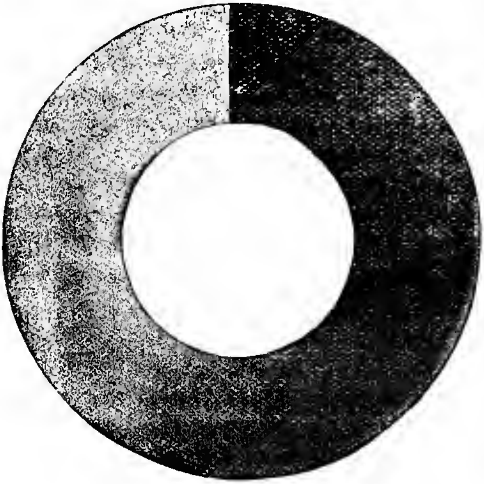


Fig. 45.

Wedges such as these have been graduated by both plans, and the measurements in each have been found practically to coincide, showing that the scattering by the very finely divided black pigment used is inappreciable.

Having graduated a wedge, or this new sensitometer, we have another plan of measuring densities open to us. We can use the same screen as before, and use one light from behind and the other from the front; but it is now better to throw an image of a flame, placed edgewise to the screen, on to the wedge, and alter the illumination of the part of the oblong (see Fig. 38) which receives the front light by moving the wedge. The position of that portion of the wedge which gives equality of illumination is read off, and from a table the amount of light transmitted is found. With Warnerke's annular wedge it is convenient to bore a hole in the centre, and rotate it round an axis placed through such hole. The length of this annular wedge is conveniently read off in degrees. A wedge, when accurate, gives a logarithmic reading which can be converted into common logarithms by multiplying by a factor, which will have been found when graduating the wedge.

CHAPTER XI.

MEASUREMENT OF THE LUMINOSITY OF COLOURS.

HAVING demonstrated the way in which the greys in a print may be measured, and also the transparency of a deposit, we must say a word on measuring the brightness of the colour of an object, say of a pigment, for we often have to deal with the correct rendering of pictures when they have to be copied by means of photography. We cannot enter into all the niceties of the subject, as it would involve far more space than can be allotted to it in a work of this description. Colour is, it must be remembered, a physiological effect, and depends upon the effect produced by waves of light on some kind of apparatus in the retina of the eye.

The kind of light which illuminates a picture has a great deal to say to the brightness of the various colours. If we analyse light from a white cloud, we shall find that practically it is reflected sunlight, and sunlight, we know, has in it a great deal more red and yellow than sky-light, as the figure will show. In the figure all the colours of the spectrum formed by sunlight are, for convenience, represented as if they were of uniform brightness, and below it we see a curve of light from the sky in which the proportions of the different colours are given. The blue end of the spectrum evidently predominates in the colour of the light coming from the sky, compared with that of sunlight. Again, we have an artificial light (gas) shown in the same figure, and here we see that the blue is almost absent compared with sunlight, whilst the red is strong.

If we had three pigments—a red, a green, and a blue—which all appeared to be equally bright to the eye in sunlight, in skylight the red would appear very much darker than the other two; whilst if we illuminated them by candlelight, the blue would be much darker than the red and the green, and the red would appear the brightest of the three. The reason for these changes in brightness would be owing to the fact that the colour of the red is due to the capacity of the pigment to reflect red rays most plentifully, that of the

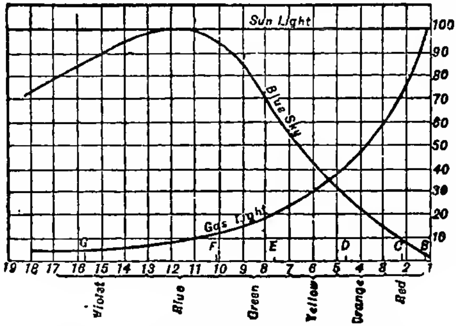


Fig. 46.

green to the pigment reflecting green rays most abundantly, and the blue pigment to its greater reflection of the blue rays. To measure the brightness of the colours under these varying conditions would be an endless task, and all that we can do is to get some light which will not be far off that in which we usually look at pictures, and refer to it as a standard. An artist will always try to paint, we believe, in any light rather than one in which the blue from the sky predominates. He likes what he calls a warm light, and a sky in which white clouds are present is one that he delights in. In other words, he likes reflected sunlight, and this is the kind of light in which pictures should be examined in justice to the artist.

Now the light from the positive pole of the electric arc light is a very fair imitation of sunlight, and as cloud-light is reflected sunlight, it may be taken as a good standard light in which to view colours, and measure them, when sunlight is not available.

We say that one colour is brighter than another, or more luminous, and we may generalise, and say that one colour has more luminosity than another. It may, perhaps, be hard to say how one may judge that a red and a green have equal luminosities. It has been said by the highest authority on colour (Helmholtz) that he could not picture a method by which a red and a green might be matched for brightness. But yet there is an intuitive instinct, if one may call it so, by which the brightness is judged, and it is this instinct which enables us to get accurate and repeatedly concordant measures of the luminosities of different colours.

We may commence our measurement of the brightness of two colours by lamplight, and may use the apparatus described at page 92. Instead of the reflected light from the mirror we may use a second lamp. We must, however, exclude as far as possible all scattered light, so that the screen should be placed in a box which cuts off all light except that proposed to be used (see Fig. 39). Instead of a square of grey, we may insert a square of any colour—say green—and use the sectors as described, or else move one lamp. The white may be made first evidently too bright, and then too dark, and then, by gentle oscillation, we find the place where they appear equally bright.

The aperture of the sector, or the distance of the lamp which illuminates the colour, is then read off, and noted. We can then replace the green colour by a red, and we go through the same operation. Evidently, then, we can tell the relative brightness of the red to the green by a simple reference of both to the white. But here, again, we are met with our first difficulty. Supposing we reduce equally the light falling on each, we shall see that the brightnesses no longer hold. For instance, if we illumine the two colours, placed side by side, with a lamp, the red may be much the brighter of the two; we can cut off the same amount of light from each by the sectors, or by moving the lamp very far back, and we shall soon see that when the light is feeble the red becomes the darker of the two colours, showing that the intensity of the light falling on them has much to do with the luminosity. To judge, then, of the luminosity of the colours, we must know the intensity of the light which calls them into being. Thus, a picture in which there was red and green might, under bright illumination, show a particular red as brighter than a particular green, whereas, in a sombre light, the reverse might be the case. It is well known that towards evening, the last colours in a painting which appear vivid to the eye in a picture gallery are the blues, the reds disappearing early. One thing must be said, however, that after a certain illumination is attained, the relative brightness of colours does not alter, so that if we use a very bright light for our measurement, or even a light equal to one candle power, placed at, say, six feet distance, we are not doing an injustice to any colour.

To know difficulty is to surmount it, but another crops up, which is also physiological. If we place a blue-green and a red in juxtaposition in large masses, the blue-green may appear much brighter than when the same colours are presented in small portions (we are only taking these as typical colours), and there must be some reason for the change. The reason is to be found in the fact that we have a yellow dye staining a small central part of the retina, and that this dye cuts off a large proportion of the blue when the light forming the image has to pass through it, as is the case when the masses are small. When the masses are large, the image partly falls on the retina beyond this yellow spot, and the full effect of the colour is felt in this outside portion. In a picture, then, it is evident that the luminosity of a small patch of blue will not be the same as it would be if the patch were large. We can imitate what is seen by the retina beneath the yellow spot by placing a pale yellow glass over half a patch of blue. The blue is very largely cut off by the yellow glass, as it is by the yellow spot. When we examine a picture, only a small area will be in focus on the retina, and this area will fall on its centre, where the yellow pigment is situated. The picture is practically taken in by a movement of the eyes, so that each area in succession is examined, and it is the sum of these impressions which gives us the mental image of the picture. No one can doubt that if we are to measure the brightness of a colour in a picture, we ought then to receive the colour so that practically it will fall upon the yellow spot; and if we do so, we shall be on the right road to obtain measurements which are practically useful.

If we wish to reproduce by photography the various luminosities of colour in a picture—of course, in black-and-white—we should seek to render them as nearly as possible as they appear on that area. Now it may be considered that a measurement of the brightness of the pigments as used in a picture is unnecessary, and so it is if we measure the brightness of, say, four standard pigments in the same light, and are then able to reproduce their luminosities accurately in black-and-white by means of photography; for if these can be reproduced, then all other colours will also be accurately reproduced. Most fortunately, as we have already said, the light from the positive pole of the electric arc light is a very close approximation to sunlight of ordinary character, and if we use this as the light illuminating the pigments we shall not go far wrong in our measurements, and hence we use this quality of light as a standard light. The standard pigments are not difficult to choose. If we take a vermilion, an emerald green, and a French ultra-marine, together with chrome yellow, as a further test, and, having measured their brightness, can reproduce them faithfully in black-and-white by means of photography, we shall also be able to reproduce any other colours correctly on the same kind of plates. What these plates are to be we leave for the present; all we wish to demonstrate is the way in which the brightness can be measured in such a standard light.

We may practically adopt the very same arrangement as we did for measuring the colours with lamplight, using the electric light for the purpose; but we must exclude the arc as far as possible, as this radiates violet light to some extent. What we ought to use is light from the hottest part of the positive pole, which we call the crater. We can place the electric lamp in a box in which an orifice is cut sufficiently large to hold a lens which may throw a fairly large image of the crater on an opaque screen, on which a circular hole of, say, one-eighth of an inch is cut. The screen can be moved so that the crater just falls upon the hole, and the only light which then traverses the screen is that which we require. Now we have to devise some means by which this beam can be cast directly on the coloured square, and also as a comparison light to proceed from another point at an angle with the white square. We can effect this by placing in the path of the beam a piece of plain flat glass close to the hole, and reflect a portion at an angle of about 45° with the original direction, and at the distance necessary to give the proper parallax we may place a silvered mirror, and reflect the beam on to the squares which are side by side (as in Fig. 39), the direct beam also falling on them. The rod placed in position, as in the same figure, will cast two shadows, one of which gives much feebler illumination than the other. In the stronger one we can place the sectors. As before, we shall make at first one square—say the coloured—appear too dark, and then, by altering the aperture of the sectors, make it appear brighter than the white. Somewhere intermediate between the two the brightness or luminosity will be equal when this point is arrived at, and the aperture noted. The coloured square also, as before, can be replaced by a white square, and equality of brightness again established. The ratio of the two apertures of the sectors is the ratio of the brightness of the pigment to that of white. Suppose in one case the aperture used to make the brightness of the pigment the same as that of the white was 35°, and to make the two whites equally illuminated 140°, then the pigment would only reflect $\frac{35}{140}$, or 25 per cent. of the light that the white did. If sunlight be available, a similar artifice may be employed, but in this case the light should be first reflected from the surface of a plain glass to avoid the illumination being too great. A plain mirror, as described, should be placed in the path of the beam which falls on the squares, and the second mirror should be used as before. (There is no necessity to have an image of the sun in this case, as there is no arc light to be cut off.) The sizes of the squares, coloured and white, should not be more than one inch, and the eyes should not be less than three feet away when the equality is being judged, for reasons stated at the beginning of this chapter.

We can get a very fair approximation to the brightness or luminosity of a pigment in daylight by the following artifice. Cut a rectangular hole, say half inch by one inch, in a piece of blackened card, and place the coloured square on the table, or against the wall, so that it occupies half the rectangle forming a coloured square of half an inch side. Bring beneath the other half greys of different depths, and note one which appears lighter at first glance. Then insert a deeper one, and note that it appears too dark. Then try a grey of intermediate tint. It will soon be ascertained which is the grey which is the nearest match. A very suitable series of greys can be made in a sensitometer such as Spurge's by exposure of platinotype paper, though, of course, the same can be effected by other means. The white contained in these greys can be measured as described in Chapter X., and thus the luminosity of the different pigments can be estimated.

The subject would be incomplete if an idea were not given as to how we may estimate the relative luminosity of pure spectrum colours.

The accompanying diagram (Fig. 46A) will give a very good idea of the method employed. The source of light may be the sun reflected by a heliostat on to L_1, or it may be the carbon poles of the electric light. In either case the image is focussed on the slit S_1, which can be of any desired width, say $\frac{1}{1000}$, or even $\frac{1}{25}$ of an inch. The lens, L_2, makes the rays parallel as they emerge to fall on the prisms, P_1 and P_2. A lens, L_3, attached to a camera, B, with a swing-back, as shown, makes a spectrum on D, in which there is a slit, S_2, through which any ray may be caused to emerge by moving D in the spectrum. A lens, L_4, when D is removed, collects all the rays of the spectrum, and by giving it a slight tilt, as shown, a colourless image of the first surface of P_1 is thrown on a screen, F. When D is inserted, any ray of light coming through S_2 forms a patch of approximately monochromatic light at F.

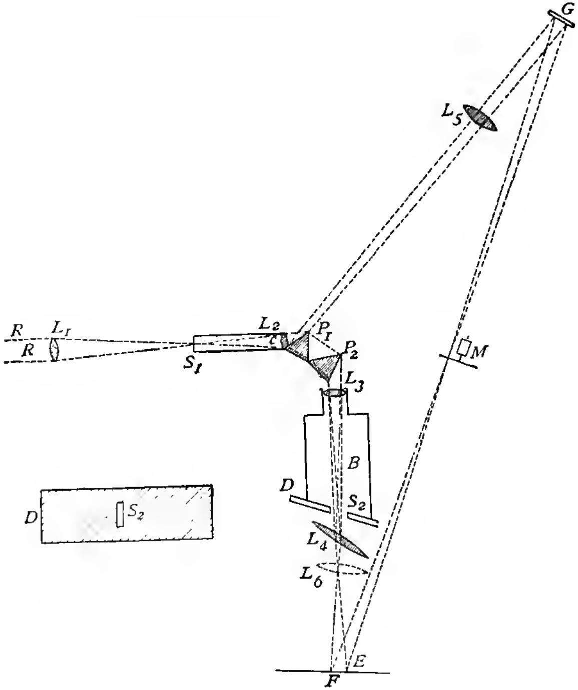


Fig. 46*a*.

