



Dichromatic Fabrics - A Challenge in Colourimetry

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Abstract: When a textile is woven, different colour threads may be used for the warp (vertical) and the weft (horizontal). The primary colour is seen on viewing the textile orthogonally (at right angles) to a flat surface. But a secondary colour may be seen if the textile is tilted or rotated (dichromatism). The colours of the main threads in six dichromatic textiles were measured by microscopy using a rotating stage. Colours did not change with rotation, although to an observer to one side of the microscope the whole sample appeared to change colour on rotation. Several methods of illumination were used to show that a wide angle of illumination and recording was required to produce dichromatism. Relationships between microcolourimetry and macrocolorimetry then became detectable. Chromaticity x in a fibre was correlated ($r = 0.85$, $P < 0.025$) with chromaticity x of primary macroscopic reflectance as well as with the chromaticity x of secondary macroscopic reflectance ($r = 0.86$, $P < 0.025$).

Keywords: Microscopy, Textiles, Colourimetry, Dichromatism

INTRODUCTION

Iridescent structures change colour interactively as they are rotated or tilted. Robert Hooke in 1665 used microscopy to reveal the two main mechanisms, either refractive interference or multilayer interference [1]. This holds true for a wide variety of iridescent shells, minerals, plants, feathers, insects, meat and fish [2-9] but what about dichromatic textiles [10]? A textile that changes colour as it is rotated or tilted might reasonably be called dichromatic rather than iridescent. For many years we have known that colour is a sensation of the human brain that can be partly understood by objective spectrophotometry [11], but now there is three ways split - colour as humans see it directly, colour as measured by classical analogue optical instruments, and colour as it is recorded by digital cameras and transmitted on the internet.

APPARATUS

A diagram of the computer controlled apparatus is shown in Fig. 1 with full descriptions of hardware and software available [12, 13]. A Zeiss Universal microscope fitted for reflectance was the main component with additional parts added for fibre optics. Incoming optical fibres allowed sample illumination via the gap between the sample and long distance objectives, as well as direct illumination of macroscopic samples. Outgoing optical fibres allowed reflectance (sterance) from macroscopic samples to be measured with the same components used for microscopic samples (thus minimizing instrumental error). The custom made rotary stage (diameter 3 cm) was driven directly by a brushless DC electric motor (5840-31ZY, 12 V 10 RPM) driven at 8 v 2a. Samples were mounted on metal discs (diameter 1.8 cm). The calibration disc was coated with a diffuse white reflectance standard (Munsell Color, New Windsor, NY).

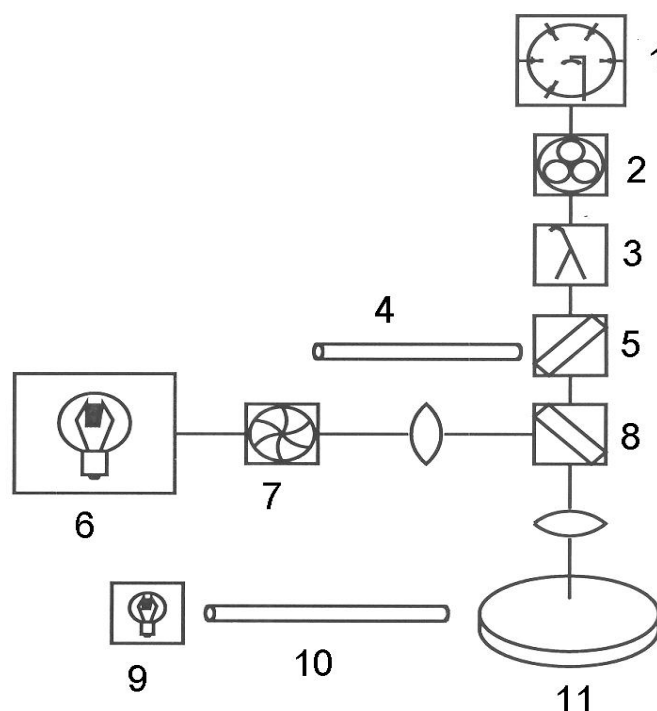


Fig. 1: Photomultiplier, 1; stray light filters, 2; grating monochromator, 3; incoming optical fibres, 4; mirror, 5; illuminator, 6; shutter, 7; mirror, 8; secondary illuminator, 9; outgoing optical fibres, 10; and rotary stage, 11.

