The Paradox of the Piano Player.

WHEN a number of notes in different parts of the keyboard of a pianoforte are struck by means of levers actuated by a common pneumatic pressure, it appears to be the universally prevailing belief that the only variations possible are those in which the whole chord is made to sound louder or softer by increasing or decreasing the pressure. It is commonly regarded as an impossibility to vary the *relative* intensities of the sounds produced by the various notes so as to make, *e.g.*, the bass parts sound louder and the treble softer, or *vice versâ*.

On the other hand, dynamical considerations suggest that the intensities of the sounds excited in the different strings of the piano depend, not only on the total pressure applied to the mechanism, but also on the way in which this pressure is made to vary during at least part of the interval from the instant at which the key is first touched to the instant at which the hammer leaves the strings. A short, sharp impulse suddenly cut off should produce its greatest effect on the notes of higher pitch, while a heavy, sustained or increasing pressure should make its effect most marked on the lower notes of the instrument. During the last few months, I have given considerable attention to the practical application of this theory, and the effects which I find it possible to produce, provided that the accentuation is performed at exactly the right instant of time, are most remarkable. The treble or bass parts may be made to stand out in so conspicuous a way as to make it difficult to believe that different notes of the chords are not struck by different human fingers. The matter opens up a wide field of discussion, and suggests considerable possibilities in the way of quantitative laboratory measurements. For the present, it may be sufficient to suggest that those of your readers who possess the new musical instruments of the twentieth century suitable for the purpose should, if they have not already done so, perform the experiment for themselves; they will soon be rewarded by being able to enjoy their music in a way they have never enjoyed it previously.

G. H. BRYAN.

Cost of Scientific Education in Germany and England.

I NOTICE, in the issue of NATURE of December 4, that you quote Mr. Holzapfel's letter to the *Times* on the cost of scientific education in Germany and England. Although, unfortunately, there can be no dispute as to the great difference between the fees charged in Germany and in England, I think it right that the fees of King's College should be correctly stated. The sum quoted by Mr. Holzapfel represents the charge made for chemistry and *physics*; for chemistry only it was 34*l*. 18*s*. for the year. I have no knowledge of the amount of instruction which the other son obtained for 7*l*. at Aachen.

WALTER SMITH, Secretary.

King's College, London, W.C., December 9.

THE REPRODUCTION OF COLOURS BY PHOTOGRAPHY.

THE services which photography has rendered to science are now well recognised, and its value for urposes both of observation and record is well known and admitted. It is probably not so well known that methods now exist by which not only the form, but the colour, of natural objects can be represented with approximate fidelity. We are fortunate in being able to illustrate this fact by a plate giving some excellent reproductions of birds' eggs, produced under the superintendence of Mr. H. E. Dresser, entirely by photographic methods, and without the intervention of an artist.

There is no need to dwell on the value of such work. For many scientific purposes it is as important to record colour as shape, and if this can be done in a trustworthy manner, a new and useful power is placed at the disposal of the teacher of science and of the writer of scientific books. The difficulty about the three-colour process of photography is that it is extremely difficult to make certain that the colours are reproduced with sufficient accuracy for scientific work. Accuracy enough for pictorial purposes is easily attained, but absolute truth to nature is quite another thing. The reasons for this are various. The photographic gradation of light intensities, in the case of both white light and of its various components, is generally different from the visual gradation, and even if accuracy is ensured in a narrow range of tones, it is hardly possible to make certain of its being secured in wider ranges. Another difficulty is that pigments have to be employed, and such pigments can never, of course, give pure colours. The consequence of this is that in the production of the picture it is necessary to vary the intensity of the different colouring agents employed until a satisfactory result is obtained. There is thus considerable room for judgment and dexterity, and the final result is not automatic, but depends on the artistic skill of the person who produces the picture. The whole process is, it must be admitted, of the character of a makeshift, but at the same time, when carefully employed it is a makeshift of considerable practical use.

