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The new physiology of vision—Chapter XIX. Perception of colour and the trichromatic hypothesis

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The colouring of textiles with the aid of dye-stuffs is an art of great antiquity. The availability at the present time of synthetic dyes of varied sorts has greatly enlarged the range of the colours which can be fixed on textile fibres. In consequence, the student who wishes to study dyed textiles has at his disposal sufficient material with which the entire field of colour could be covered. The present chapter records some observations made by the author on dyed silks with a view to determine the relationship between their perceived colours and the spectral character of the light which emerges from the material after escaping absorption in its interior. As the particular dye-stuff employed in the case of each specimen was unknown, the observations have been set out in the order of the colours exhibited by the materials studied. These observations were intended to supplement those described in the preceding chapter in which the spectral character of the light transmitted by various colour filters was studied in relation to its perceived colour. The results were there set out separately for each of the materials used as a filter. They and the results obtained and reported here using a wholly different technique have been found to be completely in agreement.

The picture of the relationship between the perceived colour of polychromatic light and its spectral character which emerges from these studies bears no resemblance whatever to that envisaged by the so-called trichromatic theory of colour perception. It follows that the ideas underlying that theory are unsustainable. This aspect of the matter will be dealt with more fully as we proceed.

The sensation of purple: The purple dye with which the togas of the Roman Emperors were tinted was a very expensive material derived from a kind of shell-fish. A purple colour can however be readily produced with the aid of synthetic dyes. Indeed, purple silk is not infrequently adopted as the material for academic costumes. The author has in his possession, three such costumes acquired at widely different dates. One is a full gown of purple silk, another a gown and hood of scarlet-coloured wool with facings of purple silk, and a third is a gown and hood of scarlet silk, with the addition of an academic cap of a dark purple velvet with an inside lining and an outer edging of purple silk. The three samples of purple silk present somewhat different shades of colour. But on a spectroscopic examination, all showed in a very conspicuous fashion a common feature, viz., that while the red, green and blue sectors in the spectrum were present in strength, the yellow of the spectrum was totally absent. There is a large drop in intensity between the green and the red sectors, the minimum being located at about 590 mμ. The purple silk edging in the third sample showed a well-defined dark band in the spectrum covering the spectral range between 580 and 610 mμ.

The luminosity of the red sector relatively to those of the blue and green sectors varied as between the three samples. The full gown of purple silk which showed a violet shade of colour showed the blue sector of the spectrum more brilliantly than the other two. *Per contra*, the purple silk of the third sample which exhibited a distinctly red shade of colour, exhibited the red sector rather more conspicuously in its spectrum. In every case, the green sector of the spectrum was conspicuous and was more luminous than the blue sector.

The behaviour of the three samples of purple-coloured silk demonstrates conclusively that the purple sensation has its origin in the suppression of the yellow sector of the spectrum by its absorption in the material, the blue, green and red sector continuing to be present in full strength, this being about the same in relation to each other as in white light. Deviations of the red-blue ratio from the normal value result in the exhibition of different shades of purple. We have here a clear contradiction with the ideas regarding colour embodied in the trichromatic theory of colour perception. According to that theory, the purple sensation is complementary to the green and arises from its absence. In other words, the more fully the green sector of the spectrum is extinguished, the deeper or more fully saturated would be the resulting purple sensation. So far from this being actually the case, we find that a fully saturated purple sensation is perceived despite the presence with undiminished intensity of the green sector in the spectrum of the light issuing from the material.

The sensation of blue: Spectroscopic examination of a sample of blue silk showed a complete extinction of the yellow region in its spectrum. This extinction manifested itself as a dark band covering the wavelength range from 560 to 590 mμ. The red sector of the spectrum also exhibited a notable diminution of brightness, as also a dark band crossing the spectrum and covering the spectral range from 620 to 650 mμ. Despite these manifestations of absorption in it, the red sector of the spectrum was very far indeed from total extinction. The green sector of the spectrum in the wavelength range from 500 to 560 mμ was also conspicuous. Though the blue sector showed an enhancement relatively to the green as compared with what is observed with white light, nevertheless, the green sector of the spectrum as seen through the instrument was not less luminous than the blue.

