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The new physiology of vision—Chapter XXXII. Defects in colour vision

SIR C V RAMAN

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John Dalton who in his later years achieved fame as the founder of the atomic chemical theory presented in October 1794 a communication entitled "Extraordinary facts relating to the vision of colours" to the Manchester Literary and Philosophical Society. This was published in the Memoirs of that Society in the year 1798. The observations on which Dalton's memoir was based were those of his own visual deficiency and that of his brother in the perception of colour. Dalton said that he could distinguish in the spectrum two hues which he called yellow and blue, his yellow embracing the red, the orange, the yellow and the green of normal subjects, while his blue appeared in the part of the spectrum which follows the green; he said further that the colour described by others as the violet which appears at the end of the spectrum seemed to him to be a little different from the blue perceived by himself, being more saturated in hue.

Dalton's scientific analysis of his own personal colour perceptions laid the foundations of a subject the literature of which received vast accretions in subsequent years. The measure of attention devoted to the topic is ascribable to the interest attaching to it from diverse standpoints. The defects in colour vision described by Dalton were clearly not in the nature of a disease. They are congenital in character and are acquired by inheritance from or through the parents of the person exhibiting them. Numerous studies made on this aspect of the matter have shown that the deficiencies are far more frequent in men than in women and are indeed comparatively rare in the latter cases. Daltonism (by which name the phenomenon is still frequently referred to) may be exhibited by men to the extent of two or three per cent of the male population. The predominance of the males in this respect is explained by the laws of heredity: anomalies of colour vision are transmitted by the chromosomes which determine the sex. In the case of a man, if a single chromosome X carries the defect, this is sufficient to make his vision abnormal, but with the woman both the X chromosomes must be affected before the infirmity shows itself; otherwise, the woman acts simply as a carrier and transmits the defect without exhibiting it herself.

In our daily life and activities, the ability to distinguish between colours such as red, yellow, green and blue is extremely useful. There are various occupations in which the ability to recognise such colour differences is essential. Then, again, there are specialised activities in which the capacity for recognising the finer nuances of colour is extremely important. Considering all these circumstances, it is scarcely surprising that much attention has been devoted to the subject of colour discrimination as affected by the presence of defects and anomalies in colour perception. Numerous tests have been devised for the evaluation of the ability to perceive colour differences, and for the detection and classification of the various cases in which it is not so high as it normally is.

The tests for "colour-blindness" commonly in use at the present time are charts from which the person examined is asked to read out numbers which appear as arrays of coloured dots interspersed amongst dots of other colours. The colours employed are, of course, not pure spectral colours, but are of various hues and shades. The sizes of the dots, the colours in which they are printed, the way in which they are arranged, the distance from which the observer is asked to view the charts, as well as the strength and colour of the illumination employed, all play a significant role in these tests. Hence, the exact significance of the tests and even their actual usefulness are matters needing consideration.

A third reason why daltonism and other types of deficiency in colour perception have attracted much attention is the bearing of the subject on the fundamental aspects of the physiology of vision. The following questions arise. What exactly is the nature of the differences between normal and defective colour perception, and how do these differences arise? In seeking for answers to these questions, it is clearly desirable that we simplify the issues as much as possible. We may do so by limiting ourselves to the case of the pure spectral colours, deferring the more complex problems of the perception of polychromatic radiation for consideration at a later stage. We may further limit ourself to the case of daltonism, leaving aside other known types of defect or anomaly in the perception of colour which may be regarded as of lesser importance. These may be conveniently discussed after the characteristics of daltonism have been fully explored and elucidated.

The nature and origin of daltonism: The purpose of the present chapter is to describe new methods of study in this field and to discuss their results and their significance. We may, however, usefully begin by asking ourself what the acceptance of Dalton's descriptions of his own colour sensations would imply in relation to the fundamental problems of colour perception. What Dalton perceived in the sector of the spectrum which we have designated as the blue sector was obviously not different from that experienced in that sector by normal observers. In the parts of the spectrum which we have designated as the red, yellow and green sectors and in which normal observers perceive these different colours, Dalton perceived only one colour termed by him as yellow. If we assume that Dalton's yellow is the same as that perceived by normal observers in the yellow sector of the spectrum, important consequences would follow. In the first place, since the sensations of green and of red were not experienced by Dalton, his yellow could not possibly have been the result of a superposition of the green and red sensations. We are thus forced to concede that yellow is a sensation which has its own independent origin. Further, since yellow is a highly luminous sensation, it can claim to be regarded as being of major importance, while red and green are only auxiliaries which can be left out without any serious impairment of the other visual faculties.

The observational evidence already on record supports the views regarding the nature and origin of daltonism set forth above. The test charts for "colour-blindness" which are commercially available contain as the first of the series, one in which the number 12 is pictured by an array of dots of orange hue, surrounded by a field filled up with dots of a pale blue colour. This chart is read correctly and without the slightest difficulty or hesitation by all subjects, both normal and "colour-blind". This indicates that though "colour-blind" persons may confuse red and green, the blue and yellow are never mistaken for each other. In other words, blue and yellow are basic colours alike for normal persons and for the "colour-blind".

