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The new physiology of vision—Chapter VI. Vision in dim light

SIR C V RAMAN

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The results which emerged from the investigations set forth in the three preceding chapters are evidently of far-reaching character. They indicate fresh lines of approach to the basic problems which confront us in the physiology of vision. In the present chapter, we shall make use of some of the findings to elucidate the nature and origin of the differences between visual sensations at low and at high levels of illumination. We may begin by mentioning some facts of observation which indicate that there is a real difference in the visual processes operating at those levels.

When an observer who has been out-of-doors enters a dimly lit room, his first feeling is that of finding himself in complete darkness. After a few minutes, however, he begins to perceive the most brightly illuminated objects in the room; later, those which are less bright come into view, one after another. The effect of a prolonged stay in complete darkness is even more striking; the sensitivity of the eye to feeble light is thereby enormously enhanced. *Per contra*, even a short stay in brightly illuminated surroundings suffices to destroy the sensitivity thus generated. We have, as it were, a process of "switching on" of the apparatus which enables the eye to function in dim light. There is also a "switching-off" of that apparatus which results from exposure of the eye to bright light and this is a fairly rapid process.

Chromatic sensations in dim light: Remarkable changes in our ability to perceive colour follow as a result of lowering the level of illumination of the objects under view. This effect may be exhibited in the following manner. A set of five steel plates of the same size may be painted over with enamels of brilliant hues and set side by side in the following order: White, blue, green, yellow and red. The observations may be made in a room which has been darkened and into which skylight can be admitted through a circular window provided with an iris-diaphragm of which the opening can be altered as desired from a diameter of 25 cm down to 5 mm. The illumination of the plates under view can thus be altered over a ratio of 2500:1.

As the iris is progressively closed down, very striking changes are noticed in the appearance of the set of plates. The plate which is red and exhibits that hue brilliantly when the iris is fully open becomes darker and darker as the illumination is diminished by closing down the iris. The plate then turns black and remains completely black. This, of course, is the well-known Purkinje phenomenon. A perfect contrast with the behaviour of the red plate is provided by the plate which is white. This exhibits no change whatever and remains throughout as the brightest of all the plates. The brilliant colours shown by the yellow, green and blue plates become much less brilliant as the iris is progressively closed down. At low levels of illumination, the yellow plate continues to exhibit that hue but much enfeebled. It also appears more luminous than the other two plates but is inferior to the white plate in that respect. Next in order of brightness is green plate which continues to exhibit a greenish hue. The blue plate appears in the same circumstances to be of a darker hue with a bluish tinge.

The colour-luminosity relationship: The changes in chromatic sensations manifested at low levels of illumination have in the past been sought to be explained on the basis of an assumed duality of the human retina, viz., a day-retina which perceives colour and a night-retina which has only colourless vision; in the day-retina the cones are the receptors of vision, while in the night-retina, the rods perform that function. That this approach to the theory of colour perception cannot be sustained is evident from the facts of observation recalled in an article by the author entitled "Stars, Nebulae and the Physiology of Vision" published in the issue of *Current Science* dated the 20th of May 1964. When we look at the sky by night and fix our attention on any particular star, its image is formed on the foveal region of the retina, and since this contains only cones and no rods, it is cone-vision and not rod-vision that is functioning. The effective surface-temperatures of the stars show a great range of variation. Nevertheless, it is a fact of observation that the vast majority of the stars visible to the naked eye appear merely as specks of light without any hint of colour. But as seen through a telescope with an objective of adequate size and correspondingly great light-gathering power, the colours of the individual stars and the differences between them are much more evident. Then again, the gaseous nebulae, e.g., the Great Nebula in Orion, as seen through small telescopes appears as areas of diffuse luminosity without noticeable colour. On the other hand, as viewed through giant telescopes, they exhibit brilliant and variegated hues. It is thus clear that the factor which determines the observability of colour is the magnitude of the light-flux which reaches the eye of the observer. Hence also, a distinction between rod-vision and cone-vision is irrelevant in this context. In the fifth chapter of this treatise, observations have already been described showing that a change in the level of the illumination of the object under view profoundly influences the chromatic sensations which it excites, thus affording an experimental confirmation of the same result as that emerging from the visual observations in the field of astronomy referred to above.

The colours of the spectrum: A technique has been devised by the author for a critical study of the chromatic sensations excited by a pure spectrum at all levels of illumination. It is both simple and flexible and yields results free from all uncertainty or possibility of error. The observer places himself in a large room which can be completely darkened and in which there are no sources of light present which can disturb or distract his vision. The light under observation enters the room from outside through a long narrow opening of which the actual width can be varied within wide limits. Such an opening is readily provided by a suitable adjustment of the wooden shutters which cover one or another of the windows of the room. The observer sits facing the opening at some considerable distance from it and holds close to his eye a diffraction-grating of good quality, as for instance, one of the replica gratings supplied by the firm of Adam Hilger in London. The observer's field of vision then includes besides the opening itself, the diffraction spectra of various orders on either side of it. The spectral resolution provided by the grating is such that even with these simple arrangements a great many Fraunhofer lines can be seen in the spectra. If the observer is sufficiently far away from the window, the opening between its shutters can be increased by a ratio of 100:1 without any serious loss of purity in the spectra, while their brightness is increased in that ratio. Still larger variations in the light-flux can be obtained by merely choosing the time of the day at which the observations are made. The light of the sky which enters through the opening has practically zero intensity on a dark moonless night. It is much brighter when the sky is lit up by the light of the moon. In daytime when the sun is well above the horizon, it is enormously brighter. During the hours of twilight, before dawn or after sunset, it exhibits a progressive increase or a progressive diminution, as the case may be. The observer is thereby enabled without using any special equipment to study the chromatic sensations excited by the rays of the spectrum at all levels of illumination, ranging from zero upwards to high values.

