Maxwell’s disappointment and Sutton’s accident

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Abstract

It has almost become somewhat of an urban legend or internet myth that James Clerk Maxwell created the first colour image and had demonstrated this at the Royal Institution in London in May 1861. He did present something, but what? In ‘The scientific papers of James Clerk Maxwell’ the experiment and resulting colour projection was regarded as a failure and barely mentioned. Thomas Sutton, a well-established and respected photographer, was tasked with carrying out Maxwell’s thought-experiment using the latest photographic processes. Sutton, himself author of various books on photography, does not mention the experiment in any of his publications. Move forward to the 1930’s and enter the photo-chemist Douglas Arthur Spencer, who gained access to the original lanternslides and made copies of the three colour separations. He made the first and only physical print of the 1861 tartan ribbon and it is this colour print that we now see everywhere as Maxwell’s first colour photograph. In 1961, the 100th anniversary, Ralph M Evans published a paper in Scientific American trying to solve the riddle of the famous tartan ribbon. The original glass plate photographs were made using the wet-collodion process which has a very narrow spectral sensitivity centred in the blue light wavelength. Sutton could not have recorded in the green and red part of the spectrum. Evans deduced from an experiment with modern materials that Sutton had possibly recorded the ultraviolet reflection present in the red of the tartan ribbon and “accidently” presenting itself as the red slide and the resulting image can be considered a ‘false colour’ image. Now, 160 years since that first experiment, we are exploring and executing some of the material and technical truths about wet-plate collodion and what might have actually been recorded and why is it that both Maxwell and Sutton regarded the experiment such a failure, but the rest of the world did not.

Keywords: Maxwell’s colour theory, colour photography, Wet-Collodion, optical spectra

Introduction

The paper is dedicated to Michael Berry’s interest in 19th century optics. The 19th century was a remarkable century for discovery and inventions (the twenties century looks slow compared to it), especially when it comes to optics, photography, and photomechanical reproduction. In this paper, we will discuss a scientific experiment which turned into a present-day urban legend: Maxwell’s first colour photograph. Based on Newton’s discovery (1) that light is a mixture of many wavelengths, Young (2) and Helmholtz (3) developed trichromatic colour theory (or Young-Helmholtz theory) stating that all human colour perception is based on three photoreceptors in the eye which are sensitive to overlapping blue, green and red wavelength ranges in the visible spectrum. Maxwell recognized that it should be therefore possible to capture colour on photographic plates by recording through red, green and blue colour filters (4). Today, no conference on colour starts without Maxwell’s first colour photograph, the tartan ribbon. The process works when modern materials are used (see Figure 1). But what happened really in 1861?

1.1 Historical context

In 1861 James Clerk Maxwell presented what is considered the first ever colour photograph. That story is, in fact, a lot more complex and many elements of it have been distorted and misinterpreted through innumerable retellings of this 160-year-old epic saga. May 17, 1861, Maxwell delivered a lecture at the Royal Institution in London, where he demonstrated, using a lantern slide projection, his theory for colour perception in the human eye via the additive colour process known today as RGB.

Figure 1: A street in Lacock. Recorded through Cokin red, green blue filters on black and white Fomapan 200, digitally reconstructed in Photoshop.

Three images from three separate slide projectors were projected onto a surface. The same colour filters with which they had been photographed were placed in front of each lens, the projections were then carefully realigned, and what has been called "the first colour photograph" was supposed to have been created. One would expect that a breakthrough of this magnitude being demonstrated publicly for the first time in history would attract attention of every contemporary scholarly publication and that even some of the daily newspapers would have covered it. There was virtually nothing written about it in the academic or popular press. One would also expect Maxwell to have written about the event himself, again, there is oddly little mention; it's relegated to a footnote in his collected writings: '…*By finding photographic materials more sensitive to the less refrangible rays, the representation of the colours of objects might be greatly improved*.'(5)

This lack of interest is what we consider Maxwell's great disappointment and perhaps it's why the event wasn't spoken of again for more than 35 years; when in 1896 Fredrick E. Ives revives interest in Maxwell to reference his own new invention the Photochromoscope (6).