Part of the beam which strikes P_1 is reflected to G, a silvered mirror which reflects the light on F, and in its path we place a lens, L_6, which also forms an image of the first surface of P_1. The coloured and the light images overlap at P. If we place a rod near F, a coloured stripe may be made to fall alongside a white stripe, the latter being made purposely the brighter. At M are placed the sectors, and the two stripes are made to be equally luminous to the eye, and the aperture at which this occurs is noted, and so on for each part of the spectrum.

There is a small part of the apparatus not shown in the figure. A very small part of the beam is made to pass beyond P_2, and this is caught by a mirror and sent to illuminate the back of D, on which is a fine scale. Projecting from the back of the camera is a vertical needle, and the shadow of this is thrown by the beam last mentioned on the scale. The scale indicates at what position S_2 is situated when the scale numbers shown for the issue of, say, the lithium, and sodium, and magnesium lines are known. The apparatus is thus complete. With a collinator of about one foot, and the lens, L_3, of about thirty inch focus, a spectrum more than three inches in length is obtained. Fig. 47 gives the luminosity of the spectrum of the crater of the positive pole of the arc light.

The luminosity is shown in the vertical heights, and the maximum luminosity is taken as 100, the others being reduced to that scale. The small figure is the part from 0 to 22 of the scale, the vertical scale being enlarged ten times. In the above figure we have the luminosity of the spectrum as measured by the central part of the retina. The wave-lengths of the scale numbers of the prismatic spectrum can be readily obtained, owing to the fact that very approximately the square of the reciprocals of the wave-length can be found from the length of the spectrum. If the square of the reciprocals of (say) the two lithium lines are set up on a scale, which represent the distances apart of

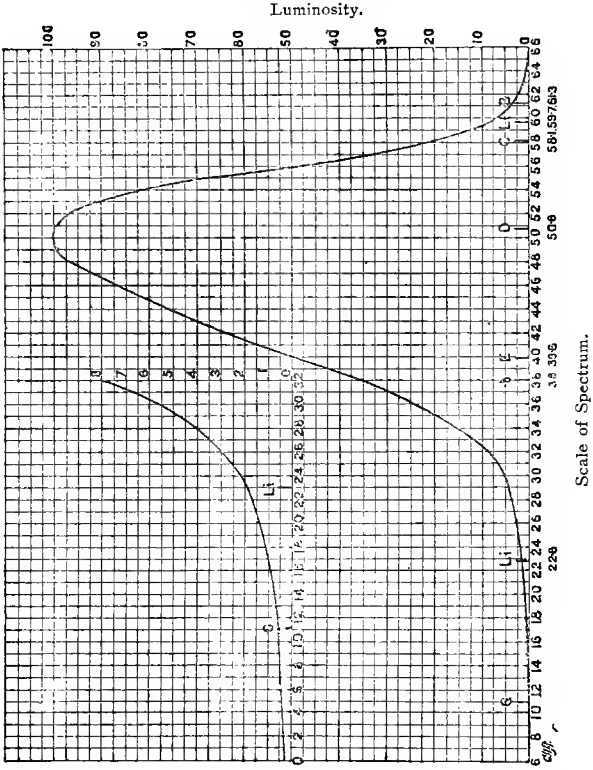


Fig. 47.

these lines in the spectrum, and the tops be joined by a straight line, the square of the reciprocal of the wave-length of any scale number will be found by measuring the height of this line about it. This can be either calculated, or measured from a diagram (see Appendix for tables of luminosities).

It should be noticed that in the arrangement shown, the fluctuations in the source of light are equally felt in the spectrum and in the white light with which the colour is compared. This is a great point when using sunlight, since any small temporary passing haze is thereby discounted.

It may be asked how we know that the method we use in measuring luminosity is a correct one. We can answer this very readily—there is a strip of red in the spectrum which, combined with a blue green, gives a white light of the same quality as the comparison light. If we make this artificial white light by using two apertures in D (Fig. 46A), and measure the luminosity of each component separately, and add them together, we shall find that they are together equal to the luminosity of the artificial white light. No one doubts that white light can be measured against white light. By taking a yellow and a blue in the same way we add additional proof to the correctness of the method.

CHAPTER XII.

EFFECT OF TEMPERATURE ON SENSITIVENESS.

WE have already shown that a phosphorescent plate is increased in luminosity by the application of heat. Let us make an experiment to impress this fact once more on the mind. A plate covered with calcium sulphide (Balmain's luminous paint), exposed to a fairly strong light for a second or two, will be found to glow when taken into a dark-room. If a warm body, such as a flat iron, be applied to the back of the plate whilst it is glowing, an image of the part so applied will at once be seen as an increased brilliancy of phosphorescent light. On removing the iron, if we watch the plate, it will be noticed that the phosphorescent surface will, after a short time, become of equal brilliancy throughout, but that after a further lapse of time the portion which the iron warmed will become darker than the rest of the plate. Let us consider the reason of these changes of luminosity. The molecules of the phosphorescent material have had transferred to them a certain amount of energy by their exposure to light. A part of this energy they store up, and gradually give out again as phosphorescent light. At the part of the plate where the flat iron is applied, the molecules or the atoms were made to oscillate more violently by the warmth imparted, and consequently there is an increase of phosphorescence, but at the expense of the original energy stored up. It follows that, when the heat is withdrawn (or, indeed, the same would occur if the iron was still kept in contact with the plate), the light energy at that portion having been largely consumed, rapidly becomes darker than the surrounding portions. It might be thought that the flat iron had communicated fresh energy; but another experiment will show that any energy it does give is not such as can be given out as light. If a plate, covered with the same material, but not exposed, be taken into the dark-room, and the hot iron be applied as before, the heating of a portion of the plate will have no effect whatever—the blackness of the plate will be unaltered. What we are wishing to inculcate is this—viz., that a heating effect may stir up the molecules to greater motion, and thus allow the atoms a greater swing and greater freedom of path. If this be so, then sensitive salts should, under such circumstances, be more sensitive when heated than when exposed at ordinary temperature, for what is true for one kind of matter ought to be true for another.

We may press a hot flat iron against the back surface of a gelatine bromide plate, and examine the film by reflected daylight. The colour of the sensitive salt will be seen to be altered, becoming deeper. On the plate cooling, the film resumes its normal colour. Place iodide of silver in an intense cold, such as produced by carbonic acid snow and ether, and the iodide will be found to have a grey colour, quite different to that it assumes at a normal temperature. Such changes of colour mean something, and that "something" ought to show itself when exposing these sensitive compounds.

Now, can we prove that this is the case? A theoretical deduction should always be capable of experimental demonstration. If we heat a portion of an ordinary sensitive plate, and expose the cold and hot portion to the same light, and develop, we can see at once whether the hot portion is more sensitive than the cold. The same heated flat iron may be used as before. We can lay it on black paper lying against the back of a gelatine plate, and then expose to some feeble light for a second or two. If we at once proceeded to develop the plate, it might very correctly be said that those parts of the plate which were heated would render the developer more active, and that consequently we ought to get a greater reduction of silver. To guard against this, the plate should be put on one side till it is perfectly cool all over, and then the development may be proceeded with. The image of the hot iron will be perfectly evident, indicating that the increased temperature of the sensitive material during exposure has increased the sensitiveness. But gelatine is a treacherous substance, and it may be thought that the heat has in some way or another altered the sensitiveness of the material permanently, so we can repeat the experiment of heating the plate as before, but in this instance we should allow it to cool before exposing it to the feeble light. On development there will be no trace of any action of the heated body. We will now give an example of how photographers may fall into pitfalls, and be unable to extricate themselves, unless they know something of the theoretical aspect of photographic action. In the days immediately preceding the advent of gelatine plates the photographer worked with collodio-bromide emulsion, and had he experimented with plates coated with emulsion, and used the flat iron to heat a part, he often might get exactly the opposite results to that which he would obtain with a gelatine plate. The result of such an experiment might have been to cause him to believe that the increase in the temperature of a plate *lessened* its sensitiveness, and that the theoretical reasoning, which would make it the reverse, was altogether wrong, and that there was a screw loose somewhere. No doubt we can picture him looking at his developed plate, and uttering the wise saw—wise, that is to say, when properly applied—that an ounce of practice is worth a pound of theory. But, after all, the good old practical photographer would have been wrong, as he very often is. It is lucky that he is so often wrong, as if he were less frequently so it may be opined that the pages of photographic literature would be considerably curtailed from lack of matter. If the old practical photographer had known that a certain amount of moisture in the film, or an equivalent to such moisture, was a necessity for sensitiveness, he would not fall into the error. Suppose we had instructed him to coat a plate with collodio-bromide, and to dip it all into cold water, next to plunge one end only into hot water, and then to expose to the feeble light, he would have found that where the hot water had been in contact with the sensitive surface the plate would show increased sensitiveness compared with that on which the cold water rested, and this would have been on all fours with the experiment narrated with the gelatine plate.

We may take it, then, as an axiom, that by increasing the temperature of the sensitive surface we increase the sensitiveness. The converse of this should also be true, that if we diminish the temperature we should also diminish the sensitiveness. Let us make an experiment as to this:—Warm up the dark room to about 90° F., and instead of heating the flat iron, let us immerse it in a mixture of snow and salt or pounded ice and salt. The metal will acquire a temperature considerably below freezing point, and when thus chilled we can place it in contact with the back of a plate which has the temperature of the warm room, and expose as before to the feeble light. When the part of the plate which was lowered in temperature has regained the heat which it had lost, we can develop, and we shall find that the image of the iron is less dense than the surrounding parts of the exposed surface, and consequently we may assume that the plate has become less sensitive by the lowering of the temperature. This may not be quite conclusive; it may be said that the water in the gelatine was frozen, and that therefore the conclusion might not be justified. A reference to Daguerreotype plates will settle that. Sensitise two of them as we were taught to do, and freeze one and not the other, and expose them side by side to the light. When both become of equal temperature, develop them together. We shall find that it is always the cold plate that shows the feeblest deposit of mercury. It may be asked, why expose two plates, and why not use a portion of one plate? The reply is, that a Daguerrotype plate, being metal, is a good conductor, and that therefore the cold would be communicated throughout.

We have now shown that a low temperature is adverse to the greatest speed.

Professor Dewar recently showed that the speed of a film at the extremely low temperatures with which he is now accustomed to work (—180 to —200 Centigrade) is reduced to, at least, a quarter of what it is at ordinary temperatures. The writer, in a communication to the Camera Club, gave evidence that between the temperatures of 100° F. and 0° F. the speed of a rapid plate was reduced by even more.

In regard to a supposed phosphorescence of bromide of silver at these moderate temperatures, we may say that we have fair evidence that it is absent. The writer has arranged a phosphorescope in a manner different to that ordinarily employed. A beam of the electric light of the diameter of a threepenny bit was allowed to fall on a screen, and in the path was placed a revolving disc in which twenty-four apertures of five degrees each were cut out. At an angle with the beam of light was placed a tube, through which the eye looked at the screen. When the beam of light was cut off from the screen by the opaque part of the sector, the eye would see the screen through one of the apertures; whereas when the beam of light fell on the screen, the screen was invisible to the eye, the view being cut off by another portion of the sector. The screen was replaced by a sensitive plate, and the disc caused to revolve 100 times a second, so that an aperture passed through the beam 2,400 times a second. Allowing that the screen was cut off from the eye, and also from the beam for the equal intervals, it follows that any phosphorescence which lasted a little more than $\frac{1}{2400}$th part of a second would have been visible; but not a glimmer was visible. If there be any phosphorescence at all, it must last less than this interval, and we can scarcely credit that any will be found if the revolutions are still further increased. This is, of course, by the way.

Having thus arrived at a definite conclusion by means of qualitative experiments, we turned our attention to devising quantitative experiments with a view of forming some idea of the increase and diminution of the sensitiveness by known heat and cold. The next few pages will give the results.

The method of exposure was as follows: The apparatus (Fig. 48) used was a simple box (B B), with a smaller tin box (A A), when cold is required inside within it. Between the box and the tin was placed a mixture of ice and salt (I), which reduced the temperature of the box to 0° F. about. This is further facilitated by placing in the tin box a similar mixture up to a level which is regulated by the plate (P). The plate was suspended in a pair of grooves cut in two stays (V V), which are pendant from the lid. In the lid a small hole is cut to allow the bulb of a thermometer (T) to be thrust to the level of the plate, and it thus acquired the same temperature as the plate. A square hole (A) was cut in a sliding batton which moved across a slot-like aperture cut in the lid, and over this was a mirror (M) supported at an angle of 45° to reflect light vertically down from a horizontal beam of light (R R) on to the plate. The source of light being at some distance from the mirror, the light impressed the plate with an image of the hole (in this case square), and as the hole is moved along horizontally, so different parts of the plate can be exposed for different periods. The plate was exposed at the ordinary temperature of the dark-room, next at —18° C., and then at about 34° C. This last was effected by removing A A, and heating the box, by placing at the bottom a heated brick to keep the temperature constant during exposure. The order of these exposures could be varied, of course, but in all cases the same length of exposure was given to each series, so as to be strictly comparable. The source of light used was either a small argand paraffin light, or else the amyl acetate lamp which has been so much used by myself for these and for other similar experiments. The square aperture has a means, of course, of being closed and opened when required. The plate is backed with black paper to prevent the light transmitted through it from being

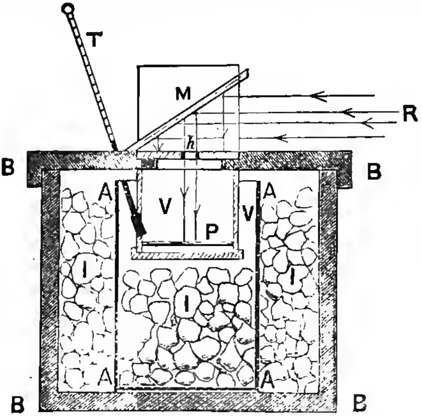
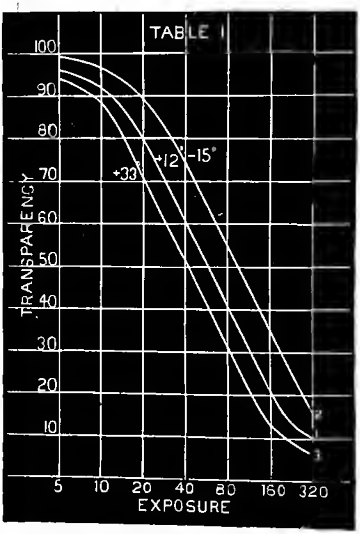


Fig. 48.

reflected from the ice, and causing fog. These small matters, it may be stated, were the outcome of practical experience.

