Róża Starczak, M.Sc. Eng.
Jagiellonian University, Faculty of Chemistry, Department of Analytical Chemistry
Prof. Jolanta Wąs-Gubała (corresponding author)
Institute of Forensic Research, Department of Criminalistics
jwas@ies.krakow.pl

Colour as a basic feature in comparative studies of fibre microtraces

Summary

Forensic evidence in the form of fibres is recovered in cases involving sexual offenses, assault, murder and road accidents. In the event when a connection between persons is determined, fibres transferred from an offender's to a victim's clothing and vice versa are sought for. Colour is the first physico-chemical property verified during forensic analysis. Any colour differences between materials recovered at the crime scene and those originating from a suspect's clothing suggest that fibres cannot have come from the same source. The aim of this article is to introduce the colour-related issues as they pertain to forensic fibre evidence.

Keywords microtraces, fibres, colour, ultraviolet-visible microspectrophotometry

Fibre fragments as forensic evidence

Single fibre fragments are among the most commonly encountered microtraces at a crime scene. The search for microtraces transferred between clothing materials of the event participants or those separated from clothing and transferred onto the objects present at the scene at the time of the event (e.g. vehicle elements, tools of crime, chairs, carpets etc.) was a trend initiated in the 1970's, mainly in Great Britain, Germany and United States.

Fibre fragments analyses performed in forensic laboratories allow the determination of characteristic morphological features such as colour, shape, surface characteristics, thickness, crystallinity, fluorescent properties or chemical composition, based on which fibres can be identified/classified and compared against other fibres making up a specific material (e.g. victim's or perpetrator's garments).

Nowadays, owing to mass production of fibres and textiles, it is not possible to perform individual identification of this type of microtraces, because a single fibre generally does not acquire any identifiable features during the production process. In the conclusions of the examination report, an expert typically states whether a particular microtrace element can originate from a specific textile product subjected to comparative studies. Such inference can be augmented by taking into account the popularity of particular fibre types and colours on the consumer market, as well as the prevalence of specific fibre fragments in the environment (assessed on the basis of the results of the so-called population studies of fibres). However, a large supply of textiles on the consumer market can also have positive effects from a forensic standpoint. These days, people wish to dress in a way that expresses their individuality, whereby the availability, prices and variety of textile products are the enabling factors. For this reason, situations where two different persons wear the same elements of garment, i.e. the same brand, production line and colour (with the exception of formal attire and dress codes) of both the top (e.g. sweater, shirt, blouse, jacket,) and bottom (e.g. trousers, skirt) part of clothing are becoming increasingly rare.

Colour is the most variable feature of textile materials on the consumer market. While the fashion designers point out the top colours for a few upcoming months (seasons), clothing brands are striving to satisfy the needs of their customers by supplying garments in the indicated, most fashionable colours and shades thereof, obtained in technological processes as a result of applying the entire range of dyes and their mixtures of different percent compositions. Consequently, whenever fragmented coloured fibre traces are subjected to forensic analyses, the colour constitutes the first and most important feature to be evaluated by the laboratory.

Colour perception

Colour plays an important role in a person's life. Not only does it facilitate physical recognition and distinguishing between the surrounding phenomena and objects, but it also has an impact on people's psyche and moods, by means of certain selected color compositions.

In Polish language, the terms *kolor* and *barwa* are interchangeable [Translator's note: both terms are translated into English as colour], except in a scientific context when certain differentiation is applied. Specialist and printing literature prefer the use of *barwa* [Translator's note: for reasons of clarity, hereinafter referred to as colour], applying this term not only to psycho-physical impressions, but also to measurands assigned numerical parameters, which describe colour spaces [1].

Colour carries the meaning of a psycho-physical feature of visual perception, which links closely with consciousness and sensory organs of a man or an animal equipped with adequately differentiated light-sensitive receptor. In other words, colour constitutes a kind of electromagnetic radiation perceived by the eye. Visual perception is only possible when all the following three processes occur: (i) light emission; (ii) stimulation of retinal receptors and (iii) processing in the cerebral cortex of the stimuli transmitted via the optic nerve [2].

The formation of colour is dependent on light (a specific region of the electromagnetic radiation spectrum). Colour appears when a particular object is illuminated, and changes accordingly to the type of light and the object's ability to absorb the energy of electromagnetic radiation and convert it within a specific wavelength range. The object's colour is a function of selective absorption and the combined action of all remaining light beams that were either unabsorbed (transparent bodies) or reflected (opaque bodies) by the object.

