Proc. Indian Acad. Sci. **A63** 5–8 (1966)

The new physiology of vision—Chapter XXXI. The integration of colour by the retina

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Received November 17, 1965

In the preceding chapter, it has been demonstrated that the successful reproduction of colour by the well-known half-tone process is made possible by the remarkable power of our eyes to integrate the impression produced by a mosaic of spots of different colours into a single colour determined by the areas occupied respectively by the different colours in the mosaic. In a general way, anyone can satisfy himself of the correctness of this statement by a simple inspection through a magnifying lens of a few half-tone pictures in colour. In the last chapter, a sufficient number of examples have been set out which illustrate this situation. We return to the subject for the reason that the integration of colour by the retina is a fact of great scientific interest. Ample material is forthcoming not only to demonstrate the phenomenon but also to place it on a quantitative basis. Further, it can also be observed by using entirely different techniques which reveal other features of interest.

Insect colours: In the *National Geographic Magazine* some years ago, an article appeared under the title "Insect Rivals of the Rainbow" containing pictures of no fewer than 263 insects of various sorts which were reproduced in 24 colour plates. In the same magazine in another issue, an article, under the title "Strange Habits of Familiar Moths and Butterflies", was illustrated by pictures of no fewer than 162 species of moths and butterflies in 15 colour plates. The range of hues covered by these illustrations is very great. Hence these reproductions are valuable as an aid to the study of the relationship between the mosaics of colour and the visual impressions which they produce.

As has already been set out in the preceding chapter, the representation of colour by the half-tone process is achieved by the use of just four printing inks, viz., black, yellow, magenta (or process red) and cyan (or process blue) on white paper. If we assume the total available area of a given mosaic to be divided into 16 equal parts and the parts filled by the four inks range in number from 0 to 16, (the total, of course, should not exceed 16, the unfilled part being white) the number of the different possible colours thus resulting would be quite large. Even only binary combinations, e.g., yellow and white, magenta and white, cyan and white, yellow and black, magenta and black, cyan and black, yellow and magenta, yellow and cyan, magenta and cyan, would give us great number of different hues. Examining the insect pictures through a magnifying lens, each of these binary combinations and the characteristic hues which they generate can be recognised in individual insects or in the individual areas of colour displayed by them. We shall content ourself with a few selected examples.

We may begin with some strong colours. The red areas are represented by magenta ink and appear of a deeper and darker hue when a substantial proportion of magenta is replaced by black. Various shades ranging from a bright yellow to a deep orange are exhibited by mosaics of which the areas are occupied by yellow and magenta inks in different proportions. Various shades ranging from a bright green to a greenish-blue are exhibited by areas of which cyan ink occupies a substantial part, the rest being occupied by yellow ink. Various shades ranging from a bright blue to a deep purple are exhibited by mosaics occupied by the cyan and magenta inks in varying proportions. If, in addition, areas of black ink are present, the colours appear to be of a deeper and darker hue. *Vice-versa*, if areas of white are present, the colours are lighter and brighter.

Interference colours: Excellent illustrations of the manner in which our eyes integrate colour-sensations appearing in areas which are contiguous are furnished by the colours of thin films. Reference has already been made in an earlier chapter to the remarkable fact that when Newton's rings are formed between two plates of glass, one of which is flat and the other has a radius of curvature of 3·6 m, the interference pattern exhibits no colour at all when viewed from the usual distance of distinct vision, even though the rings are themselves seen quite clearly. The pattern occupies an area of over one square cm and what is actually visible is a dark central patch surrounding which appear a succession of bright and dark rings, some six or seven in number, which approach more closely as we proceed outwards. Viewed under a low magnifying power a few more rings can be seen and counted in the pattern, but the pattern remains achromatic. To observe colour, the interference pattern has to be viewed from close quarters using fairly high magnifying powers. All the rings then show brilliant colours.

Newton's rings can also be observed on a much smaller scale using surfaces of which the radii of curvature are not large. In such cases, even merely to see the rings, we require a fairly high magnification, and it is to be remarked that the colours in such cases are scarcely noticeable. The greater the magnifying power employed, the more clearly are the colours seen.

By using two glass plates which deviate from planeness by a very little, Newton's rings can be obtained on such a large scale that brilliant colours are exhibited and are conspicuously visible without any optical aid. Likewise, using two circular disks of optically plane glass, a wedge-shaped air film may be obtained between them by exerting pressure at the end of one common diameter while leaving the other end free. The straight fringes exhibited by such films being on a large scale, a brilliant succession of colours is exhibited by the film. A comparative study of such interference colours when viewed from various distances is particularly instructive.

The colours of Newton's rings even observed on a large scale disappear from view when viewed from a distance of a few metres, the pattern then appearing achromatic. This change is not sudden but progressive and can be followed step by step as the distance of the ring pattern from the observer is increased. Remarkably enough, the colours which first cease to be observed are those of the rings immediately surrounding the first dark minimum. The colours of the outer rings which are narrower nevertheless continue to be visible till the observer has moved much further away. Finally, these also appear achromatic.

The straight fringes of a wedge-shaped film behave rather differently. The spacing of the fringes makes a much closer approximation to uniformity than is the case with Newton's rings. The fringes of higher order are thus of about the same width as those of lower orders. Here again, we find that it is the fringes of lower order that cease to exhibit colour first as the distance of the observer is progressively increased. The colours of higher orders on the other hand show a less rapid weakening and indeed they continue to be recognisable so long as the rings themselves can be discerned.

Still another type of behaviour is shown by films of which the interferences of higher orders are enclosed by those of lower orders and are more widely separated than the latter. Such films can readily be obtained by clamping two thick plates of glass together at their edges. At close quarters, the interferences of all orders show brilliant colours. As the observer moves away, the fringes of lower orders lose colour and become achromatic and they are followed in succession by those of higher orders. But the central fringe of highest order which is very broad continues to exhibit brilliant colour even when the observer is far away from the glass plates.

It is clear from these facts of observation that the replacement of the individual colours in a given area by an integrated colour-sensation manifests itself only when the angular dimensions of the area as perceived by the eye are small enough. It is also significant that differences in luminosity continue to be observed when differences in colour cease to be perceived. That there is a relationship between the effects now under consideration and the phenomena of visual acuity is thereby made evident. But what exactly is the nature of such relationship requires further elucidation.

A further question arises in regard to the precise nature of the colour synthesis which is effective when a mosaic of areas exhibiting different colours comes under observation. So far as the present observations go, it would seem that the general ideas which emerged from the studies on the visual synthesis of colour described in earlier chapters are valid also in the present context.