It would, of course, be useless to give details of every experiment made, but three examples are recorded: first of all where the temperature employed varied between 33° C. and about —18·5 C. These temperatures it was difficult to obtain in every case quite exactly, but the variation of a degree makes no practical difference in the general result. From the diagrams and tables given it will be seen that there is not necessarily any variation in the gradation of the curves; that is, their general slopes are usually parallel to one another, as might be expected, since the varying exposures are made by altering the time, but that the rapidity is altered—but not to the same degree—for each kind of plate. In every case the rapidity is invariably less with those cold temperatures which the photographer sometimes meets with. The exposures were successively doubled, and for convenience these successive exposures are made the scale of abscissæ. Thus 10, 20, 40, 80 seconds' exposure are shown as 1, 2, 3, 4, and the transparency of the deposit is shown on the vertical scale as ordinates, 100 being total transparency. For a lantern plate (Fig. 49), the distance apart of the "hot" and "cold" curves is 1·2 of the scale divisions, which implies, as each successive scale number means double the exposure of the previous one, that the chemical decomposition at —16° C. is $2^{1\cdot 2}$ times, or 2·3 times less than that at +33° C. With the "lightning" rapid plate (Fig. 50) it is just double, whilst with a Fitch film (Fig. 51) it is only $2^{\cdot 7}$ times, or 1·6 times.

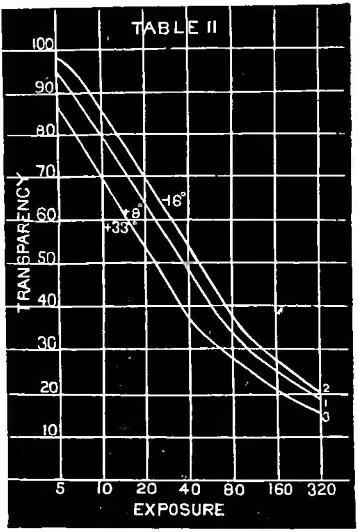
These numbers indicate that all degrees of sensitiveness are not equally affected. The "lightning" plate and the slow lantern plate are not very far off one another, but the film which is intermediate is so much less that there must be some reason for it. Whatever may be the cause, we find, however, that when time of exposure, multiplied by the intensity of the light, is a constant quantity, the chemical action is different, and that the colder the surface the less sensitive it becomes.



Mawson Lantern Plate Exposed to Paraffin Lamp at 5 ft., visually equal to an Amyl Acetate at 39 inches.

Fig. 49.

A reference has been made to the effect of heat and cold on a collodio-bromide plate, and experiments were made with it to ascertain the diminished rapidity between 17° C., and + 32° C. Only two exposures were made at these temperatures, 12 minutes and 6 minutes. A scale was made at ordinary temperature, from which to determine the difference in rapidity.

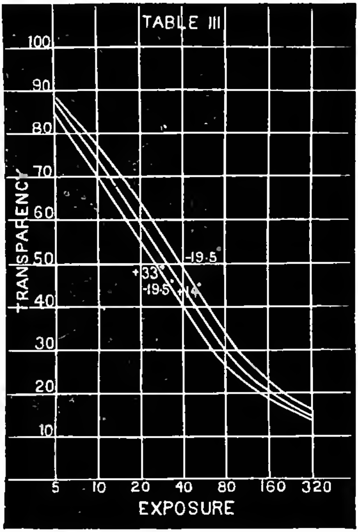


Lightning Plate Exposed to Amyl Acetate at 6 feet.

Fig. 50.

From this experiment we gather that the same opacity as is got with the hot exposure is only obtained when the cold exposure is increased by $\frac{149}{32{\cdot}6}$ or $\frac{74}{16{\cdot}3}$, or 4·5 times (see Table IIIA).

In these and other experiments we shall use the word "gradation" to express the slope of the curves in their straightest part. This is a proper word to use when it is considered that the transparency of deposit and time of exposure are expressed by these curves.



A Fitch Film Exposed at 5 ft. to an Amyl Acetate Lamp.

Fig. 51.

From several experiments made, in which the "hot" exposure was above 33° C., it appeared that the gradation changed. A lantern plate was exposed at 4 feet from a paraffin lamp at —18° C., and the heat increased to 40° C. (see Table IV.)

Fig. 52 shows that there is an alteration in the gradation, although it is a time exposure. As we shall see from a subsequent chapter, the gradation given by time exposures under any ordinary conditions to the same plate is the same—that is, the curves are always parallel to one another.

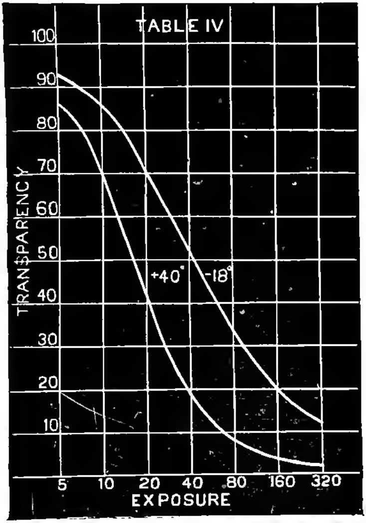


Fig. 52.

The following will help to throw light upon the cause of the different gradation :—

A Mawson lantern plate was exposed to a paraffin lamp at 5 feet (visually equal to an amyl lamp at 33 inches). The exposures were made in the following order (see table V) :—Expose at + 18° C., next at — 18° C., next at + 38° C., and finally at + 18° C.

It will be seen in Fig. 53 that in this case we have a probable explanation of the different behaviour of the curves. A plate was exposed at an ordinary temperature, then to the cold, and the curves so obtained are parallel to one another. The temperature was then

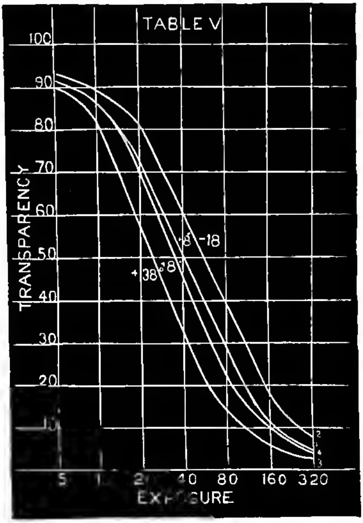


Fig. 53.

raised to 38° C., and the curve is of the same character, as regards gradation, as given in Fig. 52—that is, it is not parallel to other two curves. When the plate was cooled down, and before it had time to absorb moisture, an exposure at the ordinary temperature was again given, when *its curve became parallel to the "hot" curve.* In the same way a plate was exposed as follows:—

1st to —18°, 2nd to ordinary temperature, 3rd to +38°, 4th to —18°. The first two curves and the last two were parallel to each other, but these last showed a steeper gradation. Evidently by heating to 38° we have something altered in the plate, which alteration remains after it is cooled for some little time—long enough, indeed, to allow another complete set of exposures to be made after the cooling is complete, and before it resumes its normal condition. From this it appears that up to 33° C., at all events, the heat has no effect on the plate beyond making it more rapid.

The natural and most probably correct conclusion to draw from this is, that at near 38° the water which is in the gelatine begins to be eliminated, and alters the condition of the film. There is nothing unusual in this combination of water with gelatine. Professor Guthrie some years ago made exhaustive researches into what he called chryohydrates, and showed that water, although not what is usually called chemically combined, still had the power of acting almost as if it were so combined. At —18° C., or near zero F., it is quite possible that the amount of water present would be such that it would not freeze, leaving the water in the state in which it can take its usual part in combining with the halogen when released from the sensitive salt.

The question of whether exposure to *different intensities* of light *for a fixed time* was equivalent to a fixed intensity and variable times, was a matter which next called for attention, for it cannot be too well remembered that it is the former we have to deal with in a camera exposure, and not with a variation in time. There were some difficulties in carrying out these experiments, but they were gradually smoothed away. A scale consisting of squares of gradation of known transparency was laid upon the plate. The light was admitted through a thickness of blotting paper, which took the place of a portion of the lid of the box, and thus equal illumination of the whole length of the plate was obtained. Only one example need be given (see Table VI.).

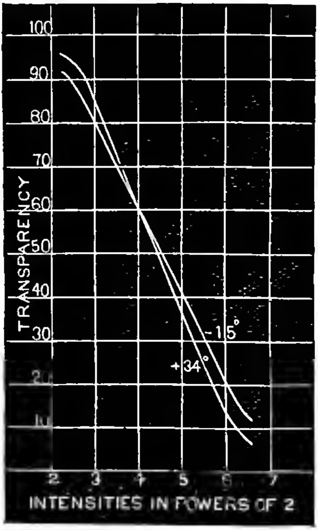


Fig. 54.

The light in the two cases was not exactly the same, being rather stronger for the "cold" exposure than for the "hot." But as it was not sought to get the absolute values, but only the gradation, this is immaterial.

It will be seen from Fig. 54 that in this case, as in all others tried, the "hot" curve is steeper than the "cold" curve. To sum up these experiments, we see that the effect of heat is to increase the apparent rapidity of the plate with time exposures, and to increase the steepness of gradation of the plate with different intensities of light.

CHAPTER XIII.

EFFECT OF INTERMITTANCE OF EXPOSURE.

THE experiments which led the writer to try the experiments described in the Chapters XIV. and XV. were based on a difference which was observed in the amount of chemical action obtained from a continuous and an intermittent exposure, the time during which the sensitive surface was exposed being the same in both cases. Now let us see whether, theoretically, there should be any difference, or, at all events, admitting there is a difference, whether it can be accounted for.

Suppose we have the amplitude of the swing of an atom of a molecule increased by the impact on it of a ray of light, and further, suppose that the light is suddenly shut off, the tendency of the atom will be to revert to its normal swing; if we again admit the ray of light for another brief interval, the atom will again increase in its swing, but perhaps just not sufficient to allow it to swing away from the attraction of the molecule. The swing or amplitude attained by the atom will not be so great as it would be when the two exposures were combined into one, for in the latter case there would be no falling back towards the normal swing. In the first case, then, the atom might not leave the molecule; in the last case it might do so. The minimum number of exposures have been supposed, for simplicity's sake, but the same arguments hold when the exposures are increased.

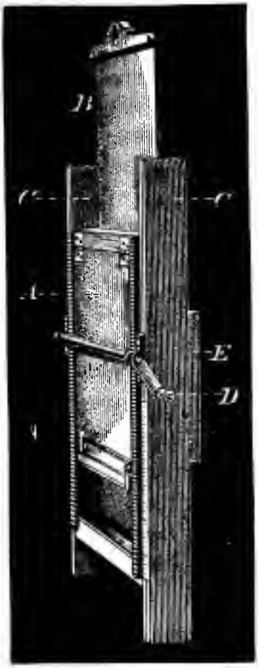


Fig. 55.

To make the experiments it is convenient, though not necessary, to have a special slide, which will enable any number (within limits) of exposures to be made on the same plate. The slide, as made by Meagher with his usual ability, is shown in Fig. 55. It is really an ordinary back for 7½ by 5 plates, which worked between two grooves C C, as shown, the plate when the front was opened being protected by D, to which the projecting piece E is attached. The front view is shown in Fig. 56. A thin metal batten, F, can pass through E, in which a slot is cut, as shown. In the batten a

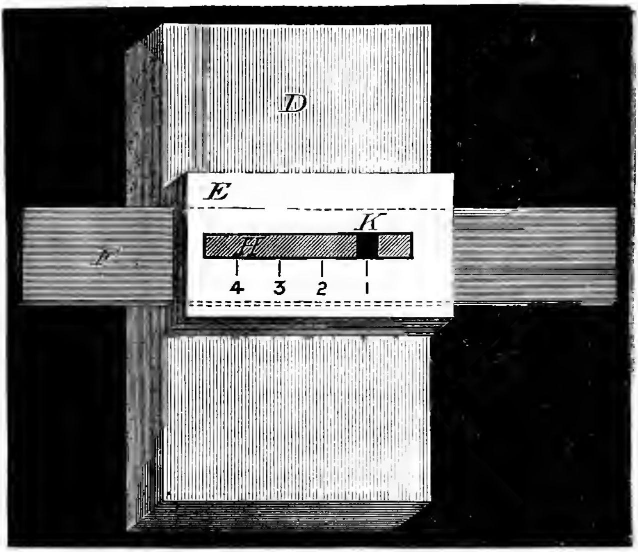


Fig. 56.

hole, K, is pierced, which can be moved to any part of the slot. The slide itself is raised or lowered by a rack and pinion, a scale being attached at the side on C, to register the movement. It will be seen that a large number of exposures may be given on the same plate by raising the slide and moving the hole K. In a later pattern F has been done away with, and six holes pierced in E instead of the slot, all or any one of which can be covered up at pleasure. Carriers for half-, 5 by 4, and quarter-plates are provided for the slide. In the subsequent experiments this piece of apparatus was employed.

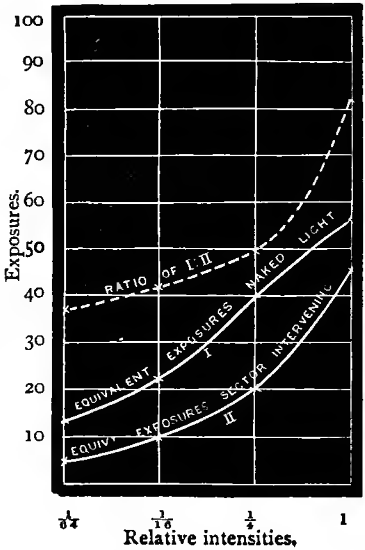


Fig. 57.