Furthermore, the object's colour is spectral in its nature, i.e. it corresponds to an unabsorbed component part of a split beam, which can be simple or composite. Usually, the object's colour is a sum of a few spectral colours like in the case of carrots, whose colour comes from carotene – a substance assuming yellow-orange colour as a result of high absorption within blue and cyan regions of the spectrum (the remaining unabsorbed split beam components making up the observable colour).

Absorption of light radiation is not only limited to the visible spectrum (wavelength range 380–780 nm), but it extends far beyond this range, into both ultraviolet and infrared spectra. Thus, the colour of an object is determined by the distribution of absorption bands within visible and non-visible regions of the spectrum.

Each color can be fully and unambiguously defined by three attributes, e.g. hue, lightness and saturation.

The easiest attribute to recognize is a hue, described as yellow, red, blue, brown etc. Hue depends on the type of radiation that reaches the eye and gives an impression of colour. Colours with specific hues are referred to as chromatic, as opposed to achromatic colours that possess no hue, e.g. white, grey or black.

The second attribute is lightness, which refers to illuminated surfaces. Lightness is an impression that the surface reflects a bigger or smaller portion of illumination it receives. The perception of lightness depends on the size of a fraction of incident light that is reflected by the surroundings of the observed surface; for larger reflected fraction, lightness will appear smaller and vice versa.

Colours with identical hue and lightness may differ in a third attribute – saturation. According to the definition given by the International Commission on Illumination (abbreviated as CIE from its French title: Comission Internationale de l'Eclarage), saturation is the perceived proportion of pure chromatic colour in a mixture with achromatic colour. Hence, saturation describes the purity of a colour [2, 3].

Colour perception can be affected by multiple external factors such as the spectral composition of light, amount of light energy, presence of other colours in the observer's field of vision, surroundings of the observed colour, type of lighting, individual characteristics of the observer such as health condition, well-being, mood, experience and know-how in regard to the use of the sense of sight [3].

In the case of fibers, the colour is determined by dyes used in the staining process. Dyes are chemical compounds with the capacity for intense absorption of electromagnetic radiation in the visible, ultraviolet and near-infrared spectra. Subsequently, dyes convert absorbed energy and pass this ability onto other objects. Depending on the nature of energy absorbed, dyes have different practical applications; those used to stain fabrics, fibres, plastics, etc. convert absorbed electromagnetic radiation into heat energy which is then emitted into the environment in the form of heat. As a result, gaps appear in the reflected light spectrum - the remaining reflected light beams give man the impression of colour [4].

Objective assessment of fibre colour

As mentioned earlier, the impression of colour is a physiological-physical phenomenon, and as such it can be qualified as subjective experience dependent on a range of properties of internal perception organs. The human eye is extremely sensitive to even slight deviation in a wavelength of monochrome stream, yet it may lose this sensitivity in certain cases. The optical system of the eye shows image reproduction defects, the so-called geometric or chromatic aberrations.

With regard to comparative studies of colourful objects, such as individual fibre fragments, it should be noted that when the eye notices the contrast between brightness and hue, this means that they are different, however, when the eye does not notice the contrast, this does not necessarily mean that they are identical. This feature is especially important in comparative studies of fibres conducted with the use of optical microscopy techniques (biological, polarizing, and especially fluorescent).

In determining colour differences, the precision of subjective methods is therefore limited by the threshold of eye sensitivity. In view of the above, it is understandable that the observer should be decoupled from a subjective factor such as the visual apparatus, which should be replaced with other available analytical resources such as colorimetry or spectrophotometry.

Microspectrophotometry is an analytical method combining optical microscopy and spectrophotometry techniques. The former technique allows the use of various lighting methods and viewing samples under transmitted and reflected light, while the latter is a measurement method that consists in measuring the intensity of radiation transmitted and/or reflected from the test sample in terms of wavelength or wavenumber. Microspectrophotometry (MSP) technique has found its application in forensic studies since the mid-1970's, as the obtained study results are objectified and independent of an observer. MSP enables measurement and comparison of colours even for very small sample sizes, such as single fibre fragments no longer than one millimeter and with a diameter of as little as several micrometers. In addition, it is used to test varnish and ink particles as well as other coating materials. The result of a study involving the use of microspectrophotometry technique is the spectrophotometric curve (spectrum). In the case of fibres, microspectrophotometric measurements are performed under transmitted light, mainly in the visible spectrum (wavelength range of 380-780 nm). However, due to the fact that the colour of a body can be determined by absorption band layouts within both visible and non-visible spectral regions, it is worth applying an extended measuring range, by including also the ultraviolet and infrared areas (Fig. 1 and Fig. 2).

