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Some Notes on Maxwell's Colour Photograph

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ABSTRACT. An investigation of Maxwell's famous demonstration of three-colour photography in 1861 reveals that the picture he projected was in fact based on three-colour separation negatives in spite of the fact that the photographic material was not sensitive to either green or red. The filters used gave colour separation in the blue and ultra-violet. The reason he obtained red separation correctly seems to be due to the fact that the red cloth he used had a secondary reflectance band in the ultra-violet as do most red cloths available today

JUST over 100 years ago J. Clerk Maxwell enlisted the services of a well-known if somewhat controversial expert on photography to help him with a lecture he was preparing for the Royal Institution. The person thus engaged was Thomas Sutton, teacher and lecturer on photography and editor of *Photo News*, a lively but short-lived publication concerned with photography and lenses. Sutton himself later designed a wide-angle lens remarkable for its time.

As nearly as one can judge from the few published statements, the task which Maxwell set for Sutton was to help him prove two points for his lecture, by means of photography. The first point was that all colours (hues) could be produced by the use of just three colours of light and hence if a scene were broken into three colours it could be reassembled. (Maxwell had suggested the possible use of photography for three colour synthesis several years earlier.) The second point was that green and not yellow was the best choice to go with red and blue for such a task. The burden of his famous lecture was not so much the trichromatic nature of visual facts as such—since this was fairly well known at the time—but the fact that green and not yellow was the centre member of the trio.

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In pursuance of his engagement Sutton[1] placed "a bow made of ribbon, striped with various colours" on a piece of black velvet, took it and his camera into the sunlight and proceeded to photograph it by blue, green, yellow and red light.

(It apparently was Maxwell's contention that the yellow would act like a combination of the green and the red.)

In so doing he produced the colour separation pictures which subsequently, in Maxwell's lecture, became the world's first trichromatic colour photograph. He also bequeathed to posterity a pretty little technical problem in that the photographic materials that he used for the purpose were sensitive only to the extreme *blue* end of the spectrum and had no sensitivity *at all* for spectral green, yellow or red.

As we approach the centennial of their public display, it seems appropriate to reconsider what actually occurred. It does not detract from the fact that the result was the first three-colour photograph, to inquire how it happened to be successful. The fact[2] is that "When these (projected separation positives) were superposed, a coloured image was seen, which, if the red and green images had been as fully photographed as the blue, would have been a truly coloured image of the ribbon." Sutton says "was produced in the natural colours."

The photographic material used by Sutton was wet collodion in which the sensitive material is silver iodide. While the actual wavelength sensitivity of wet collodion does not appear to have been published (probably because of its extremely low sensitivity at any wavelength) the sensitivity to light of silver iodide in other media is well known[3]. It is sensitive from the shortest wavelengths to about 430mμ, where it cuts off sharply; there is no sensitivity at all for wavelengths longer than about 430mμ in the extreme blue.

To get his colour separation Sutton used for the red, green and blue filters glass cells filled with liquids well known to chemists of the time, and for the yellow a piece of "lemon-coloured glass." The yellow glass we cannot identify but its exact nature is rather incidental to the present problem. The other colours we have from Sutton's own description.

"The experiments were made out-of-doors, in a good light, and the results were as follow:—

1st. A plate-glass bath, containing the ammoniacal sulphate of copper which chemists use for the blue solution in the bottles in their windows, was first placed immediately in front of the lens. With an exposure of six seconds a perfect negative was obtained. This exposure was about double that required when the coloured solution was removed.

2nd. A similar bath was used, containing a green solution of chloride of copper. With an exposure of twelve *minutes* not the slightest trace of a negative was obtained, although the image was clearly visible upon the ground glass. It was therefore found advisable to dilute the solution considerably; and by doing this, and making the green tinge of the water *very* much paler, a tolerable negative was eventually obtained in twelve minutes.

3rd. A sheet of lemon-coloured glass was next placed in front of the lens, and a good negative obtained with an exposure of two minutes.

