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Proceeding now to the question of development, I found that exposed films would develop in water at from 85 deg. to 95 deg. Fahr. It is true that they took over twenty minutes, but in no case was any difficulty met with. Personally, I have not met with any trouble from using water above 100 deg., and I think too much stress is laid by the makers on this point. On the other hand, it is as well to add to the water, if the tissue appears obstinate, some alkali, ammonia or soda, or, as I have already stated, common yellow soap acts well. These certainly permit of coaxing out an over-exposed or stubborn print.

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Gelatine	10 gms.	150 grs.
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2. To obtain a close approximation to the colour of the object photographed the lamina system must be of considerable depth and must be transparent. Neither of these conditions is fulfilled. The Lippmann film is very thin (not over .01 mm.) and strongly absorbing.

3. It appears from the micro-sections made by H. Lehmann[2] that the lamina system, owing to the scattering of the incident light and other causes, dies down much more rapidly than that predicted from calculation. The light reflected is therefore always less pure than that acting to produce the laminæ. The frequent resemblance of Lippmann pictures to tinted "ambrotypes" and Daguerrotypes may be explained by this general admixture of white.

4. From experiments made by H. Lehmann[3] on photographing two and three colours simultaneously it appears (and theoretical study of the lamina system resulting from mixed colours confirms) that mixed colours are rendered with a loss of luminosity of the components as compared with the rendering of the components alone.

It follows from this that if colours of different degrees of purity occur in an object photographed their reflective luminosities will be wrongly rendered. For instance, an area illuminated by a sodium flame and an area illuminated by a broad spectral region including red and green, while appearing the same colour to the eye, and adjusted to the same apparent brilliancy, would be rendered as of quite different brilliancies. Certain types of colours, such as those of some aniline dyes, in whose spectra two or more maxima occur, would suffer greatly in this respect.

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All of these facts impose obstacles to the complete success of the original Lippmann process. A detailed study of the rendering of mixed colours and the conditions essential for the best results is now being carried on by the writer and will be published in the near future. The above conclusions on the reproduction of colours of all types, have, however, been confirmed, and the recourse to the three-colour process as the means of rendering all kinds of colours faithfully (to the eye), while employing the Lippmann film, is the practical result.

The determining reason for this step is as follows:—The Lippmann process is, as seen above, not fitted to render all types of colours faithfully. For the three-colour process all that is needed are narrow spectrum bands; these the Lippmann film is thick enough and transparent enough to give.

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Proceeding now to the practical details as worked out. It is, of course, necessary to have a set of three-colour negatives or colour records. Each of these must represent the amount of one of the primary colours, red, green, and blue, necessary to mix with the proper amounts of the others to counterfeit to the eye the colour of the object photographed. The three-colour records used were positives made for the Krömskop.[4]

The first apparatus constructed consisted of an enlarging camera by means of which an image of any one of the three-colour positives was projected on the plate; a heliostat to send a beam of sunlight through positive and projecting lens, and an opaque line screen or grating in contact with the plate, having opaque spaces twice the width of the transparent. By means of this latter, one-third of the surface of the plate could be exposed at a time. For coloured light three-colour screens, identical with those used in the Krömskop were tried; a ruby-red glass, a pot-green glass, and a combined cobalt-blue and signal-green glass. These give narrow, well separated spectrum bands, quite pure enough to give the best results. The procedure was to make three exposures in succession, between each of which the three-colour positive was changed, the colour screen changed, and the opaque-line screen moved the width of a transparent space (one three-hundredth of an inch). The method is in all respects similar to that employed by the writer to produce diffraction colour pictures.[5]

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With this apparatus three-colour standing-wave pictures were obtained which compare favourably with the Krömskop, and have qualities rarely, if ever, seen in the ordinary Lippmann pictures. The colour and luminosity values are faithfully rendered and the peculiar metallic appearance so common in most interference pictures is entirely absent. They are not, of course, colour pictures taken directly in the camera, the ideal for which we aim, but they are faithful colour pictures produced by entirely photographic means; they are held in the hand to observe, and may be duplicated indefinitely. They do not fulfil the popular conception of a colour photograph so well as would Lippmann pictures taken directly in the camera, were the latter free from the unavoidable defects outlined above. They are perhaps the nearest we can come to a true colour photograph at present.

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Before leaving the question of the sensitiser, it is probably well known that a mixture of a bichromate and alcohol will not keep, so that too much should not be mixed at once.