Mr. Dresser, in the article printed below, deals only with the representation of natural objects for purposes of book illustration. An equally valuable application of the process is for the production of lantern slides for purposes of demonstration, and, as many of our readers are well aware, the process is beginning to be largely used for such purposes. A lantern slide coloured by hand is at best but a poor thing, and though a few very skilful operators—such as Mr. Cyril Davenport, of the British Museum—have by a combination of microscopic sight and great deftness of manipulation succeeded in producing some remarkable results, even these will hardly stand the large amount of magnification required by the lantern. Now a slide made by the three-colour process will stand as much enlarging as any ordinary photographic slide, and will give a reasonably close approximation to the natural colours of the subject. The process is applicable to any specimen which can be photographed. Excellent reproductions of microscopic objects have thus been produced; botanical specimens, birds, beetles and butterflies have all been rendered with great beauty and with really close accuracy to nature. Those who were present at Prof. Poulton's lectures at the Royal Institution last session had the opportunity of admiring the exquisitely coloured pictures he showed of insects, all produced by the process, which, first practically demonstrated by Mr. F. E. Ives, has since been further developed by Mr. Sanger Shepherd and others in this country.

Although, as said above, absolute accuracy is very difficult, or even impossible, to ensure—certainly not by automatic means—it is not too much to say that any photographer ought, after a very little practice, to be able to produce useful and serviceable illustrations for lecture purposes if he is content with something which, though not perhaps the best possible, is infinitely superior to anything which can be produced by painting an ordinary monochrome lantern slide.

Mr. Dresser in his remarks places, perhaps, needless stress on the difficulties of the process, and we are not quite disposed to agree with him as to its unsuitability for many purposes which he mentions. Although the exposures he gives may have been necessary by reason of the conditions under which his pictures were produced—namely, the photographing of the objects life size through a ruled screen and by the use of daylight at a time of the year when the light is not very good—it is a very different matter when it is required to produce illustrations for the lantern. In an ordinary studio, the exposure may take from, say, three minutes to a quarter of an hour through the red screen, which of course takes the longest time, while for out-of-door views in bright sunshine, with a moderate aperture of the lens, it is a matter of seconds only.

As a supplement to Mr. Dresser's account of the work he has carried on, we have added a summary of the account of the process given by Sir Henry Trueman Wood at the Royal Society's conversazione last May, when the rationale of the process was demonstrated.

THE THREE-COLOUR PHOTOGRAPHIC PROCESS.

To produce a photograph in colour direct from nature has for many years past been the dream and cherished aim of many photographers, but, so far as I can ascertain, these efforts have not met with success. By a happy combination, however, of the camera and the printing press, the so-called three-colour process has been so far perfected as to have become a commercial success, and, though still, perhaps, in its infancy, bids fair to become a serious rival to chromolithography, not only on account of its accuracy, but also because of its cheapness. Moreover, in the case of a larger number of copies being required, the total cost is considerably below that of chromolithography.

Upwards of twenty years ago, when the publication of my "Birds of Europe" was drawing to a close, I commenced to collect materials for a companion work on the eggs of European birds. When, however, it arrived at a question of illustrations, I found that I could not get plates sufficiently well and cheaply executed by any then known process. Besides which I could find no artist who could reproduce eggs in water-colour satisfactorily, and indeed, at the present time, I know of only one, a Danish artist, who can paint eggs with sufficient accuracy, and he is at present engaged on the illustrations for the British Museum "Catalogue of Eggs." Nor can he copy all sorts of eggs correctly, for in some species the markings are so minute and varied that no artist could exactly reproduce them.

In 1900, however, I saw a plate of fruit, photographed directly from the object, without the intervention of an artist, and reproduced by the three-colour process, which gave me the idea that it would be specially suited for the reproduction of natural history objects, and I at once commenced a series of experiments to test it with the assistance of Mr. I. D. Geddes, manager to Messrs. André and Sleigh, Ltd., of Bushey, Herts, and to his active cooperation I am indebted for the success that has crowned my endeavours. To produce the coloured picture three negatives are made from the objects on specially sensitised plates, which are exposed through "light filters" placed behind the lens. These filters separate out the colours of the objects into what are known as the primary colours—approximately red, blue and green. The negatives so obtained are then employed in the usual manner for the production of half-tone blocks—that is to say, each of the three pictures representing the separated red, blue and green images are etched as type blocks on copper for printing in the ordinary press, and it must be noted that the pictures as engraved on the copper blocks are made up of very fine dots. The plates are printed in the colour complementary to that of the filter through which each was taken, *i.e.* the red-filter picture in blue, the green in red and the blue in yellow. The printing of the plates is effected on three presses, one for each colour; the yellow image is first printed, then the red over the yellow printing, and, lastly, the blue over the red and yellow, and in each case the colour is allowed to dry before the next colour is printed. The registration of one colour over the other must be accurate, otherwise a blurring of the whole picture occurs. The colours used for printing are mixed each to a standard tint, which is only departed from in very exceptional cases.

