

course, they exhibit individual variations among themselves, just as other groups of persons do). . . . The figures disprove the assertion of those who declare that crime is a disease." Coming from one who, in virtue of his work, his experience, and his writings, is among the foremost authorities on the subject in Great Britain, and is himself a medical man, this is a most significant pronouncement. Both in the medical and in the educational world there are still numerous writers and administrators who do not realize how opinion upon this point has changed. The trouble seems to be that laymen and Government officials are alike inclined to think that the qualified expert in mental science must be the medical man. Psychology, owing doubtless to the publicity given to its more sensational problems, is confused with psycho-analysis, and not yet regarded as a science in its own right. Many of the pioneers who have urged that the prime need of the adult criminal is treatment rather than punishment have done so on entirely misleading grounds, namely, that "crime is a pathological symptom, and therefore the criminal should be accorded the same medical care as any other mental sufferer". Similarly, when child guidance centres were established they were called 'clinics' (as though backward pupils as well as young delinquents were mentally diseased); and it has been the official policy of the Child Guidance Council itself that "since crime is a form of illness, the child guidance clinics at which such cases are examined should be under a medical director". No doubt, in a small proportion of the cases, moral delinquency, like educational backwardness, may be the outcome of physical or mental illness; and in every case the first step is unquestionably to investigate the possibility of such illness as a contributory factor. Recent investigations, however, like those of Dr. East, prove conclusively that it is, as a rule, only a minor factor, and a comparatively rare one at that. Hence, as recent experience has shown, there is considerable danger that exclusive or excessive emphasis on the need for a medical approach may lead to the neglect of other lines of study and treatment that are far more important—the social, the educational, or the psychological.

In all cases of delinquency or crime it is the psychological rather than the physical or pathological characteristics of the individual that call for first consideration. But in early years it is the social and educational environment—the home and the school—that are usually the deciding factors. "The home," says Dr. East, "should be the first training ground." The lad who comes from a broken home or from a family where discipline is unduly harsh, unduly lax, or so erratic as to be virtually non-existent, is not only more liable to drift into vice and crime, but also more resistive to subsequent efforts at reform. A wholesome training in the school is equally essential as a supplement to, and often as the only substitute for, the training in the home. "But its value is not to be measured by its success in teaching a lad how to acquire knowledge or even by its material usefulness in after life: . . . the formation of moral principles and habits is the most important part of education." "For this and other reasons," Dr. East observes, "the criminologist will welcome the proposal to raise the school-leaving age." As regards economic conditions, he finds that the relative amount of unemployment among offenders was not appreciably greater than that obtaining among the general population: but they seemed far more liable to commit their offences

during spells of unemployment than at other times. In particular, he urges the importance of vocational guidance as a means of combating delinquency: among adolescents more especially, it would seem. "wrong placements tend to invite anti-social behaviour".

As to punishment, Dr. East notes that "the tradition that imprisonment is solely punitive still persists in certain quarters; but it cannot be too widely known that its modern purpose is treatment and training". This, as he points out, is the attitude taken in the Criminal Justice Bill of 1938, which was before Parliament before the outbreak of the War. That penal measures do not altogether fail is, in his view, borne out by after records: thus "of 17,918 males and 2,749 females who were over the age of 16 years in 1932, and were found guilty in that year of offences sufficiently serious to warrant the taking of finger-prints, and had no previous proved offences recorded against them, 90 per cent of the older males, and over 70 per cent of the younger, were free from any further charges during the subsequent five years: the figures for females were nearly 90 per cent".

Due attention to the psychological study of the criminal must be one of the items that should claim a foremost place in the programme for post-war reconstruction. Since at the moment the urgent need is knowledge, more detailed, more precise, and, in a word, more scientific, about the reactions of the individual mind, one of the first steps should be to establish "an institution where research into the problems of criminal behaviour, and the scientific treatment of offenders, can be carried out". "And the conclusion of the whole matter," says Dr. East, "seems to lie in the fact that a democratic State can no longer afford to ignore the effects of social hazards which are harmful and preventable; the treatment of delinquent and criminal behaviour are not merely matters that concern lawyers, administrators and scientists; they are matters that concern us all."

