Proc. Indian Acad. Sci. **A60** 375–378 (1964)

The new physiology of vision—Chapter VII. The perception of colour in dim light

SIR C V RAMAN

Received November 25, 1964

The existence in the human retina of the two kinds of structures known respectively as the rods and the cones led to the widespread belief that these structures have different functions to perform; that the cones form the "day-retina" which perceives colours and which adapts itself to darkness quickly but only to a small extent: that the rods on the other hand constitute a "night-retina" which has only colourless vision and a sensitivity which increases but slowly and over a wide range as the period in darkness becomes longer. We have now to consider whether it is possible to reconcile these beliefs—any of them or all of them—with the facts of observation elicited by the author's studies and set out in the two preceding chapters. The answer to these queries will become evident when the circumstances in which those observations were made are recalled, as we shall presently proceed to do.

The facts which may be grouped together under the description of the colour-luminosity relationship may first be considered. This relationship emerges when the chromatic sensations excited by the individual rays of the spectrum are studied in relation to the magnitude of the light-flux which reaches the retina. The observer views an extended surface on which the light is incident. It is found that as the illumination of the surface is progressively diminished, the chromatic sensation becomes weaker and weaker and tends to approach an achromatic sensation in its character. This effect is manifested by light from all parts of the spectrum and over the entire range of illumination covered by the observations. It is thus clearly a general characteristic of human vision. No question of differentiating between rod-vision and cone-vision can therefore arise in the context of colour perception.

The second group of observations concerns itself with the relative luminosity of the different parts of the spectrum as perceived by the eye at various levels of illumination. The observations are made by a very simple method; the spectrum of the light-source is viewed directly, a diffraction-grating held in front of the observer's eye enabling this to be done. The features of the spectrum as thus observed are found to be quite different at the higher and at the lower levels of illumination. In the former case, the entire spectrum ranging from the red to the violet is observed. But, in the spectrum as observed in dim light, the red region is totally absent; the rest of the spectrum which extends into the green and blue-violet exhibits colour in a perceptible measure, though much less impressively than in the spectrum as seen in bright light. These features are perceived only if the observer has adapted his vision by a sufficient stay in semi-darkness to the low level of illumination at which they manifest themselves. In either case, when viewing the diffraction spectra and recognising their characteristics, the observer makes use of the foveal region of his retina which, as is well-known, contains only cones and no rods.

Thus, while recognising that human vision exhibits different characteristics in "bright light" and in "dim light", we have to remark that the facts do not require us to describe them as vision with colour and without colour respectively. Neither do they require us to identify them with the functioning of the cones and the rods respectively. The need for a lengthy period of adaptation which is a characteristic of "dim light" vision is readily explicable. It is clear that the material needed for the perception of very feeble light is only slowly replenished in the retina when the eye is in the dark and that, *per contra*, it is rapidly removed or destroyed when the eye is exposed to bright light. We are under no compulsion to assume that such replenishment is a specific function of the rods in the retina. On the contrary, it seems more probable that this is accomplished elsewhere in the retina and that the material, if present, would be available for use alike by the rods and by the cones. The facts of observations set forth above indeed suggest that this is actually the case. They indicate that the cones can also function in dimlight and in doing so utilize the material present in the retina which makes such vision possible.

Chromatic sensations in dim light: What has been stated above leads us back to a topic which was briefly touched upon in the previous chapter of the work, viz., the colours exhibited by various objects in dim light as compared with their appearance in bright light. It is not possible for us to deal with this topic here at all fully, for the reason that colour as seen in daylight is the sensation resulting from the synthesis by the eye of the whole spectrum of radiations falling upon the object and returned to the eye after scattering or diffusion by the material of which it is composed. The visual synthesis of colour thus coming into play is a great subject in itself and we shall not here anticipate what will appear about it in later chapters. But it is appropriate that a few observations and remarks are recorded here, supplementing what has been said under the same heading in the preceding chapter.