The Temperature for Development.

Proceeding now to the question of development, I found that exposed films would develop in water at from 85 deg. to 95 deg. Fahr. It is true that they took over twenty minutes, but in no case was any difficulty met with. Personally, I have not met with any trouble from using water above 100 deg., and I think too much stress is laid by the makers on this point. On the other hand, it is as well to add to the water, if the tissue appears obstinate, some alkali, ammonia or soda, or, as I have already stated, common yellow soap acts well. These certainly permit of coaxing out an over-exposed or stubborn print.

Cementing the Constituent Prints.

This is a comparatively simple matter, yet there are pitfalls and possibilities of failure, and cases are not unknown in which the images some time after being finished have begun to separate. One correspondent suggested in the B.J. that this could be overcome by binding the edges of the print with lantern-slide binding strips; but I have seen a print begin to bubble in the middle.

This separation may be caused by squeegeeing too roughly, and thus forcing out too much of the cementing gelatine solution. I also believe that in some cases it is due to the use of chrome alum in this solution; this I consider quite an unnecessary addition; and further, the stripping may be caused by the gelatine solution becoming chilled, and thus no proper adherence being obtained.

A Stock Cementing Solution.

I have entirely discarded the makers' formula, in the first place because I am particularly lazy and object to have to make the solution up fresh every time, and secondly, because I think I get better results by my method, which at any rate gives me a solution that will keep. It is made as follows:—

Gelatine	10 gms.	150 grs.
Glacial acetic acid	10 ccs.	150 min.
Distilled water	240 ccs.	8½ oz.

Allow to soak for a short time, then heat in a water bath to 150 deg. Fahr., and add slowly and with constant stirring,

Methylated spirit	750 ccs.	26 oz.

If this is carefully done, no gelatine will be thrown out, or at least, it will not remain out of solution, though just at first it may come out as milky white threads. This solution keeps well, but must be heated before use, and I just paint it freely over the print, leave the same for a few minutes till the best of the spirit has evaporated and the surface becomes tacky, and then the next image, which is allowed to drain well and begin to get surface dry, is lowered into position. If the two films are not too dry there will be no difficulty in placing them in coincidence, and in even shifting them.

There need be no fear of reticulation of the wet image by the alcohol if the latter is allowed to evaporate sufficiently. If this is not done, and the upper image lowered at once, then slight reticulation may make its appearance.

It is not essential, however, to use a gelatine solution; white dextrine will answer just as well, probably also any adhesive almost could be employed.

When accurate register is obtained, the two images are not squeegeed together, but just ironed with a heavy flatiron that is nicely warmed—not hot—a piece of smooth, hard paper being placed over the celluloid to prevent any possible damage.

It is, of course, hardly necessary to say that before cementing the films down the rubber is carefully removed from each by gentle friction with a swab saturated with benzole, and this is done three times for each print.

Surfacing the Print.

Some objection has been raised to the half matt, half glossy appearance of the finished prints. To remove this, the old carbon worker's dodge of squeegeeing the finished print to collodionised matt opal glass may be adopted. It is probably quite unnecessary to say more than that the glass should be dusted with French chalk, excess brushed off, and then coated with any enamel collodion. When this has well set, it should be washed till all greasy marks have disappeared, then flowed over with a thin warm gelatine solution, or the above-mentioned alcoholic solution of gelatine may be used, provided more water is added, and the print squeegeed down and allowed to dry, when it will peel off with a very fine matt surface. A much easier method than this would obviously be to be able to paint the surface of the film with a varnish, which should dry matt and perfectly transparent.

A few experiments have been carried out in this direction, but up to the present I have failed to obtain a perfectly satisfactory varnish—that is, one that shall not dry milky, is perfectly hard, and yet adheres well. So far the best results have been obtained with ordinary enamel collodion with the addition of xylol. A more resistant film will be obtained, I believe, with celluloid instead of pyroxyline in the enamel collodion, but I have not yet had an opportunity to try it. The enamel collodion plus xylol gives a non-milky matt film, which is sufficiently transparent in a thin film.

E. J. Wall, F.R.P.S.

THREE - COLOUR INTERFERENCE PICTURES. IVES

[A communication from the physical laboratory of the John Hopkins University published in the "Physical Review.]

