cent work of Professor George A. Hill with the prime vertical transit. There can be no question of the zeal and industry with which Mr. Hill has for five years continued a series of observations bearing on one of the most important problems in exact astronomy with which we are dealing to-day. Yet the results of his work so far as published show now and then anomalies and irregularities leading to the suspicion that there is something wrong about the instrument. The cause can be found only by critical investigation. It would certainly be very regrettable if such rare qualities as those of Mr. Hill should fail to be productive of their best results through adverse circumstances which would be speedily remedied under a proper system of administration; and we hope the Committee will either demonstrate that the suspected defects of the work are unreal, or show their cause if they exist.

THE DIFFRACTION PROCESS OF COLOR PHOTOGRAPHY.

THE production of color by photography has been accomplished in two radically different ways up to the present time. In one, the so-called Lippman process, the waves of light form directly in the photographic film laminæ of varying thickness, depending on the wave-length or color of the light. These thin laminæ show interference colors in reflected light in the same way that the soap bubble does, and these colors approximate closely the tints of the original. The technical difficulties involved in this process are so great that really very few satisfactory pictures have ever been made by it. The other, or three-color process, has been developed along several distinct lines; the most satisfactory results having been produced by Ives with his stereoscopic 'Kromskop,' in which the reproduction is so perfect that in the case of still-life subjects it would be almost impossible to distinguish between the picture and the original seen through a slightly concave lens. The theory of the three-color method is so well known that it will be unnecessary to devote any space to it, except to remind the reader of the two chief ways in which the synthesis of the finished picture is effected from the three negatives. We have, first, the triple lantern and the Kromscope, in which the synthesis is optical, there being a direct addition of light to light in the compound colors, yellow being produced, for example, by the addition of red and green. The second method is illustrated by the modern trichromic printing in pigments. Here we do not have an addition of light to light, and, consequently, cannot produce yellow from red and green, having to produce the green by a mixture of yellow and blue. Still a third method, that of Joly & McDonough, accomplishes an optical synthesis on the retina of the eye, the picture being a linear mosaic in red, green and blue, the individual lines being too fine to be distinguished as such.

The diffraction process, which I have briefly described in the April number of the London, Edinburgh and Dublin *Philosophical Magazine*, is really a variation of the three-color process, though it possesses some advantages which the other methods do not have, such as the complete elimination of colored screens and pigments from the finished picture, and the possibility of printing one picture from another. The idea of using a diffraction grating occurred to me while endeavoring to think of some way of impressing a surface with a structure capable of sending light of a certain color to the eye, and then superposing on this a second structure capable of sending light of another color, without in any way interfering with the light furnished by the first structure. This cannot, of course, be done with inks, since if we print green ink over red the result will not be a mixture of red light and green light, but almost perfect absence of any light whatever; in other words, instead of getting yellow, we get black. Let us consider, first, how a picture in color might be produced by diffraction. Place a diffraction grating (which is merely a glass plate with fine lines ruled on its surface) before a lens, and allow the light of a lamp to fall upon it. There will be formed, on a sheet of paper placed in the focal plane of the lens, an image of the lamp flame, and spectra, or rainbow-colored bands, on each side of it. Now, make a small hole in the sheet of paper in the red part of one of these spectra. This hole is receiving red light from the whole surface of the grating; consequently, if we get behind the paper and look through the hole we shall see the grating illuminated in pure red light over its whole extent. This is indicated in Fig. 1, where we have the red

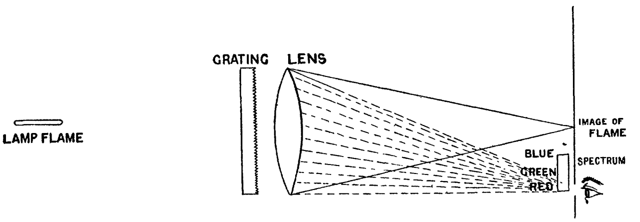

FIG. 1.

end of the spectrum falling on the hole, the paths of the red rays from the grating to the eye being indicated by dotted lines. Now, the position of the spectra, with reference to the central image of the flame, depends on the number of lines to the inch with which the grating is ruled. The finer the ruling the farther removed from the central image are the colored bands removed. Suppose, now, we remove the grating in Fig. 1, and substitute for it one with closer ruling. The spectrum will be a little lower down in the diagram, and, instead of the red falling on the hole, there will be green; consequently, if we look through the hole we shall see this grating illuminated in green light. A still finer ruling will give us a grating which will appear blue. Now, suppose that the two first gratings be put in front of the lens together, overlapping, as shown in Fig. 2. This

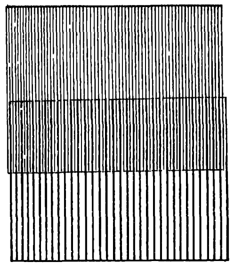

FIG. 2.

combination will form two overlapping spectra, the red of the one falling in the same place as the green of the other, namely, on the eye-hole. The upper strip, where we have the close ruling, sends green light to the eye and appears green; the under strip, with the coarser ruling, sends red light to the eye and appears red; while the middle portion, where we have both rulings, sends both red and green light to the eye, and in consequence appears yellow, since the simultaneous action of red and green light on any portion of the retina causes the sensation of yellow. In other words, we have, in superposed diffraction gratings, a structure capable of sending several colors at once to the eye.

If we add the third grating we shall see the portion where all three overlap illuminated in white, produced by the mixture of red, green and blue light.