The three images that constitute the original three separations are still in existence and reside at the Cavendish Laboratory of the University of Cambridge (Figure 2).They are contact prints of the original wet-collodion negatives.

Figure 2: Sutton's original lantern slides for Maxwell's lecture at the Royal Institution, presently at the Cavendish Laboratory in Cambridge.

These transparencies were created by the eminent and distinguished photographer Thomas Sutton, editor in chief of the publication *Photographic Notes* (1856-67) and inventor of the panoramic/wide angle lens and camera. Sutton was contracted by Maxwell to physically manifest his colour theory. There is no documentation regarding how this collaboration came about but one thing is clear – Maxwell was not a photographer, and these were not his photographs. This is a common source of confusion. On June 15th, a few months after the demonstration, Sutton published a very short explanation of how he created the transparencies used by Maxwell for his interested followers in the Photographic Notes. *'A bow made of ribbon, striped with various colours, was pinned upon a background of black velvet, and copied by photography by means of a portrait lens of full aperture, having various coloured fluids placed immediately in front of it and through which the light from the object had to pass before it reached the lens. The experiments were made out-of-doors in good light, and the results were as follows:-….' (7).* This is all we have from that evening in May 1861 – we do not have the ribbon, we do not have AN actual printed photograph, and we have no way of truly knowing what the re-aligned projected image looked like.

What then did Thomas Sutton create sometime in the spring of 1861? And was it a real tri-colour separation of that tartan ribbon? The prevailing theory is that Sutton captured a sort of tri-colour separation using wet-collodion - a colour-blind photographic emulsion - and, accidentally, luckily captured the ultra-violet reflectance of the red portions of the ribbon on the red slide (8).

1.2 The Wet-Collodion Process

In 1851 Archer (9) introduced collodion to the photographic world. It was meant to be an improvement on the imperfections of paper photography and an alternative to albumen. Collodion itself is not light sensitive (10) . It is a viscous solution of pyroxilin nitrocellulose or guncotton in ether and ethanol. It acts as a carrier and protective layer for light sensitive silver halide. When dry, collodion turns into a transparent, waterproof film. Wet-Collodion photography requires that the whole process, from plate preparation to fixing of the image must be done while the collodion layer is wet.

Table 1: Spectral sensitivity of different silver halides in wet collodion from (11)

AgX	Sensitivity range in nm	Maximal sensitivity in nm
AgI	UV – 437	420 – 425
AgI:AgBr, 2:1	380 – 527	425
AgI:AgBr, 1:1	380 - 530	440
AgBr	390 - 500	450

It means that the photographer must carry a darkroom with all necessary chemicals in addition to the camera. The short time between plate preparation, exposure and developing of the images means that the grain is extremely fine, invisible to the naked eye.

Sutton describes the necessary steps in (12):

1. The plate must be cleaned and polished
2. It is coated with iodized collodion
3. It is rendered sensitive to light
4. It is exposed in the camera
5. The image is developed
6. It is fixed and
7. varnished.

As a cleaning agent Sutton recommended nitric acid. He iodized the collodion with ammonium iodide and sensitized with silver nitrate (12). The photosensitive component is silver iodide which is not sensitive to wavelength longer than 440 nm (11). To render wet-collodion more suitable for photographic purposes, bromide salts were added from 1853 onwards.

We do not know which combination Sutton used in his experiment, but from Table 1 it is clear that he could not record any wavelength longer than 530 nm. He could not record red. The maximal sensitivity for all combinations lies in the blue. Figure 3 shows the blue shift of sensitized wet collodion films in comparison to a modern panchromatic black and white film.

What if instead of actually filtering differing wavelengths of colour Sutton merely created neutral density filters creating differences in exposure, not colour – such that that they could be separated into three distinct slides, and created a false tri-colour image?

The experiment

2.1 *The filters*

Maxwell's idea how to record colour with the help of a black and white emulsion is based on the Young-Helmholtz theory. The human eye has four types of detectors: three for colour, the cones, and one for intensity only, the rod. Figure 4 shows the spectral sensitivity of retinal cone cells. Originally the cone cells were called red, green and blue cells.The names have changed to S, M and L for the short, medium and long wavelength range the cells are covering.