## A PHYSIOLOGICAL THEORY OF COLOUR PERCEPTION

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IT is nowadays possible to record the discharge of the retinal elements directly by leading off to electrodes from more or less isolated fibres of the optic nerve. The electrical impulses following upon illumination are the physiological means of communication between the retina and the higher centres. They are amplified and led to an oscillograph for photographic recording and at the same time listened to in a loud-speaker. This is the technique for which the well-known work of Prof. E. D. Adrian and his collaborators originally laid a solid basis. For isolation of the fibres in the optic nerve a method of micro-dissection around the blind spot has been developed by Hartline<sup>1</sup> and a micro-electrode technique for picking up from the fibres inside the eye by Granit and Svætichin<sup>2</sup>. The latter method is a great deal simpler and faster than the former, and for this reason it is the natural instrument for a rapid survey of the colour properties of a large number of single or grouped units in the response of the eye to illumination with spectral light of known energy

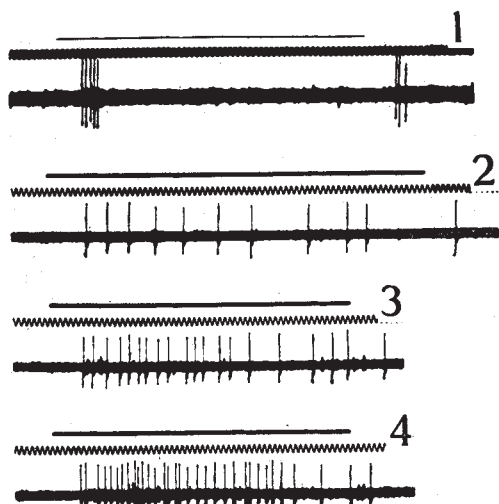


Fig. 1. IMPULSES PICKED UP BY A MICRO-ELECTRODE PLACED ON THE NERVE FIBRES INSIDE THE RETINA. ABOVE EACH OSCILLOGRAM IS THE TIME RECORD (50 PER SEC.) AND LIGHT SIGNAL.

1. "On-off"-element from photopic cat's retina responding to light of wave-length  $0.660 \mu$ . Somewhat above threshold.
- 2-4. "On"-element from scotopic retina of guinea pig responding to "white" light: 2, at strength  $0.006$  m.c.; 3, at  $0.018$  m.c.; and 4, at  $0.061$  m.c. Note increasing frequency and shortening latent period, as stimulus intensity increases.

content. Mammalian eyes can be studied with the micro-electrode as easily as eyes of the cold-blooded animals, to which the technique of micro-dissection is limited if it is to be used for analytical purposes. The animal is anaesthetized, cornea and lens removed, and the micro-electrode inserted with the aid of a micro-manipulator under suitable optical magnification.

Successful isolation, in mammals particularly easy to accomplish, leads to a discharge of spikes of impulses (Fig. 1). In different elements a response follows onset of illumination or both onset and cessation of illumination, as first noted by Hartline<sup>1</sup> with the frog's eye. In the latter and in some other eyes, there are also elements which merely respond to cessation of illumination. But these different types of responses are of less interest in this connexion because of the absence of any definite correlation between type of discharge and type of colour sensitivity, to judge by the work so far carried out.

