COLOUR PHOTOGRAPHY.

THE scientific event of last week was the description and demonstration of colour photography given by Prof. Lippmann before the Royal Society. On the occasion of the centenary celebrations of the Institute of France last year, Lord Kelvin invited Prof. Lippmann to give the Royal Society an account of his researches on photography in colours, and last Thursday's meeting was the result. The methods employed by Prof. Lippmann are well known among men of science, but few of the Royal Society were prepared to see such remarkable results as those obtained and exhibited by the distinguished French physicist. The honour and fine feeling which such visits bring to the Society, and the extreme interest aroused, should help to make similar occasions of more frequent occurrence. We print Prof. Lippmann's lecture below, and our only regret is that it cannot give an at all adequate conception of the striking achievement with which it deals.

The problem of colour photography is as old as photography itself. The desire of fixing the colours as well as the design of the beautiful image thrown on the screen of the camera, very naturally occurred to the earliest observers. Since the beginning of this century three distinct solutions of the problem have been realised.

The first solution, not quite a complete one, is founded on the peculiar properties of a silver compound, the violet subchloride of silver. E. Becquerel (1860) converted the surface of a daguerreotype plate into this silver compound, and by projecting on it the image of the solar spectrum, and other objects, obtained good coloured impressions. Poitevin substituted paper for the silver plate as a substratum. No other substance has been discovered that can play the part of the subchloride of silver. Moreover the image is not fixed, in the photographic sense of the word; that is, the coloured impression is retained for any length of time in the dark, but it is blotted out by the action of daylight. The reason of it is this: the Becquerel images are formed by coloured silver-compounds, which remain sensible to light; so that they are destroyed by the continued action of light, in virtue of the same action which gave them birth. Despite the numerous experiments made by Becquerel, Poitevin, Zenther, and others, no substance has been found that is capable of destroying the sensibility of the subchloride for light without at the same time destroying its colour.

The second method for colour photography is an indirect one, and may be called the three-colour method. It was invented in France by Ch. Cros, and at the same time by M. Ducos du Hauron (1869). German authorities claim the priority of the idea for Baron Bonstetten. Three separate negatives (colourless) are taken of an object through three coloured screens. From these three positives (equally colourless) are made; and, lastly, the colour is supplied to these positives by means of aniline dyes or coloured inks. Thus three coloured monochromatic positives are obtained, which by superposition give a coloured image of the model. In the ingenious process lately invented by Prof. Joly, the three negatives, and apparently the corresponding three positives, are obtained interwoven on one and the same plate. The three-coloured method can give a very good approximation to the truth, and has probably a great future before it. We may call it, nevertheless, an indirect method, since the colours are not generated by the action of light, but are later supplied by the application of aniline dyes or other pigments. Moreover, the choice of these pigments, as well as of the coloured screens through which the negatives have been obtained, is in some degree an arbitrary choice.

The third and latest method by which colour photography has been realised is the interferential method, which I published in 1891, and the results of which I beg to lay before you this evening. It gives fixed images, the colours of which are due to the direct action of the luminous rays.

For obtaining coloured photographs by this method, only two conditions are to be fulfilled. We want (1) a transparent grainless photographic film of any kind, capable of giving a colourless fixed image by the usual means; and (2) we want a metallic mirror, placed in immediate contact with the film during the time of exposition.

A mirror is easily formed by means of mercury. The photographic plate being first enclosed in a camera-slide, a quantity of mercury is allowed to flow in behind the plate from this small reservoir, which is connected with the slide by a piece of india-rubber tubing.[1] The slide is then adapted to the camera, and the action of light allowed to take place. After exposure the slide is separated from the camera, the mercury reservoir lowered so as to allow the mercury to flow back into it; the photographic plate is then taken out, developed and fixed. When dry, and examined by reflected light, it appears brilliantly coloured.

The sensitive film may be made either of chloride, iodide, or bromide of silver, contained in a substratum either of albumen, collodion, or gelatine. The corresponding developers, either acid or alkaline, have to be applied; the fixation may be cyanide or bromide of potassium. All these processes I have tried with success. For instance, the photograph of the electric spectrum now projected before your eyes, has been made on a layer of gelatino-bromide of silver, developed with amidol, and fixed with cyanide of potassium.

As you see, bright colour photographs may be obtained without changing the technique of ordinary photography; the same films, developers and fixators have to be employed; even the secondary operations of intensification and of isochromatisation are made use of with full success. The presence of the mirror behind the film during exposure makes the whole difference. From a chemical point of view nothing is changed, the result being a deposit of reduced silver left in the film, a brownish, colourless deposit. And yet the presence of a mirror during exposure causes the colourless deposit to show bright colours. Of course we want to know how this is done; we require to understand the theory of those colours.