4th. A plate-glass bath, similar to the others, and containing a strong red solution of sulphocyanide of iron was next used, and a good negative obtained with an exposure of eight minutes."

"The thickness of fluid through which the light had to pass was about three-quarters of an inch."

"The negatives taken in the manner described were printed by the Tannin process upon glass, and exhibited as transparencies. The picture taken through the red medium was at the lecture illuminated by red light,— that through the blue medium by blue light,—that through the yellow medium by yellow light,—and that through the green medium by green light; and when these different coloured images were superposed upon the screen a sort of photograph of the striped ribbon was produced in the natural colours."

(In spite of Sutton's statement above, it is quite clear from other sources that the positive from the yellow filter was *not* used by Maxwell in his demonstration at the lecture.)

In 1940 Dr. D. A. Spencer[4] wrote that he had found through Sir William Pope that the original positives used by Maxwell were still in existence at the Cavendish Laboratories. Spencer borrowed these positives and published a colour reproduction of the projected appearance of the picture in the above cited article. In this reproduction are seen reds, greens, blues and purples and the background is distinctly green.

In pursuance of our problem (since Spencer's copies had been destroyed during the war) copy positives were obtained by the writer through the courtesies of Dr. Spencer, the Cavendish Laboratories and Kodak Limited.

Since the chemicals of the filter solutions and the times of exposure were known, all that was needed to repeat the "curious experiments which our readers will like to hear about" (Sutton) was a photographic material having the same sensitivity distribution as wet collodion. This material was kindly supplied to the writer by Dr. Burt Carroll of the Kodak Research Laboratories, Rochester.

This new material, of course, was of a different "speed" than that used by Sutton, but Sutton had carefully noted that with the blue filter the exposure was twice that *without any* filter. This is the necessary clue to the determination of all concentrations, none of which were stated. (Sutton evidently was no chemist.)

Accordingly, successive trial exposures at different concentrations were made for each of the three solutions until the *ratios* of all exposures were the same as those used by Sutton. The blue concentration was altered until it took twice the exposure time required without a filter to get a "perfect negative." The concentration of the green copper chloride was decreased (to "*very* much paler") until a "tolerable negative was eventually obtained," at 120 times that of the blue filter exposure. Similarly the red solution was modified until a "good negative" was obtained with an exposure 80 times that of the blue.

It is interesting that copper chloride has since been used as the classical example of a solution that changes colour (from green toward blue) as the solution is diluted.

The fact that images were obtained at all, of course, indicates that *all* the filters transmit light of wavelength shorter than 430mμ.

Spectrophotometric curves were then run on all the solutions, as used, with the results shown in Fig. 1. At the left is shown the cut-off caused by glass of the approximate thickness of that in Sutton's lens. At 430mμ is shown the cut-off due to the film sensitivity. It is at once apparent that these filters rather neatly divide the blue and *ultraviolet* regions of the spectrum into three quite distinct bands, although the green is contained within the blue. They are separation filters but for the short wave rather

