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The new physiology of vision—Chapter XIII. Blue, indigo and violet in the spectrum

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The studies of colour in the spectral range between 5000 and 4000 Å at various levels of brightness made by the author and presently to be described have yielded results of great interest. It is found that the basic sensation excited by radiations falling anywhere within this spectral range is that of violet. In other words, light everywhere in this spectral region exhibits a violet colour if its brightness does not much exceed the minimum needed for the perception of sensible colour. As the intensity is increased, the violet passes over at a fairly definite level of brightness to a sensation which may aptly and correctly be described as indigo. At a still higher level of brightness, the colour changes over to a bright blue colour. These remarkable results have been established using several different techniques of observation which will be set out fully as we proceed. All the three colours, viz., blue, indigo and violet may be perceived following each other in the order stated in the spectrum of continuous radiation if this has the appropriate intensities.

Another result of great interest which has emerged from the present investigation is that in the spectrum of continuous radiation, three maxima of luminosity separated by regions of lower brightness may be observed visually. The positions of these maxima have been located at 470, 435 and 410 mμ. These maxima of visual brightness appear in the same positions as the known maxima of absorptive strength in the spectrum of the visual pigment xanthophyll functioning in this region of the spectrum.

Techniques of observation: One of the simplest methods for the study of the colour-luminosity relationship in the spectrum is visual observation with the aid of a replica diffraction grating of the light from the linear source furnished by an opening between the wooden shutters of a darkened room. The observer holds the grating before his eye and scans the diffraction spectra seen in his field of view. The best time for such observations is in the early morning hours; the window should face eastwards, so that a strip of the brilliantly luminous sky in the vicinity of the sun is seen through the opening between the shutters. At that hour, owing to the rays of the sun having traversed a great depth of atmosphere, light having the shortest wavelengths is much attenuated. Examination with a pocket

spectroscope shows a rapid falling off in brightness between 450 and 430 mμ and no observable intensity at smaller wavelengths. But the observations can also be made at other times when the spectrum extends to lower wavelengths.

The width of the opening and the distance of the observer from it may both be adjusted so that the diffraction spectra have adequate intensity and at the same time exhibit adequate resolution and dispersion. A further device which is extremely useful is for the observer to place immediately before the diffraction grating, a colour filter of gelatine film dyed with "disulphine blue". (The preparation of such filters will be described fully in a later chapter.) This filter effectively cuts off the red, orange and yellow of the spectrum and allows only wavelengths less than 560 mμ to reach the eye of the observer. Apart from making it easier to observe the colours in the rest of the spectrum without dazzle or interference, the cut-off of wavelengths greater than 560 mμ prevents the overlap of the diffraction spectra of higher orders with each other. It then becomes possible to study the colours exhibited between 500 and 430 mμ not only in the first-order diffraction spectrum but also in the second-order and third-order spectra. These are, of course, of much lower intensities.

Results of the study: With the arrangements described above, it is found that the appearance of the spectrum in the region following the green sector is altogether different in the first, second and third-order diffraction spectra. The intensity of the spectra can be controlled by varying the width of the opening between the shutters, the observer retaining his position at a convenient distance from it. It is best to adjust the luminosity so that the third-order spectrum is just sufficiently bright for it to be clearly perceived. The first-order spectrum then exhibits a blue colour between 490 and 460 mμ and an indigo between 460 and 430 mμ. In the second-order spectrum, on the other hand, the blue is unobservable and the region between 490 and 430 mμ exhibits the indigo colour. The third-order spectrum exhibits a violet hue over the entire region.

Very similar results are obtained using the artificial light source provided by a tubular lamp with a tungsten filament stretched along its axis and heated by an electric current. The observer views the diffraction spectra of different orders of this light source with a replica grating and the "disulphine blue" colour filter held before his eye. The luminosity of the spectrum may be quickly and rapidly controlled by moving the slide on the rheostat which varies the current heating the tungsten filament. The same result can also be achieved by the observer moving away from or towards the lamp. The entire sequence of changes in the colour exhibited over the whole spectral change can thus be quickly and conveniently followed.

Still another procedure which enables the colour-luminosity relationships to be studied in a quantitative fashion is to observe the spectrum of the continuous radiation of a tungsten-filament lamp through a wavelength spectrometer. A coiled-coil filament lamp giving a brilliant white light of the type used in

projection work is very suitable for such observations. A sheet of opal glass placed immediately in front of the slit of the spectrometer helps to diffuse the light entering the instrument and enables its full aperture to be utilised. By moving the light source away from the opal-glass sheet, the level of illumination in the spectrum under observation can be varied over a great range in a calculable fashion. The observer can then view the spectrum in the focal plane of the instrument through an eyepiece and follow the changes in the colour sequence as the lamp is moved away from the opal-glass sheet. It will be noticed that the blue part of the spectrum progressively contracts, being replaced by the indigo and finally by the violet colour which is the basic hue of the spectrum throughout the wavelength range between 500 and 400 mμ.

Observations with sunlight: If sunlight is admitted into a darkened room through a narrow slit and the emerging pencil of rays after traversing a dense flint-glass prism of 60° angle is received on a white screen placed at a suitable distance, one observes the solar spectrum after the manner of Newton. The differences in colour between the blue, indigo and violet regions in the spectrum then observed are so very striking that one can only wonder why later writers have not accepted Newton's description of the colours of the spectrum. Had they taken the trouble to repeat Newton's experiments making use of the high luminosities made possible by sunlight, they would have realised that his description was entirely accurate. Incidentally, it should be remarked that in the spectrum seen under these conditions, the maximum visual brightness appears in the yellow region and not in the greenish-yellow.