The subject of the following paper is an application of the Lippmann process to the production of three-colour pictures. The method consists in using a set of three-colour negatives to make a picture composed of juxtaposed coloured lines, red, green, and blue, after the manner of the Joly colour picture, substituting, however, the laminated structure of the Lippmann film for the pigments which impart colour to the true Joly picture. By this combination of the three-colour and standing-wave processes pictures are obtained by an indirect though wholly photographic means, possessing the fidelity of the best three-colour processes with advantages peculiar to the Lippmann picture. The colours are in the picture itself, so that no viewing device is necessary to render them visible, and from the original three-colour negatives an indefinite number of colour pictures can be made.

Up to the present Lippmann photographs of natural objects (as distinguished from spectra or monochromatic sources) have been

made directly in the camera. A departure from this simple and straightforward procedure of course needs ample justification. This will be found in a consideration of previous attempts to photograph mixed colours, such as those of natural objects, and the conclusions, both theoretical, and practical, to be drawn therefrom.

Essential Conditions of the Lippmann Process.

It has long been recognised that while spectra are easily and satisfactorily photographed by the Lippmann process, such objects as landscapes, still life, etc., are very difficult and rarely reproduce with great fidelity. The principal reasons therefore may be briefly summarised as follows:—

1. Complete isochromatism of plates is essential.

In photographing spectra with non-isochromatic plates all the colours may be made to give strong action by mere long exposure. Additional exposure of the photographically more active colours after their maximum effect is produced causes no increase of action within wide limits. In photographing natural objects recourse to long exposure to produce isochromatic action is obviously destructive of light and shade values, since these are rendered entirely by difference of exposure. The dependence of the best results on careful choosing of exposure has often been noticed.[1]

2. To obtain a close approximation to the colour of the object photographed the lamina system must be of considerable depth and must be transparent. Neither of these conditions is fulfilled. The Lippmann film is very thin (not over .01 mm.) and strongly absorbing.

3. It appears from the micro-sections made by H. Lehmann[2] that the lamina system, owing to the scattering of the incident light and other causes, dies down much more rapidly than that predicted from calculation. The light reflected is therefore always less pure than that acting to produce the laminæ. The frequent resemblance of Lippmann pictures to tinted "ambrotypes" and Daguerrotypes may be explained by this general admixture of white.

4. From experiments made by H. Lehmann[3] on photographing two and three colours simultaneously it appears (and theoretical study of the lamina system resulting from mixed colours confirms) that mixed colours are rendered with a loss of luminosity of the components as compared with the rendering of the components alone.

It follows from this that if colours of different degrees of purity occur in an object photographed their reflective luminosities will be wrongly rendered. For instance, an area illuminated by a sodium flame and an area illuminated by a broad spectral region including red and green, while appearing the same colour to the eye, and adjusted to the same apparent brilliancy, would be rendered as of quite different brilliancies. Certain types of colours, such as those of some aniline dyes, in whose spectra two or more maxima occur, would suffer greatly in this respect.

The Limitations of Lippmann Photographs.

All of these facts impose obstacles to the complete success of the original Lippmann process. A detailed study of the rendering of mixed colours and the conditions essential for the best results is now being carried on by the writer and will be published in the near future. The above conclusions on the reproduction of colours of all types, have, however, been confirmed, and the recourse to the three-colour process as the means of rendering all kinds of colours faithfully (to the eye), while employing the Lippmann film, is the practical result.

The determining reason for this step is as follows:—The Lippmann process is, as seen above, not fitted to render all types of colours faithfully. For the three-colour process all that is needed are narrow spectrum bands; these the Lippmann film is thick enough and transparent enough to give.

Lippmann Three-Colour.

Proceeding now to the practical details as worked out. It is, of course, necessary to have a set of three-colour negatives or colour records. Each of these must represent the amount of one of the primary colours, red, green, and blue, necessary to mix with the proper amounts of the others to counterfeit to the eye the colour of the object photographed. The three-colour records used were positives made for the Krömskop.[4]

The first apparatus constructed consisted of an enlarging camera by means of which an image of any one of the three-colour positives was projected on the plate; a heliostat to send a beam of sunlight through positive and projecting lens, and an opaque line screen or grating in contact with the plate, having opaque spaces twice the width of the transparent. By means of this latter, one-third of the surface of the plate could be exposed at a time. For coloured light three-colour screens, identical with those used in the Krömskop were tried; a ruby-red glass, a pot-green glass, and a combined cobalt-blue and signal-green glass. These give narrow, well separated spectrum bands, quite pure enough to give the best results. The procedure was to make three exposures in succession, between each of which the three-colour positive was changed, the colour screen changed, and the opaque-line screen moved the width of a transparent space (one three-hundredth of an inch). The method is in all respects similar to that employed by the writer to produce diffraction colour pictures.[5]

