How to print a rainbow

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Abstract

In the 21st century, methods for translating additive colours as seen on screens (Red Green Blue (RGB)) into subtractive colours (Cyan Magenta Yellow Black (CMYK)) for industrial print are based on 4-colour halftoning. CMYK are so called process colours, used for printing on opaque substrates, from paper to glass and metal, when photomechanical reproduction is desired. These reproductions surround us, from images in books and magazines, on packaging to prints on clothing, homeware and advertising banners. Additive RGB colours are traditionally used in transmittance, i.e. in backlit applications, for example in mobile phones, laptops, tablets etc. Spectraval™ pearlescent pigments produced by Merck open the possibility of RGB, i.e. additive, colour printing on opaque substrates. We present here a characterisation of the optical features of these effect pigments and discuss print applications.

Introduction

In 1861 James Clerk Maxwell demonstrated, maybe for the first time in human history, that a photographic colour image can be generated by taking three black and white negatives through three different colour filters (RGB) (Figure 1). From the three negatives, three lantern slides were made and when the three slides were projected on top of each other through a red, a green and a blue filter, the colour of the original object was reproduced [1]. Maxwell presented this experiment at the Royal Institution to support the trichromatic colour theory by Young [2] and Helmholtz [3] which has been proven to be correct. Young and Helmholtz suggested that the human retina has a minimum of three different types of colour sensitive cone cells that respond to a light stimulus by sending an electric signal to the brain which is then processed into a colour perception. The sensitivity of the three types peaks near 554 – 574 nm (yellow, L cone), 524 – 544 nm (green, M cone) and 410 – 430 nm (blue, S cone) (Figure 2). When the S and L cones are stimulated simultaneously, the observer sees white or gray [4]. Modern display technology is based on three colour filters (liquid crystal displays) or three colour emitters (OLED displays) which have combined spectra covering the visible spectrum.

Figure 3 shows the transmission spectra of Lee Tricolour Filters. In a display, RGB filters are side by side and, when they transmit at the same time, most of the wavelengths of the visible spectrum enter the eye of the observer, are absorbed by the three different cone types and generates the impression of white.

When the filters are stacked, transmission through all three filters will combine to black since the wave band transmitted by each will be absorbed by the others.

To achieve a full colour print on an opaque substrate, like paper for example, Cros [5] demonstrated that lithographic plates obtained from the colour separated negatives have to be inked in the complementary colours.

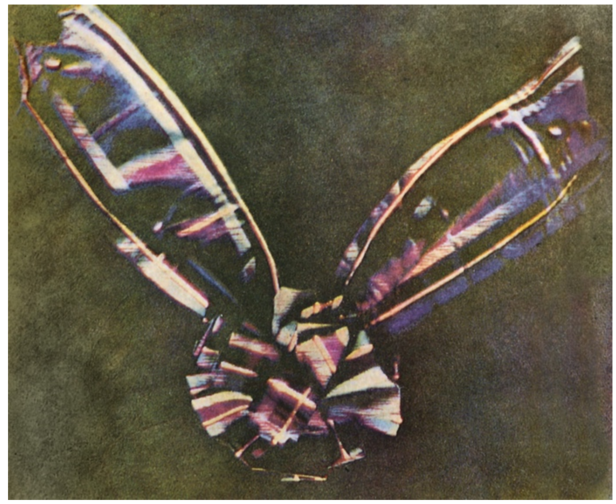

Figure 1: *The famous tartan ribbon by James Clerk Maxwell (original photographic slides), scanned from [6]*

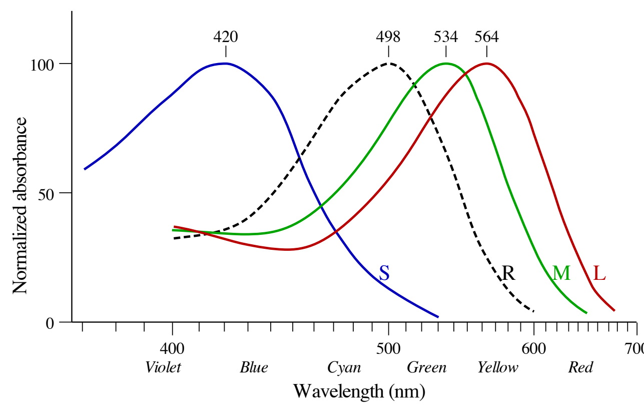

Figure 2: *Normalized absorbance spectra of human cone cells, S, M, and L types and rod cells, R, cells responsible for black and white vision in dim lighting conditions* [7].