A striking result in intermittent exposures was obtained with a gelatino-bromide lantern plate. Two sets of exposures were given at different distances from the source of light. Exposures at each distance were made (1st) with the naked light and (2nd) with a rotating sector intervening, having twelve apertures of 5° each; the exposure in the second case had to be, therefore, six times longer than in the first case, to make the total exposures equal, for the total number of apertures was only equal to 60°. From the note which the apertures gave when a current of air was projected against them, it was found 720 exposures were given per second.

Fig. 57 shows graphically this result (see Table VII).

The apparent loss of exposure by the intervention of the sectors increases as the actual intensity of the light diminishes, the ratios of the single exposures to that of the intermitting exposures being—

For intensity 1	..	..	1 to ·815
„ „ $\frac{1}{4}$	..	..	1 „ ·500
„ „ $\frac{1}{16}$	..	..	1 „ ·423
„ „ $\frac{1}{64}$	..	..	1 „ ·370

(See Table VII.) What shape the curve of these ratios would assume when the intensity of the light is greater or less than that shown, can only be guessed at. One point which this experiment makes clear is that there is no error introduced by any want of accuracy in the apertures of the sectors which can account for the great differences in the apparent exposures, for were it so the ratio would not be variable as it is.

We have thus arrived at the conclusion that the sum of small exposures is not equivalent to one exposure for the same length of time.

Now the question arises whether a long rest after a short exposure, and then another exposure, and again a long interval of rest, is conducive to minimize chemical action. The reasoning is not difficult when we take the same lines as we took in our last argument. A long interval of rest after a short exposure must inevitably give a longer time to those atoms which are not swung out of the molecules to come back to their original swing; hence, the shorter the time of exposure is to the time of rest, the less chemical action there should be. This was tested experimentally.

For this purpose a sector with moveable apertures was employed, and the exposures were made with the sectors set to different apertures. As the sectors had two apertures opposite one another, the maximum aperture was 2 × 90°—that is, 180°, but without the intervening sectors it is 360°. The plate was a slow gelatino-bromide, and different small portions were exposed to an amyl lamp for times depending on the aperture. A time scale added as before enabled the chemical action resulting to be measured. The continuous curve in Fig. 58 shows the results (see Table VIII.).

It will be noticed that although equivalent exposures were given in each case, there is a gradual reduction of chemical action as the aperture is diminished. As the speed of rotation was the same in all cases—viz., 48 per second, this indicates that the longer the period of rest between two exposures the less action there is, as our theory led us to suppose would be the case.

Another slow plate was next tried in a similar manner, but two series of exposures were given to it, one with a speed of fifty revolutions of the sector per second, and the other once a second. These two series of exposures were given to ascertain what effect the time of revolution —that is, the shortness of exposure—had. It will be seen from the dotted curves in Fig. 58 that the difference in chemical action between intermittent exposures and a single one was less with the slower rate than with the quick rate of revolution, as theoretical considerations foretell (see Table IX.). It happens that the curve given by the slow rotations in this experiment almost coincides with the curve given by the quick rotation in the last one.

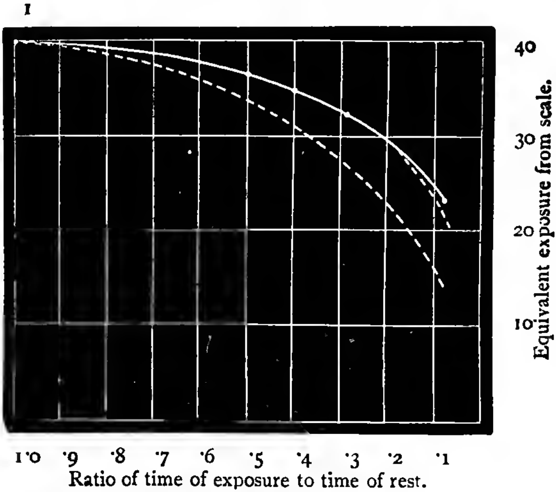


Fig. 58.

With the fast revolution the ratio of the chemical action given by exposure through the 10° aperture to the continuous exposure is 3·33, and for the slow only 2·0. With a quicker plate the ratios were ·7 and ·5.

The effect of varying the length of each individual exposure, the ratio of interval of exposure to that of rest remaining the same, was found by the following experiment. A rotating drum, the light to which was admitted through an adjustable slit, was brought into requisition. The slit was kept at a fixed width of $\frac{1}{20}$ inch, and the exposure was made to the light of a paraffin lamp, placed 27 inches away from it. The drum was covered with fairly sensitive bromide paper, and in all cases was exposed for the same length of time. As the drum was 12·25 inches in circumference, it follows that the ratio of the time of exposure to the time of rest was about 1 to 250 in all cases, whatever the velocity of rotation might be. A scale, as usual, was made on the same paper, and five exposures were given with the drum rotating at different speeds (see Table X.).

Fig. 59 shows these results graphically. The theoretical conclusions, as epitomised at the beginning of this chapter, again seem amply justified.

These results show that apart from any influence that ratio of the time of exposure to the time of rest may exercise, the absolute duration of exposure affects the result. When, as in this case, the absolute duration is 200 times greater in one than in the other, the chemical action is rather more than doubled.

It has already been shown that the length of the interval which elapses between successive and equal exposures has an effect upon the apparent exposure, but it became necessary to trace the result when *the exposures were equal in length, but the intervals of rest between such exposures differed* in amount. To make this experiment, discs of thin black paper were cut out, and radiating from the centre of these discs, apertures having angles of 10° were cut out at equal intervals round the centre. The discs used had 1, 3, 6, 12, and 24 apertures cut out, as above, respectively. These were held in position between two glass discs, and rotated in front of the sensitive surface for periods which make the product of intensity and time the same. A scale of density was likewise impressed on the surface, for the purpose of arriving at the apparent exposures.

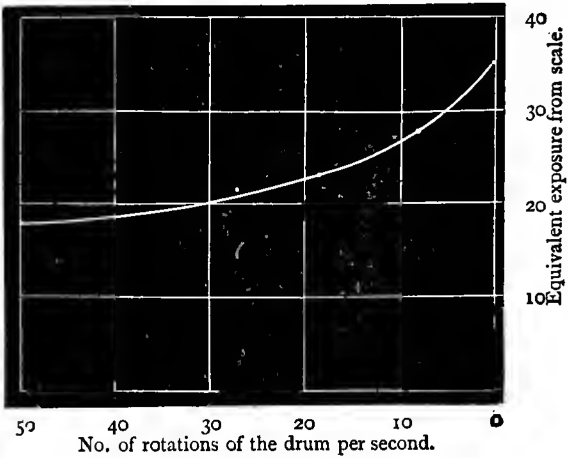


Fig. 59.

During all the exposures uniformity of rotation of the discs was secured, and the only difference between them is the alteration in the period of rest between successive insolations. The number of revolutions made was 43 per second.

In Fig. 60 the continuous curve shows that as the number of apertures is diminished, the less does the chemical action (as derived from the scale) become (see Table XI.).

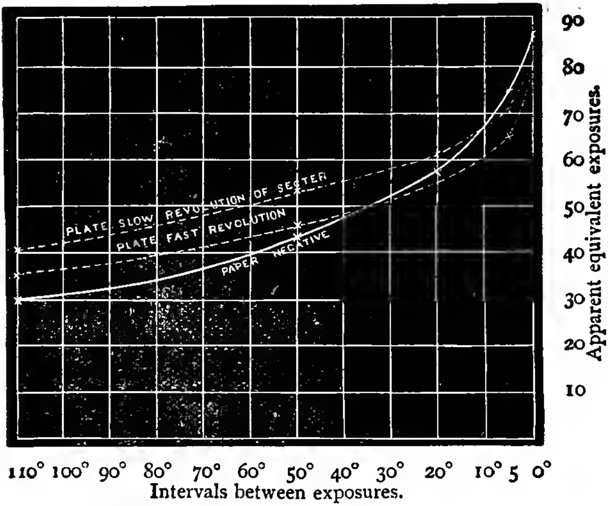


Fig. 60.

This is again more fully shown in a slow plate. It was exposed four feet away from the amyl acetate lamp, and the apertures used were the same as in the last, but another single aperture of 10° was added. Moreover, two sets of exposures were made, one with the sectors rotating at the speed of one revolution in $\frac{1}{16}$th second, and the other with one revolution in one second.

The results are also graphically shown in Fig. 60 by the two dotted curves, with the exception of the last exposure to the single aperture of 10°. The quicker rotation in this case gives the greater diminution in the apparent chemical action.

We have now answered the questions we proposed, and it will be seen that theoretical considerations are not to be despised even in a branch of applied science, such as is photography. We have by these experiments gained an idea of the relative times necessary to increase the amplitude of a swing, and for the swing to subside.

CHAPTER XIV.

EFFECT OF SMALL INTENSITIES OF LIGHT.

WE have next to deal with an effect of light which is, if not unexpected, at least contrary to generally received opinion. When a plate is exposed for a certain time to a light of given intensity, we say commonly that a plate has received so much exposure. If the time is altered, and the intensity also, so that the exposure (time multiplied by intensity) is the same, we have been taught that the same chemical effect will ensue, or, to put it in other words, the exposure will be the same. Now, as matter of fact, this is not true in every case, though it is true under the conditions under which a photographer usually works. Let us look at the matter from the beginning. We have in our sensitive salt the atoms composing it vibrating, and when light acts on it we have the oscillations increased, and the amplitudes greater. We can scarcely conceive that there should be any difference of effect produced by a series of impulses of a certain strength prolonged over a certain time, and a series of impulses of a fraction of that strength, lasting over a proportionally longer time. Yet there is a difference, as experiment shows. A perfectly satisfactory explanation of this deviation from what might be expected is at present wanting. We may, however, look upon the matter in the following way. Suppose we have a series of waves of light falling on a particle, which is, of course, composed of an almost infinite number of molecules, and that in the oscillation of these last, some one atom feels the impact of one wave of light, and the extra swing so given is just able to send it off from its mother molecule, then that molecule will be liable to decomposition by the developer. Now supposing we have a series of waves carrying half the energy, it might be supposed that it would require two of these blows to send the atom away from the molecule; but it by no means follows that the *same* atom would receive the second blow. Some other atom might be in the line of the waves and get the blow instead, or, if the original atom received it, it might not be in that part of the swing which would render the blow most effective. In either event the atom would not leave, but would be kept in the group of the mother molecule. In the case cited the intensity of the light in the first would be double that of the second, but the time of exposure would only be half that of the other. It will be noticed, of course, that this explanation depends on the fact that a certain amount of "light energy" has to be expended in separating the atoms from the molecules. This is a common experience in photography, for a very short exposure to a bright light, or an exposure to a very feeble intensity for a longer time, will fail to show any signs of chemical decomposition on a plate. The question is one of averages, and can be explained on the doctrine of chances. The general look of the curves given by the absolute measures support this view, since it is somewhat of the character of the law of error.

There is still another explanation into which it would be difficult to enter, unless one were to make high mathematics play a considerable part, but it may be briefly put in ordinary language. When Helmholtz gave his explanation of anomalous dispersion he founded it on the theory that when matter (molecules or atoms) was in contact with the ether or wave medium, although the latter might be considered as frictionless, yet when the two were together, a certain amount of viscosity or resistance to motion might be experienced. If, then, an atomic swing was increased by the motion of the ether waves, there nevertheless would be a retardation, and the full amount of energy would not be expended in increasing the swing, but part would be used up in overcoming what may be called the inertia. If this be the case, then, the increase in amplitude of swing of the atoms by a large number of small shocks would not be so great as that produced by a smaller number of greater shocks, though the same energy might be expended in the two cases. In the former, the increased swing might be sufficient to send the atom out of the mother molecule; in the latter, it might not. These two explanations are offered, either of which, or both together, seem to be applicable.

The writer had often suspected the failure of the assumption made, that on the same sensitive surface, when the product of intensity of light and time were equal, the chemical action would be the same, before he made any quantitative experiments. Thus, in his presidential address to the Mathematical Section of the British Association, he stated: "One word as to a problem which we may say is only qualitatively and not quantitatively solved. I refer to the interchangeability of length of exposure for intensity of light. Put it in this way. Suppose that with a strong light L a short exposure E be given, a chemical change C is obtained: will the same change C be obtained if the time is only an *n*th of the light L, but with *n* times the exposure? Now this is a very important point, more particularly when the body acted upon is fairly stable, as, for instance, some of the water-colour pigments which are known to fade in sunshine, but might not be supposed to do so in the light of an ordinary room even with prolonged exposure. Many experiments have been made at South Kensington as regards this, more especially with the salts of silver; and it is found that for any ordinary light, intensity and exposure are interchangeable; but that when the intensity of light is very feeble—say the $\frac{1}{1000000}$ of daylight—the exposure is rather more prolonged than it should be, supposing the exact interchangeability always held good; but it has never been found that a light was so feeble that no action could take place. Of course it must be borne in mind that the stability of the substance acted upon may have some effect; but the same results were obtained with matter which is vastly more stable than the ordinary silver salts." In his address to the Photographic Society on the 8th November, 1892, he also said, "And I would point out that up to the present time it has been held that if time and intensity of light gave a certain chemical change in a body, then the same will be produced if the two multiplied together give the same constant. I think we must put this law on the same basis as that of gravity . . . When we get intensities of light which are almost infinitely feebler than those with which we are accustomed to deal, the 'time into intensity' law will be found to break down. This follows almost from physico-mathematical considerations."

