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The new physiology of vision—Chapter XXXIX. Daltonian colour vision

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The following questions arise regarding the abnormal colour perceptions exhibited by certain individuals. What exactly are the colours which they perceive and in what other respects do their visual perceptions differ from those of normal individuals? Further, what is the origin of these differences: in other words, what is the difference in the nature of the visual processes which is responsible for these abnormalities? Colour, though determined by the physical nature of the light which is perceived, is nevertheless a subjective phenomenon. This circumstance may make it difficult to ascertain what the actual facts are in any particular case. Complications would also arise, if the cases of defective colour vision met with are not all of the same kind, as is generally believed.

In earlier chapters, the subject of defective colour vision has been considered and it has already been shown that normal and abnormal colour vision can be brought into an intelligible relationship with each other. A few cases have also been considered in detail and it has been shown that they support the correctness of the approach made to the subject. Nevertheless, it was evident that further studies were necessary to obtain a fuller and deeper understanding of the facts observed. Hopes of further advance lay in the direction of applying new methods of investigation to the study of abnormal colour vision and of relating the results to those already established in the case of normal vision. While it was evidently desirable to extend the study to more cases, it was clear from the outset that it would be particularly useful to work with selected individuals exhibiting abnormal colour vision who by reason of their scientific training and experience could be relied upon to render trustworthy reports of their own personal observations in the contemplated studies.

In the present chapter, we shall set out the results which have emerged from an intensive study of abnormal colour vision made with the aid of an individual who will be referred to in what follows as Dhruva, which, of course, is not his real name. Dhruva is a highly qualified physicist. That his colour vision was abnormal was discovered in the course of surveys undertaken by the author to find such cases. His scientific competence and his enthusiastic co-operation in the investigation has made a real advance possible in our knowledge and understanding of the subject of abnormal colour vision and of its relationship to normal vision.

The colour sequence in the spectrum: It is a remarkable fact that a person endowed with normal vision is capable of recognising quite small differences in colour if these are presented to him in an appropriate fashion. For example, the two yellow lines in the spectrum of a mercury lamp whose wavelengths are respectively 5770 and 5790 Å and which are of equal intensity when seen simultaneously through the eye-piece of a spectrometer exhibit an observable difference in colour, the former line appearing of a greenish hue while the latter is a pure yellow. This fact suggested to the author that an arrangement by which the entire continuous spectrum is presented as a series of discrete lines but without any change in the relative intensities of its different parts would be a useful device for the study of the spectrum colours and especially for exhibiting the differences in the rate of progression of colour in different parts of the spectrum.

The idea indicated above can be realised in practice by setting two half-silvered plates of glass in parallel positions before the slit of a wavelength spectrometer and viewing the spectrum of a brilliant source of white light of restricted area normally through the combination. The entire spectrum is then seen as an array of discrete lines or bands in a dark field, their number and spacing being determined by the separation between the plates. By making one of the plates movable with respect to the other, the number of lines or bands seen in the spectrum can be varied within wide limits. The more numerous they are, the smaller would be the difference in wavelengths between adjacent ones. If such difference is large enough, they would exhibit an observable difference in colour. But this would not be the case, if the bands are numerous and therefore closely spaced. Much would depend on the particular part of the spectrum and the rate at which the progression of colour is manifested therein.

A channelled spectrum with approximately 100 bands in it produced in the manner explained was presented to Dhruva. He examined it through the eye-piece of a wavelength spectrometer and listed the parts of the spectrum which appeared to him to be different in colour and their respective wavelength limits. His findings are exhibited on the right-hand side of figure 1, while those of an observer with normal colour vision made under exactly the same conditions are shown on the left-hand side of the figure.

A comparative study of the two sides of figure 1 is very instructive. To a normal observer, the yellow of the spectrum appears as a narrow strip in the wavelength range from 575 to 585 mμ. But, to Dhruva under the particular conditions of observation, it appears as a wide tract of the spectrum and the regions in which a normal observer perceives the colours of red and green have for the most part also been replaced by colours related to or resembling yellow. It is clear from the diagram that Dhruva's vision is daltonian. It would nevertheless not be correct to say that he is either red-blind or green-blind or both red-blind and green-blind. A correct description of what is actually observed is that the sensation of yellow perceived by him has extended itself so as to cover a large part of the spectrum and modify the colours seen by a normal observer in adjoining areas. In this