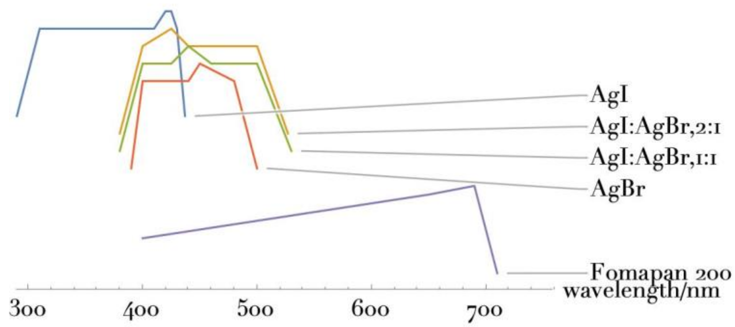

Figure 3: Spectral range of sensitized wet collodion films from table 1 and a modern panchromatic black and white film, Fomapan 200, based on (13)

These three colour channels of the eye led Maxwell to the idea that exposing three black and white photographic plates through a red, green and blue filter would record all information the brain needs to reconstruct a full colour image when the resulting lantern slides are illuminated through the same filters and projected on top of each other (see p. 284 of (4)). Sutton, task with the photographic realization, must have started out with dye solutions similar in density to modern colour separation filters as in Figure 5 . When recording through the filters, the exposure time is adapted to the transmittance of the filters to generate negatives of the same density, i.e. the exposure time through the blue and green filters must be twice as long as through the red filter.

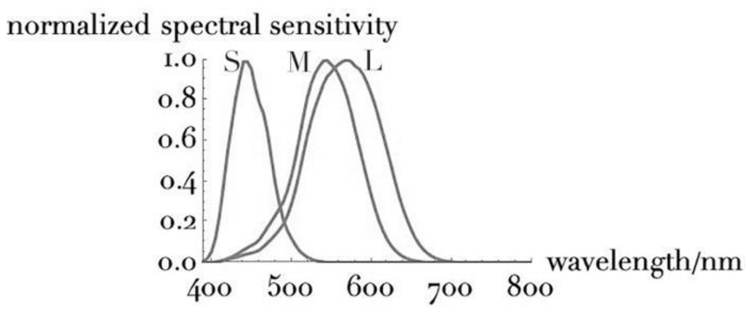

Figure 4: Normalized spectral sensitivity of cone cells based on (14)

Modern panchromatic film is certainly capable of recording intensities through all three filters, since they are sensitive to light in the visible range, see Figure 6.

It is different story for wet collodion plates. Figure 7 shows that wet collodion plates cannot record anything transmitted through a red filter and very little through a green filter. In a camera, the lens system will suppress UV light and the maximal recording range is about 380 to 530 nm. Sutton used dye solution as filters. He kept the density of the blue filter but used for the green and red filters dye solutions which he diluted until he saw images on the 'red' and the 'green' plate.

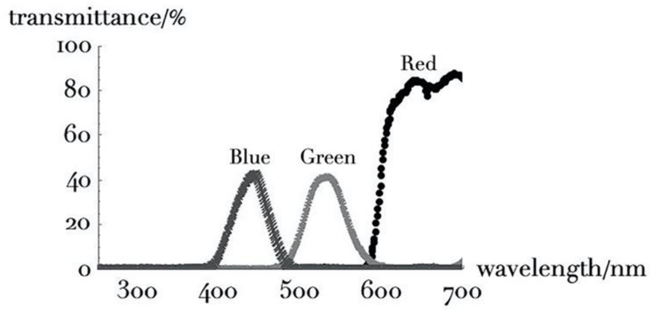

Figure 5: Transmittance through modern colour separation Lee filters: blue, green, and red

How much he diluted we will never know. His own words are rather vague: '…*It is impossible to describe in words the exact shades of colour or intensity of these solutions*.'(7) Instead of using dye solutions, we used Kodak colour compensating filters: for blue Wratten No47b, equicalent to the blue Lee colour separation filter, for green CC20G and for red CC20R. The choice is an educated guess based on the extensive experience of one of the authors with wet-collodion photography. From Figure 8 it is clear that the CC20G, the green filter, and CC20R, the red filter, are transmitting in the wavelength range from 290 to 530 nm where wet collodion plates record.