Numerous other examples of blue silk were examined spectroscopically. In all cases, the yellow of the spectrum was powerfully absorbed and indeed except in the case of one sample which was of a light blue colour, it was quite inconspicuous. The red of the spectrum was also much weakened but never actually extinguished. The brightness of the green sector relatively to that of the blue sector varied from specimen to specimen. It could be stated as a general rule that the deeper the colour of the silk, in other words, the more nearly it approaches an indigo colour, the less was the intensity of the green sector relatively to that of the blue.

It is evident from these studies that an elimination, more or less complete, of the yellow sector of the spectrum is essential for the perception of a blue colour. Equally essential is a substantial reduction in the luminosity of the red sector. The part played by the green sector is less obvious. That a saturated blue colour is observed even though the green and red are conspicuously present in the spectrum can scarcely be reconciled with the assumption that the sensory impressions produced by polychromatic radiation represent a simple summation of the visual sensations excited by the different parts of it. Indeed, what we actually observe may be described as masking of the visual sensations excited by the red and green sectors by that of the blue sector. It has, however, to be recognised that the progressive elimination of the green sector by absorption results in the observed blue colour assuming a deeper hue.

The sensation of red: A bright red colour frequently appears in the gorgeously coloured silk sarees for which Bangalore is famous. It was, therefore, possible for the author to examine numerous specimens of red silk spectroscopically. They all exhibited a remarkable effect, viz., a dark absorption band covering the yellow of the spectrum and separating the red from the adjoining green in the spectrum. If the absorption band is absent, the colour of the silk is not red but either scarlet or orange as the case may be, depending on the proportion of yellow light escaping from the material. If, on the other hand, the absorption extends towards greater wavelengths, the colour of the silk is a darker red.

It is evident from these observations that the extinction of the yellow in the spectrum is an essential requisite for the material to exhibit a red colour. But what is particularly remarkable is that all the specimens examined exhibit the green and blue sectors in their spectra though with enfeebled intensity. It would appear in these cases the sensation excited by the red sector of the spectrum results in a masking of the effects of the green and blue sectors by reason of their lower intensities.

The sensation of green: Silk which has been dyed green exhibits a whole range of colours varying from what may be described as a light green at one end to a deep green at the other. Spectroscopic examination reveals that the appearance of even a light shade of green is accompanied by a weakening of both the blue and red sectors of the spectrum. Noticeable also is a fall in brightness of the range of wavelengths between 560 and 600 mμ relatively to the wavelength range between

500 and 560 mμ, in consequence of which the maximum of luminosity in the spectrum shifts visibly towards smaller wavelengths. These features are all accentuated in the case of the specimens exhibiting deeper colours, so much so that silk which appears a full green shows a nearly complete extinction of the yellow of the spectrum and the maximum of luminosity appears at 530 mμ. Silk which is of a deep green colour exhibits the maximum of luminosity at 525 mμ and the fall of the luminosity with increasing wavelength beyond 550 mμ is so marked that a dark band separating the green and the red in the spectrum is clearly recognisable. The blue of the spectrum is very weak and may be perceived extending beyond the green towards shorter wavelengths. The red of the spectrum is also weakened but remains a conspicuous feature in the spectrum of even the darkest green silk. But it does not exert any observable influence on the perceived colour.

We may sum up by stating that an extinction of the yellow sector of the spectrum is essential for the material to exhibit a green colour. The red of the spectrum continues to be observable but is masked from perception by the more luminous green.

The blue-green sequence: Silk may be dyed so as to exhibit a whole range of colours which may be described as intermediates between green and blue. Spectroscopic examination reveals certain features common to the whole sequence and other features which exhibit a regular progression in the series. The common feature of the whole range of colours is a large fall in the brightness of the red sector as well as a practically complete extinction of the yellow sector. The progressive feature is the extension of the spectrum towards shorter wavelengths and the increase of the intensity of the blue sector. Remarkably enough, however, in all these cases, the green sector of the spectrum as observed through the instrument appears much more luminous than the blue.

Rose-coloured silk: Of exceptional interest is the case of dyed silk which exhibits a rose-red hue which is both brilliant and attractive. Spectroscopic examination reveals that this colour has its origin in an extinction of the green sector of the spectrum, while the rest of the spectrum including especially the blue sector, remains of undiminished intensity. That the colour resulting from this extinction of the green of the spectrum is a brilliant rose-red is a particularly significant fact. It presents us with a clear-cut contradiction of the ideas of the trichromatic theory according to which the sensation resulting from a suppression of the green in the spectrum should have been a highly saturated purple.