Three gratings, with 2,000 lines, 2,400 lines and 2,750 lines to the inch, will send red, green and blue light in the same direction, or, in other words, to the same spot on the screen behind the lens.

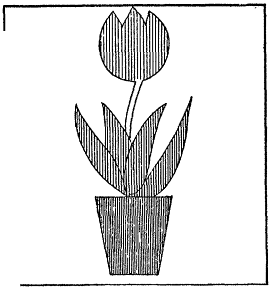

FIG. 3.

Suppose, now, we have a glass plate with a design of a tulip, with its blossom ruled with 2,000 lines to the inch, its leaves ruled with 2,400 and the pot in which it is growing ruled with 2,750 lines, and place this plate before the lens. On looking through the hole we shall see a red tulip with green leaves growing in a blue pot. Thus we see how it is possible to produce a colored picture by means of diffraction lines, which are in themselves colorless. Those portions of the plate where there are no lines send no light to the eye and appear black.

We have, now, to consider how this principle can be applied to photography. That photographs which show color on this principle can be made depends on the fact that a diffraction grating can be copied by contact printing in sunlight on glass coated with a thin film of bichromated gelatine. The general method which I have found best is as follows. Three gratings ruled on glass with the requisite spacing were first prepared.* To produce a picture in color, three negatives were taken through red, green and blue color filters in the usual manner. From these three ordinary lantern-slide positives were made. A sheet of thin plate glass was coated with chrom gelatine, dried, and cut up into pieces of suitable size; one of these was placed with the sensitive film in contact with the ruled surface of the 2,000-line grating, and the whole covered with the positive representing the action of the red light in the picture. An exposure of thirty seconds to sunlight impressed the lines of the grating on the film in those places which lay under the transparent parts of the positive. The second grating and the positive representing the green were now substituted for the others and a second exposure was made. The yellows in the picture being transparent in both positives, both sets of lines were printed superposed in these parts of the picture, while the green parts received the impression of 2,400 lines to the inch only.

The same was done for the blue, and the plate then washed for a few seconds in warm water. On drying it appeared as a colored photograph when placed in front of the lens and viewed through the hole in the screen. Proper registration during the triple printing is secured by making reference marks on the plates. A picture of this sort once produced can be reproduced indefinitely by making contact prints, since the arrangement of the lines will be the same in all of the copies as in the original. The finished picture is perfectly transparent and is merely a diffraction grating on gelatine with variable spacing. In some parts of the picture there will be a double grating, and in other parts (the whites) there will be a triple set of lines. Having had some difficulty in getting three sets of lines on a single film in such a way as to produce a good white, I have adopted the method of making the red and green gratings on one plate and the blue on another, and then mounting the two with the films in contact. It is very little trouble to multiply the pictures once the original red-green grating picture is made.

The pictures are viewed with a very simple piece of apparatus shown in Fig. 4,

*These gratings were ruled for us on the dividing engine at Cornell University, through the courtesy of Professor E. L. Nichols.

consisting of a lens cut square like a reading glass, mounted on a light frame provided with a black screen perforated with an eye hole through which the pictures are viewed.

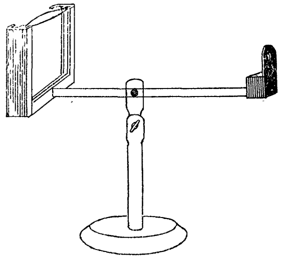

FIG. 4.

The colors are extremely brilliant, and there is a peculiar fascination in the pictures, since, if the viewing apparatus be slowly turned so that its direction with reference to the light varies, the colors change in a most delightful manner, giving us, for example, green roses with red leaves, or blue roses with purple leaves, a feature which should appeal to the impressionists. The reason of this kaleidoscopic effect is evident, for, by turning the viewing apparatus, we bring the eye into different parts of the overlapping spectra.

It is possible to project the pictures by employing a very intense light and placing a projecting lens in place of the eye behind the perforation in the screen. Of course, a very large per cent. of the light is lost; consequently great amplification cannot well be obtained. I have found that sunlight gives the best results, and have thrown up a three-inch picture on a four-foot sheet, so that it could be seen by a fair-sized audience.

By employing a lens of suitable focus it it possible to make the viewing apparatus binocular, for similar sets of superposed spectra are formed on each side of the central image by the gratings, so that we may have two eyeholes if the distance between the spectra corresponds to the interocular distance.

It is interesting to consider that it is theoretically possible to produce one of these diffraction pictures directly in the camera on a single plate. If a photographic plate of fine grain were to be exposed in succession in the camera under red, green and blue screens, on the surfaces of which diffraction gratings had been ruled or photographed, the plate on development should appear as a colored positive when seen in viewing apparatus. I have done this for a single color, but the commercial plates are too coarse-grained to take the impression of more than a single set of lines. With specially-made plates I hope to obtain better results.

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THE MENTAL FATIGUE DUE TO SCHOOL WORK.

THE meaning of the results obtained by the different investigators of fatigue among school children has been much confused because either the experimenter has not proved that what he measured was fatigue at all or has so arranged his experiments that the influence of practice on the one hand, and of unwillingness and lack of interest on the other, have not been discounted. Especially when, as has so often been the case, the teacher gives the work as a part of the school routine one may be measuring only a conventional habit of the school children of doing less at a certain time of day, or an unwillingness to work due to ennui. What a person *does* do need not be a measure of what he *could* do.

The experiments a summary of which follows were devised in order to get an answer to the question: "Does the work of a school-session fatigue the pupils mentally, make them really less able to do mental work than they were at its commencement, and, if so, to what extent?"

The method was to give to a sufficient