The fact that colour perception is at all possible in dim light is itself both interesting and important. For the observations to possess any real significance, it is necessary that the observer should have adapted himself by a sufficiently prolonged stay in semi-darkness to the low levels of illumination employed. Further, it is necessary that the illumination under which the objects are viewed is itself not stronger than can properly be described as "dim light". To enable this condition to be satisfied, the observations should be made in a room of which the illumination can be controlled and brought down to the desired low values. The arrangement described earlier—a circular window through which sky-light is admitted and of which the diameter can be reduced by an iris-diaphragm—is well suited for the purpose. A convenient test-object which ensures that the illumination is low enough is a plastic sheet of brilliant red colour having a clean polished surface. When the illumination falling on the sheet is reduced sufficiently, it turns completely black, so much so that a plate of black glass held against it is invisible. It is desirable that the objects under view are also held or viewed against a dark background. This is conveniently arranged by placing them against a plastic sheet of brilliant red colour, or alternatively on a steel plate covered by enamel of a brilliant red colour. As seen in dim light, either of these devices serves the desired purpose in a very satisfactory manner.

A great variety of material offers itself as suitable for studies of the kind indicated. Perhaps the most interesting materials are flowers, by reason of the availability of numerous colours and shades of colour from plants of the same species, thereby enabling some useful comparisons to be made. Roses, for example, can be had which are perfectly white; others are of various shades ranging from the palest to the deepest yellow: other roses exhibit colours ranging between a brilliant orange and a flaming scarlet; roses are also common which are various shades of red, ranging from the palest rose to the deepest crimson. One can arrange a whole series of coloured roses in a row and observe how the observed colours alter as the illumination is progressively reduced down to the dimmest possible.

Useful material for a study of colour at low levels of illumination is also available in the form of the plastic sheets of various hues, the colour in such cases being exhibited by the light diffused within the material, the sheets themselves being more or less perfectly opaque to light and exhibiting a smooth polished surface which does not scatter light. Varied colours and varied shades and depths of colour are readily available. The author had samples of thirty different sorts at his disposal which could be arranged in a regular colour sequence, thereby enabling their behaviours to be readily compared with each other.

We shall content ourself by briefly stating the general nature of the effects observed in such studies. All objects which are a brilliant red in colour become black and are practically invisible in dim light. *Per contra*, all objects which are white in bright light continue to be white in dim light. This is not such a trivial observation as it might seem to be at first sight. Indeed, it might well be considered to be a remarkable and significant fact that when the entire region of the spectrum which appears red in bright light has been eliminated, the visual effect of the rest of the spectrum as perceived in dim light remains unaffected.

Another noteworthy observation is the behaviour in dim light of objects which exhibit a yellow colour in bright-light. Spectroscopic examination shows that the colour of such objects is the result of the elimination of the blue-violet sector of the spectrum; the more complete this extinction is, the more brilliant is the yellow. Yellow flowers or other objects exhibiting that colour are conspicuously luminous as seen in daylight. They continue to be luminous objects as seen in dim light and their yellow colour is also readily recognisable in such light. As in the case of white flowers, the elimination of the red region of the spectrum has no perceivable effect on the observed results.

Spectroscopic examination shows that flowers which appear of an orange colour in daylight exhibit a powerful absorption in the green part of the spectrum, the yellow and the red sectors remaining unaffected. In dim light, these flowers are barely visible objects even against a dark background and their colour is scarcely noticeable. These results are not surprising since in the spectrum of dim light, the red sector is totally absent while the green sector which is its most luminous part ceases to be effective by reason of its absorption by the material of the flower.

By far the most familiar objects exhibiting a green colour are the leaves of plants. The hues exhibited by them vary, a greenish-yellow, a vivid green and a dark green being the shades most commonly observed. In a later chapter we shall have occasion to discuss in detail the origin and nature of these variations. Here it is sufficient to remark that after the necessary adaptation of his vision to the dimly lit surroundings, the observer can readily recognise the green colour of leaves and their variations. The highly decorative deep blue flowers of the "Morning Glory" are barely visible in dim light and then exhibit a just detectable bluish hue.