The theory of colour perception: The facts of observations set out above and in the preceding chapters enable us to form fairly clear ideas regarding the nature of the relationship which exists between the spectral character of polychromatic radiation and its perceived colour. It is also possible to go further and to venture upon an interpretation of the facts, basing ourself on a recognition of the corpuscular nature of light and the part that it plays in the perception of the colours of monochromatic radiation.

The spectrum of white light presents to our vision a continuous progression of colour in which we can distinguish a great many different hues. At some points in the spectrum, the progression of colour is exceptionally rapid and at others it is relatively slow. These experiences become intelligible when it is recalled that the energy associated with a light corpuscle increases progressively from one end of the spectrum to the other and that the perception of light arises from the absorption of the energy of the corpuscle and its transformation in the retina into the energy of electrical impulses which travel to the centres of perception. The variations of the luminous efficiency of radiation and of the power of colour discrimination in the spectrum arise as consequences of the spectroscopic behaviour of the visual pigments in the retina. Further, each different colour which we can perceive in the spectrum is "a fundamental visual sensation" and can claim recognition as such equally with every other colour in the spectrum.

It is the conjoint effect of the sensations excited by all individual parts of the spectrum of polychromatic radiation that determines its colour. By reason of the varying luminous efficiency of radiation in the spectrum, these individual contributions differ greatly, apart from the variations determined by the varying absorption in the material. Some sections in the spectrum may therefore be expected to contribute to the visual effect much more than others. In earlier chapters, factual evidence has been presented that the major visual sensations are those associated with the yellow sector of the spectrum. It is therefore not at all surprising and indeed could have been confidently anticipated that the removal of the yellow sector from the spectrum would result in notable chromatic effects and that the presence or absence of that sector would be the principal determining factor for the observed colour of the light. This, indeed, is what we actually find to be the case.

It is convenient in considering the colour sensations excited by polychromatic radiation to consider its spectrum to consist of four sectors: the blue sector from 400 to 500 mμ; the green sector from 500 to 560 mμ; the yellow sector from 560 to 600 mμ and the red sector from 600 to 700 mμ. We may ask ourself, what would be the result of removing the yellow sector from the spectrum of white light, other things remaining the same. We have the blue and green sectors on one side and the red sector on the other side. What observation tells us is that the result is a purple sensation. We can therefore identify this sensation as the result of the superposition of the blue, green and red sectors, the yellow sector being absent. Observation likewise tells us that when the red is also weakened, even if it is not actually extinguished, the sensation perceived is blue. In other words, the observed sensation changes from purple to blue if the balance is tilted towards shorter wavelengths by lowering the intensity of greater wavelengths. If, further, the blue sector is much weakened, the sensation perceived is green, even though the red has not been totally extinguished. Thus, in every case, it would be seen that the perception of colour is determined by the domination or masking of the weaker by the stronger sensations. It is also evident from the facts that the blue and the green sectors are not antagonistic to each other, the perceived sensation arising from their co-operation being a blue or a green or an intermediate colour, according to the circumstances of the case. Other examples of transitional colours present themselves in the sequence of hues ranging from a pure yellow to a pure red through the intermediates of an orange yellow, an orange and a scarlet.

The trichromatic hypothesis: From the theoretical standpoint, each of the numerous distinguishable colours we can perceive in the spectrum is an independent visual sensation. The trichromatic theory of colours bases itself on the idea that the perceived colours of polychromatic radiation can be described in terms of "three fundamental sensations" and that these may be summed up making use of a set of empirically determined coefficients (positive or negative as the case may be) which vary from point to point over the spectrum. That the procedure is highly artificial is obvious, and its claim to acceptance disappears when the basic idea and its consequences are found to be flatly contradicted by the facts of observation. As we have seen, the circumstances in which polychromatic radiation actually presents itself to our perceptions as exhibiting such readily recognisable colours as purple, blue, green and red are very different from those contemplated by the trichromatic hypothesis.

One of the reasons for this failure of the trichromatic hypothesis stands out clearly. That hypothesis regards red, green and blue as the major visual sensations and relegates the sensation of yellow to a minor and secondary or derivative position. Actually, it is yellow which is the major visual sensation, while the red, green and blue though more colourful are only its subsidiaries. They are perceived as full colours only when the yellow is put out of the way.