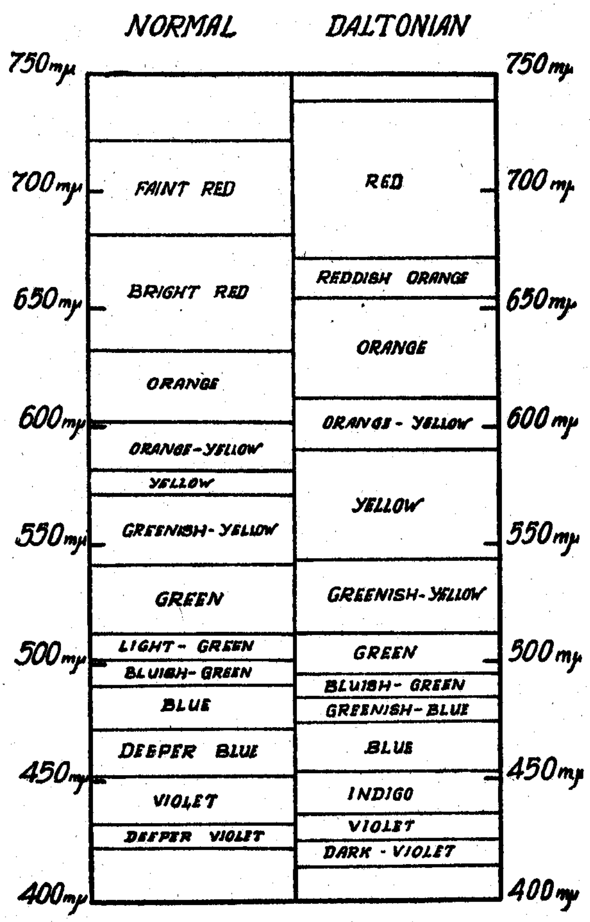

Figure 1. Colour sequence in the spectrum.

context, it is noteworthy that to Dhruva, the part of the spectrum which appeared to be the most luminous is that in which a normal observer locates the yellow strip.

Effect of luminosity on the spectrum colours: A remarkable and convincing demonstration that daltonian vision arises by reason of an abnormal enhancement of the sensation of yellow in relation to other colours in the spectrum is forthcoming from the observations of Dhruva on the emission spectrum of a heated tungsten filament over a wide range of temperatures. The filament is a straight long coil of fine wire and is heated by the passage of an electric current through it. This current could be controlled by a rheostat, and the temperature of the filament could therefore be stepped up over a great range, beginning with its emission barely visible as a dull red glow and going up to one at which the filament emits a brilliant white light. The spectrum of the emission can be examined very simply by viewing the luminous filament from an appropriate distance through a replica diffraction grating held in front of the observer's eye. As the temperature is raised a whole series of changes manifests itself in the colours visible in the diffraction spectrum of the first order. The observations are made in a completely darkened room, a dark background being provided so that the spectrum could be viewed against it. The observations of Dhruva are reproduced below exactly as recorded by him at the time.

(1) *Extremely low levels*: At these faint and barely perceptible levels, only the green portion of the spectrum is visible.
(2) At slightly higher levels, the red region faintly makes its appearance, though the green is brighter. The relative lengths of the regions are green (1); red (0·5).
(3) At still higher levels, the intensity maximum shifts to the red region, and at the stage when the maximum is definitely at the red, the relative lengths are green (1); red (1).
(4) The next stage is reached when the yellow distinctly appears. Simultaneously the maximum intensity region moves over to orange-yellow. The blue also makes its appearance about this stage. Relative lengths are: blue (1); green (1·5); yellow (1); red *plus* orange (1·5).
(5) At higher luminosity, the yellow invades the red and assumes the position of maximum luminosity. At this stage, the relative lengths are: blue (1·5); green (1); yellow (2); red *plus* orange (2).
(6) This trend is continued at higher levels, the yellow becoming most intense and invading the red and the green. The relative lengths of the colour regions at this brightest stage are: blue (2); green (0·5); yellow (4); red (1).

An observer with normal colour vision observing the spectrum of the glowing tungsten filament under exactly the same conditions as in the observations by Dhruva also notices changes in the character of the spectrum of the emitted light, including especially the manifestation and progressive increase in luminosity of the yellow sector. But there is a great difference between Dhruva's observations and those of the normal individual. The development of the yellow sector, and its invasion of the green and red sectors are far more striking in daltonian vision than for a normal observer. The normal observer does not observe the contraction of the green and red sectors conspicuously evident in daltonian vision.

The yellow of the spectrum is the major visual sensation to an observer with normal colour vision at ordinary or daylight levels of illumination. It is totally absent in night-vision; *per contra*, at extremely high levels of brightness, as has been described in an earlier chapter, the yellow sensation becomes the dominant sensation to an extraordinary extent, reducing the rest of the spectrum to a relatively insignificant position. In other words, the characteristics of daltonian vision resemble those exhibited by normal colour vision at exceptionally high luminous intensities. The abnormality which is responsible for their manifestation is thus connected with the visual mechanism which determines the strength of the yellow sensation at various levels of brightness.

The perception of red: It will be noticed from figure 1 that the part of the spectrum described as red by Dhruva is of very low luminosity to a normal observer, while the part which is bright red to a normal observer appears as orange to Dhruva. It follows that while it would be entirely incorrect to describe Dhruva as red-blind, nevertheless his perceptions of red would be much weaker than those of normal individuals. This is borne out by the studies made of the characteristics of his vision. When the colour test-charts published by the American Optical Society were shown to him, he was unable to recognise the numeral 9 very clearly exhibited as a sequence of spots of a red colour surrounded by other spots of similar shapes of which some were grey and the others black. Likewise, in these charts, he was unable to recognise numerals printed as dots in various shades and depths of a red hue in a field surrounded by dots printed in various shades and depths of green and greenish-yellow. He was also unable to recognise numerals printed in dots of pale red colour in a field of dots exhibiting various shades of pale yellow and brown.