For red, green and blue filters, the colours of the inks are cyan, magenta and yellow. Today, these are the standard basic inks for process colours in halftoning processes on opaque substrates.

Merck has developed a series of pigments, Spectraval™ pearlescent pigments, which are selectively reflective and allow additive RGB printing on black substrates.

The pigments

Spectraval™ pigments are mica pigments which come in red, green, blue and white to allow RGB printing on a black substrate [8]. The thin plates are poly-dispersed and have diameters ranging from 5 to 25 μm (see Figure 4). To test their optical properties, we prepared water-based inks for screen and linseed oil-based inks for photogravure printing.

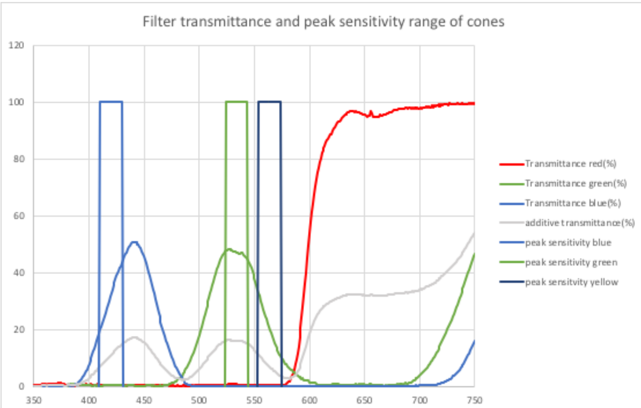

Figure 3: *Measured transmittance of Lee Tricolour filters with their additive transmittance and the peak sensitivity range of S, M and L cones.*

The water-based inks were made by folding the pigment into the solvent, the oil-based inks were either mixed in a traditional way using a glass muller or by gentle milling with a Fritsch Pulverisette at 200 rpm and with 0.8 mm YTZ beads. We did not observe any change in the size distribution of the pigments (see Figure 4) after the inks were prepared and printed on black paper.

Optical measurements

To record the selective reflection of the pigments, we measured the transmittance as a function of wavelength of the linseed oil inks on a microscope slide with a HP UV-vis spectrometer. The inks were applied with a glass rod and to a certain extend shear aligned. The red ink is red in reflection and green in transmission. The blue ink is blue in reflection and yellow in transmission. The green ink is green in reflection, but rather yellow in transmission. The data is quite noisy because a) of scattering and b) of the viewing angle dependency of the colour. We averaged over intervals of 5 nm to generate a clearer plot. Figure 5 shows that the red pigment reflects between 475 and 530 nm and 600 and 650 nm, stimulating not only the L cones but also S and M cones, which lead to a perceived colour of red with white pearlescent. The green pigment has a transmission peak between 410 and 455 nm and reflects, almost evenly, the rest of the visible spectrum, stimulating all three cones, just missing the sensitivity maxima of the S cone, i.e. not generating much of a blue signal in the brain. The resulting colour is a yellowish green with white pearlescent. The blue pigment has a transmission peak between 350 and 400 nm and reflects strongly between 420 and 530 nm. The resulting colour is a dark blue with white pearlescent.

We used a Konica-Minolta FD-7 spectrometer to represent the data in the CIE 1931 colour space coordinate system [9]. Some print samples were provided by Merck, some were screen printed, some were photogravure prints. All prints were on black paper or card board. The illumination is a D65 light source, which sits as a ring around the detector. We measured the CIE 1931 xyY colour coordinates for a standard 2° observer.

