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PIGMENTS IN ANOMALOUS TRICHROMATS

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LORD RAYLEIGH (1881) found, when subjects were set to match a yellow light with a mixture of red and green, that a perfect match could always be made, but that about 5 per cent of males differed from the majority in the red/green ratio required. Those who require too much red are called "protanomalous", those requiring too much green "deuteranomalous". These subjects differ sharply from protanopes and deuteranopes to whom all wave lengths in the red–green spectral range appear the same in colour and can be matched by adjustment of intensity only. Rayleigh's anomalous trichromats require both red and green in the mixture to match yellow, but they do not accept the proportions which satisfy normal subjects, protanomalous insisting upon a (red + green) mixture which the normal judges far too red; the deuteranomalous match being far too green.

Much work has been done on the colour vision in these common and interesting conditions notably by Wright and his colleagues (WRIGHT, 1946). It is frequently claimed that the pigments are normal but that the organization of nerve signals is not. For instance, that protanomalous have the normal "red" and "green" cones, but that the "red" cones are too few in number, or generate nerve signals that are too small, so that more red light than usual must be added to the mixture to produce "red signals" as large as "green signals"—which is conceived as the condition for matching "yellow signals". This is not an example of clear thinking and it contradicts the Principle of Univariance to which we shall adhere. That may be stated as follows: "The intrinsic effect of light upon a visual pigment depends only upon the effective quantum catch by that pigment and does not depend upon what quanta are caught", (see the first of these three papers, RUSHTON, POWELL and WHITE, 1973 hereafter referred to as RPW1).

Now, if a normal subject in making a Rayleigh match adjusts the red/green ratio and also the yellow intensity so that the quantum catch by *each* of the cone pigments involved is the same from the yellow field as from the (red + green) mixture, then each field will affect each pigment identically and neither pigment will be able to distinguish the one from the other. It is an experimental fact that from this position any movement of the red/green setting produces a colour mismatch which cannot be re-matched by any increased change in the red/green setting or by any change of intensity of the yellow. Thus there is only one setting for the match, namely the one with which we started—when quanta are caught equally from the two fields on each of the cone pigments. Indeed, if the pigments cannot distinguish the fields, nothing else in the visual system can.

Now if the anomalous trichromat has the *normal* cone pigments, then a Rayleigh match that was indistinguishable to normal pigments would be indistinguishable to him. This is sharply contradicted by observation. Protanomalous say the yellow is too red, deuteranomalous say it is too green. Their discrimination is readily made, and at least one pigment must differ from normal in spectral sensitivity to make it.

Retinal densitometry in living man (BAKER and RUSHTON, 1965) has revealed in the normal eye two pigments similar to the chlorolabe and erythrolabe of the protanope and deuteranope. But such pigment measurements on anomalous trichromats detect only one pigment—only chlorolabe, in the protanomalous; only erythrolabe in the deuteranomalous. The other pigment must be either very scarce, or differ very little in absorption spectrum from the main pigment measured.

Many have accepted that in the red–green range, protanopes and deuteranopes have only one pigment, that normals have them both (König's primaries), and that in anomalous trichromats one of these pigments is replaced by a new pigment whose spectral sensitivity lies intermediate between those of the two normal pigments. ROSMANIT's (1914) schema on these lines has been widely accepted, though his curve for the protanope has its maximum close to Pitt's for the deuteranope.

If we accept the anomalous colour matching functions (e.g. PITT, 1935), only one further measurement is needed to determine which of the possible linear transforms is the one that corresponds to the anomalous pigment. Though many examples of such a critical measurement have been proposed, it is not easy to establish a sound theoretical basis for accepting any one of them, nor any *a postiori* justification.

An obvious hope is to use Stiles's two-colour increment threshold technique to find the anomalous π mechanism, as he has found the normal green (π_4) and red (π_5). His criterion of a stable mechanism was that, in his range of measurements, the test flash should always excite the same mechanism, tested by the t.v.i. curves (threshold vs intensity) always having the same (unsegmented) fixed shape when plotted on double logarithmic co-ordinates. The spectral sensitivity of this isolated mechanism was the relation between energy and wave length of a *background* adjusted to raise the increment threshold of this mechanism by a fixed amount in conditions of steady adaptation.

Even with these strict criteria it is not easy to interpret the five or more mechanisms that Stiles has isolated, and naturally there are yet greater difficulties in appreciating properly the large mass of published material where two-colour thresholds are obtained without any criteria of that sort.

WATKINS (1969a, 1969b), for instance has made a rather detailed analysis of normal and anomalous eyes in terms of all Stiles's seven π mechanisms, but he did not employ Stiles' great range of cross checkings, selecting merely a few key wave lengths from which to infer the spectral sensitivities of all the mechanisms involved. Though this may leave his conclusions less compelling, we do confirm his estimates of the anomalous pigments. However, it does appear to be very difficult, using Stiles's criteria, to obtain with an anomalous trichromat a π mechanism whose background field sensitivity might be accepted as corresponding to his abnormal pigment, (ALPERN and TORII, 1968a, 1968b).

TWO-COLOUR INCREMENT THRESHOLDS

It is hard to know what to make of the very numerous researches where photopic thresholds have been measured with flashes of one colour applied to a retina adapted in some way to another colour.

With any fixed condition of adaptation the curve of threshold energy vs wave length