In the following experiments, which are culled from the original paper in the *Photographic Journal*, vol. xviii.,

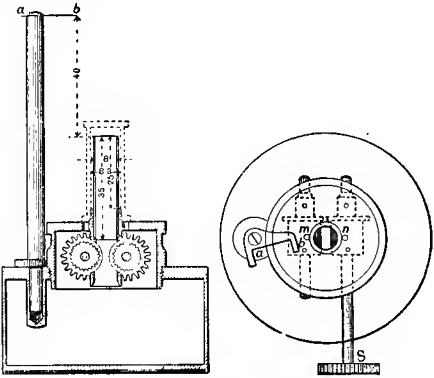


Fig. 61.

page 56, the source of light most usually employed was an amyl acetate lamp, known as the Siemens' unit light, as any variation in it is excessively small. The point to attend to is to light the lamp some ten minutes before it is to be used, and adjust it so that the tip of the flame just reaches the gauge pointer *a b* (Fig. 61). After this period it will remain at the same height almost as long as any amyl acetate remains in the reservoir. Every part of the flame could always be seen from each part of the surface exposed. Fig. 61 gives a section and plan of the lamp.

The first experiments that it is proposed to describe are those relating to the amount of chemical action produced by different intensities of light. An obvious experiment was to expose the same sensitive surfaces at different distances from a source of light, increasing the time of exposure as the distance was increased.

In the first instance, the sensitive surface was bromide paper of medium rapidity. Small squares, on a quarter-plate size, of this sensitive material were exposed at different distances to the amyl acetate lamp. The times were calculated so that the product of intensity and time ($I \times t$) was a constant, however much I or t varied, which, in accordance with the assumption usually accepted, should give equal chemical action as shown by the blackness on development, I being the intensity of the light, and t the time of exposure. A scale of exposures was added on the same paper by exposing different parts for known times, the distance of the lamp remaining constant. The paper was then developed carefully, and fixed. When dry, the scale of blackness was measured, as also was the blackness of the small squares, which had been exposed at different distances, and the latter referred to the former.

The measurement of the greyness produced was made by the method which the writer has described in

Chapter X. The lowest curve in Fig. 62 gives the

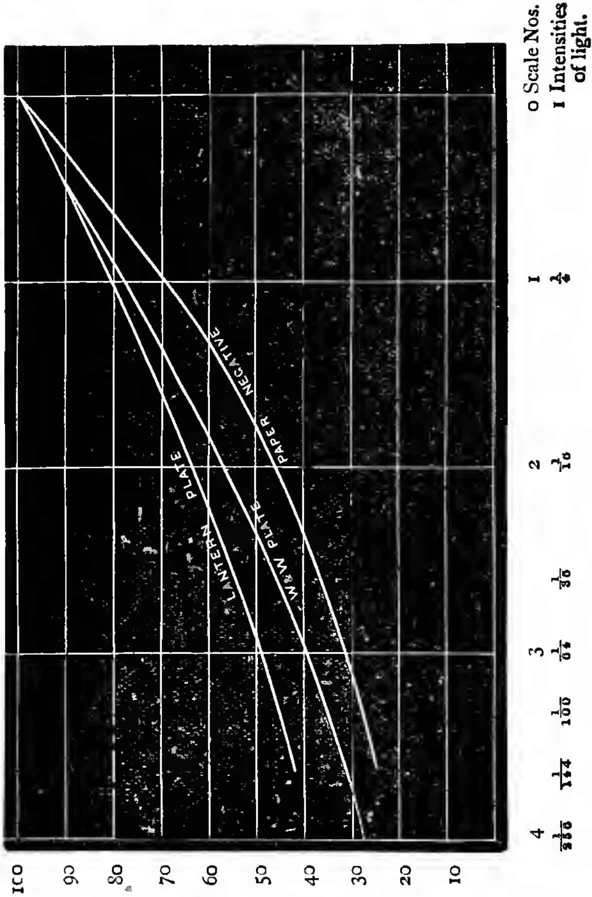


Fig. 62.

results. If there were no alteration in chemical action the curve should be a straight horizontal line (see Tables XIII. and XIV.).

As a fact the energy usefully expended at twenty-four feet was less than a quarter of that expended at two feet on the sensitive surface, although the time of exposure was proportionally lengthened to make the intensity and time a constant.

A lantern plate more sensitive than the foregoing paper was similarly treated as in the last exposure, and the top curve in Fig. 62 shows the results. The energy usefully expended at 24 feet was only ⅖th of that expended at 2 feet (see Tables XV. and XVI.).

The foregoing are decidedly "slow" sensitive surfaces. The next experiment was with one of Wratten and Wainwright's plates. The amyl-acetate flame was reduced in height, so that the result does not absolutely compare with the two former. Here the energy usefully expended at 24 feet is only ¼ of that expended at 1½ feet. The results are shown in Fig. 62 (see Tables XVII. and XVIII.).

It might be imagined that these differences were due to atmospheric absorption, as the decrease is so regular. It will, however, be seen that such cannot be the cause, since the ratios of the decrease are by no means the same when the sensitive surface is altered. The more rapid the plate, the less divergence from the assumed law has, as a rule, been found. There are means, however, besides altering the distance from the sensitive surface, which allow of a direct proof.

A Spurge's sensitometer, consisting of fine holes of different diameters in the centre of different small square diameters, and at the same distance from the plate, was brought into requisition. Every third hole doubles the area through which the light is admitted to the sensitive surface, and the same kind of results was obtained—viz., that the smaller the hole the greater was the extra time required to effect the same chemical action on the plate.

The next series of experiments to be recorded are those which were undertaken to ascertain if there is any difference in the gradation (see page 133 for the definition of the term), when different intensities of light were employed at *fixed distances, and progressive times of exposure* were given, so that time × intensity was kept the same. Only two experiments out of a number will be quoted as indicating the results always obtained.

We give as examples a slow lantern and a quicker plate. They were exposed to a light at 2 feet and 8 feet, the times of exposure being 1 to 16.

Fig. 63 gives the plotted curves, and each pair of curves are parallel. The "gradation" is therefore practically the same. (For measures see Tables XIX. and XX.) It will be noticed that, though the curves are parallel, they do not coincide (in a Euclidean sense), as they would do if the chemical action were the same for the same constant exposure.

We may sum up these results so far as to say that with slow and moderately quick plates the intensity of the light acting on a plate alters its apparent rapidity in a marked manner, but the alteration is smaller as the rapidity of the plate increases, until with a very rapid plate no practical alteration is made at all.

As we shall see in the next chapter, the intensities of light we are considering are moderate ones, and when we come to very intense lights the conditions and the results are changed. The camera image is formed by different *intensities* of light, and a fixed time exposure.

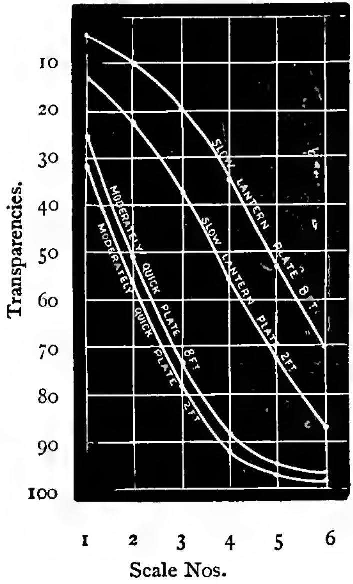


Fig. 63.

It follows that the gradation of some plates will be different in the camera to what it would be if the image was impressed by varying the times of exposure.

CHAPTER XV.

ACTION OF VERY INTENSE LIGHT ON PLATES.

THERE is another phenomenon to which reference has been made in the last chapter, which is that when the light acting on a plate is very intense, the results approximate to those which are found with very feeble intensities—that is, that the chemical action produced is lessened for a constant exposure (time multiplied by intensity) when the light is very intense, and that consequently there is some one intensity which will give the greatest chemical action. We must recall our former picture of the atomic swings to form an idea of how this may occur. The removable atoms are swinging with their ordinary swing, and a series of waves of light of great amplitude fall upon them. Let us suppose that the passage of two waves through the space occupied by the molecule is sufficient to destroy it as before by swinging out one of the atoms. Now let us double the energy carried by the waves; then the energy of one wave ought to be sufficient to cause the same effect, but the one wave would pass through the space in exactly half the time that the two waves took. The chances that the atom was at such a period of its swing that the energy could be properly applied to effect this result would be half in the latter case than in the former. The same kind of result would obtain with a larger number of waves.

In the case of low intensities the chances of "hit or miss" of an atom by a wave are the same, but with them we have to use the argument that a large number of blows are sufficient to increase the swing to shift the atom from the molecule, whilst with high intensities the number of blows required is reduced to a minimum, and the times in which the blows can be given are proportionally reduced. We thus have an investigation in which the calculation rests on the chances of a sufficient number of blows being effective in a given time, the strength of the blow being inversely proportional to the time. An investigation of this kind will show that there is some one energy due to wave motion that will in a given time decompose the greatest number of molecules.

We gave another possible explanation of the phenomena also when the intensities of the light acting were feeble. We took Helmholtz's explanation of anomalous dispersion, and applied it to our molecules. In this case we have a viscosity or resistance to motion to deal with. If we suppose that a comparatively heavy blow given to an atom will not give the full swing to it that it would take supposing there were no resistance to the motion, we can conceive that with a still heavier blow the resistance would be further increased (somewhat in the same way that atmospheric resistance to the passage of a body increases more rapidly than the velocity), and the length of swing given would be proportionately curtailed.

Thus, if an atom received two blows, one double the energy of the other, it is possible that the blow of double energy would not increase the swing of the atom to the extent it would reach from two blows of the other. This being the case, there would be some amplitude of wave which would give the greatest effect, while exposure (time multiplied by intensity) remained constant.

It is not proposed to give many experimental details through which the above result was arrived at; the original papers in January and March 1894 of the *Camera Club Journal* should be consulted if more are required. In the experiments given in the last chapter no great intensity of light was employed, and the variation in intensities was given by altering the distances of an amyl-acetate lamp from the plate, but in no case was the light closer than 1½ feet. With these different intensities, which are feeble compared with those now under consideration, it was shown that slow plates were markedly different in their sensitiveness. In other words, though the product of time of exposure and intensity of light might be the same, yet the opacity produced on development of a series of exposures on the different parts of the same plate was always less as the intensity became feebler. With rapid plates no marked difference resulted, however.

The times of exposure, be it remarked, lasted several seconds, the least being 5 seconds; but we often take a photograph in $\frac{1}{50}$th part of a second, which might be supposed to mean that the same amount of chemical action should be obtained in the densest parts of the negative in that fraction of a second as would be obtained in (say) 100 seconds to the feebler light. That, roughly, may mean that one light is 5,000 times brighter than the other.

If by any means we can get deposits produced by varying intensities of light acting for such a short period of time as the $\frac{1}{50}$th of a second, and then produce others with feebler light, but having the same proportional variation in intensity, we can compare the two gradations of transparency with great facility. We can make a scale of varying transparencies (*i. e.*, to allow different intensities of light to pass) by exposing a plate to an amyl-acetate lamp for varying times, and developing it. The deposits will allow different intensities of light to pass to a plate which is in contact with it.

We can measure the light transmitted by this scale of transparency by the method given before, and if the method of development has caused a jet black deposit, the optical value and the photographic value of the density will be the same. If we wish to make sure of this, we can print a positive from this scale by exposing a rapid plate behind it at a fixed distance from a light, and then, on the same plate, at the same distance from it, make another scale by giving varying time exposures to different small squares. The measurements of the two will show whether the photographic and visual opacities are identical.

Having got a scale, the next point to arrange is to give a short exposure. In the first experiment that will be described, this was accomplished by utilising an extemporised drop-shutter.

The shutter was placed close to the scale, with the aperture parallel to its length. The plate was in contact with the scale. An electric light of some 1,000 visual candle power was placed 5 or more feet away from it, the necessary distance being found by trial. An exposure was given, the time of passage of the aperture in the shutter over the scale being measured. Other exposures through the same scale were given on different parts of the plate to the comparatively feeble light of an amyl-acetate lamp placed at 3 ft. 6 in. from the negative, for varying times. It must be remembered that in all cases the variations in the intensities of the light passing through the scale were in the same proportion. After development we have upon the same plate an electric light exposure and several amyl-acetate lamp exposures. (Although the visual intensity of the electric light is only 1,000 candle power, yet photographically it is at least equal to 10,000 candles.) From these last we can pick out two—one in which the opacity given by the passage of the light through the most transparent square of the positive is nearly that given by the passage of the electric light through the same square, and the other in which the opacity of the most opaque squares is the same. In all cases, even with the most rapid plates that were tried, the gradation given by the electric light exposure was much more gentle than that given by the amyl-acetate. The following are two examples of this, which are noteworthy—one is a Barnet plate (ordinary), and the other an Edwards plate (special rapid). See Fig. 64. 1st. For both plates the amyl-acetate lamp was placed at the same distance from the standard scale of density, and in both cases one of the exposures selected and measured was for 30 seconds.

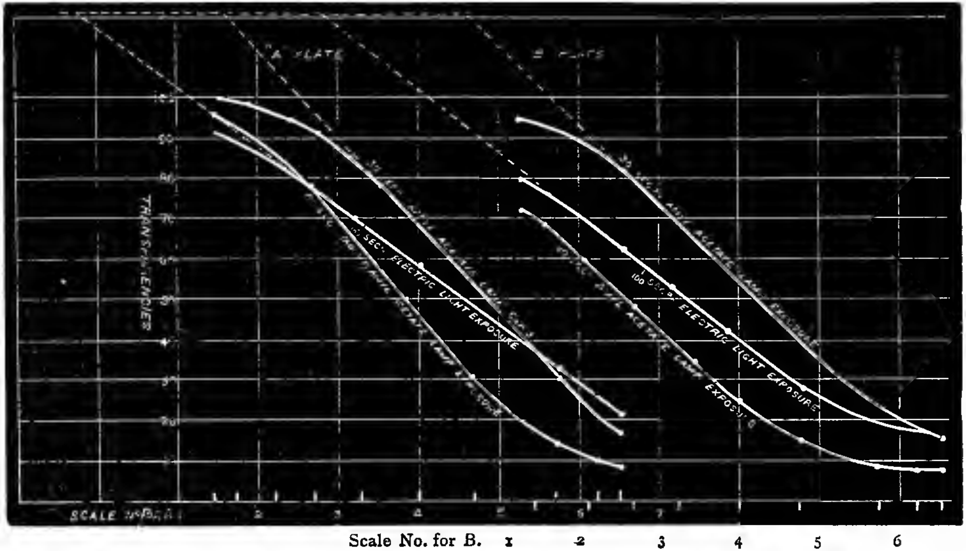

"A" PLATE
"B" PLATE
TRANSPARENCIES
SCALE No. FOR A
30 SECS. AMYL ACETATE LAMP EXPOSURE
1/100 SECS. ELECTRIC LIGHT EXPOSURE
AMYL ACETATE LAMP EXPOSURE
SECS. ELECTRIC LIGHT EXPOSURE
AMYL ACETATE LAMP EXPOSURE
2
3
4
5
6
7
Scale No. for B.
1
2
3
4
5
6

Fig. 64.