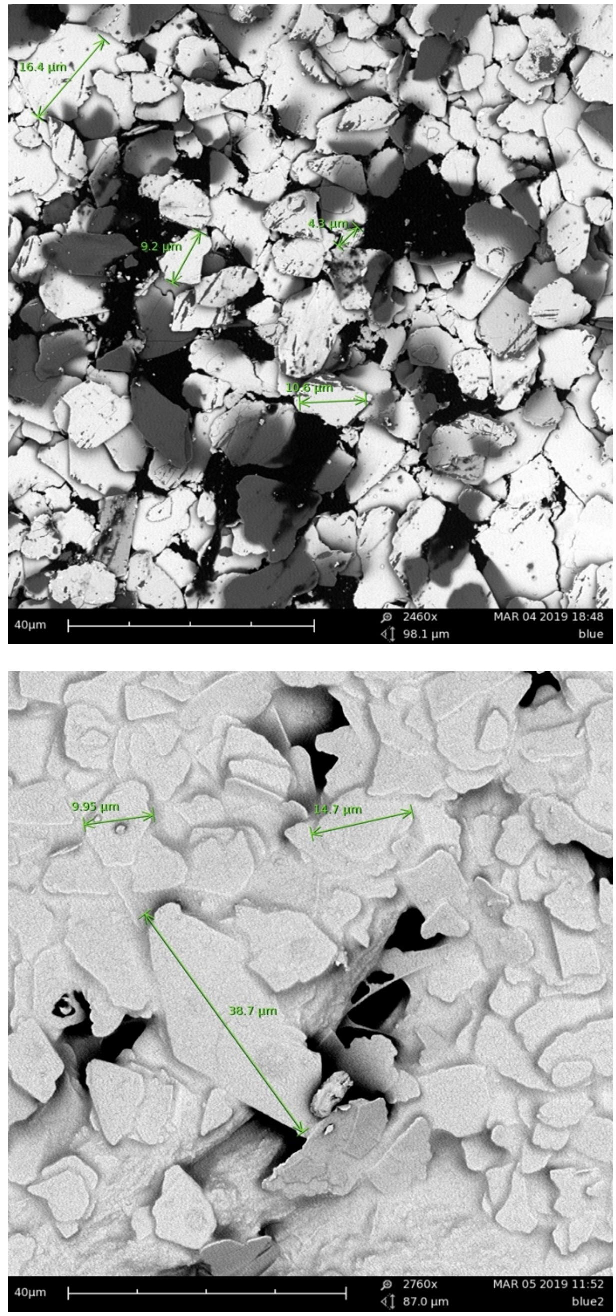

Figure 4: *Scanning micrograph of a Spectraval pigment. Top: as received; Bottom: after gentle milling into linseed oil.*

With the Konica-Minolta FD-7 spectrometer is not possible to measure the spectra of the reflected light as a function of the viewing angle. Averaging of 6 samples gave the values in table 1. They are all close to the x,y coordinates of the CIE Standard Illuminant D65 with x= 0.31271 and y=0.32902 [10] and represent a small gamut.

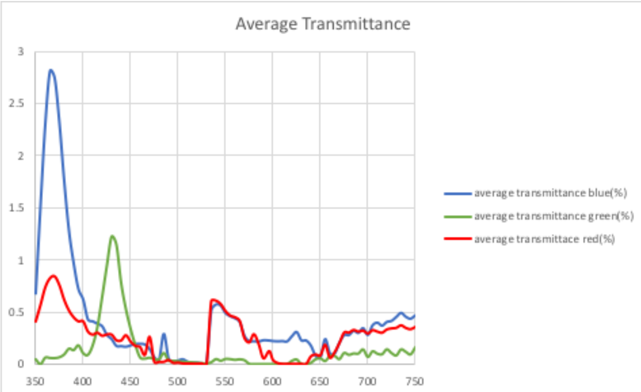

Figure 5: *Transmittance spectra of red, green and blue Spectraval pigments as a function of wavelength*

Table 1: CIE 1931 xyY colour coordinates for Spectraval Red, Green and Blue pigments

	Red	Green	Blue
x	0.333533	0.3263	0.250714
Standard deviation	0.126205	0.005577	0.011657
y	0.291183	0.367117	0.2511
Standard deviation	0.007368	0.007883	0.015531
Y	8.97	15.74667	10.16143
Standard deviation	3.379059	7.272608	4.730516

Printing

As the gamut of the Spectraval RGB pigments is much smaller than the gamut of sRGB or Adobe RGB (1998) colour spaces, the pigments are not suited to be used for realistic RGB colour prints. The closeness of the colour coordinates to the white point desaturates the image. Orange and yellow cannot be achieved (see Figure 6).

Figure 6 b) would not be acceptable as a true representation of 6 a) since it generates a strange interference with realistic expectations. The observer has immediately the impression that the colours are wrong. On the other hand figure 6 c) and 6 d) are obviously not realistic colour schemes and therefore acceptable. Viewing angle dependence and a metallic appearance make the pigments interesting for applications where eye catching light effects are the main feature of the image.

The different pigments react to different illuminations with different degrees of illuminant metameric failure. Red and blue are quite robust. Only when the illuminant lacks frequencies in the reflectance bands, a colour shift will be observed since the transmitted wavelength are absorbed by the black substrate and have no influence on the reflected colour. Since the green pigment reflects most of the wavelengths except between 410 and 455 nm, its reflected colour is more sensitive to the frequency composition of the illuminant and illuminant metamerism occurs more easily.