We all know that colourless soap-water gives brilliant soap-bubbles; the iridescence of mother-of-pearl takes birth in colourless carbonate of lime; the gorgeous hues of tropical birds are simply reflected from the brownish substance which forms the feathers. Newton discovered the theory of these phenomena, and subjected them to measurement; he invented for the purpose the experiment called by the name of Newton's rings. Newton showed, as you know, that when two parallel reflecting surfaces are separated by a very short interval, and illumined by white light, they reflect only one of the coloured rays which are the constituents of white light. If, for instance, the interval between the reflecting surface is only $\frac{2}{10000}$ of a millimetre, violet rays are alone reflected, the rest being destroyed by interference; that is, the two surfaces send back two reflected rays whose vibrations interfere with one another, so as to destroy every vibration except that which constitutes violet light. If the interval between the reflecting surfaces be augmented to $\frac{3}{10000}$ of a millimetre, the destruction of vibration takes place for every vibration except that of red light, which alone remains visible in this case.

If we consider now this photograph of the spectrum, and especially the violet end of the image, we find that this is formed by a deposit of brown reduced silver. In the case of an ordinary photograph, this deposit would simply be a formless cloud of metallic particles; here the cloud has a definite, stratified form; it is divided into a number of thin, equidistant strata, parallel to the surface of the plate, and $\frac{2}{10000}$ of a millimetre apart. These act as the reflecting surfaces considered by Newton, and as they are at the proper distances for reflecting violet rays, and these alone, they do reflect violet rays.

The red extremity of the photograph is equally built up of strata which act in a like manner; only their distance intervals here amount to $\frac{3}{10000}$ of a millimetre, and that in the proper interval for reflecting red light. The intermediate parts of the spectral image are built up with intermediate values of the interval, and reflect the intermediate parts of the spectrum.

The appearance of colour is therefore due to the regular structure above described, imprinted on the photographic deposit. The next question is—How has this very fine, peculiar, and adequate structure been produced?

It is well known that a ray of light may be considered as a regular train of waves propagated through the ether, in the same way as waves on the surface of water. The distance between two following waves is constant, and termed the wave-length; each sort of radiation, each colour of the spectrum, being characterised by a particular value of the wave-length. Now, when a ray of light falls on a sensitive film, this train of waves simply rushes through the film with a velocity of about 300,000 kilometres per second; it impresses the film more or less strongly, but leaves no record of its wave-length, of its particular

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[1] The glass of the photographic plate has to be turned towards the objective, the film in contact with the metallic mirror.

nature or colour, every trace of its passage being swept out of form by reason of its swift displacement. The impression therefore remains both uniform and colourless. Things change, however, as soon as we pour in mercury behind the plates, or otherwise provide for a mirror being in contact with it. The presence of the *mirror* changes the propagated waves into *standing* waves. The reflected ray is, namely, thrown back on the incident ray, and interferes with its motion, both rays having equal and opposite velocities of propagation. The result is a set of standing waves—that is, of waves surging up and down each in a fixed plane. Each wave impresses the sensitive film where it stands, thus producing one of these photographic strata above alluded to. The impression is latent, but comes out by photographic development. Of course the distance between two successive strata is the distance between two neighbouring waves; this, theory shows, is exactly half the wave-length of the impressing light. In the case of violet, for instance, the wave-length being $\frac{4}{10000}$ millimetres, half the wave-length in the above quoted distance of $\frac{2}{10000}$ millimetres; this, therefore, is at the same time the interval between two standing waves, in the case of violet light, the interval between two successive photographic strata, and at last it is the interval required to exist, according to Newton's theory, for the said strata reflecting violet rays, and making these alone apparent, when illumined by white light.

The colours reflected by the film have the same nature and origin as those reflected by soap-bubbles or Newton's rings; they owe their intensity to the great number of reflecting strata. Suppose, for instance, the photographic film to have the thickness of a sheet of paper (one-tenth of a millimetre), the fabric built in it by and for a violet ray is five hundred stories high, the total height making up one-tenth of a millimetre. Lord Rayleigh, in 1887, has proved *à priori* that such a system is specially adapted to reflect the corresponding waves of light.

How are we now to prove that the above theory is really applicable to the colour photograph you have seen? How can we demonstrate that those bright colours are due not to pigments, but to the interference, as in the case of soap-bubbles? We have several ways of proving it.

First of all, we are not bound to the use of a peculiar chemical substance, such as Becquerel's subchloride of silver; we obtain colours with a variety of chemicals. We can, for instance, dispense entirely with the use of a silver salt; a film of gelatine or coagulated albumen impregnated with bichromate of potash, then washed with pure water after exposure, gives a very brilliant image of the spectrum.

Secondly, the colours on the plate are visible only in the direction of specular reflection. The position of the source by which we illumine the photograph being given, we have to put the eye in a corresponding position, so as to catch the regularly reflected rays. In every other position we see nothing but a colourless negative. Now, as you are aware, the colours of pigments are seen in any direction. By projecting again a photograph of the spectrum, and turning it to and fro, I can show you that the colours are visible only in one direction.

