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The new physiology of vision—Chapter V. Corpuscles of light and the perception of colour

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The subject of colour is of extraordinary interest and importance. The nature of the colour sensations experienced in various circumstances and the genesis of those sensations are, therefore, amongst the major problems with which the physiology of vision is confronted. In the present chapter these problems will be considered, but we shall restrict ourselves to the specially simple class of cases in which the sensations are those excited by light of spectral purity, in other words, by radiations limited to a narrow range of wavelengths in the spectrum. The sensations excited by spectrally composite radiations present a field of enquiry of a more complex nature. They will be dealt with in later chapters.

That the sensation of colour arises from and is closely related to the corpuscular nature of light is evident from the progression of colour observed in the spectrum. When white light emitted by a solid body held at a high temperature is analysed by passage through some dispersing apparatus, e.g., a prism or a diffraction grating, it appears spread out into a continuous band of colour. If the dispersion is adequate, a great many different colours may be distinguished in it. These colours form a continuous sequence, and since the light isolated from a sufficiently narrow region of the spectrum consists of corpuscles all having the same or nearly the same energy, it follows that each specific colour observed in the spectrum corresponds to a distinct set of corpuscles all having the same or nearly the same energy. The association thereby made evident between the energy of the light-corpuscles and the colour sensations excited by them is clearly of a fundamental nature. It has, of necessity, to form the basis of any attempt to ascertain or elucidate the nature of the sensations of colour.

Luminosity and colour: The visual effect of light reaching the eye is determined by two variables capable of quantitative specification and measurement, viz., the flux of light and its spectral character. We may proceed to associate these two physical variables respectively with the two characters which are noticeable in our visual sensations, viz., the brightness of the light and its chromatic effect. This way of regarding the matter is, however, not free from difficulties. It assumes without proof that luminosity and colour are independent sensations. Actually, it is possible to take a different view of the situation. While recognising that the visual effect of light is determined by two factors which can be independently varied, we may regard the sensation as being itself one and indivisible. An argument which lends support to this latter view may be based on a consideration of the effect of progressively reducing the flux of light till it reaches the vanishing point, while its spectral character remains unaltered. It is evident that the entire sensation would disappear when the flux of light is zero. This leads us to the inference that luminosity and colour are not independent sensations but are only aspects of one and the same sensation. That we can recognise a difference in brightness and/or a chromatic difference between two sources of light set side by side for comparison is a fact of observation. It shows that the visual effect of light presents certain recognisable characters. But it does not demonstrate that these characters are independent of each other, in other words, that they can be varied without mutually influencing each other.

By the use of appropriate equipment, the radiations appearing as individual lines in the spectra of metallic vapours may be isolated and the visual sensations excited by such light at various levels of intensity may be studied. What has been stated above makes it clear that we would not be justified in assuming that an alteration of the light-flux in such cases would result in altering the observed luminosity but would leave the chromatic sensation unaffected. So far from this being the case, the investigations presently to be described show that the chromatic sensations excited by such spectrally isolated radiations are profoundly modified by variations of the light-flux. The factual situation thus revealed is clearly of fundamental significance in its physiological implications.

Observations with the sodium lamp: In the spectrum of the light emitted by sodium vapour in the commercially available lamps, the yellow lines are so enormously more powerful than the other radiations present that the latter can be ignored. The sodium vapour lamp is thus a very convenient tool for a study of chromatic sensations at various levels of illumination. The lamp is enclosed in a box, and an aperture on one side of it allows the light to emerge and pass through a diffusing screen of ground glass followed by an iris-diaphragm. The opening of the iris can be varied from a diameter of 10 cm down to a few mm. The observations are made in a fairly large room (ten metres square) which can be completely darkened.

A chromatic sensation being a matter of subjective perception, it is essential to provide a means of ensuring that the experiences reported are not of an illusory nature. The following procedure has accordingly been adopted in the investigation. The lamp and the observed are located near each other at one end of the room, both facing towards its further end. A plastic screen of perfectly white material is set up on a stand facing the lamp and the observer so that the light issuing from the lamp falls on the screen. The surface of the screen is smooth and has a good polish. It accordingly reflects a part of the light falling on it and a reflected image of the source of light is seen by the observer. This exhibits a brilliant orange-yellow colour. Neither the brightness of this reflected image nor its colour shows any alteration when the iris-diaphragm is closed down from the full aperture of 10 cm down to a few mm. Likewise, neither the brightness of the reflected image nor its colour shows any alteration when the screen is moved away from its original position close to the lamp and the observer to the further end of the room.

But the part of the light falling on the screen which enters the plastic material and is diffused backwards, thereby becoming visible to the observer as a general illumination of the screen, behaves quite differently. The strength of this illumination varies enormously with the circumstances. When the iris is fully open and the screen is close to the source of light, it is quite high. As the screen is moved away from the lamp and the observer, the illumination diminishes rapidly. If further, the iris is also progressively closed down, the illumination of the screen becomes extremely feeble. In the various circumstances stated, the observer can compare the colour of the reflected image of the source with the colour of the diffuse illumination of the screen. It then becomes evident that the alterations in the brightness of the diffuse light go hand in hand with changes in the chromatic sensation excited by it. As the brightness falls, the chromaticity diminishes and the diffuse illumination becomes more nearly achromatic. Even when the light diffused by the screen is at its maximum intensity, its colour does not approach in its quality, the rich orange-yellow of the original source. In the final stages, when the illumination of the screen is very weak, the chromaticity persists but is then only barely perceptible.