By the method of determining the comparative speeds of plates, which was proposed by the writer at the Camera Club Conference, the Barnet plate from this exposure is about 2·[illegible] or 1·9 times more rapid than the Edwards plate. 2nd. The Barnet plate was exposed through the scale at 4·5 feet distance from the electric light, whilst the Edwards plate was exposed at 8 feet. This makes the intensity of illumination given to the Barnet plate $\frac{64}{20·25}$, or 3·11 times more than to the Edwards plate. The electric (arc) light was giving out approximately the same amount of light in both cases, and the time of exposure was also the same. Had they both received the same exposure in this case, the rapidity of the Barnet plate would have been almost exactly twice that of the Edwards plate, but it received about three times more light. The Edwards plate is therefore 1·5 times more rapid for intense light than is the Barnet, though with the low illumination the Barnet is about twice as rapid as the Edwards plate. This appears to indicate that the relative rapidities of plates may alter according to the intensity of the light in which they are employed (see Table XXI.).

A further development of the research was in using not only the electric arc light, but the electric spark. An electric spark has the advantage of emitting a very intense light, but of an excessively short duration. What the visual intensity may be, one can scarcely say; but the intensity must be many times greater than that of sunlight, and the fact that it scarcely makes any greater impression in the retina than a beam of sunlight, owing to its short duration, is a proof that other sensitive matter besides silver salts is not affected proportionately to the intensity. The exposure, it was proved, could not be more than the $\frac{1}{100000}$ of a second, and might be considerably less. To ascertain this, a 5 inch plate was rotated round its centre about 60 times in a second, and in front of it sharply defined small apertures were placed lying 2 inches from the centre of rotation. A spark illuminated the plate through the apertures—1st, when at rest, and 2nd, during revolution, and no trace of movement could be detected. Now, if the spark had lasted a time sufficiently long to have allowed the plate to move the $\frac{1}{100}$ of an inch it would have been readily detected. The plate at 2 inches from the centre moved about 750 inches per second, or 1 inch in the $\frac{1}{750}$ second. It therefore moved $\frac{1}{100}$ inch in $\frac{1}{75000}$ second.

In the experiments that are to be described, the spark was taken between the terminals of a spark-gap apparatus, the knobs being usually $\frac{1}{3}$ of an inch apart. One terminal was in connection with the inside, and the other with the outside coatings of five Leyden jars, which were charged by a Wimshurst machine. The machine was worked till the spark passed across the gap, the plate being exposed, through the graduated screen, to its action. The operation was naturally carried out in a darkened room. Another portion of the same plate was exposed to the action of the electric arc light as before described, and another portion to an amyl-acetate lamp (in both cases, of course, through the graduated screen), and a "time scale" of density was also impressed by the amyl-acetate lamp.

Fig. 65 gives the result of exposing an ordinary plate to two sparks at 18 inches, then to the electric light at 5 ft. 6 in. distance for $\frac{1}{100}$ second, and, lastly, to an amyl-acetate lamp for 5 minutes at 3 ft. 6 in. from the plate (see Table XXIII.).

The quick plates, which were mostly experimented with, were a brand of snap-shot plates, manufactured by Cadett and Neall, and labelled as 133 H. and D.

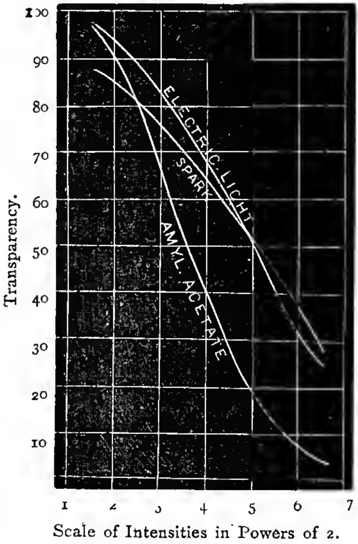


Fig. 65.

As the lowest number for a snap-shot plate is 1.00, it may be presumed that this brand of 133 is a very rapid one, and thus was very interesting to experiment with. With these plates the spark-gap was placed 18 inches from the plate, and exposure given. The plate was then transferred to the drop-shutter apparatus, and exposed for the $\frac{1}{100}$ of a second to the electric light at a distance of 7 feet, which was found to give about the same general intensity of image as the spark, and it was then exposed at 5 feet, for two minutes, to an amyl-acetate lamp. Thus the exposure given to the last was at least 12,000,000 times greater than the first, and 12,000 times that of the second.

A time scale taken with the amyl-acetate lamp at 10 feet distance was also impressed.

The results are seen in the following diagram (see Table XXIV.) :—

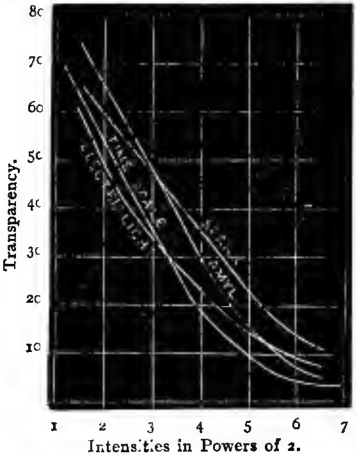


Fig. 66.

Similar experiments were carried out with other plates, and with a like result.

The figures show that the more intense the light the less steep gradation within the limits used there is.

The next set of experiments are full of interest, and give the curious but not unexpected results already referred to. They demonstrate that *if the intensity of the light is increased beyond a certain limit, the product of intensity and time being kept constant, the energy used up in the work of chemical decomposition diminishes.* The first experiment that was made was with a snap-shot plate, exposed naked at 18 inches and 12 ft. distance, the exposures being 1 spark and 64 sparks respectively. The writer was not prepared for the enormous difference in results; the one spark showed but a feeble deposit, whilst the exposure at 12 ft. distance to 64 sparks caused opaqueness. Another plate (an Ilford ordinary) was exposed (without any graduated screen intervening) at 12, 9, 6, 3, and 1½ feet distance, and the illumination of 64, 36, 16, 4, and 1 sparks—the equivalent number of sparks—were given respectively at these distances; a time scale was also impressed on the same plate, and the whole developed together. Now, although the *absolute* equivalent exposure cannot, of course, be told by applying the measures of transparency given by the spark exposures to the measures of the time scale, yet their *relative values* can be. Taking the result of the exposure at 12 feet as 1, that at 9 feet is ·87, at 6 feet ·72, at 3 feet ·41, at 1½ foot ·22.

This shows that there is apparently less than a quarter of the energy usefully employed in producing chemical action at 1½ ft. as compared with that at 12 ft., a result which seems somewhat marvellous. It might be thought that this result was due to "reversal" of the image, but other experiments proved that it was not so.

Another experiment made was with the same brand of plate, but the exposures were made through the standard scale at the same distances, omitting those at 9 ft. and 3 ft. The number of sparks multiplied by the inverse square of the distance is the same in all cases. The results of these exposures are given in Table XXVI., and a similar result is to be seen in Fig. 67, and when

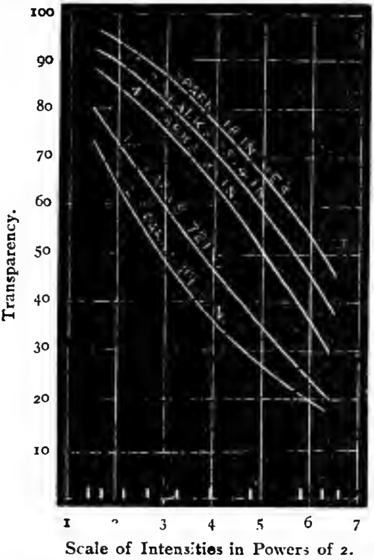


Fig. 67.

looked at diagrammatically, show at once that there is no case of reversal in it. If there had been the feeble intensity given by the most opaque square of the scale of density would have indicated a greater intensity than the most transparent one. But the best indication that there is no reversal is the absolute freedom from halation which is shown on this plate, whilst the most opaque portions, with the 64 sparks, show decided halation. Several brands of plates were experimented with, and the same results were invariably obtained.

So far the action on rapid plates has been described, but to make the matter more complete, slower plates were experimented with. A slow lantern plate was exposed at different distances with an equivalent number of sparks, and the results were instructive. Although the exposure at 1 foot appeared a little less than at 8 ft., there is far less difference than when the quicker plates are used. This is what was to be expected. In the preceding chapter it was shown that with these plates the energy expended with feeble intensities and equivalent exposures was much less than with stronger intensities, whereas with the rapid plates there was not much difference. The rapid plate must therefore evidently arrive sooner at the point where the energy expended was at its maximum than would the slow plate.

Combining these experiments, we are able to deduce the fact that for every plate there is an intensity of light which has a maximum effect upon it with a given exposure, and that on either side of this maximum the useful energy decreases.

CHAPTER XVI.

MEASUREMENT OF SPECTRA.

IF we turn to page 25 and look at Fig. 9, we have there a photograph of the spectrum taken on three kinds of sensitive surfaces. No. II. is a plain bromide plate, which apparently shows greatest action about the violet marked G, whilst No. III. is taken on a bromide plate with a maximum action near the extreme limit of the violet H. No. I. is a spectrum taken on a new plate introduced by Mr. Cadett, which is sensitive far into the red. This last plate is an orthochromatic plate, and contains at least two, and probably more, kinds of sensitive matter, the sensitiveness in the yellow and red being due to the presence of colouring matter. Photographs such as these may be called qualitative, as they do not indicate the exact degree of sensitiveness to each ray. But by calling into use the measuring apparatus already described in Chapter X., we can, if we attach a scale of opacities to it—the opacities being caused by different intensities of light acting for the same time—measure the opacities at each part of the spectrum and that of the scale, and, by comparing the former with the latter, deduce from the spectrum opacity the intensity of photographic light that was acting at each part. We will give one example of this. In Fig. 68 we have three

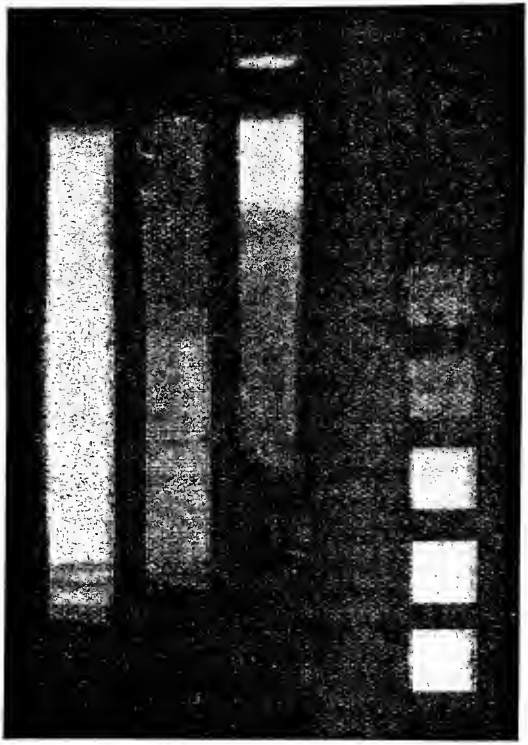


Fig. 68.

photographs of the spectrum. Nos. I. and II. are photographs of the spectrum of sunlight, the difference between them being that No. I. is taken with a wide slit to obliterate the fine lines which traverse it when the slit is narrow. No. II. was taken with a fine slit. No. I. is the spectrum that was measured, and II. used as a "position-finder," that is to tell us what parts of the spectrum we were measuring. No. III. is the spectrum of a gas flame, in which it will be seen that the blue and violet rays are largely absent. No. IV. is a scale of opacities which were measured, and a curve of light transmitted drawn. The intensity of the light causing the deposit being known, was used as the base on which the curve was erected. These photographs were measured in the two ways indicated in Chapter X., and the results are very close to one another.

Fig. 69 gives the result of these measures, and we can at once compare the effect of sunlight and gaslight on the same plate. The wavy appearance of the curves is somewhat remarkable, but the bends probably mean either inactive absorption of some kind when there are depressions, and active absorptions (that is where work is done) in the rises. It will be noticed that generally the depressions and rises are in the same positions in the gas and solar spectra curves. In the figure a third curve of the luminosity of sunlight to the eye is introduced, from which it will be seen that the solar spectrum would be very far short of rendering properly the luminosities of the colours as seen in daylight.