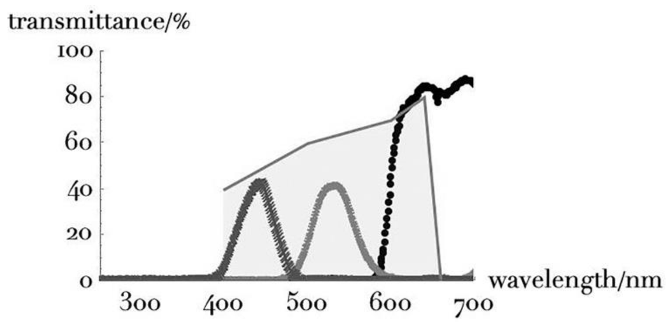

Figure 6 : Comparison of the transmittance of Lee colour filters and the spectral range of Fomapan 200 in arbitrary units.

In (8) Evans tries to explain the 'colour separation' in Suttons plates by ultra-violet reflections from any red dyestuff in the tartan ribbon which would be possible when such diluted filters are used. We are suggesting another explanation. Figure 8 shows that CC20G and CC20R act as neutral density filters in the spectral range from 290 to 470 nm. In that range the two curves are very similar to neutral density filters (Figure 9) , i.e. there is no colour separation. Therefore they could be replaced by neutral density filters without any loss of colour information. Only between 470 nm and 530 nm the transmittances of the 'diluted' colour filters start diverging,

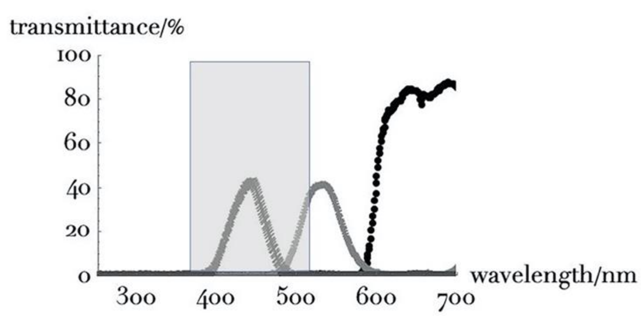

Figure 7 : Comparison of the transmittance of lee colour filters and the widest possible recording range for wet-collodion through a lens system (grey rectangle).

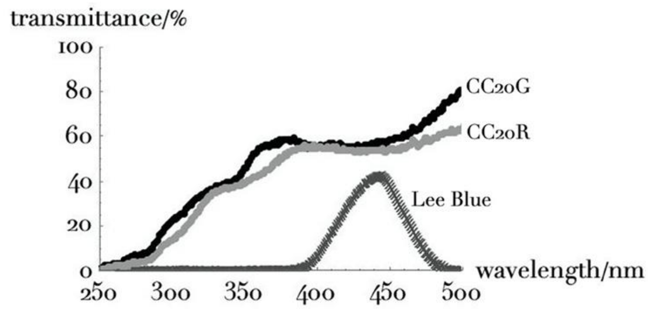

Figure 8: Transmittance in % of the Kodak colour compensating filters and the blue Lee colour separation filter used in the experiment.

To demonstrate that Sutton did not record a colour separation but generated a 'false' colour image by illuminating lantern slides recorded through the equivalent of different density filters, we recorded through Kodak ND0.1, ND0.6 and ND0.6+ND1.0 as well.

2.2 *The colour samples*

In order to test our assumption that Sutton did not produce a colour separation but a 'density' separation we prepared colour swatches by applying a thick layer of linseed oil based printing inks on off white Plike paper, a highly calendered 100% virging elemental cholorin free wood pulp paper.

For red we used: Van Son Pantone Red 032, Lawrence Crimson Red, Caligo Etching Naphtol Red RDC163599 and Van Son Process Magenta VS1631.

For green we used: French 88 Mid-Green, Van Son Forest Green and Van Son Pantone Green. For blue we used: Caligo Etching Ultramarine BLC124914, Caligo Relief Violet VLC171139, Van Son Pantone Blue 072 and Van Son Process Cyan VS1632.For yellow we used Van Son Process Yellow VS1630.