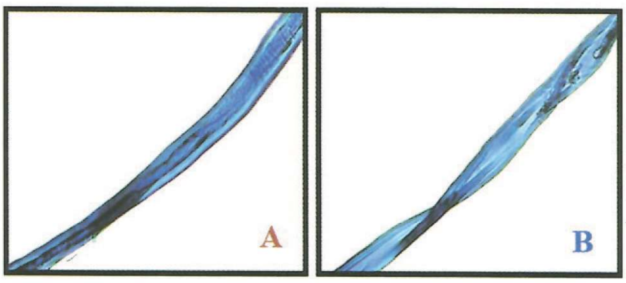

Fig. 1. Microscopic images of fibres stained with Reactive Blue 184 (A) and Reactive Blue 238 (B) dyes – conc. 3% (lens magnification 40x) viewed under ordinary illumination.

Fig. 1 shows fibres stained with Reactive Blue 184 and Reactive Blue 238 dyes showing almost identical colour under a microscope. In the presented case, only the application of a full spectral range made it possible to distinguish between samples with similar colour appearances.

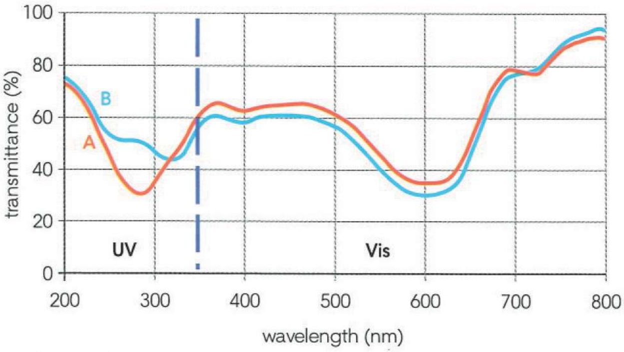

Fig. 2. Comparison of the UV-Vis averaged transmission spectra of fibres stained with Reactive blue 184 (A) and Reactive Blue 238 (B) dyes – conc. 3%.

The use of a full UV-Vis range entails higher costs of testing and can cause fibre colour fading under the influence of UV light. However, in many cases it is useful for distinguishing between fibers characterized by similar colour and visible light spectrum.

Spectrum-based determination of fibre colour

In the case of fibre-related measurements, a coordinate system is frequently used wherein absorbance units (A) are plotted along the axis of ordinates and wavelength values (λ) along the axis of abscissa. The color is identified by the whole spectral shape – although it can be generally defined based on the projection of the maximum of this curve on the axis of abscissa (λ max), the final colour and hue of an object are determined by the curve shape, i.e. the local maxima and points of inflection (Fig. 3).

If λ max lies in the range of 380–435 nm, the test substance selectively absorbs light radiation corresponding to a spectral violet color, thus assuming

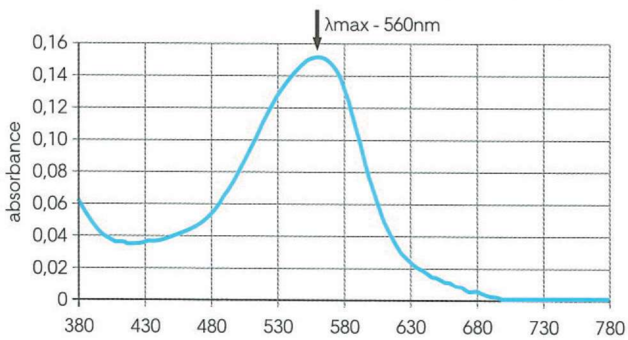

Fig. 3. Exemplary spectrophotometric curve (absorption spectrum) of violet fibre.

yellow-green (complementary) observable colour; in the 435–480 nm range the observable colour is yellow, etc.

Table 1 shows the way the complementary (observed) colours change as the maximum absorption of the object shifts toward longer wavelengths of light.

Table 1. Absorbed and complementary (observed) colours [5]

Wavelength range (nm)	Absorbed colours	Observed colours
380–435	violet	yellow-green
435–480	blue	yellow
480–490	green-blue	orange
490–500	blue-green	red
500–560	green	purple
560–580	yellow-green	violet
580–595	yellow	blue
595–605	orange	green-blue
605–800	red	blue-green

In the case when the spectral shape consists of several maxima, the colour of an object is the result of aggregated complementary colours. For example, the presence of three absorption maxima: at 430 nm (complementary colour – yellow), 594 nm (complementary colour – blue) and 630 nm (complementary colour – blue-green) determines green colour (Fig. 4). However, the absorption bandwidth may be a sign of colour purity – the wider band, the greater admixture of gray, meaning less pure hue of an object.