In order to analyse the colour sensitivity of such discharges, we proceed to measure the amount of energy necessary for eliciting a threshold response in the different wave-lengths of the spectrum. If the element under the electrode has low sensitivity for light of a given wave-length, much energy is needed to elicit a discharge; if it has high sensitivity, little energy is required. Thus the inverse value of the energy necessary for a threshold response in each wave-length is the ordinate (per cent of the maximum) plotted in the curves of Figs. 2 and 3, illustrating the spectral properties of the retinal receptors. I shall briefly direct attention to some results of general interest from work published during 1940-42 (*Acta Physiologica Scandinavica*; preliminary review, *J. Amer. Opt. Soc.*, **31**, 570 (1941)). Since then the number of animals studied has been extended and principles have emerged which in my opinion suggest a relatively simple interpretation of some of the fundamental facts of colour vision, particularly of the differentiation of our sensations into the two categories of brightness (or luminosity) and colour. The

principles discovered may also be of practical importance.

Analytically, the simpler structure is the dark-adapted eye with its rods fully charged with visual purple. We are familiar with the absorption curve of this substance. It was first accurately determined, with in every respect satisfactory and up-to-date technique, by the late R. J. Lythgoe<sup>3</sup>, of University College, London. Our electro-physiological analysis of eyes of different animals in dark-adaptation has shown that a plot of the inverse value of the energy necessary for a threshold response reproduces the absorption curve for visual purple with perfect fidelity, provided that the curves are corrected for presentation in terms of quantum intensity, a necessity first pointed out by Dartnall and Goodeve<sup>4</sup> in *NATURE*. The maximum of this absorption curve is around  $0.500 \mu$ . Visual purple also determines the luminosity curve of the dark-adapted human eye (scotopic spectrum). After the latter has been light-adapted the maximum of our luminosity curve shifts to the region of  $0.560 \mu$  (Purkinje shift) and the new curve obtained determines the distribution of brightness in a spectrum strong enough to elicit sensations of colour (photopic spectrum). As is well known, the retina is then supposed to utilize cones as receptor elements.

In light-adapted eyes of animals the simple spectral sensitivity curves recorded with the micro-electrode technique are of two types: (i) broad absorption bands, here called *dominators*; and (ii) narrow bands, here called *modulators*. The most interesting fact about the photopic dominator, apart from the width of the curve, is the localization of its maximum to the region around  $0.560 \mu$ , as shown in Fig. 2 for frog and snake (*Tropidonotus*), the latter a pure cone eye which need not be light-adapted to give this curve. The same dominator has been found in the eye of the cat. The dominator is lacking in the eyes of guinea pigs and rats. The form and spectral locus of the dominator is practically identical with the average curve obtained from massed receptors in the light-adapted eyes of the same species. In this sense the dominator may be called the carrier of the Purkinje shift. This and its good correspondence with respect to form and locus with the luminosity curve of the light-adapted human eye necessitate the conclusion that the dominator is responsible for

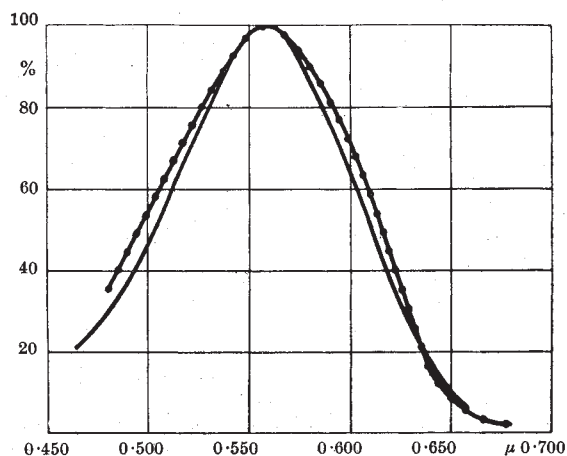


Fig. 2. DISTRIBUTION OF SENSITIVITY OF "DOMINATOR" ELEMENT IN THE RETINA OF FROG (UNINTERRUPTED LINE) AND SNAKE (LINE INTERRUPTED BY DOTS).

