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The new physiology of vision—Chapter XXXIV. The nature and origin of defects in colour-vision

SIR C V RAMAN

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The studies described in the two preceding chapters provided an insight into the problem of explaining why certain individuals differ in their perceptions of colour from most other persons. At the same time, it became evident to the author that the new methods of study introduced by him in this field should be applied to more cases of the kind and carried out more exhaustively than was found possible in the examples first described. The present communication sets out the results of such a fuller study carried out in particularly favourable circumstances. It owes much to the co-operative spirit and scientific competence of the person whose colour-vision is here described and discussed in detail. He will be named here as Asoka which of course is not his real name. Asoka is a physicist of several years' standing with academic experience and had long been aware that his colour-perceptions are not of the normal kind. This fact came to his notice when he found that the $\lambda 5461$ radiation of a mercury lamp appeared to him to exhibit the same colour as the $\lambda 5770$–5790 doublet, whereas the first is usually described as green and the second as yellow.

The spectrum of white light from a brilliant source was focused on a ground-glass screen at the observing end of a glass spectrograph successively at three different levels of illumination, and Asoka was asked to indicate and describe what he saw in each case. Seen at the highest level of brightness, the spectrum appeared to him to begin at the long-wave end at about the same place as for a normal individual. But it commenced with an orange region and this was followed by bright yellow and then successively by a light blue, a dark blue and then violet. The change from yellow to blue appeared in the region when normal observers notice the change from green to blue. The short-wave end of the spectrum also agreed in position with those of normal observers. Asoka, when asked to locate the part of the spectrum which appeared to him to be the most luminous, put his pointer on the spot which appears yellow to normal individuals. At a lower level of intensity, the spectrum appeared to have become shorter at both ends, but the yellow part remained unaffected. At the lowest level of intensity which was attained by introducing a sheet of opal glass between the source of the

light and the spectrograph, only the part which appeared yellow in the first case could be seen, but it did not exhibit colour except at the long-wave end where it showed a weak orange tint.

Asoka was asked to hold a diffraction grating before his eye and to view through it, a slit between the two nearly-closed wooden shutters through which the light from the brilliantly illuminated sunlit sky found entry into the room. In the highly luminous first-order diffraction spectrum seen in these circumstances, Asoka reported seeing the colour sequence of red, orange, yellow, blue, indigo and violet. He could also see the Fraunhofer lines in the spectrum, as both the dispersion and resolution were adequate.

Asoka's colour perceptions were then tested by presenting to him in succession four different examples of interference patterns exhibiting colour and asking him to write down a detailed description of what he saw in them. The following is his description of a pattern of circular rings of the well-known Newtonian type. "The centre of the system is dark. This is surrounded by circular rings. The first ring is colourless. This is followed by (1) an orange, (2) deep blue, (3) orange, (4) light blue, (5) yellow, (6) light blue, and (7) light yellow. Beyond these rings, four alternate dark and colourless rings are also observed." Another pattern of the same type but on a slightly smaller scale was described by him as follows: "The centre of the pattern is dark. This is followed by coloured circular rings in the following order: (1) colourless, (2) deep orange, (3) deep blue, (4) orange, (5) light blue, and (6) light yellow. This is followed by three alternate dark and bright (colourless) rings."

The interference colours exhibited by a wedge-shaped air-film between two flat plates of glass was described by Asoka as follows: "The pattern consists of several bands more or less of uniform width. The band at the edge where the thickness of the wedge is minimum is dark. This is followed by (1) colourless, (2) red, (3) deep blue, (4) deep orange, (5) blue, (6) light orange, (7) light blue, and (8) very light yellow bands. This is followed by five alternate dark and bright (colourless) bands."

The fourth interference pattern was of a special type obtained by using two rectangular glass plates clamped together at the edges. This was viewed normally by reflected skylight incident on the plates in the direction of observation. Asoka described what he saw as follows: "The pattern consists of a central region which is light yellow surrounded by several ovals. Three of the ovals are alternately bright (no colour) and dark. The fourth one is orange followed by (5) blue, (6) orange, (7) deep blue, (8) deep orange, (9) deep blue, and (10) red ovals."

Commentary on the foregoing: Before reporting on further observations of other kinds by Asoka, we may usefully pause here to consider the significance of his descriptions of the interference patterns quoted above *in extenso*. They are remakable in several respects. Firstly, they are totally different from the descriptions which would be given by a normal observer. Secondly, they report

the appearance of alternations of intensity without any manifestations of colour precisely in those regions of the pattern where a normal observer would report alternations of colour without alternations of intensity. Thirdly, they report alternations of colour in the regions where to a normal observer the major features which present themselves are the alternations of intensity. These features are a highly characteristic expression of the differences between normal and daltonian colour-vision.