Using optoelectronic apparatus approaching 50 years of age there were some concerns - front silvered mirrors and diffraction monochromators may become corroded and photomultipliers may become unreliable. The available wavelengths are shown in Fig. 2, note the absence of Wood's anomalies from the diffraction grating that can cause problems in calculating chromaticity coordinates.

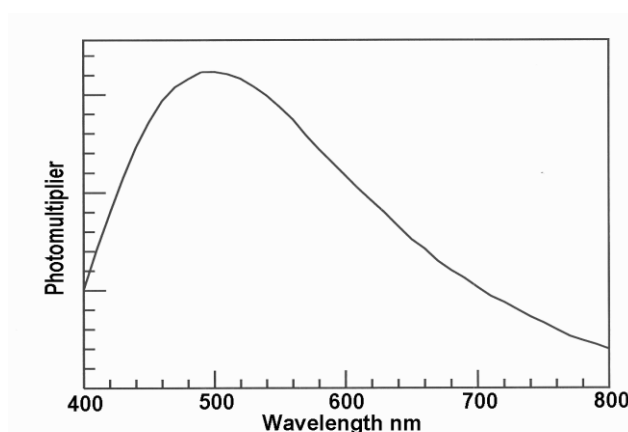


Fig. 2: Photomultiplier voltage output (un-calibrated) as a function of wavelength from a tungsten illuminator and a Munsell white standard.

Another required check on the apparatus was to make sure that rotation of the Munsell white standard disk did not skew the photometric data. Rotating in steps of 90°, the data remained consistent.

chromaticity coordinates x and y remained at 0.33 and $Y\%$ at 100 (the centre white for colour coordinates). Chromaticity coordinates were calculated by the weighted ordinate method [14]. Thus, with vertical illumination, microspectrophotometry was reliable, but with low angle illumination problems were anticipated from a red shift (as seen on an iridescent oil slick). In other words, the idea of using angled fibre optics to simulate rotating a hand-held textile would have to be treated with caution. When the apparatus was standardized (reflectance = 1 from 400 to 700 nm) using vertical illumination the chromaticity coordinate changes from 90 to 360° with 45° illumination were $x = 0.37$, to 0.27, to 0.27 to 0.33; with $y = 0.31$, to 0.28, 0.28 to 0.30; and $Y\% = 80.3$, to 48.8, to 48, to 63.7, all showing a red shift. Thus, the apparatus had to be standardized with 45° illumination for samples measured in this way. Then, rotating at 90°, chromaticity coordinates x and y remained at 0.33 and $Y\%$ at 100 as with vertical illumination.

RESULTS AND DISCUSSION

In Canada, despite metrication in the 1970's, the thread counts of fabrics are usually given as the number of threads per inch, for which thread counting microscopes are calibrated. But scientific reporting requires metric units, and if threads per inch is converted to threads per millimetre mathematically the answer is wrong because the thread number now becomes a fraction rather than an integer. Fortunately, a metric thread counter (Alfred Suter, Orangeburg, NY, 0-10 cm, x14 lens) was available courtesy of the Canadian Fashion History Museum (Stratford, Ontario). But as seen in Fig. 3, thread counting in one direction does not give the full story because the warp and weft threads may not be equal in diameter. The example shown in Fig. 3, appeared subjectively as Pantone 18-1649 in one orientation and Pantone 17-3628 orthogonally (Pantone, Carlstadt, New Jersey).