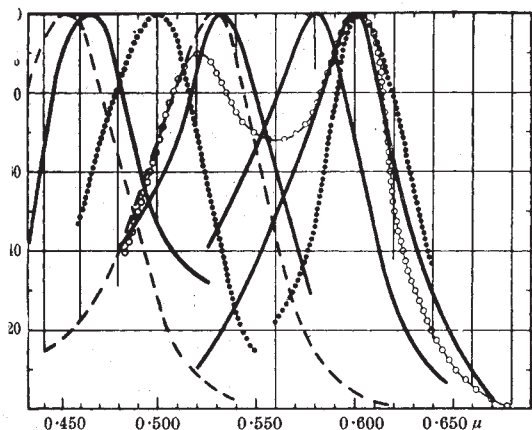


Fig. 3. DISTRIBUTION OF SENSITIVITY OF "MODULATOR" ELEMENTS FROM EYES OF RAT (DOTS), GUINEA PIG (BROKEN LINE), FROG (LINE IN FULL) AND SNAKE (LINE INTERRUPTED BY CIRCLES). NOTE THAT ALL CURVES ARE IN PERCENTAGE OF THE MAXIMUM AND THAT A NUMBER OF ORDINATES ON EITHER SIDE OF 0.560  $\mu$  ARE DRAWN DOWN TO INDICATE "DOMINATOR" VALUES. ALL SPECTRA OF EQUAL QUANTUM INTENSITY IN BOTH FIG. 2 AND FIG. 3.

the sensation of brightness, which thus is our dominant impression, coming, as it does, from the dominant receptor, dominant also in the sense that it is the most frequent one.

How then is colour vision possible? Modulation of the dominant impression of brightness to colour would seem to be the task of the much rarer modulators which occupy very narrow bands of sensitivity in three preferential regions around 0.580–0.600  $\mu$ , 0.520–0.540  $\mu$  and 0.450–0.470  $\mu$ . These are shown in Fig. 3. In addition, there is also in some eyes (rat, guinea pig) a narrow band in the region of 0.500  $\mu$ , which is the spectral locus of the maximum of the absorption curve for visual purple. The rat has 1 per cent cones, the guinea pig still less, if any. It is an interesting fact that in these eyes, which lack dominator and Purkinje shift, light-adaptation does not completely remove the absorption curve for visual purple but changes it to a very much narrower curve of modulator type, still placed in the same region. Light-adapted rods in this case serve as cones.

The most regularly recurring modulator in the different species studied has been the 'red' one with maximum at 0.600  $\mu$ . It has even been found in the eye of the rat, which lacks the dominator, but not in guinea pigs. In the cone eye of the snake the 'red' modulator was generally, though not always, connected to a 'green' hump at 0.520  $\mu$ , which sometimes was more, sometimes less, developed. Its narrowness (see Fig. 3) suggested a 'green' modulator which, however, was never obtained in the isolated state in this animal. But in guinea pigs and frogs 'green' modulators with maxima around 0.530  $\mu$  were seen. The 'blue' modulator was first found in the eye of the frog, then in the guinea pig. In both retinae it is quite common in the shape of a hump on other curves, but it is difficult to isolate. The frog, of all the animals studied, has the most complete set of modulators (cf. Fig. 3). As rods and cones may converge towards a common retinal ganglion cell (Polyak<sup>5</sup>), and as many other factors antagonize isolation, it is clear that all attempts to interpret complex curves as well as to understand the nature of the sensory message as a whole must begin by emphasizing the positive character of the evidence for the existence of curves as simple as the modula-

tors. Complex curves with several humps are, of course, common.

The experiments with the cone-eye of the snake suggested that the dominator itself is composed of modulators joined together in such a fashion—either photochemically or by connexions in the retinal synapses—as to operate as a *functional unit*. However, this assumption, though probable, is not essential to the theory based on the experiments. But it would explain why stimulation of all modulators together also causes an impression of white, and not of all colours confused. The modulators would in this case merely add to the effect of the dominator. Alternatively, the modulators could be coupled in antagonistic pairs which simultaneously neutralized each other at the retinal or some higher level. As a matter of fact, in eyes where both 'red' and 'green' modulators are present, they are very difficult to isolate from each other.