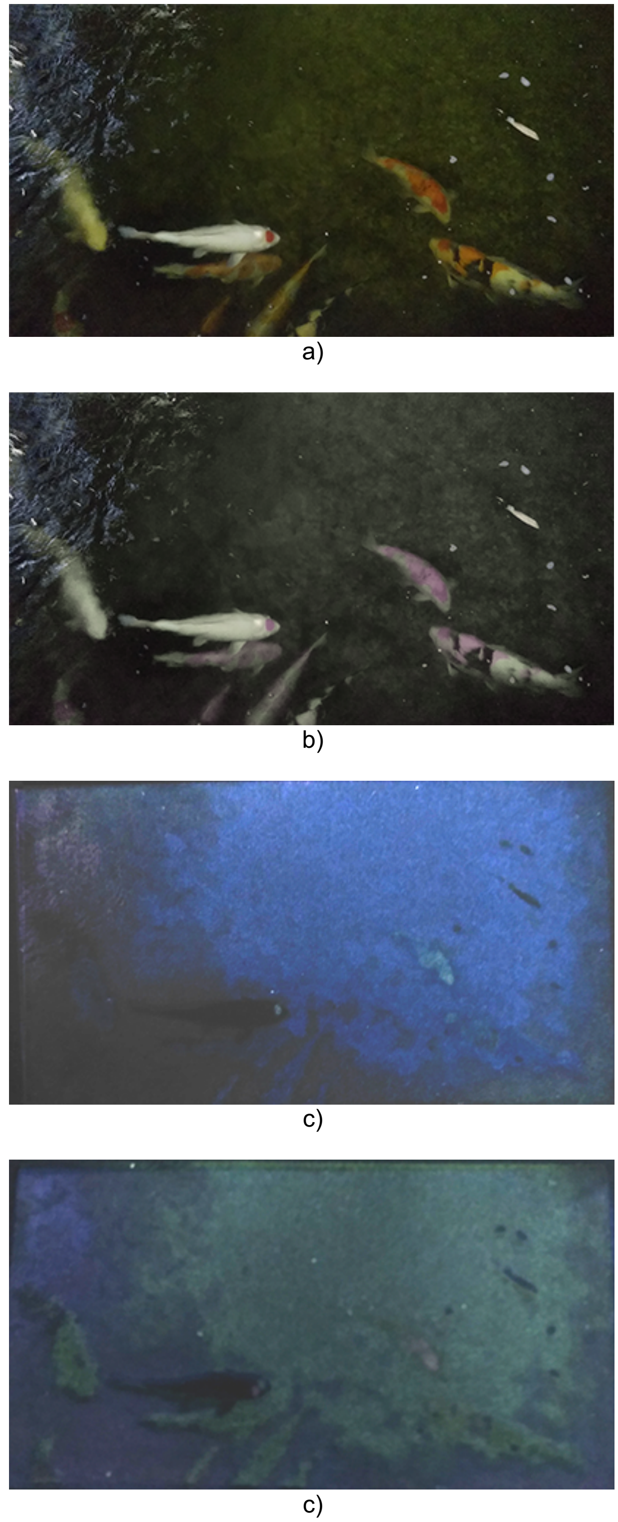

Figure 6*: a) image with Adobe RGB (1998) colour profile, b) image with colour profile form table 1, c) print where the cyan plate was inked red, the magenta plate green and the yellow plate blue, d) print where the cyan plate was inked blue, the magenta plate red and the yellow plate green.*

Conclusions

The colours of the Spectraval™ pigment range are generated by selective reflection, and not by absorption. This makes it possible to print additively since the light, which is not reflected, is transmitted to the layer underneath and finally absorbed by the black substrate. Spectraval™ come in red, green, blue and white. We have only characterized the red, green and blue pigments. All these pigments reflect between 475 and 530 nm. The difference in colour is caused by strong reflectance (red, blue) and/or prominent transmission peaks (green and blue). The CIExyY coordinates of the pigments are clustered around the D65 white point which is not surprising since they all show a white pearlescence. We have not yet recorded the reflectance as a function of viewing angle, but will do so in the future.

Acknowledgements

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Author Biography

Susanne Klein is a physicist by training and has lived and worked in the UK since 1995, first as a Royal Society Research Associate at the University of Bristol, and then as a Senior Research Scientist at Hewlett Packard Labs Bristol. She has been appointed an EPSRC Manufacturing Fellowship at the Centre for Fine Print Research starting January 2018. She is working on the reinvention of old printing technologies, such as Woodburytype and Lippmann photograph.

Carinna Parraman's understanding of 2.5D printing has evolved through her training in in fine art print-making. She is Professor of Design Colour and Printing and Director at the Centre for Fine Print Research, and has in-depth knowledge of traditional colour mixing, colour printing and photomechanical printing processes. She collaborates with many different sectors including industry, heritage and fine-art print.

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