The length of exposure for the process varies very much according to the conditions. As carried out for me by Messrs. André and Sleigh, in which the pictures were taken with a light-filter, a prism and a ruled screen interposed, the exposures were very long, the blue, approximately, ten to fifteen minutes, the green thirty to forty minutes, and the red nearly two hours. This process is eminently adapted for the copying of paintings, but the sole aim of the experiments made has been with a view to reproduce natural history objects, and more especially eggs, without the intervention of an artist.

Mammals cannot be photographed from living examples, as the exposure required is too long, and can only be done from paintings, for the reproductions are so very accurate that if photographed from stuffed specimens it is painfully apparent that they were stuffed. The same may be said with regard to birds, but when photographed from well-stuffed skins every character is most accurately reproduced, and such plates are consequently of extreme scientific value. Some fishes and crustaceans retain their colours for some time after death, whereas others fade almost immediately; the former of these can in most cases be reproduced from the specimens direct, but as regards the latter it will be necessary to employ an artist.

Shells of all kinds are specially adapted for this process, as colour-photography brings out even the bright iridescent colourings so characteristic of some species.

Flowers and plants, however, present serious difficulties, owing also to the long exposure required. Cut flowers will move and fade, and growing plants are sure also to move within three hours and thus spoil the pictures. Butterflies, moths and other insects can be photographed from the specimens direct if these are perfect, but they are often slightly damaged in catching, or in drying they become somewhat distorted, and any slight imperfection cannot be hidden, but is most faithfully reproduced; hence it is generally advisable to photograph from water-colour drawings of these objects.

Birds' eggs have chiefly occupied my attention, and with these I have been most successful, so much so that I purpose now to bring out my work on eggs, illustrated by this process from the eggs direct, without the intervention of an artist. At first I found a difficulty with the shadows, and tried the effect of a dark background; but as this took from the characteristic colours of some species, I had to revert to a pale background, and by degrees have overcome the difficulties, as will be seen from the plate accompanying the present article. The eggs figured on this plate are as follows:—

Figs. 1, 2, 3, eggs of the Lesser Kestrel, *Falco cenchris;* Figs. 4, 5, eggs of the Honey Buzzard, *Pernis apivorus;* Fig. 6, egg of the Levant Sparrowhawk, *Astur brevipes;* Fig. 7, egg of the Shikra Sparrowhawk, *Astur badius;* Figs. 8, 9, 10, eggs of the Blackwinged Kite, *Elanus coeruleus.* All these specimens have been selected to show the greatest variation in these eggs, and also to test the process.

H. E. DRESSER.

PRINCIPLES OF THREE-COLOUR PHOTOGRAPHY.[1]

The reproduction of the camera picture in its natural colours is still an unsolved problem, for Lippmann's results can hardly be said to have passed the experimental stage. They still lack practical application. All that can be done by photographic means is to select and combine colours, so as to produce an approximately correct reproduction of the colours of any natural object. The colour itself must be provided by the use of dyes, stains or pigments.

The principal application of the three-colour process

[1] Subject-matter of a demonstration given at the conversazione of the Royal Society on May 14 by Sir H. Trueman Wood.

is for the production of printed illustrations, but for purposes of demonstration its application to the production of pictures for exhibition by the lantern is much more convenient. By the use of a triple lantern the light from a single source can be divided up into three beams. If in the path of the beams we place screens of coloured glass of colours corresponding with the three primary colour sensations—red, green and blue—we have, of course, a disc of each colour projected on the lantern screen. If by moving the lantern lenses the three discs are caused to overlap, the colours will be mixed and combined. Where all three colours overlap there will be a white patch. Where only two overlap there will be a patch caused by the combination of those two colours, and this of necessity will be complementary to the third. We have therefore on the screen a coloured pattern showing white, the three primaries and their three complementary colours.

If in front of each lens of the lantern we introduce a simple pattern cut out of black paper, we shall, when the three images are separated on the lantern sheet, get three coloured reproductions of the three patterns. If they are of a suitable shape and suitably arranged we can combine these into a variegated pattern on the screen. We may take, for instance, such a simple pattern as a half-circle; then if we arrange the three half-circles in such a way that they do not coincide when projected together on the lantern sheet, but combine and overlap so as to form one complete circle, this circle will be divided into six sectors, three of which will show the primary colours and the other three their complementaries.