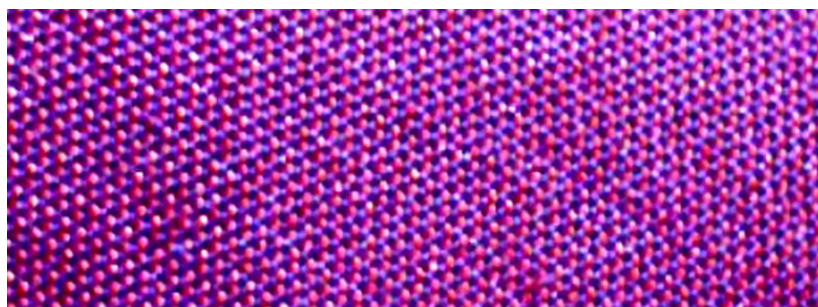


Fig. 3: The structure of sample 1 with 5 threads per millimetre photographed with a digital camera (Moticam 580 with a 12 mm lens).

When examined under the microscope, the specular reflectance of some fibres exceeded the Lambertian reflectance of the Munsell white standard. The jumble of reflectance spectra, too difficult to identify on a graph, was unravelled by calculating their chromaticity coordinates (Table 1). The chromaticity coordinates (x , y and $Y\%$) show the hue, the 400/700 nm ratio show the general slope of the spectra, the mean shows average reflectances, distance from white shows the distance from white in the CIE diagram, r shows a linear regression a spectrum ($r = 1$ for no shape), and $Y_{\max}/Y_{\min}$ shows the overall slope of the spectrum. These data show that, at the microscopic level, the textile fibres had a

range from those with high specular reflectance to those with strong absorbance especially around 650 nm. Note that sample 2 had three fibres, one of which was iridescent green.

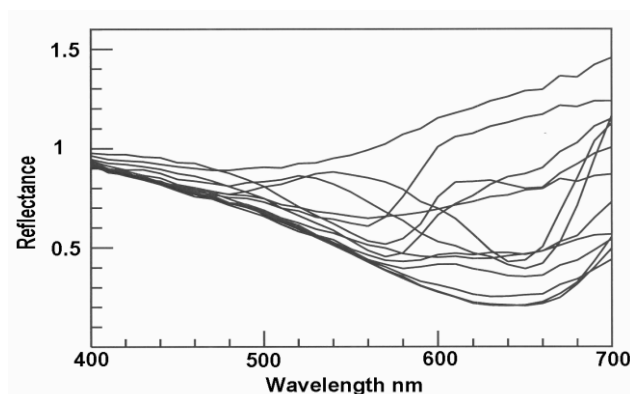


Fig. 4: Reflectance of fibres in samples 1 to 6 measured by microscopy with a low power objective (LD Epiplan $\times 4$).

Table 1: Chromaticity analysis of spectra in Fig. 4.

Sample	x	y	Y%	400/700 nm	mean	From white	r	Ymax/Ymin
1-1	.25	.27	45	2.09	.53	.09	.92	2.09
1-2	.36	.31	77	0.74	.89	.07	.67	1.35
2-1	.27	.27	49	1.73	.58	.08	.89	1.73
2-2	.29	.32	70	0.80	.74	.04	.51	1.24
2-3	.32	.29	67	0.97	.81	.04	.19	1.03
3-1	.31	.34	78	0.82	.78	.02	.31	1.22
3-2	.32	.28	61	0.82	.79	.05	.10	1.21
4-1	.29	.29	54	1.64	.62	.06	.87	1.64
4-2	.32	.31	69	1.06	.77	.02	.19	1.06
5-1	.24	.27	43	1.64	.52	.11	.89	1.64
5-2	.28	.28	51	1.27	.62	.06	.75	1.27
6-1	.24	.27	43	1.84	.51	.11	.91	1.84
6-2	.36	.34	102	.66	1.07	0.31	.90	1.51

The most interesting finding was that the reflectance values in Fig. 4 and Table 1 did not change as textile samples were rotated 360° with vertical illumination and measurement - individual fibres rotated but did not change colour. Samples were angled at 30° on the rotating stage - but still did not change colour on rotation. Even when illuminated at 60° , fibres maintained their colour while rotated. Yet to the observer on one side of the microscope watching samples rotate, there were major changes in colour when macroscopic samples were rotated and tilted. The illumination was changed - placing a wide angle tungsten lamp to illuminate the whole sample. As the sample was rotated, the spectrophotometric colour changes matched those seen by the observer to one side of the microscope (Fig. 5). Thus, colour changes in dichromatic textiles require wide angle illumination to match the wide angle colour sensation of an observer.