We measured the transmittance of the inks with an HP UV-vis spectrometer. For that the inks were thinly applied on microscop slides. Figure 10 shows that all inks except yellow transmit around 450 nm, i.e. should record on the Wet-Collodion plate.

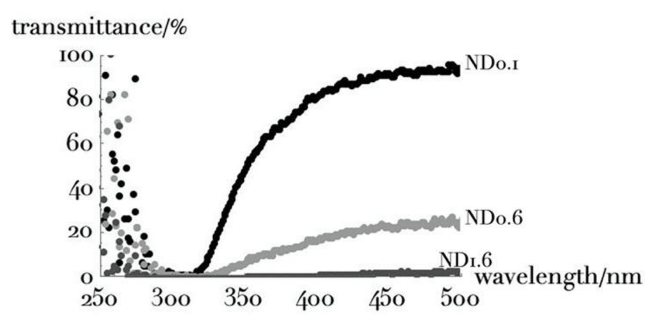

Figure 9: Transmittance of the neutral density filters which replace the Kodak colour compensating filters.

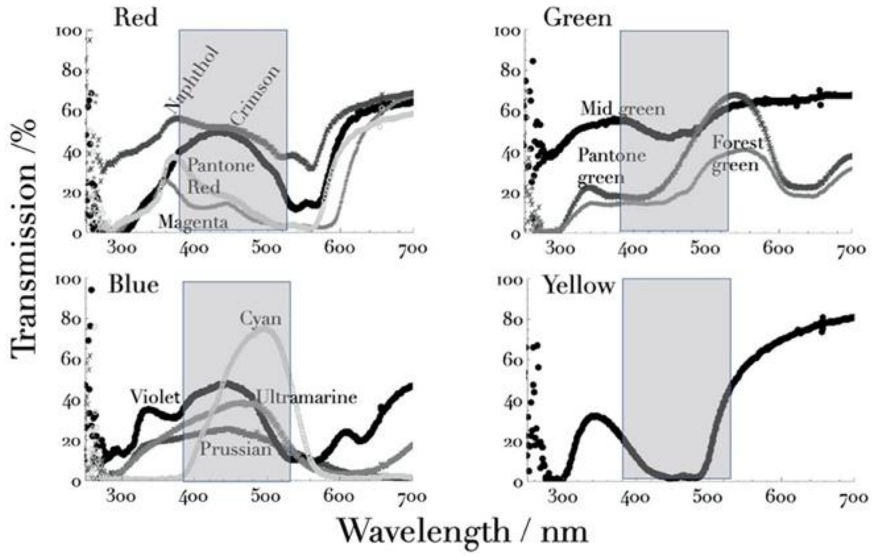

Figure 10: Transmittance of the inks used for the test swatches. The grey rectangle indicates the maximal recording range of wet-collodion through a lens system (380 to 530 nm).

2.2.1 Red inks. As can be seen in Figure 10 the red inks show transmission in the range 380 – 530 nm when applied in a thin layer on a transparent microscope slide. The thicker the layer of ink the more this transmission will be supressed in the recording range for wet-collodion. When the ink is applied as an opaque layer on paper, only Crimson Red reflects, not very much though, in the range where wet-collodion can record (Figure 11).
Let us assume that we have some reflection from red in the range from 380 to 530 mn. As an example we will look at Crimson Red. What would be the spectrum transmitted through the two filter sets, the 'diluted' Sutton filters and the neutral density filters. In Figure 12a) we have caluclated the transmittance of Crimson Red through the blue Lee colour separation filter, the Kodak colour correction filtes CC20R and CC20G by multiplying the spectrum in Figure 10 with the normalized transmittance of the spectra in Figure 8. The spectra through CC20R and CC20G in the range between 380 and 530 nm are almost identical. It means that no decernable colour information is encoded since the intensities on the 'red' and the 'green' plate are not shifted by any band width of the filters.