Further striking evidence that blue and yellow are perceived alike by normal and by "colour-blind" persons is furnished by the published studies of the so-called "unilateral colour-blindness". There have been quite a few cases which have come to notice and in which colour-deficiency is much more marked in vision with one eye than with the other. In such cases, it is evidently possible for the person concerned to compare the colour-sensations experienced by him with his two eyes. It has been reported that in all such cases, blue radiation at 450 mμ and yellow radiation at 575 mμ exhibit colours which are not different as seen respectively with the two eyes. Dalton's description of the two-colour spectrum thus receives an impressive confirmation.

The colours of interference: The author has devised a new method for the study of "colour-blindness" which enables the sensations of normal observers to be quickly compared with those having defective colour-vision. The person whose vision is under study is asked to view a pattern of interference colours as seen with white light and to describe in his own words what he observes. For this purpose, the most suitable set of interference colours are the well-known rings of Newton but produced on a much larger scale than usual so that no optical aid is needed to observe them and examine their characteristics. Such rings can be produced by placing two fairly thick plates of glass in contact with each other in an appropriate orientation. They are seen by reason of the fact that such plates, though intended to be quite flat, actually exhibit over extensive areas a cylindrical curvature of very large radius. The geometry of the interference pattern exhibited by the air film enclosed between two such plates is determined by their relative orientation. The fringes appear as straight lines when the axes of the cylindrical elevations on the two plates are parallel to each other; they appear as elliptic rings when these directions are inclined and as circular rings when they are exactly in the crossed positions. Circular ring-patterns exhibiting brilliant colours and covering an area 5 cm × 5 cm may thus be readily obtained.

The appearance of such interference patterns as seen by an observer with normal vision has already been described in an earlier chapter. The significant feature is that the pattern exhibits fluctuations of brightness as the principal feature and these are accompanied by colours which arise as incidental consequences of the variations of luminosity in the field. Measurements of the positions of the minima of brightness in the pattern as observed with white light agree with the positions of the minima of brightness in the same interference pattern observed using monochromatic illumination of wavelength 579 mμ. For an observer with normal vision, the first few rings exhibit the successive minima of illumination very conspicuously, while the outer rings appear as circles of colour which are alternately red and green.

The interference pattern as seen by an observer with normal colour vision, may therefore be described as a pattern of fluctuating brightness due principally to the yellow sector of the spectrum, accompanied by fluctuations of colour in which the red and green sectors manifest themselves visibly in the neighbourhood of the regions where the yellow has the minimum luminosity. It is evident that in these circumstances, the pattern would present a very different appearance to a person with normal colour vision and to one who is unable to perceive the red and the green of the spectrum.

Colour and luminosity in the spectrum: Another method for testing colour vision is for the person under study to be presented with the spectrum of a very brilliant source of white light appearing on the ground-glass screen of a constant deviation spectrograph, arrangements being made to vary the brightness of the spectrum over a wide range of values. The subject is asked firstly to describe in his own language what he observes on the screen. He is also asked to indicate with a pointer, the exact points at which the spectrum appears to him to commence and to end, the positions where the colour in the spectrum as seen by him appears to alter, and the position or positions in the spectrum which appears to him to exhibit the maximum luminosity. These tests may be made at three different levels of spectral luminosity, one of which is very low, another medium and a third which is quite high. The low-intensity spectrum may be obtained by interposing an opal-glass sheet between the source of light and the slit of the spectrograph, while the medium and high-intensity spectra are obtained without the opal-glass sheet, by merely moving the spectrograph from a distant position to one much nearer the source of light.

The tests described above are very simple and can be very quickly made. They may be usefully preceded by even simpler tests, such as asking the subject to name the colours of variously brightly hued plates shown to him, then asking him to read the numbers on the test-charts of the usual kind and also to notice and name the colours of the individual dots appearing on such charts.

Results of the tests: We proceed to describe the observations reported by a person who will be referred to here as C D. He was a competent man of science and could therefore be trusted to state accurately what he himself observed. Without any hesitation, C D correctly named the colour of a yellow cardboard box shown to him. He immediately recognised the number 12 on the first sheet of the test-chart printed as a set of orange dots which were surrounded by a field of pale blue dots. But the other sheets of the test-chart conveyed nothing to him. When the coloured rings of the interference pattern were presented to him, he had no difficulty in counting the number of rings visible in it, which he gave as seven. But the rings appeared to him to be yellow in colour, presenting the same hue as the cardboard box mentioned above; the successive rings appeared to him to be separated from each other by darker circles. He also noticed that indications of blue appeared in the first two or three rings of the series.

C D also placed the commencement of a spectrum of moderate or high luminosity at the long-wave end precisely where it is placed by an observer with normal vision. But he described the parts of the spectrum where a normal observer sees red, orange, yellow and green as being yellow in colour. He also placed the point of maximum luminosity in the spectrum at the same point, viz., 579 mμ as an observer with normal vision. He observed the luminosity to fall off in the region of transition from green to blue as is also noticed by a normal observer. The blue of the spectrum was named by him as blue, and its termination as placed by him agreed in its position with that noticed by normal observers. The spectrum at the lowest level of luminosity did not appear to C D to exhibit colour at all, though to a normal observer, the green was quite clear. The red end of the spectrum had shifted towards shorter wavelengths, alike to C D and to an observer with normal vision. The point of maximum luminosity in the spectrum of low brightness had also shifted considerably towards shorter wavelengths and to the same extent for C D as to a normal observer.

It is clear from these observations that C D exhibited daltonism in a typical fashion. Further it is clear that his observations support the views regarding the nature and origin of daltonism set forth above.