Thirdly, if we change the incidence of the illuminating rays, that is, if we look at the plate first in a normal direction, then more and more slantingly, we find that the colours change with the incidence exactly as they do in the case of soap-bubbles, or of Newton's rings; they change according to the same law, and for the same reasons. The red end of the spectrum turns successively to orange, yellow, green, blue, and violet. The whole system of colours, the image of the spectrum, is seen to move down into the part impressed by the infra-red. This is what we expect to happen with interference colours, and what again we cannot obtain with pigments.

Fourthly, if while looking at the film normally, we suffer it to absorb moisture—this can be done by breathing repeatedly on its surface—we see that the colours again change, but in an order opposite to that above described. Here the blue end of the spectrum is seen to turn gradually green, yellow, orange, red, and finally infra-red, that is, invisible. The spectrum this time seems to move up into the ultra-violet part of the improved film. By suffering the water to evaporate, the whole image moves back into its proper place; this experiment may be repeated any number of times.

The same phenomenon may be obtained with Newton's apparatus, by slowly lifting the lens out of contact with the plane surface. The explanation is the same in both cases. The gelatine swells up when imbibing moisture. If we consider, for instance, the v of the spectrum, the small intervals between the strata, corresponding to violet rays, gradually swell up to the values proper for green, and for red, and for infra-red; green, then red, then infra-red, are therefore successively reflected.

We will wet this photograph of the spectrum with water, project it on the screen, and watch the colours coming back in the order prescribed by theory.

It is necessary to use a transparent film, since an opaque one, such as is commonly in use, would hide the mirror from view; the sensitive substance must be grainless, or, at least, the grains must be much finer than the dimensions of the strata they are intended to form, and therefore wholly invisible. The preparation of transparent layers gave me at first much trouble; I despaired for years to find a proper method for making them. The method, however, is simply thus: if the sensitive substance (the silver bromide, for instance) be formed in presence of a sufficient quantity of organic matter, such as albumen, gelatine, or collodion, it does not appear as a precipitate; it remains invisible; it *is* formed, but seems to remain dissolved in the organic substratum. If, for instance, we prepare a film of albumeno-iodide in the usual way, only taking care to lessen the proportions of iodide to half per cent. of the albumen, we get a perfectly transparent plate, adapted to colour photography.

We want now to go a step further. It is very well for physicists to be contented with working on the spectrum, since that contains the elements of every compound colour; but we all desire to be able to photograph other objects than the spectrum—common objects with the most compound colours. We have again but to take theory as a guide, and that tells us that the same process is able to give us either simple or compound colours. We have then to take a transparent and correctly isochromatised film, expose it with its mercury backing, then develop and fix it in the usual way; the plate, after drying, gives a correct coloured image of the objects placed before the camera. Only one exposure, only one operation is necessary for getting an image with every colour complete.

A plausible objection was offered at first to the possibility of photographing a mixture of simple colours. The objection was this: a ray of violet gives rise to a set of strata separated by a given interval; red light produces another set of strata with another interval; if both co-exist, the strata formed by the red are sure to block out here and there the intervals left between the strata formed by the violet. Is it not to be feared that one fabric will be blurred out by the other, and the whole effect marred? The confusion would be still worse if we consider the action of white light, which contains an infinity of simple components; every interval here is sure to be blocked up.

Mathematical analysis, however, shows this objection to be unfounded; we have great complexity, but not confusion. Every compound ray, both coloured and white, is faithfully rendered. As an experimental proof of this, we will project on the screen photographs of very different objects, namely, stained-glass windows, landscapes from nature, a portrait made from life, and vases and flowers.

That the colours here observed are due to interference, and not to the presence of pigments, can be shown in the same way as with the spectrum. Here, again, we observe that the colours are visible only in the direction of specular reflection, that they change with the angle of incidence, that they change and disappear by wetting, and reappear by drying. Pigments remain equally visible and unaltered in colour under every incidence. If we attempted to touch up one of our photographs with oil or water-colours, the adulterated place would stand out on a colourless background by merely obscuring by diffused light. It is therefore impossible either to imitate or touch up a colour photograph made by the above described interferential method.

THE INFLUENCE OF ATMOSPHERIC AND OCEANIC CURRENTS UPON TERRESTRIAL LATITUDES.[1]

ALTHOUGH the following theorem should be implicitly contained in the formula for the rotation of a spheroid carrying a fluid on its surface, I have nowhere seen it explicitly stated.

Theorem.—Let an unconstrained, rigid sphere, with equal moments of inertia, be in a state of free rotation:

Let this sphere bear on its surface a sheet or sheets of continuous movable matter:

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[1] Reprinted from the *Astronomical Journal*, No. 371, Apri 6.