But let us now see what kind of theory of colour vision would be a direct consequence of the experimental subdivision of the receptors into a great number of almost identical dominators and a smaller number of narrow modulators varying somewhat in shape, locus, sensitivity and number within three preferential spectral regions. No further assumptions will be introduced beyond the original one, that the dominator stands for the dominant impression of brightness, and is modulated by the modulators so as to give the higher centres a cue for their integration of 'colour'.

(1) The greater the distance in the spectrum from the centre of the dominator the darker the colour. Colours towards the ends of the visible spectrum must be dark by comparison with those near the top of the dominator. This we know to be true.

(2) W. D. Wright<sup>6</sup> has shown that selective adaptation of the human eye to any colour causes chiefly a large general reduction of brightness and an insignificant selective effect on the fatiguing colour. This also is a direct consequence of a dominator for the perception of brightness. Classical theories would seem to require not only a much larger selective effect on the fatiguing colour but also a considerable shift of the luminosity curve.

(3) As it is improbable that all receptors would be of exactly the same threshold, a diminution of intensity should, on classical theories, lead to perception of coloured spots. Instead we know that it leads to the spectrum becoming colourless, with the brightness distribution of the dominator, as required by the presence of this most common receptor.

(4) Similarly, a reduction of area of the visual object, which is known to lead to disappearance of its colour with maintained brightness distribution, must do so because the 'small' stimulus merely has a chance of hitting upon the common dominators.

(5) Colour-blindness need not, but *can* be possible without parallel change of the photopic luminosity curve. A colour-blindness of this type would be the common form of red-green blindness known as deuteranopia, to be interpreted as absence of the 'red' and 'green' modulators, with the remaining dominator alone giving the normal luminosity curve. Without a separate structure for the perception of brightness as distinct from colour, no theory can ever hope to explain colour-blindness unaccompanied by considerable 'luminosity blindness' to light from the 'blind' region of the spectrum.

Many of the animals studied represent different types of colour-blindness if considered from the point

of view of the complete colour sense of man. The guinea pig probably comes very near the totally colour-blind, the cat near the deuteranope. The cat has the typical dominator but no definite 'red' modulator. The guinea pig, however, has a number of different modulators in the short wave-lengths and hence may be able to discriminate colours in this region. But it lacks dominator and Purkinje shift. The totally colour-blind human has a photopic luminosity curve practically identical with the luminosity distribution of the normal dark-adapted eye dominated by visual purple. The guinea pig has the same scotopic and photopic sensitivity curve, slightly distorted by a hump in the blue in the photopic state.

With the three preferential regions for the modulators, it is clear that this theory can do what the trichromatic theory does and also that it demonstrates the essential correctness of Thomas Young's great generalization, although it is necessary to assume a greater or lesser number of somewhat different modulators within these regions. The main crux of the trichromatic theory and, indeed, of any classical theory, is the lack of precision in the concepts accounting for the perception of white as a separate entity which, nevertheless, somehow is intimately connected with the perception of colour. The trichromatic theory regards white as due to the summed effects of, chiefly, the 'red' and the 'green' sensitivity curves. This forces the theory to accept the consequence that removal of 'red' and/or 'green' should cause removal of the perception of luminosity in the same region of the spectrum. Hence there can be no colour-blindness without profound changes in the form and locus of the luminosity curve. It is an admission of failure to have to explain so important a phenomenon as deuteranopia by pushing it aside to be taken care of by the 'higher centres'.

Many of the phenomena to which the trichromatic theory has directed attention need not be discussed for the reason that my theory does not necessarily exclude the explanations already available. Thus, for example, the fineness of colour discrimination in different regions of the spectrum may be explained in the classical way, or else by the assumption that the number of slightly different modulators is particularly great in the regions where the maxima of colour discrimination are placed.