The results of the study: The diffraction spectra seen when the light of the sun-lit sky is admitted through the opening between the shutters are of the usual type in which the luminosity of the red region of the spectrum is conspicuously greater than that of the blue region. Simple inspection enables the observer to discover for himself some very significant results. For example, with the particular grating employed, the first-order spectrum on one side is very bright and the second-order spectrum on the same side is very weak. Comparison of the two spectra shows that the visible difference in their luminosities goes hand in hand with a notable difference in their chromaticities. This difference is exhibited by every part of the spectrum ranging from the red end to the violet. But the blue-violet regions in the two spectra which are the least luminous show the difference in a particularly striking fashion. Likewise, a diminution in chromaticity can be observed at all points in the spectra of all orders when the illumination is lowered by a large reduction in the width of the opening through which the light is admitted. The variations in chromaticity as between the spectra of different orders are particularly conspicuous when the observations are made early in the morning or late in the evening when the light-flux reaching the eye of the observer is rather low.

The spectra as seen under "dim-light" conditions, e.g. at night-time using the moon-lit sky present a totally different appearance. They are much shortened, the red region being totally absent. The first-order spectra exhibit a greenish hue for the greater part, while their terminations on either side exhibit slightly different hues. The second-order spectra on either side which are of much lower intensity can be seen but do not exhibit any recognisable colour.

The change in the character of the spectra in passing from high-level to low-level illumination can be followed by making the observations during twilight hours. The changes from one type of spectrum to the other can also be quickly effected and observed by the use of two polaroids between which the diffraction grating is interposed. If the polaroids are in the crossed position, the spectra are completely cut off. By rotating one polaroid with respect to the other, the light is restored and the progressive increase in the brightness of the red region relatively to the rest of the spectrum can be readily followed.

We may sum up the results of the observations as follows. At the higher levels of illumination, the chromaticity of the spectrum colours is profoundly influenced by the magnitude of the light-flux which reaches the eye, falling off rapidly as the light-flux diminishes. This effect is exhibited by all parts of every spectrum. At low levels of illumination, the red end of the spectrum is cut off, as is to be expected in view of the Purkinje phenomenon. But the other spectrum colours continue to be observable even at such levels, though in an attenuated form, their chromaticity decreasing progressively as the level of illumination is lowered.

Observations with colour filters: The studies described in the preceding chapter and in the present one may be usefully supplemented by the aid of colour filters suitably chosen and judiciously employed. The most suitable filters are those which transmit restricted regions of the spectrum and effectively cut off the rest. If such a filter is interposed between the eye of the observer and a diffraction grating in the method of observation described earlier, the overlap of the spectra of higher orders with each other is effectively avoided and it becomes possible for the observer directly to compare with each other the spectra of all the orders. Four or five orders are exhibited on each side by the replica grating, their intensities falling off with increasing order. The fall in chromaticity which goes hand in hand with the decrease in luminosity is then very strikingly exhibited. As all the spectra can be seen simultaneously, this is a highly impressive demonstration of the fact that colour and luminosity are inseparable aspects of our visual sensations and have to be considered together in physiological theory. Four filters suitable for observations of this kind have been used, one transmitting a band at the violet end of the spectrum, the second a band in the blue, the third a band in the green, while the fourth transmitted the red region in its entirety and cut out the rest of the spectrum. All the four filters exhibit the stated effects in a very striking fashion.

If a colour filter be held in front of an observer's eye and a white surface under daylight illumination is viewed through the filter, the appearance of the surface depends greatly on the actual level of such illumination. These variations can be demonstrated in an impressive fashion by making the observations in a darkened room, the illumination being controlled by the use of a circular window covered by an iris diaphragm, as has been described earlier. The observer should view alternately the window through which the light is admitted into the room and the surface on which the light falls, holding the filter in front of his eye all the time. A striking difference is then observed between the chromatic effects noticed in the two cases. As the iris is progressively shut down, the window as seen through the iris continues to exhibit the same brightness and the same brilliant colour throughout. On the other hand, the chromatic sensation excited by the illuminated surface progressively becomes weaker and weaker and approximates more and more nearly to an achromatic sensation as the iris is shut down.

Finally, mention should be made here of a remarkable effect noticed in observations of the same nature as that mentioned above when a red filter is held in front of the observer's eye and the object viewed under daylight illumination is itself an object of a brilliant red colour, e.g., a plastic sheet of that colour, or a steel plate covered with red enamel. By reason of the Purkinje effect, the surface under observation would appear black if its illumination by daylight is below a certain level. If, however, the illumination is a little above that level, it would continue to be visible, but would exhibit a dark red colour. In these circumstances, the effect of interposing a red filter before the observer's eye and then removing it is a dramatic change in its appearance. Without the filter, the surface appears dark red; as seen through the filter, it seems almost perfectly white.