The basis for an understanding of daltonian colour-vision is furnished by the fact emerging from studies with normal observers that the yellow of the spectrum exhibiting its maximum of luminosity at 579 mμ plays the major role in their colour-perception, while the red and green observed on either side of the yellow in the spectrum are only subsidiaries or accompaniments of it. If, therefore, the red and the green sensations were left out, we would be left with the yellow and the blue sectors of the spectrum. This fits with Dalton's description of the colours in the spectrum as perceived by himself.

In the colours exhibited by interference patterns as seen by a normal observer, the fringes of higher order show bands of colours which may be described as alternations of red and green respectively. If these colours are not perceived, the same regions would exhibit the effects arising from the yellow and the blue sectors of the spectrum. The yellow being much the more intense may be expected to produce alternations of intensity in these regions. But the superposition of the effect of the blue sector would result in these alternations of brightness appearing more or less perfectly achromatic. This agrees with the observations of Asoka in all the four cases examined by him. In the interferences of lower orders, the alternations of intensity due to the yellow sector would be superposed on those due to the blue sector. These would not coincide with one another. Hence, in these regions, alternations of colour would be observed, the colours becoming progressively less saturated as we proceed from the lower to the higher orders of interference. This also agrees with the observations of Asoka.

A feature of special interest is the appearance of orange in Asoka's descriptions both of the colours of the spectrum as also of the interference patterns. That orange and yellow were perceived by him as distinct colours is clear from his recognition of these colours in various flowers shown to him. In particular, when shown the cluster of flowers of *Bignonia venusta* which he had not seen previously, he named their colour as orange without any hesitation. Since orange follows red in the succession of colours in the spectrum, this is an indication that the sensation of red was not completely absent in his perceptions of colour. It is noteworthy that in his description of the solar spectrum as observed at a high level of intensity, red does find a place. It also finds a place in his description of the fringes of lowest order in two of the interference patterns shown to him.

But on the other hand, there is evidence that his perception of red is much weaker than those of normal individuals. This is clear from his inability to read the test-chart No. 10 in the set published by the American Optical Company

(1940), which had evidently been designed to reveal such a weakness. In this test-chart, the numeral 9 is figured very conspicuously as a sequence of curiously shaped spots of a dull red hue, surrounded by spots of similar shape and printed in grey and black. The contrast of colours is very striking, but Asoka could not perceive it. A further indication of the weakness of his perception of red is the noticeable shortening of the spectrum at the long-wave end when its brightness is diminished.

Other observations: It may be worth listing here Asoka's readings of the test-charts commonly employed to reveal defective colour-vision. Both the Ishihara charts and those published by the American Optical Company exhibit as the first of the series, the numeral 12 in orange surrounded by a field of spot of a bluish colour. This is read without difficulty or hesitation alike by normal persons and by those with defective colour-vision. Charts 2 to 9 in the Ishihara set are designed so that persons with normal and defective colour-vision would read the numbers differently. Asoka responded to every one of them in the manner expected of one with defective colour-perception. He was unable to decipher the numbers appearing in Charts 10 to 17 and also in Charts 22 to 24 of the set of the Ishihara series.

Asoka was also presented with the test-charts published by the American Optical Company. This contained a set of 19 sheets. He did not succeed in reading the numerals appearing in Charts 2, 3, 6, 7, 8, 9, 10, 11, 14, 15, 16 and 17. But he read correctly and without hesitation the numerals appearing in Charts 4, 5, 12, 13, 18 and 19. It may be noted that these latter charts exhibit numerals printed in pale yellows and reds and surrounded by a field of dots of varying depths of green, or vice-versa. That he could do so indicates that his perceptions of red and green differed noticeably from each other.

Asoka was taken round the gardens of the Institute and asked to name the colours of various flowers shown to him. All yellow flowers were recognised by him as such without any hesitation; likewise, flowers with orange hues, viz., marigold and *Bignonia venusta*. The scarlet flowers of *Cordia sebestina* were described by him as red tending to orange. Various red and crimson flowers were named by him without hesitation as red and deep red respectively.

The deep blue flowers of the Morning Glory were named by him after some hesitation as violet in colour. The purplish-red flowers of the ground Orchid *Spathoglottis plicata* were also described by him as violet in colour. The flowers of the blue iris, and the pale blue flowers of *Plumbago capensis* were with some hesitation named by him as light blue.

His description of the colours of the bracts of different varieties of bougainvillea differed markedly from that of a normal observer. The light purple and the deep purple varieties were alike described by him as blue, while the rose-red bracts of another well-known variety were described by him as purple.

His naming of the colours of different varieties of pelargonium were not widely

different from those of normal observers. Remarkably enough, Asoka said he had no difficulty in recognising the green colour of leaves as such, provided they were deep enough, and not the paler hues often manifested.

Concluding remarks: Summing up, the colour perceptions of Asoka may be described as being approximately daltonian in character but not absolutely typical since his reds and greens were not wholly indistinguishable from each other. There are indications that Asoka's perceptions of red are much weaker and his perceptions of yellow much stronger than those of normal individuals.