Again, we give another example of a plate known as Lumière's red-yellow sensitive plate, the spectra being taken of the crater of the positive pole of the arc light

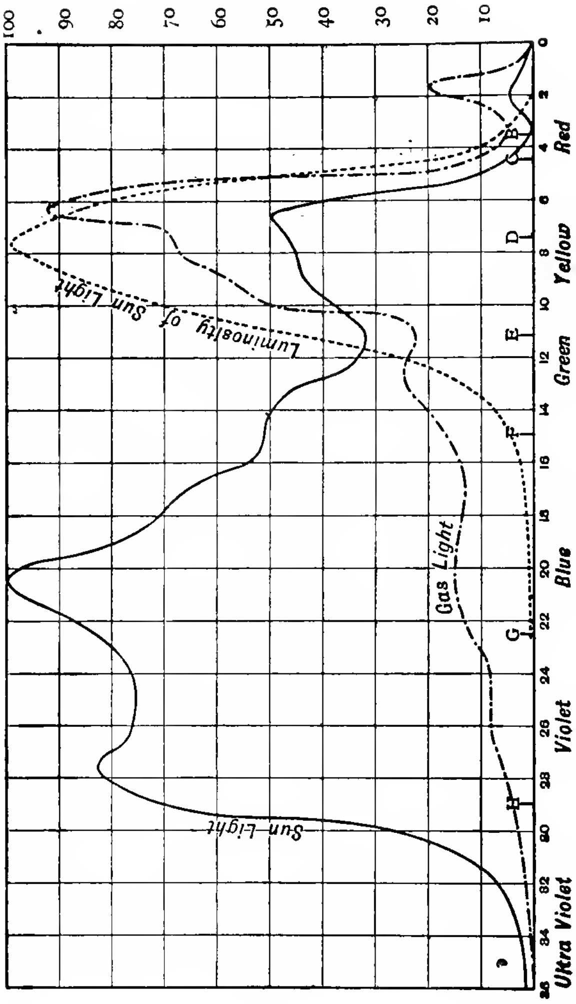

100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
Red
Yellow
Green
Blue
Violet
Ultra Violet
B
C
D
E
F
G
H
Luminosity of Sun Light
Gas Light
Sun Light

Fig. 69.

and of gaslight; and as a third curve we have the visual luminosity of the arc light. It will be seen that neither one nor the other photographed spectra lie at all near the visual curve. It follows, then, that the colours cannot be photographed to give correct luminosity without some extraneous aid.

The curve of sensitiveness of ordinary bromide is practically the same as the curve in Fig. 70 to the left of E, which, it will be seen, is far and away the worst for rendering colours in their true luminosity, though it should be remarked it conveys the idea of other wave-lengths besides those absolutely in tune with the swing of the atoms being capable of increasing the amplitude.

We can, by cutting off rays which are not required, produce photographs which give colours very nearly their correct luminosities. The diagrams of the plates which are most sensitive throughout the spectrum are seen in Figs. 69 and 70. It will be noticed in them that there are spaces where the sensitiveness is smaller than at places on each side of them. So far as we know, there are no plates which give a continuous smooth curve. The difficulty of these gaps may be got over to a very large extent, because the colours in nature are mixed colours, occupying a considerable space in the spectrum, and the gaps can thus be "bridged over." If we can obtain a photograph on them which will render truly the luminosities of a red, a green, and a blue, that are mixed colours, we shall be able very approximately to photograph any other colours in nature. It is not necessary that the colour should be reflected. It may be transmitted, so that if we can photograph correctly the luminosities of the colours which are transmitted through a ruby glass,

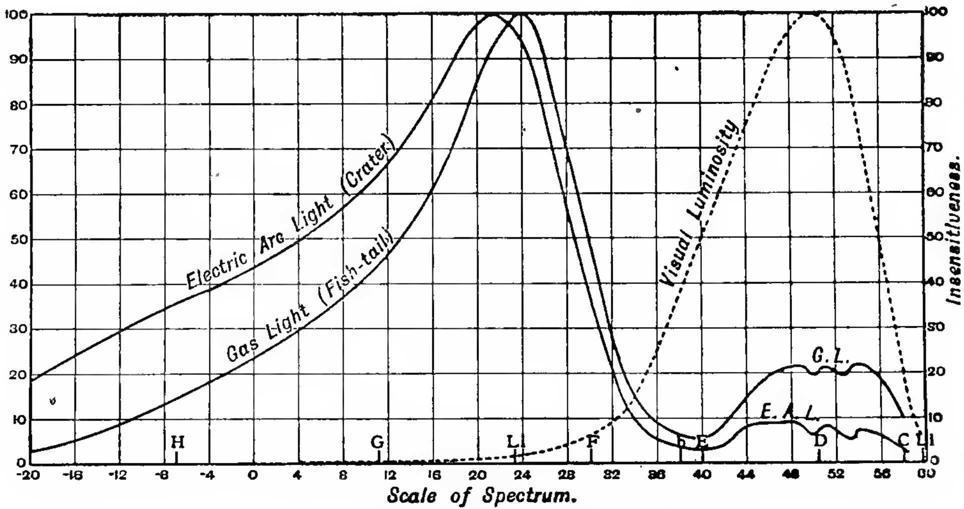

Electric Arc Light (Crater)
Gas Light (Fish-tail)
Visual Luminosity
G.L.
E.A.L.
Insensitiveness.
H
G
L1
F
b
E
D
C
L1
Scale of Spectrum.
100
90
80
70
60
50
40
30
20
10
0
-20
-16
-12
-8
-4
0
4
8
12
16
20
24
28
32
36
40
44
48
52
56
60

Fig. 70.

a green glass, a blue glass, and a white glass, we may take it that any intermediate colours will not be very incorrectly rendered, owing to the fact that each of the coloured glasses transmits a considerable quantity of the rays on each side of those colours of the spectrum which most nearly match them. Thus the red will transmit red and yellow; the yellow—red, yellow, and a little green; the green—yellow and blue as well as green: and the blue glass will allow some green, a little red, and a large proportion of blue to pass. The question arises, how can we best arrive at a solution of this problem in a simple manner? Suppose we reduce the luminosity of the light passing through these glasses to a common luminosity, say, to that of the darkest, then, if we have a colour-correct plate, with equal times of exposure, all the opacities in a developed plate should be identical.

The writer formed a sensitometer of these glasses by placing four small squares of the different colours in a row. He measured the luminosity of the light coming through each small square, and then cut out sectors (which can rotate in front of them) to cut off the light necessary to make all appear of equal luminosity. We can place a plate behind such a screen, and expose it to the same kind of light as that in which the luminosity of the light coming through these glasses was measured with these sectors rotating in front of them. If a plate were properly colour-sensitive, the impression made by the light coming through these squares should show the same opacity; but in no case will they do so. Suppose we find that the squares exposed through the blue and white show greater opacity, evidently we must cut off, by a yellow screen, some of the blue. We can cut off red by a green screen, and we can cut off green by a red-screen. We can guess what depth of each we shall require, and make an exposure with these screens in front of the light, and then see what further alterations are required. We can go on making alterations in the screens till the densities under all squares are all the same, and then use the absorbing medium so found for camera exposures.

This test of the qualities of an orthochromatic plate is a very searching one, and in it we have had to use several of the methods of measurement we have already described in this work. It is a useful application of what we have endeavoured to teach in the earlier chapters, and may be regarded in the light of an experiment.

If the reader has travelled through these pages thus far, it is hoped that the journey may not have been fruitless, and we take our leave of him with the wish that what he has read may lead him to continue his study by consulting other works on the subjects which have been touched upon here.

FINIS.

APPENDIX.

EFFECT OF TEMPERATURE ON SENSITIVENESS.

Mawson Lantern Plate.

Exposed to a paraffin lamp at 5 feet, being visually equal to an amyl-acetate lamp at 39 inches.

Table I. (see Fig. 49, page 129).

Temperature.	− 15° C.	+ 12° C.	+ 33° C.
Exposure in Seconds.	Readings.		
0	100	100	100
5	99	96	94
10	97	92	89
20	90	80	71
40	75	60	51
80	55	40	30
160	35	21	12.5
320	15·5	10·2	5·5

A LIGHTNING PLATE.

Exposure to amyl-acetate lamp at 6 ft.

TABLE II. (see Fig. 50, page 130).

Temperature.	− 16° C.	+ 6° C.	+ 33° C.
Exposure in Seconds.	Measures of Transparency.		
0	100	100	100
5	98	94	86
10	86	80	70
20	69	64	53
40	53	49	38
80	38	36	28
160	28	26	20
320	20·5	18	16·2

A FITCH FILM—Exposed at 5 feet to an amyl-acetate lamp.

TABLE III. (see Fig. 51, page 131).

Temperature.	− 19.5° C.	+ 14° C.	+ 33° C.
Exposure in Seconds.	Measures of Transparency.		
0	100	100	100
5	88	87	84
10	77	74	70
20	64	59	55
40	49	45	40
80	34	30	27
160	22·5	20·5	19
320	15·8	14·3	13·2

COLLODIO-BROMIDE PLATE.

Exposed at 3 feet from a paraffin lamp.

TABLE IIIA.

Temperature.	+ 32° C.	— 17° C.	+ 32° C.	— 17° C.
Exposure.	Measures of Transparency.		Energy used as chemical decomposition derived from the salt.	
12 min.	24·5	71	149	32·6
6 min.	46·5	86	74	16·3
0 min.	100	100		

SCALE OF OPACITY TO THE FOREGOING.

Exposures.	Measures of Transparencies.
0	100
10 sec.	92
20 ,,	83
40 ,,	62
80 ,,	40
160 ,,	22
320 ,,	12·7

LANTERN PLATE.
TABLE IV. (see Fig. 52, page 132).

Temperature.	— 18° C.	+ 40° C.
Exposure in Seconds.	Measures of Transparency.	
0	100	100
5	93	86
10	85	68
20	70	40·5
40	51	17·0
80	53	7·7
160	19	3·5
320	12·5	1·9

MAWSON LANTERN PLATE.
TABLE V. (see Fig. 53, page 133).

Temperature.	+ 18° C.	— 18° C.	+ 38° C.	+ 18° C.
Exposure in seconds.	Measures of Transparency.			
0	100	100	100	100
5	91	93	90	91
10	87	89	82	87
20	72	81	56	70
40	50	60	32	44
80	27	39	13·5	21·4
160	11·5	19	5·7	9·5
320	4·8	7·2	2·4	4·0

EXPOSURE OF PLATE THROUGH GRADUATED SCALE.

TABLE VI. (see Fig. 54, page 135).

Temperature.	+ 34° C.	— 15° C.
Intensities in powers of 2.	Measures of Transparency.	
0	100	100
2·2	95	92
2·7	91	86
3·3	80	77
4·0	60	62
4·8	41	44
5·8	16	24
6·3	10·5	15
6·5	7·2	12

EFFECT OF INTERMITTENT EXPOSURE.

◆

Lantern Plate.

Table VII. (see Fig. 57, page 140).

Scale taken at 3 feet.		Distance in feet.	Relative intensities.	Exposure.	Reading of Transparency.	Comparative chemical action derived from scale.	Ratio of the plain to sectorial chemical action.
Exposure.	Reading of Transparency.						
sec.				m. s.			
5	87·6	1½	1	0 10	27.8	56·4	·815
10	75·3	*1½*	*1*	*1 0*	*33·3*	*46·0*	
20	55·0	3	¼	0 40	37	40	·500
40	37·0	*3*	¼	*4 0*	*55*	*20*	
80	18·0	6	1/16	2 40	53	22·2	·423
		6	1/16	*16 0*	*76·5*	*9·4*	
		12	1/64	10 40	69·5	12·7	·370
		12	1/64	*64 0*	*88·8*	*4·7*	

The figures in italics are those which relate to the exposure with the sector. The ratio of exposure to interval of rest is 1 : 5.

SLOW PLATE.

TABLE VIII. (see Fig. 58, page 143).

Scale.		Aperture.	Ratio of exposure to non-exposure.	Exposure given	Reading of Transparency.	Chemical action derived from scale.
Exposure.	Reading of Transparency.					
				m. s.		
5	92	360	—	— 40	19	40
10	73·5	twice 90°	·50	1 20	19·8	37
20	39·0	„ 70°	·39	1 43	21·6	35
40	21·0	„ 50°	.28	2 24	22·8	33
60	11·2	„ 30°	·17	4 0	26·5	29
80	5·4	„ 20°	·11	6 0	30·0	25
		„ 10°	·06	12 0	35·2	22·5

SLOW PLATE.

TABLE IX. (see Fig. 58, page 143).

Scale.		Aperture.	Ratio of exposure to non-exposure.	Exposure.	Readings of Transparencies.		Chemical action derived from scale.	
Exposure.	Reading of Transparency.				Fast.	Slow.	Fast.	Slow.
		°		m. s.				
Bare glass	100	360	—	— 40	59	59	40	40
secs.		twice 90	·50	1 20	63	61	35	37
10	90	„ 70	·39	1 43	65	63	32	35
15	81	„ 50	·28	2 24	70	65	25	32
30	67	„ 30	·17	4 —	75	68	20	28
40	59	„ 20	·11	6 —	80	71	15·5	24
50	57	„ 10	·06	12 —	86	77	12	20

EXPOSURE OF NEGATIVE PAPER.

TABLE X. (see Fig. 59, page 145).

Scale at 8 feet.		Duration of each exposure.	Rotations of drum per second.	Reading of greyness.	Chemical action derived from scale.
Exposure.	Reading of greyness.				
Bare glass	100	sec.			
5 sec.	96·0	$\frac{1}{62}$	¼	44	35
10 ,,	83·0	$\frac{1}{2150}$	8¾	52	27
20 ,,	64·0	$\frac{1}{4300}$	17½	56	24
30 ,,	48·5	$\frac{1}{6500}$	26	59	22
40 ,,	42·0	$\frac{1}{12500}$	50	69	17

EXPOSURE OF MODERATELY QUICK PLATE.

TABLE XI. (see Fig. 60, page 146).

Scale.		No. of intervals in disc.	Intervals between exposure.	Expo-sure.	Reading of Trans-parency.	Chemical action derived from scale.
Exposure.	Readings of Transparency.					
Bare glass	100			m.		
secs.		0	0	1	36·4	85·6
10	94	24 of 10°	5°	1½	40·0	74·4
20	80·5	12 ,, ,,	20°	3	48·5	58·4
40	57	6 ,, ,,	50°	6	59·5	42·8
80	37·5	3 ,, ,,	110°	12	67·0	31·4

Exposure of Slow Plate.

Table XII. (see Fig. 60, page 146).