The colour vision of Dhruva was also tested by showing numerous hard-cover books which he had not seen previously and asking him to name their colours. Amongst them were several exhibiting hues ranging from a brilliant red to a dark brown tinged with red. In several cases, he named as red, books of which the cover was more nearly brown than red. From these and other instances, it was evident that his perceptions of red differed rather widely from those of normal individuals. Similar differences become evident when he was presented with a set of samples of dyed silk fabrics and asked to classify them and to name their colours.

Perception of green: It is evident from figure 1 that the sharp distinction between green and yellow manifested in the colour vision of normal individuals does not exist for Dhruva. Indeed, the yellow lines at 579 mμ and the green line at 546 mμ of the mercury lamp did not appear to him to be distinguishable in colour. Figure 1 indicates that Dhruva perceives as green in colour a part of the spectrum adjoining the blue at about 500 mμ. Presumably therefore in certain cases, he should be capable of recognising as different from each other in colour the objects which are named respectively as green, yellow and red by normal observers.

Presented with several books bound in hard-covers of various colours, Dhruva in most cases named as green or dark green the books which would be described in the same manner by normal observers. There were however a few cases in which his naming of colours differed quite sharply from the usual ones. A book with an orange-yellow cover was named as green, and another as ash-grey which was a light greenish-blue. A third book which was a pale yellow was named as a greenish-yellow. In his naming of the colours of a series of dyed silks, it was evident that Dhruva found it difficult to distinguish pure greens from bluish greens and likewise to distinguish blues from bluish-green colours.

In the tests made with the colour charts of the American Optical Company, Dhruva read without error or hesitation the numerals in the charts in which they were printed as dots in greenish colours surrounded by a field of dots printed in colours ranging from yellow to orange. Likewise, he could read without error or hesitation numerals printed as dots ranging in colour from pale yellow to orange surrounded by a field of dots printed in colours of various shades of green.

The purple sensation: The studies of composite colours described in earlier chapters made it evident that a purple sensation results when the yellow sector is eliminated from the spectrum of white light while the blue, green and red sectors are left without change. Any alteration in the relative strength of the red sector as compared with the strength of the blue and green sector taken together results in different shades of purple. The weakening of the red sector results in the purple assuming bluer shades, while any weakening of the blue or green sectors results in the purple exhibiting hues more nearly akin to red.

In view of the foregoing remarks, it is significant that when Dhruva was shown the flowers of the ground orchid "*Spathoglottis plicata*" he named their colour as blue, whereas to a normal observer they exhibit a reddish purple colour. Spectroscopic examination reveals three well defined absorption bands in the light transmitted through or reflected by the petals of the flower. The principal band extinguishes the yellow sector, while the two other weaker bands appear respectively in the green and in the greenish-blue, thus accounting for the reddish-purple colour of the flower. That Dhruva perceives the flowers as blue in colour is a demonstration that his perception of red is very weak.

Bougainvillia with its clusters of brilliantly-coloured bracts is one of the best-known and most highly favoured of ornamental plants. Several varieties of it are known with bracts exhibiting purple hues. Bracts of three such varieties were shown to Dhruva. He named all of them as blue flowers, qualified by the remark in brackets (tinge of violet) in the case of the deepest purple, and (light) in the case of the palest purple.

The colours of interference: Dhruva was shown three items of apparatus exhibiting interference colours brilliantly on a large scale. The following is a description in his own words of the region surrounding the central dark spots in the pattern exhibiting Newton's Rings: First ring—Reddish inside grading over to darkness; this is followed by a brighter region where the colours change radially blue to yellow before the next dark ring is reached. There is a further bright zone where the colours change from blue to yellow; the next dark ring is fainter, i.e., contrast is less. As we move across radially, further rings appear, but it occurs to me as if the bluish tinge is less and less and the contrast drops very sharply—rings beyond the fifth or sixth being barely visible. Up to the fourth ring, the yellow looks prominent in the bright region, beyond which it is a uniform grey (except for alternation of intensities due to the rings).

Interference fringes of wedge-shaped film: These are described by Dhruva as follows: Starting from the top of the plate, the first dark band is bordered by red and orange at the top and blue at the bottom. This is followed (proceeding downwards) by orange, black (i.e., the dark band) and blue for the second band. The third band is bordered by orange red at the top but the blue is much fainter. Three more bands are visible, but with decreasing contrast. The colour variations for these are not visible—they can only be described as shades of grey.

The interference fringes in a pattern of ovals: The outermost dark oval ring is followed by patches of blue and orange red, to the second (inner) dark ring. The transition to the third ring is similar, but the bluish tinge is much weaker here. The fourth and innermost ring is much fainter in contrast and appears as a dull brownish-red. The patch inside this ring has the same contour, and shows up as a dull grey contrast to the background.