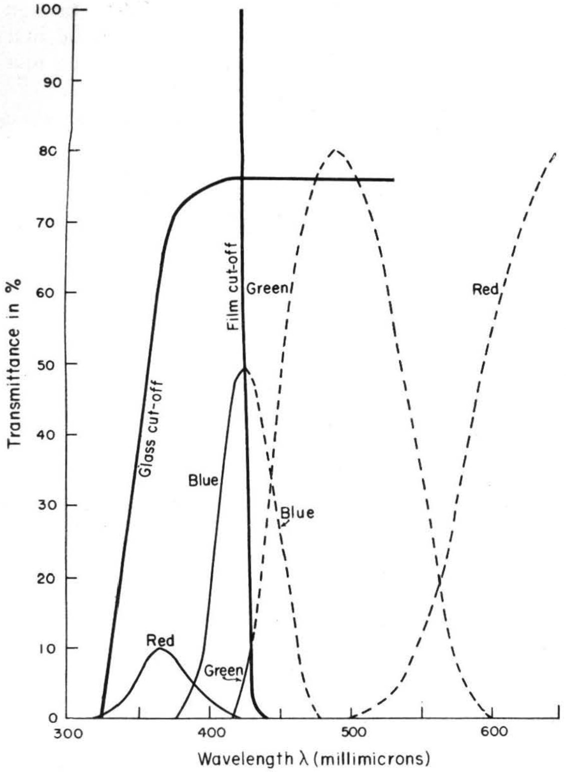

Fig. 1. Transmittance curves for the red, green and blue filters and the lens glass and a curve showing the long wavelength cut-off of the film (film sensitive to all shorter wavelengths).

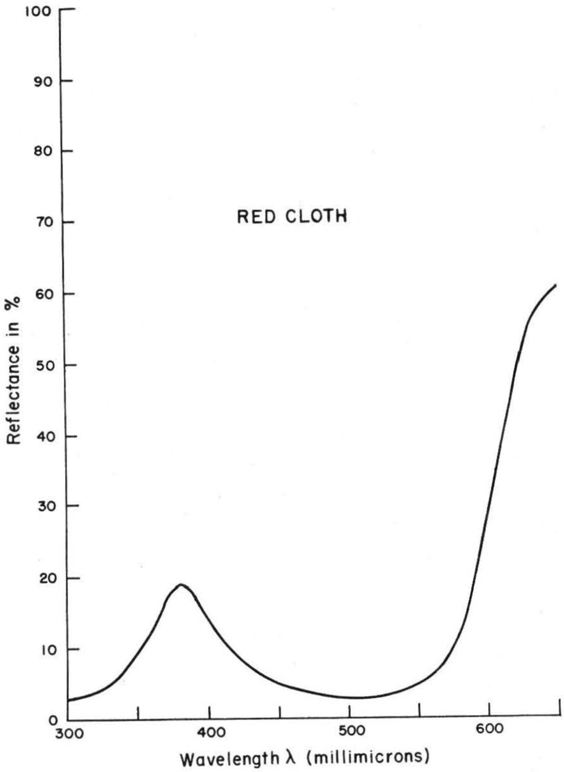

Fig. 2. Reflectance curve for a sample of red cloth.

than the visible spectrum. It must be remembered in looking at these curves that the green exposure was 120 times and the red 80 times the blue exposure. The curves shown have *not* been multiplied by these factors.

The blue is seen to cover the near ultraviolet and blue, and the green just reaches the longest wavelength blue to which the film is sensitive, but the red centres beyond the blue in the ultraviolet.

Now one can imagine the blues to be nicely separated from other colours and that a good green might be separated from blues or reds even though just barely for some blues, but how about the reds?

The identity of the tartan displayed by the ribbon has not been possible to established. Since the date of the work was only two or three years after the discovery of the first synthetic dye, there could have been only three or four red dyes available, but pure samples of these were not located. However, a systematic study of a considerable number of red-dyed materials has revealed that *nearly all* of them have a secondary reflectance region in the ultraviolet. A curve for such a material is shown in Fig. 2.

It is not too much to assume, therefore, that the red used by Sutton had a relatively high reflectance in the ultraviolet and, accordingly, photographed through his "red" filter much as it would have if his film were actually sensitive to red light.

In fact, using our versions of his filters, fairly good colour photographs with reasonably good reds were actually produced. This result was also checked using interference filters with narrow pass bands in the region 420mμ, 405mμ and 382mμ, for green, blue and red respectively.

Incidentally, it is interesting that had Sutton had true panchromatic materials his choice of filters would have been excellent! The slight ultraviolet transmission of the red would have done no harm, and the green form of copper chloride is an excellent green separation filter.