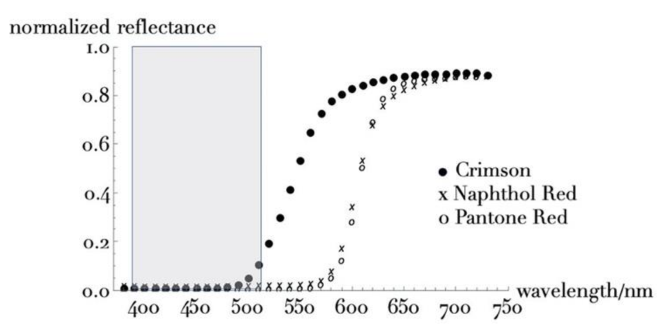

Figure 11: Normalized reflectance from red printing inks applied as an opaque layer on off white Plike paper, measured with X-Rite i1 Profiler. The grey rectangle indicates the maximal recording range of wet-collodion.

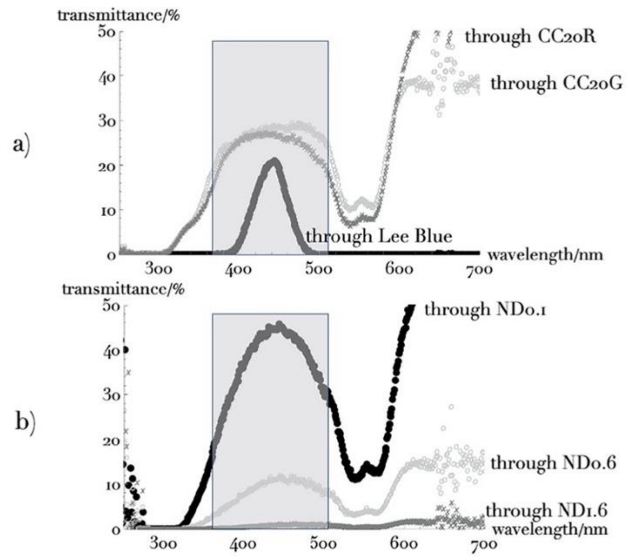

Figure 12: Comparison between the spectrum of Crimson Red ink in Figure 11 transmitted through a) a blue Lee filter, CC20R and CC20G colour correction filters and b) Kodak Neutral Density filters ND0.1, ND0.6 and ND1.6. The grey rectangle indicates the recording range of wet-collodion.

In Figure 12b) we did the same but replaced the colour filters with Kodak neutral density filters ND0.1, ND0.6 and ND1.6. The densities were chosen by one of the authors who has extensive experience in wet-collodion photograph on the basis of the density and greyscale in Figure 2.

From Figure 12 it is obvious that the transmission through CC20G and CC20R is similar to the transmission through the neutral density filters in so far that the position of the peak of the spectrum of Crimson red is preserved and only changed in height. We will still get different images when record throught the different neutral density filters since all film emulsions are not only sensitive to the amount of light but also to the intensity (15).

2.3 *The recording*

The test image in Figure 13 was recorded on the 14th and 16th of August 2021 at 45.54°N, 75.87°W. The first set of images was taken with the Kodak colour filters, the second set with the neutral density filters. As mentioned before, the wet-collodion plates were prepared, exposed and developed within less then 30 min, The plate itself stays wet for about 20 min, depending on environmental conditions. After that the collodion layer will start drying out and begins to deterioate rapidly.

Figure 13: Digital image of the test set up.

2.4 *The digital reconstruction*

In order to explore all colour possibilites we reconstructed the images digitally in Photoshop. For that the wet-collodion plates and the colour filters were scanned. The negatives were digitally inverted (Figure 14). To create a possible outcome of the lanternslide experiment by Maxwell and Sutton, we copied the series of three slides into three layers of a photoshop file. Each layer was coloured in by the colours of the filters it was recored through by adding a solid colour layer, in the colour coordinates of the scanned filters, blending with the multiply mode (which is equivalent to illuminating a slide with a light source of that colour) and merging the layer with the respective image layer. The three coloured layers were then combinded, using again multiply as the blending mode. As a control we did the same but using the colour coordinates of modern Lee filters.