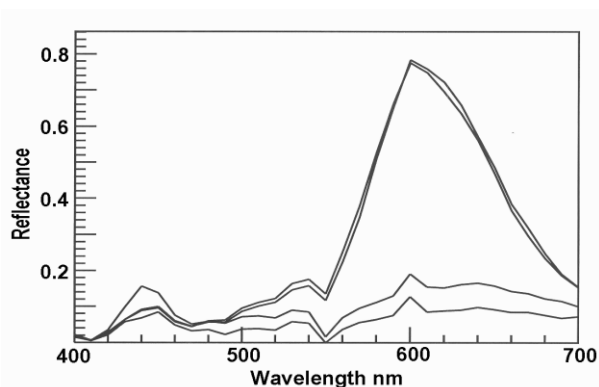


Fig. 5: Sample 1 showing 90° changes in rotation (top two lines *versus* bottom two lines).

A wide angle illumination and measurement was available by fibre optics to one side of the microscope (Fig. 1), illuminating and recording from several square centimetres and standardizing the system on white opal glass. Here it was possible for the observer to find areas of textile that changed colour with rotation and orientation then to activate the spectrophotometer. The spectrophotometry data were difficult to unravel for publication (Fig. 6), so the data were converted to chromaticity coordinates (Table 2).

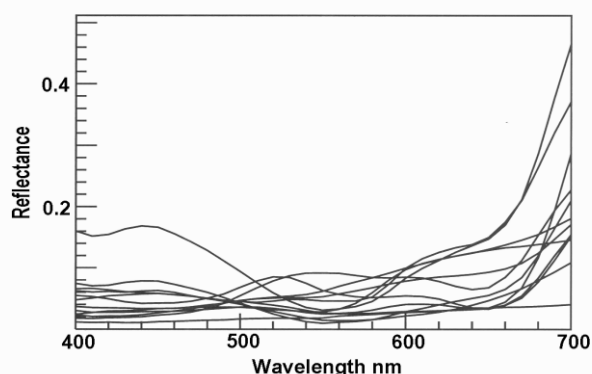


Fig. 6: Reflectance data of six textile samples measured by fibre optics before and after subjective orientation to demonstrate their dichromatic appearance.

Table 2: Chromaticity coordinates for fibre optic measurements of the spectra shown in Fig. 6.

Sample	Primary			Secondary		
	x	y	Y%	x	y	Y%
1	0.46	0.34	5.44	0.27	0.22	2.36
2	0.30	0.27	3.49	0.32	0.38	6.16
3	0.41	0.45	8.10	0.41	0.31	6.47
4	0.45	0.40	7.37	0.41	0.37	2.19
5	0.28	0.19	2.45	0.36	0.21	6.36
6	0.41	0.37	6.16	0.33	0.33	2.91

Looking at the data in tables 1 and 2, were there any relationships between microscope measurements of single fibres and macroscopic fibre optic measurements? One should not expect a strong proof because there were only six samples ($n = 6$), and only two fibres were measured microscopically, and there were two orientations measured macroscopically, and instrumental error is to be expected using two radically different optical systems (micro *versus* macro). But relationships were detected. The x in the main fibre of sample 1 was correlated ($r = 0.85$, $P < 0.025$) with the x of the primary macroscopic reflectance as well as with the x of secondary macroscopic reflectance ($r = 0.86$, $P < 0.025$).

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