In addition to this actual separation into three colour regions it was apparent from Maxwell's positives that a number of other forces were at work to add colour to his picture. In the first place the "tolerable" green negative was obviously rather badly underexposed. In the second place it was apparent that the *contrasts* of the three negatives were quite different—a not unexpected effect considering the materials involved.

When projected on the screen with the projectors so balanced (through the same three filters) that the best colours were produced, these defects would add colours not otherwise present. For example, in Spencer's reproduction the "black velvet" comes out green.

Dr. Hunt of Kodak Limited reports that the Maxwell positives are very yellow. If this was true at the time the picture was projected, a still further variation of contrast would have been introduced. We cannot be certain of the light sources in his "magic lanterns" because an "electric lamp" was used as part of one of the other lecture demonstrations, but the typical "magic lantern" of the day was the famous lime-light in which a block of calcium carbonate was heated to incandescence by an oxy-hydrogen flame. (Imagine three of these with a bag of hydrogen and one of oxygen for each of them!) The colour temperature of this source was around 3000 K. and would have seemed quite blue. It is possible that electric carbon arcs powered by galvanic cells were used but the result would be much the same. In either case the yellow colour of the positives would have given a far higher contrast picture through the blue filter than through the red and the green would have been intermediate.

The effects obtained were not all due to contrast and density mismatches, however. The existence of true colour separation among the red, green and blue pictures was demonstrated by superimposing negatives of various contrasts made from say, the blue positive over each of the other two. This was done for all combinations. In no case was it possible to "blank out" the image with a negative from a different positive. There was less separation between the green and blue than between the blue and red as we would expect. Somewhat ironically considering Maxwell's main thesis, the yellow filter negative was essentially the same as the green, and probably could have been substituted for it with little change in the result.

It would seem, therefore, that the historical occasion had been reconstructed correctly and that Maxwell and his aide Sutton had in fact produced the first three-colour separation negatives and the first projected three-colour photograph.

A lingering doubt remained, however, that in some way it was possible for Sutton's collodion plates to have had some trace of red and green sensitivity. Indeed, it is now known that under certain unusual circumstances such sensitivities may occur even without using sensitizing dyes, which were not discovered until 1874.

These doubts were happily dispelled by a discovery made one day when studying the reproduced Maxwell transparencies.

In making the photograph Sutton had used "a portrait lens of full aperture." This could only have been a Petzval lens and this lens did not cover the plate used. That is, the image formed was restricted to a circle of somewhat smaller area than the plate. The discovery was that the diameters of these circles were not all equal. The blue positive had the smallest diameter, the green next, and the red the largest. It was apparent that Sutton had *refocused* for each colour of light and that for red light the lens had been farthest away from the plate.

At the same time it was apparent, as had been noticed earlier, that the red image was the *most out of focus* of the three images. He had *focused* by visual red but photographed by the invisible ultraviolet!

The pieces of the puzzle thus all fit together nicely, and we can say that Maxwell's ingenuity in devising a proof by the new technique of photography for an old theory of Young's on the three-colour nature of vision, coupled with Sutton's knowledge of photography and lenses, led to the invention and demonstration of colour photography some 20 years before it was "possible."

It is to be regretted that Maxwell did not feel the experiment was very successful, apparently because he could not then, as we can now, also demonstrate that yellow is not the correct primary for this kind of colour photography.

So Sutton concluded that green foliage could not be reproduced by photography; Maxwell was disappointed that photography did not demonstrate that green was the correct primary; and we conclude that Maxwell invented three-colour photography.

References

(1) Sutton, Thomas. "Photographic Notes," **6**, #125, June 15 (1861).

(2) *The Scientific Papers of James Clerk Maxwell*, J. Hermann, Paris, **1**, pp. 445 (1890).

(3) Mees, C. E. K. *The Theory of the Photographic Process*, 1st ed. The Macmillan Co., N.Y. (1942).

(4) Spencer, D. A. "The First Colour Photograph," Penrose Annual, p. 99 (1940), (with accompanying colour plate reproduction of the Maxwell picture).