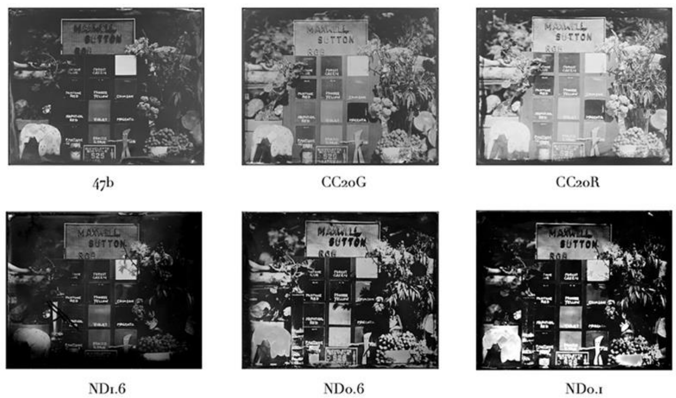

Figure 14: Digital inverted wet-collodion negatives. The second row is arranged in such a way that the greyscale and white values are similar to the first row.

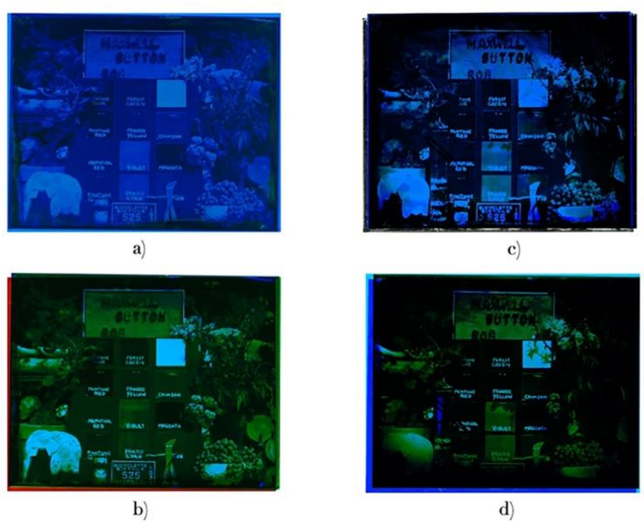

Figure 15: Digital reconstruction of the experiment by Maxwell and Sutton: a) recorded throug 47b, CC20G and CC20R, reconstructed with 47b, CC20G and CC20R; b) recorded throug 47b, CC20G and CC20R, reconstructed with Lee colour separation filter blue, green and red; c) recorded through ND0.1, ND0.6 and ND1.6, reconstructed with 47b, CC20G and CC20R; d) recorded through ND0.1, ND0.6 and ND1.6, reconstructed with Lee colour separatio filter blue, green and red.

To show that recording through density filters gives a very similar result, we followed the same procedure colouring the image recorded through ND1.6 with the colour coordinates of 47b, the one recorded through ND0.6 with the colour coordinates of CC20G and the one recorded through ND0.1 with the colour coordinates of CC20R. The results are shown in Figure 15.

Discussion and conclusions

Figure 15 shows that the projection demonstrated by Maxwell and Sutton must have been rather blue, far from a full colour image. Sutton used all the tricks of the trade to save the situation: putting the tartan ribon on a black velvet background made the shift of white to blue in the projection less obvious. Being very fuzzy in the description of the colours of the tartan clouded the comparison between the original (we suspect that Maxwell would have used his own tartan which is red and green, therefore not suitable for the demonstration) and the projection. When Spencer printed the image 76 years later, he not only used cyan, magenta and yellow but also compensated for the distortions generated by the different light paths through the lense caused by a different of refractive index between blue and the rest of the two filters. The VIVEX process allows to register images mechanically by stretching cellulose substrates with the coloured gelatine layers on them before transferring them to the final paper substrate (16).

The digital reconstruction must be taken with a pinch of salt. Photoshop is not especially suited to reproduce the grey values in a wet-collodion plate or to deal with adjusting grey values or metallic silver values when layers are fused. We would have needed to write proper code to come closer to the original but we just wanted to demonstrate the principle.

The work here made us question the standard colour separation in red, green and blue and we will explore other separations which will then be printed by other inks than cyan magenta and yellow. We will also try to recreate the wet-collodion look, which is still sought after, by the appropriate choice of filters in combination with panchromatic film or a digital camera.

We hope that Michael Berry will enjoy this paper since it combines his interests in 19th century optics, colour and Maxwell.

Acknowledgements

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