This simple experiment shows that it is possible to get a coloured picture by means of a black and white pattern and the three coloured glasses. In it, however, only the complementary colours are shown, because equal amounts of the primaries are combined. To get other tints, varying amounts of one or more of the component colours have to be used. Experimentally this is easily done by introducing in front of one of the lenses of the lantern an optical wedge—a sheet of glass coated with a neutral-tinted film, graduated from transparency at one end to opacity at the other. By cutting out, say, more or less of the red, we get a series of browns, greyish blues, &c.; by diminishing the green we get salmon colour, yellow ochre, &c. By this means it is evident that any desired tint which the human eye can appreciate can readily be produced.

Now a picture is only a complicated coloured pattern, and if we can analyse a picture and resolve its colours into the three components, arranged in their proper shapes, the combination of these three components will reproduce the picture as regards both shape and colour. Such analysis is possible by photography. A photograph taken through a red screen gives us the red component, and by using blue and green screens the blue and green components can be obtained. It is to be remembered that these photographs are merely monochrome photographs. They are simply ordinary photographs taken by a portion of the light of the spectrum, instead of by the whole of it. Making positive prints from negatives thus produced and projecting them on the screen, they show like ordinary lantern slides, except that each picture looks rather incomplete. In the red-light picture blue objects are but faintly reproduced. In the blue-light picture the red objects appear but feebly. When the coloured glass screens are interposed in front of the monochrome positives we get three pictures coloured red, green and blue respectively, and a combination of these on the sheet shows the original object in all its varied colours.[1]

[1] The ingenious photochromoscope of Mr. Ives works on precisely similar principles, except that the three coloured pictures are combined in the eye of the observer, instead of on the lantern screen.

The use of the triple lantern, however, is not very convenient, and there are certain drawbacks to its employment, though it suggests a possible means for the production of kinematograph pictures in colour. This is not yet possible, but it is conceivable that photographic films might be made capable of taking instantaneous pictures through the coloured screens, and that mechanism of sufficient accuracy could be constructed to register a series of three such pictures on a screen, so that they might be shown in the way animated photographs are now shown.

For practical purposes it is more convenient if we can have our coloured pictures in the form of an ordinary slide, which can be shown in the ordinary single lantern. Now it is quite obvious that with a single lantern we cannot use three coloured screens, one in front of the other. In the triple lantern we are mixing coloured lights, adding colour to colour. The superposition of one screen upon another in a single lantern merely means that only those rays will pass which can get through both screens, and the three screens together in the lantern would, of course, obstruct all the light, and the result would be nothing but darkness. With the triple lantern we are using a method of addition; with a single lantern we must use a method of subtraction or absorption.

The end can, however, be attained by the use of a film of bichromated gelatin, coated on a celluloid support. The film is printed and washed in the usual manner of carbon printing. The resulting relief in colourless gelatin is then stained the complementary colour to that by which the negative was taken. The need for employing the complementary colour is not difficult to understand. The bright parts of the red-screen positive represent bright red light. The dark parts represent the absence of red light, red shadows. When the film is stained, the transparent parts take little or no stain, the denser and thicker parts take the stain in proportion to their thickness. They should therefore be stained the opposite to red, the complementary to red (it is convenient to think of it as "minus red"), or blue-green. So the green-screen print must be stained "minus green," or pink, and the blue-screen print must be stained "minus blue," or yellow.

If we now take the three films and put the blue film in the lantern, we get a blue picture on the sheet. Putting in front of this the yellow film, our picture becomes partly blue, partly yellow and partly green, and we have some accession of detail. Adding again to this the pink film, we get at once all the different colours of the original object, and the picture is recognised as a practically correct reproduction of the original.

If the three films, instead of being mounted in such a way that they can be shown in the lantern, are stripped from their supports and superposed one above the other on a sheet of white paper, we get a coloured picture suitable for use as a book illustration. This process is quite practical, but it is by no means easy, and, of course, it is useless for the production of large numbers. For commercial purposes no process can be of much service which is not applicable to the printing-press. Now it must be familiar to most people that a printing-block can be produced from any photographic negative. The methods by which this is effected are well known, and they are in constant use, the great bulk of the black and white illustrations in magazines and newspapers being now produced by them. It is, therefore, not difficult to see that if from each of our negatives we make a printing-block and use the three blocks to print—the blue-screen block in yellow ink, the green-screen block in red ink and the red-screen block in blue ink—we are merely varying the process by substituting films of printing-ink for films of stained gelatin. This is, indeed, in barest outline the method by which the very numerous coloured illustrations made by the three-colour process are all produced.