The spectrum of sunlight can also be exhibited in a spectacular fashion with the aid of a diffraction grating having a large ruled area. Sunlight reflected by a heliostat enters a darkened room through an aperture of area 10 × 5 cm and after the beam has traversed a distance of two metres, it is incident on a replica diffraction grating with a ruled area also of the same size (10 × 5 cm). The first-order diffraction spectrum resulting from the passage of the light through the grating is received on a white screen 8 m away from the grating. It is then seen as a brilliant band of colour stretching over a length of 150 cm. In the region of shorter wavelengths, three regions are noticed of which the colours are quite different and readily distinguishable from each other, viz., blue, indigo and violet.

Instead of allowing the spectrum to diverge from the grating and fall on a distant screen, a more satisfactory arrangement is to use a telescopic objective of sufficient aperture (15 cm) and of sufficiently great focal length (400 cm). The first-order diffraction spectrum is brought to a focus by the objective and the intensity and the definition of the spectrum are thereby greatly improved. The spectrum is received on a ground-glass screen and is viewed by the observer. By covering up the ruled area of the diffraction grating, its aperture may be progressively reduced from 10 cm down to a mm and the brightness of the spectrum is thereby proportionately reduced. Remarkable changes are then

noticed in its colour. When the full aperture of the grating is functioning, the blue region covers the greater part of the spectrum between 500 and 400 mμ, the indigo and the violet occupying only small parts near the end. As the luminosity is diminished, the blue progressively contracts and ultimately disappears, being replaced by the indigo and then by the violet. In the final stages, the entire spectrum after the green exhibits a violet hue.

Colours in line spectra: The light emitted by the radiating atoms is localised in their spectra and appears as sharply defined lines. When these lines are observed visually through a dispersing apparatus, they would generally appear to be of much greater intensity than any continuous spectrum accompanying them. The colour-luminosity relationship would then make itself felt as an observable difference between the colour of the spectral line and of the continuous spectrum on either side of it. Such a difference is conspicuously exhibited by the λ 4358 line in the spectrum of the mercury vapour lamp when there is an accompanying continuous spectrum. It appears of a bright blue colour, while the continuous spectrum on either side exhibits a violet hue resembling that of the λ 4046 radiation.

Spectral lines of low intensity in the region between 500 and 400 mμ may exhibit colours different from those normally to be expected in that region. This phenomenon may be observed in the spectrum of a sodium vapour lamp soon after it is started, when feeble emission lines of gas atoms other than sodium are also present. Lines appear which exhibit a violet hue instead of the blue colour to be expected from their positions relatively to the stronger lines.

Origin of the three colours: The foregoing recital of the actual facts of observation leaves us with some questions which need to be answered. Why are three colours readily distinguishable from each other exhibited in the spectral range under consideration? Why do the colours alter when the level of brightness is varied? Some light is thrown on the issues here raised by a few further observations presently to be described.

The absorption spectrum of xanthophyll has already been described in detail in an earlier chapter, but it may be briefly recalled here. The absorption increases from zero at 520 mμ to a substantial value at 500 mμ. It then rises steeply and exhibits a pronounced maximum at 476 mμ. It then dips down to a minimum, beyond which it recovers and exhibits a second and even more pronounced maximum at 447 mμ. Thereafter, there is a fall which is however interrupted by the appearance of a third but less pronounced maximum at 420 mμ. There is then a continuously diminishing absorption as we pass from the visible to the ultraviolet region.

These various features show a close relationship to the visually perceived features in the same range of the spectrum. It has already been remarked that the first steep rise in absorption around 490 mμ occurs precisely where the observed

colour of the spectrum changes rapidly from green to blue. In the present study, a further remarkable parallelism has come to light. This is the appearance of bands of higher luminosity in the spectrum which coincide in their respective positions with the absorption maxima of xanthophyll. To observe these bands, the same technique is employed as that described earlier for the studies of colour in this region. The observer views the first-order diffraction spectrum of a luminous tungsten filament produced by a grating held before his eye. The bands commence with a noticeable fall in luminosity in the spectrum where the green ends and the blue begins. Following this, a bright band with a maximum of intensity at 470 mμ is readily recognisable. A further drop in luminosity is followed by a recovery and a second maximum of brightness at 435 mμ is noticed. Beyond this again, there is a further drop in intensity followed by a recovery in which the third and last maximum at 410 mμ is discernible. The first maximum at 470 mμ falls in the blue region, the second maximum at 435 mμ in the indigo and the third maximum at 410 mμ appears in the violet.

These facts of observation suggest that the reason why three distinct colours manifest themselves to our visual perceptions in the spectral range between 500 and 400 mμ is just that the absorption spectrum of xanthophyll has three maxima in this spectral range, these three maxima covering the regions in which the three colours respectively appear. This, however, leaves unanswered the question why the perceived colours alter with the level of brightness in the spectrum. But such alterations are not altogether unexpected. In the preceding chapter, we have noticed that the colour sensations which are experienced in the spectral range between 5000 and 6000 Å are strongly influenced by an increase in the level of luminosity. It need not therefore surprise us to find that in the adjoining spectral region between 4000 and 5000 Å, changes in the level of luminosity also produce striking changes in the colour sensations. That they are of a different nature need not also surprise us. For, in the former case, the visual pigments which function are heme and its derivatives which are biological products of human metabolism whereas in the latter, it is the carotenoid pigment xanthophyll, a plant material which has found its way into the human body by way of food products consumed. In the two cases, we are dealing with the pigments which differ profoundly in their chemical structure as also in their spectroscopic behaviour.