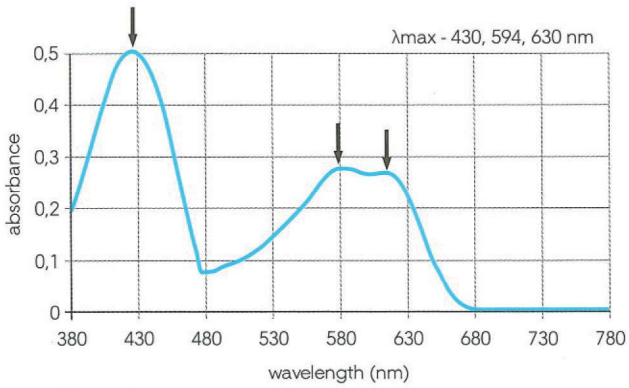

Fig. 4. Exemplary green fibre absorption spectrum.

Results of authors' own experimental studies

Forensic research carried out by the Institute of Forensic Research in Krakow involves, inter alia, physico-chemical studies of fibres. As already mentioned, the most important feature of microtraces is their colour - a colour comparison of individual fibre/object fragments can be performed by means of optical, mainly fluorescent, microscopy, or by using a more objective microspectrophotometry (MSP) technique. At present, the Institute is equipped with one of the most modern spectrophotometers for microtrace analysis from CRAIC Technologies (Fig. 5).

Fig. 5. CRAIC Technologies microspectrophotometer.

Such tests require the same sample preparation method as in the case of conventional microscopy (microscope slides, immersion liquid). The measurements can be performed under both transmitted (within the visible spectral range) and ultraviolet light.

The related scientific research carried out so far by the authors, has confirmed the relevance of the above analytical technique in comparative studies of coloured fibre fragments, both natural (cotton) and synthetic (polyester) [6, 7, 8, 9], stained with a single dye or the mixture of dyes. Even in the case of poorly stained fibres (the so-called light and very bright fibres), which are almost indistinguishable in microscopic images, the use of MSP has often made it possible to confirm or reject the hypothesis that such fibres originated from the same source. In addition, in order to compare chemical composition of dyes and their mixtures used in the studies, Raman spectroscopy was applied.

Sources of figures and table

Tab. 1: Gajdzicki B., Gniotek K.: Pomiar barwy powierzchni płaskich wyrobów włókienniczych, „Pomiary, Automatyka, Kontrola" 2007, Vol. 9, p. 53.
Figs. 1–5: authors

Bibliography

1. Zausznica A.: Nauka o barwie, Wydawnictwo Naukowe PWN, Warszawa 2012.
2. Pastuszak W.: Barwa w grafice komputerowej, Wydawnictwo Naukowe PWN, Warszawa 2000.
3. Mielicki J.: Zarys wiadomości o barwie, Wyd. Fundacja Rozwoju Polskiej Kolorystyki, Łódź 1997.
4. Gronowska J.: Podstawy fizykochemii barwników, Wyd. UMK, Toruń 1989.
5. Gajdzicki B., Gniotek K.: Pomiar barwy powierzchni płaskich wyrobów włókienniczych, „Pomiary, Automatyka, Kontrola" 2007, Vol. 9, p. 53.
6. Wąs-Gubała J., Starczak R.: Nondestructive Identification of Dye Mixtures in Polyester and Cotton Fibers Using Raman Spectroscopy and Ultraviolet-Visible (UV-Vis) Microspectrophotometry, "Applied Spectroscopy" 2015, Vol. 69, p. 296.
7. Wąs-Gubała J., Starczak R.: UV-Vis microspectrophotometry as a method of differentiation between cotton fibre evidence coloured with reactive dyes, "Spectrochimica Acta, Part A Molecular and Biomolecular Spectroscopy" 2015, Vol. 142, p. 118.
8. Starczak R., Wąs-Gubała J., Kościelniak P.: Różnicowanie barwy pojedynczych włókien bawełnianych w badaniach kryminalistycznych, „LAB – Laboratoria, Aparatura, Badania" 2014, Vol. 1, p. 16.
9. Starczak R., Wąs-Gubała J., Kościelniak P.: Interdisciplinary study of coloured cotton fibres for forensic purposes, [in:] Commodity Science in Research and Practice – Non-food products' quality and innovations, R. Salerno-Kochan (ed.), Wyd. UEK, Kraków 2014.

Translation Rafał Wierzchosławski