Scale.		No. of intervals.	Intervals between exposure.	Exposure.	Readings of Transparency.		Comparative chemical action derived from scale.	
					Revolutions.			
Exposure.	Reading of Transparency.				$\frac{1}{35}$ sec.	1 sec.	$\frac{1}{35}$ sec.	1 sec.
secs.			°	m. s.				
10	92	0	0	— 80	46	46	80	80
20	79	24 of 10°	5	2 —	51	48·5	65	72
40	65	12 ,, ,,	20	4 —	55	52·5	56	61
60	54	6 ,, ,,	50	8 —	60	56·5	47	53
80	46	3 ,, ,,	110	16 —	66	63	37	41
100	39	1 ,, ,,	350	48 —	76	73	24	27
Bare glass ..	100							

EFFECT OF SMALL INTENSITIES OF LIGHT.

Table XIII. (see Fig. 62, page 154).

Scale exposed at 4 feet.

Scale No.	Exposure. secs.	Reading of greyness.
1	5	95
2	10	90
3	20	69
3	30	58
4	40	49
5	80	29
6	160	16
White paper	... ...	100

EXPOSURE OF NEGATIVE PAPER.

TABLE XIV. (see Fig. 62, page 154).

Distance of lamp in feet.	Exposure.	Reading of greyness.	Amount of chemical action deduced from the time scale.	Relative amounts of chemical action produced.
	m. s.			
24	24 0	83	13·4	·23
20	16 40	78	15·1	·27
16	10 40	73	17·4	·31
12	6 0	67	20·6	·37
8	2 40	60	26·4	·47
4	0 40	49	40·0	·71
2	0 10	38	56·4	1·00
	White ...	100		

Column 4 is derived from seeing where the greyness of each square corresponded with the greyness of the scale; and if the law held good, each of the numbers in it should be the same.

EXPOSURE OF LANTERN PLATE.

Table XV. shows the scale made with the light at rather more than two feet distance, and Table XVI. the exposures and distances of the light.

TABLE XV.

Scale No.	Exposure.	Transmitted light.
	sec.	
1	5	58
2	10	29
3	20	6·1
	Bare glass	100

TABLE XVI. (see Fig. 62, page 154).

Distance.	Exposure.	Amount of light transmitted.	Amount of chemical action deduced from the time scale.	Relative amounts of chemical action produced.
feet.	m. s.			
2	0 10	28·0	11·5	1·00
4	0 40	34·0	9·0	·79
8	2 40	41·2	7·5	·65
12	6 0	48·2	6·3	·55
16	10 40	50·4	5·9	·51
24	24 0	62·2	4·7	·40

EXPOSURE OF A WRATTEN PLATE.

TABLE XVII. (see Fig. 62, page 154).

Scale at 3 ft. from light.

Scale No.	Exposure.	Transmitted light.
	sec.	
1	5	40·4
2	10	24·6
3	20	17·6
4	40	12·0
5	80	7·6
Bare glass ...	... ...	... 100

TABLE XVIII. (see Fig. 62, page 154).

Distance.	Exposure.	Amount of light transmitted.	Amount of chemical action duduced from the time scale.	Relative amounts of chemical action produced.
	m. s.			
1½	0 10	10	49·2	1·00
3	0 40	11·8	38·6	·78
6	2 40	14·7	28·2	·57
12	10 40	19·2	18·6	·38
24	42 40	24	12·7	·26

The last column gives the equivalent in time referred to the scale.

The results shown in the last columns of Tables XIV., XVI., and XVIII., are shown graphically in Fig. 62, page 154, the scale of the abscissæ of the curves being shown in powers of ½ intensity.

TABLE XIX.—SLOW LANTERN PLATE (see Fig. 63, page 157).

Scale No. in diagram.	2 feet.		8 feet.	
	Exposure.	Transparency of deposit.	Exposure.	Transparency of deposit.
—	Bare glass.	100	Bare glass.	100
	secs.		m. s.	
1	5	88	1 20	96
2	10	78·5	2 40	90·5
3	20	62	5 20	81
4	40	44	10 40	65
5	80	27	21 20	46
6	160	12	42 40	30

TABLE XX.—QUICKER PLATE (see Fig. 63, page 157).

Scale No. in diagram.	2 feet.		8 feet.	
	Exposure.	Transparency of deposit.	Exposure.	Transparency of deposit.
—	Bare glass.	100	Bare glass.	100
	secs.		m. s.	
1	5	68	1 20	75
2	10	43·5	2 40	50
3	20	21·0	5 20	25
4	40	8·5	10 40	10
5	80	4	21 20	5
6	160	2	42 40	3

ACTION WITH INTENSE LIGHT.

TABLE XXI. (see Fig 64, page 163).

Barnet plate (ordinary), exposed through standard scale to electric light at 4 ft. 6 in., with drop-shutter, and to an amyl-acetate lamp at 3 ft. 6 in.

Transparencies of scale in powers of 2.	Reading of Transparency.		
	Electric light at 5 ft.	Amyl-acetate, 30 secs. at 3 ft. 6 in.	Amyl-acetate, 90 secs. at 3 ft. 6 in.
. .	100	100	100
1·44	80	95	73
1·73	77	92	68
2·21	70·5	89	59
2·70	64·5	83	49
3·30	53·5	72	37
4·00	44	58	26·5
4·77	32	41	17·5
5·77	21·5	26	11
6·30	17·5	18	9
6·55	16	16	8

TABLE XXII. (see Fig. 64, page 163).

Edwards plate (special rapid), exposed through standard scale to electric light at 8 ft., with drop-shutter, for $\frac{1}{100}$ sec., and to an amyl-acetate lamp at 3 ft. 6 in. distant.

Transparencies of scale in powers of 2.	Reading of Transparency.		
	Electric light	Amyl-acetate, 30 secs. at 3 ft. 6 in.	Amyl-acetate, 60 secs. at 3 ft. 6 in.
..	100	100	100
1·44	92	100	96·6
1·73	92	98·3	92
2·21	86	98	87·3
2·70	78·6	93·3	78·6
3·30	70·6	84	64·6
4·00	61·3	75·3	50·0
4·77	48·6	54·3	31·3
5·77	32·0	33·3	14·0
6·30	25·3	22	9·3
6·55	21·3	18	8·0

SLOW PLATE.

TABLE XXIII. (see Fig. 65, page 166).

Comparative Intensity of the Light passing through the Scale in Powers of 2.	Two Sparks at 18 in.	Electric Light at 3 ft. 6 in. Drop $\frac{1}{100}$ in.	Amyl-acetate 3 ft. 2 in.
1·44	88	97	95·5
1·73	87	95·5	94·0
2·21	84	91	86·5
2·70	77	86·5	74
3·30	72·5	77	55·5
4·00	64	68	37
4·77	53	52·5	21·2
5·77	38·5	34·4	9·5
6·30	29·0	27·7	5·0
6·55	26·2	24·5	4·0

LIGHTNING PLATE.

TABLE XXIV. (see Fig. 66, page 167).

x, where 2^x is the intensity.	Spark.	Electric Light.	Amyl-Acetate.
	Reading.	Reading.	Reading.
1·44	66·5	61·5	77
1·73	63	56	70
2·21	58	47·5	62
2·70	51	38·5	54·5
3·30	44·5	31·5	44·0
4·00	36·0	23·5	30·5
4·77	25·0	16·7	19·2
5·77	16·8	10·5	10.8
6·30	13·2	9·0	7·7
6·55	11·4	8·1	6·3
Bare glass	100	100	100

Scale Amyl-acetate at 10 ft.	
Time.	Reading.
secs.	
5	77·5
10	56
20	31·5
40	19·5
80	11
160	6·3
320	3·5
Bare glass	100

TABLE XXV. (see page 168).

Distance in feet.	Number of Sparks.	Reading.	Equivalent Value for Scale.
12	64	20	1
9	36	22	·87
6	16	25	·72
3	4	35	·41
1½	1	54	
1½	1	52 } 53	·22
1½	1	54	
Bare glass	..	100	..

Scale.	
Exposures in seconds.	Reading.
Bare glass	100
10	91·2
20	70·0
40	47·5
80	32·5
160	20·0
320	12·5

TABLE XXVI. (see page 169).

Relative Intensities in Powers of 2.	Readings of Transparency.		
	64 Sparks at 12 ft.	16 Sparks at 6 ft.	1 Spark at 1½ ft.
1·44	85·5	86·2	97·5
1·73	83	85·0	97·0
2·21	72·5	81·0	97·0
2·70	66·0	74·0	96·0
3·30	52·0	65·0	95·0
4·00	41·0	56·0	92·5
4·77	30·0	42·5	87·5
5·77	20·0	30·0	80·5
6·30	15·0	25·0	77·0
6·55	12·5	23·0	75·0

TABLE OF LUMINOSITIES (see page 118).

Scale No.	Wave-length.	Luminosity.
62	6957	2
60	6728	7
58	6520	21
56	6330	50
54	6152	80
52	5996	96
50	5850	100
48	5720	97
46	5596	87
44	5481	75
42	5373	62·5
40	5270	50·0
38	5172	36
36	5085	24
34	5002	14·2
32	4924	8·5
30	4848	5·5
28	4776	4·0
26	4707	2·8
24	4639	1·8
22	4578	1·4
20	4517	1·08
18	4459	·86
16	4404	·70
14	4349	·56
12	4296	·45
10	4250	·34
8	4197	·26
6	4151	·18
4	4106	·14

A THEORY OF ALKALINE DEVELOPMENT.

So far we have treated the opacity of an image obtained by development, without reference to the principles that are involved in this operation. There has been no call to enter into this subject in the work, since the developed image has only been taken as a measure of action of light when compared with an action of light that was known. It may be well, however, to show briefly how development fits in with the ideas that we have propounded regarding the distraction of a molecule by an increase in the swings of some of the atoms. We have supposed—and the supposition is made on evidence which is most cogent—that an atom of bromine swings itself out of the sphere of attraction of the mother molecule of silver bromide, and joins some other foreign molecule which is near it. The silver bromide we have supposed to be formed of two atoms of silver and two atoms of bromine, and that only one of these atoms of bromine is removed by the action of light, leaving a much more unstable molecule (which has been called sub-bromide of silver) behind. The action of development is to bring in contact with this molecule of sub-bromide a molecule of a substance which has a greater attraction for the remaining atom of bromine than had the two atoms of silver, although when the original molecule is complete (that is, when it contains the four atoms) its attraction of all its components for one another is so great that the molecule of the developer cannot overcome it, and no atom or atoms will be separated. The flight of the atom caused by light leaves, as it were, a hiatus in the molecule of sub-bromide, and the mutual attractions are very much lessened, and thus the sub-bromide molecule is in a fit state to be broken up, and to leave the silver atoms alone uncombined except with one another. [This we express in chemical notation as follows :—The original molecule is Ag_2Br_2, and the sub-bromide Ag_2Br. After the developer has acted, Ag_2 is left behind.] Now let us consider the state of the two atoms of silver (Ag_2) so left. They have an unsatisfied attractive force inherent in them, which they endeavour to satisfy. In contact with them is a molecule of silver bromide (Ag_2Br_2), which has not been broken up by the action of light. They therefore annex themselves to this molecule, and two molecules of sub-bromide are thus formed ($Ag_2Br_2 + Ag_2 = 2Ag_2Br$). These once stable molecules themselves thus become unstable, and the developer can take away the bromine atoms from them. A new elimination of silver takes place, and those atoms of silver which are near another molecule of silver bromide again continue to form fresh molecules of the sub-bromide, and then again are reduced to metallic silver, and so development takes place, and a visible image is formed. It will be seen that for this action to take place very few—perhaps only one—molecules in a particle need be shattered by the action of light in order that the whole of that particle may be reduced to metallic silver. Taking a thinly-coated plate, and examining a small part of the surface in the microscope, then allowing white light to fall on it, and applying a developer, the particles can be compared before and after development, when it will be seen that the changes in structure that take place are minute, and that the action is confined to particles. But we have still stronger evidence that an action, at all events, somewhat of the kind that has been described, takes place. We can produce on a film which has not been exposed at all an image which has been impressed by light on another film, by contriving to bring the two surfaces in absolute contact. For this purpose there is nothing better than a film of collodion emulsion. If we coat a glass plate with collodio-bromide emulsion, and then expose it to a camera image, we can, when the film is dry, coat it with another layer of the same emulsion. The surface of the first film becomes slightly dissolved, and the second film is therefore in absolute contact with it, and some few particles of the silver bromide in each film will coalesce with one another. On applying the developer to this double film, the image will begin to appear at the junction of the two films, and will gradually go downwards and upwards, and finally we shall have the image appearing on the top film, which, it must be remembered, has never seen light. We may then place a tough sheet of gummed paper on the top surface, and remove the film from the glass. When this is done another sheet of gummed paper may be placed on the surface which was next the glass, and when dried the two sheets may be pulled asunder, and we shall find that the two films have separated, one adhering to one sheet of paper, and the other to the other, and that an image is on each. This shows that the action which we have described probably takes place.

Looking at development from this point of view, we see that it is in strict accord with what we have stated in this work. If only one molecule is decomposed, we may suppose that a certain quantity of silver will be isolated in a given time; if two molecules, twice—or nearly twice—the amount of silver, and so on. When the number of molecules so decomposed is large, it is probable that the reduction will not be so great, for the contact of the newly-formed silver atoms with the molecules which have not been reduced by light to form fresh sub-bromide must be limited, since the same unaltered molecule may be equally near two or more of the silver atoms, and there will consequently be a loss in the total reduction in a given time compared with what we might look for. There must of necessity be great difficulty in finding whether such is practically the case. The amount of silver deposited, as found by careful chemical analysis made by Messrs. Hurter and Driffield, does not indicate that such is the case, but the differences that might be expected to be found are of such an order that probably some more delicate plan must be adopted before anything definite can be offered as evidence.

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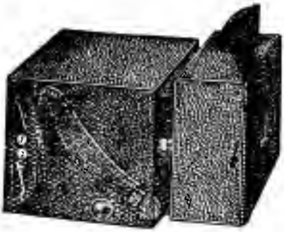

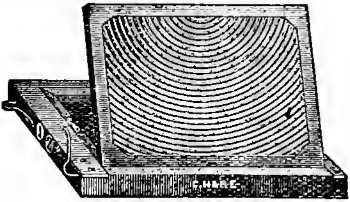

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