It was soon found that much purer colours must be used than those furnished by the colour screens, for this reason. The spectrum band by which the plate was illuminated, reproduced, as examination of the photograph in the spectroscope showed, as a much wider one. The triple-line pictures, therefore, instead of showing in the spectroscope three isolated bright bands, gave a continuous spectrum with slightly shaded spaces in the yellow and blue-green. This was confirmed by exposures with spectrum bands of varying width from a monochromatic illuminator. In all cases it was found on spectroscopic examination that these bands were rendered by broad, not sharply defined ones of from five to ten times the width of the original. The most monochromatic source then at hand a sodium flame was photographed, and the plate showed in the spectroscope a fairly narrow band, although some red and green light was still visible. Colours as pure as that obtained in this way would be quite satisfactory for three-colour work. Suitable red, green, and blue line sources were not at the time available, so, as the best that could be done, portions of the spectrum of about eighty A.U. width from a monochromatic illuminator were tried. The coloured light was thrown on the three-colour positive, which was placed directly in front of the opaque-line screen and the plate, and so cast a shadow.

With this apparatus three-colour standing-wave pictures were obtained which compare favourably with the Krömskop, and have qualities rarely, if ever, seen in the ordinary Lippmann pictures. The colour and luminosity values are faithfully rendered and the peculiar metallic appearance so common in most interference pictures is entirely absent. They are not, of course, colour pictures taken directly in the camera, the ideal for which we aim, but they are faithful colour pictures produced by entirely photographic means; they are held in the hand to observe, and may be duplicated indefinitely. They do not fulfil the popular conception of a colour photograph so well as would Lippmann pictures taken directly in the camera, were the latter free from the unavoidable defects outlined above. They are perhaps the nearest we can come to a true colour photograph at present.

Monochromatic Lights for the Process.

The defects of these new three-colour interference pictures so far made are due to the inadequate means at hand when the work was done. The coloured light used was not as monochromatic as was desired. The three bright strips of colour seen when one examines the photographs with the spectroscope are as a consequence rather wide and the spaces between not quite black, hence some degradation of colour values results. It is intended as soon as possible to make pictures by means of monochromatic light furnished by sources

[1] R. Neuhauss, "Die Farbenphotographie nach Lippmanns Verfahren," 1898, p. 45. "Das Bild giebt nur dann die Farben richtig wieder, wenn die Belichtungszeit richtig getroffen wurde. Halbfach Über- oder Unterexposition genugt schon vollständig die Platte zu verderben."

[2] "Beiträge zur Theorie und Praxis der directen Farbenphotographie," 1906, p. 81.

[3] L. c., p. 14.

[4] The Krömskop system is based on Maxwell's colour mixture diagram. The three negatives are made through colour screens which with the plates used give intensity curves that correspond to the Maxwell colour curves representing the three primary sensations. Those curves give the amounts of three narrow spectrum bands (near *C*, between *E* and *F*, between *F* and *G*) to mix to reproduce to the eye both the colour and luminosity values of all parts of the solar spectrum. The application of Maxwell's analysis to three-colour photography was first published by F. E. Ives in 1888.

[5] "Physical Review," June, 1906, p. 539, and B.J., August 3, 1906, p. 609.

such as the cadmium lines, and to make the triple (Joly) lines at least two hundred to the inch, so that they become practically invisible.

With these improvements the pictures should rank as one of the most perfect applications of the three-colour process.

The plates used were prepared according to the formula published by Valenta[6] with the exception that it was found necessary to double the quantity of gelatine; this may, however, have been due to the kind of gelatine used.[7] The pictures were mounted under a prism according to the usual method. To destroy all extra reflections possible the back of the glass and the lower surface of the prism were ground with emery before the application of asphaltum varnish to the one and Canada balsam to the other. It was further found advantageous to substitute gum styrax ($n = 1.58$) for Canada balsam in mounting the prism. By this the surface reflection from the film is less than with the balsam, and in addition (if the lower side of the prism is ground) a slight diffusion of light results so that the picture is visible through a wider angle, and the reflected image of the source of light (such as a gas flame) no longer well enough defined to be disturbing.

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