An alternative procedure which enables the observer to convince himself of the reality of the changes in chromaticity resulting from changes in luminosity is to view an illuminated white card held at arm's length and rapidly to alter the strength of its illumination by the sodium light. This may be done, for instance, by quickly reducing the aperture of the iris-diaphragm. Alternatively, with an iris opening of about 1 cm, the card may be held near the source and then moved away quickly to a greater distance. The reductions in chromaticity thus brought about are strikingly obvious.

Observation with the mercury lamp: Using a double monochromator and the arrangements already described in an earlier chapter, each of the stronger radiations of the mercury arc may be isolated and utilized for observations of the same nature as those detailed above. With the instrument set to pass the light of any selected radiation in the spectrum, the exit-slit of the monochromator when viewed directly from any position by the observer exhibits the colour of the particular radiation quite brilliantly. On the other hand, if the light diverging from the exit-slit falls upon a white card or a white plastic screen and the light diffused by it is viewed by the observer, the colour observed is relatively weak. Indeed, only when the diffusing screen is held very close to the exit-slit is the colour of the diffused light at all comparable with the colour of the light from the slit as viewed directly. The weakening of colour is thus evident even when the illumination of the screen is still fairly strong. As the screen is moved further and further away from the slit and the illumination becomes weaker by reason of the divergence of the emerging beam, the chromaticity continues to diminish continuously and progressively and the perceived sensation approaches more and more nearly to an achromatic sensation. Nevertheless, the chromaticity continues to be detectable so long as the illumination of the screen can itself be perceived.

It should here be emphasised that though effects of the nature described can be observed with every one of the radiations spectrally isolated from the light of the arc, the rapidity of the chromatic change noticed when the diffusing screen is moved away from the exit-slit is by no means the same for all of them. The most striking and rapid changes are exhibited by the $\lambda 4358$ radiation of the arc appearing in the blue region of the spectrum. Very striking also, though not so rapid, are the changes noticeable with the $\lambda 6150$ radiations in the red region of the spectrum. On the other hand, with the $\lambda 5461$ radiations in the green and the $\lambda 5770$–5790 radiations in the yellow, we have to move the receiving screen much further away from the exit-slit before the chromatic changes are as obvious as with the blue and red radiations. These differences may, at least in part, be explained in terms of the greater visual intensity of the $\lambda 5461$ and $\lambda 5770$–5790 radiations of the mercury arc as compared with the $\lambda 4358$ and the $\lambda 6150$ radiations.

The significance of the results: The highly remarkable but indisputable fact which emerges from the studies which have been described is that the chromatic sensations usually known as the colours of the spectrum fade away and progressively tend towards an achromatic sensation (though they do not actually become such) as the illumination which reaches the observer is continuously reduced. It is evident that we have here an effect of fundamental significance in the physiology of vision. The question may here be asked whether such a striking phenomenon could not be demonstrated in a simple fashion, as for example, by an observer viewing directly the spectrum of a light-source the luminosity of which is progressively diminished. The answer is that the subjective nature of the effect makes it desirable that the arrangements for its observation should be such as to exclude all possibility of error and ensure the reality of the findings reported.

We now turn to the basic question, why should the chromatic sensation excited by spectrally pure radiation fade away as the effective light-flux is diminished? The answer to this may be found in the two preceding chapters in which the perception of luminosity and the perception of form were respectively discussed. In both of those chapters, we were concerned with effects in which the corpuscular nature of light comes visibly into evidence. In both cases also the effects observed become increasingly more conspicuous as the light-flux is diminished; in both cases also, they depend notably on the spectral character of the illumination. The parallelism in these respects between the effects described in those chapters and those now under consideration is evident. It is quite appropriate therefore that we proceed to find an explanation on generally similar lines.

What the observations indicate is that the chromatic sensations which we normally associate with the different regions in the spectrum demand that the corpuscles of light reach the individual visual receptors in the retina in sufficient numbers and follow each other in such rapid succession as to give rise to a continuous and coherent sensation. These are precisely the conditions in which the fluctuations of luminosity in the field under observation would cease to be noticeable and in which the visual acuity as determined by appropriate tests would reach the optimum value. That the chromaticity is also at its best in these circumstances is readily verifiable by observation. It is found when the illumination is sufficient to meet the most stringent tests for visual acuity, the colour perceived is most brilliant. *Vice-versa*, when the illumination falls and the visual acuity is reduced thereby, the chromatic sensation is noticeably weakened. As the chromatic sensation progressively becomes weaker and weaker by reason of the diminishing light-flux, the visual acuity also suffers and touches very low levels.