In its present form the theory gives no explanation of contrast colour, though certain alternatives seem reasonable in view of the fact that different elements are so often coupled together and that the retina contains a large number of coupling synapses. If a certain percentage of the 'red' and 'green' modulators are coupled together in such a manner that both are forced to discharge when either is stimulated, the natural result to expect from the asymmetry caused by fatiguing either of them is that the other one should predominate in the neighbouring region as well as in the off-effect. The experiments themselves have not yet dealt with situations calculated to bring forth contrast phenomena.

It is impossible in this brief review to deal with the available evidence concerning the nature of the colour-sensitive substances. The hypothesis I prefer is that visual purple—which may be called the dominator of the scotopic eye—is the mother substance for the photopic dominator and the modulators. Its molecule consists of a protein nucleus serving as carrier for about ten chromophoric groups (see Broda, Goodeve and Lythgoe'). The different

colour sensitive substances may be due to changes in the linkage between carrier and chromophores.

<sup>1</sup> Hartline, *Amer. J. Physiol.*, 121, 400 (1938).

<sup>2</sup> Granit and Svaetichin, *Uppsala Läkaref. Förh. N.F.*, 45, 161 (1939).

<sup>3</sup> Lythgoe, *J. Physiol.*, 89, 331 (1937).

<sup>4</sup> Dartnall and Goodeve, *NATURE*, 139, 409 (1937).

<sup>5</sup> Polyak, *Arch. Ophthalmol.*, 15, 477 (1936).

<sup>6</sup> Wright, *Proc. Roy. Soc.*, B, 115, 49 (1934).

<sup>7</sup> Broda, Goodeve and Lythgoe, *J. Physiol.*, 98, 397 (1940).

## DARWIN'S HEALTH

By SIR BUCKSTON BROWNE, F.R.C.S.

PERSONAL experiences of great men are always interesting, and often instructive. There has lately come to light a diary of his health by the immortal Charles Robert Darwin, from 1849 until 1854. It is now in the possession of the British Association for the Advancement of Science<sup>1</sup>, and the Association's Secretary, Dr. O. J. R. Howarth, has permitted me to read it. It consists of thirty-four pages of unruled foolscap.

There is no doubt that the hardships of his five years voyage on board H.M.S. *Beagle* seriously affected Darwin's health. At first he tried to live in London, but found it impossible, and he sought a home in the country. He found it at Down House, Downe, Kent, sixteen miles from London, well away from any great road, quiet and secluded. He lived there for the rest of his life, forty years, dying in 1882, aged seventy-three. Down House is roomy, there are a large vegetable and fruit garden and considerable meadow land. It had no water or gas supply, and no bathroom. There was a cesspool—and a well. Cows and pigs were kept, the stables were large, and the dairy and coachman's house were separate buildings. There was a long path, called the "Sand-walk", along the northern side of the meadow land.

When Darwin began this daily account of his health, he had been married for ten years; he had a devoted wife, and a comfortable home, but the diary is a record of continual misery and suffering, although often the days are marked "good", and the good is sometimes underlined or even doubly underlined. His nights are disturbed by severe attacks of flatulence. In the daytime he suffers from attacks of sickness and vomiting. He has headaches and dizziness. He mentions lumbago and arthritis, and most painful of all, a succession of attacks of boils. They are allowed to burst of themselves and no antiseptics are used. One boil is described as "very large". He has pyorrhœa and sore gums and a tooth has to be extracted under chloroform. He complains that his writing has become very bad.

While the diary was kept, Darwin visited London, Eastbourne, and Great Malvern, where he tried the water-cure, and in a curtained corner of his study at Down House he kept a large shallow tin bath, and in the diary "douches" and "double douches" are mentioned. At the time a so-called electric belt was much advertised; it was tried and abandoned.

Darwin daily walked in his garden and up and down the "Sand-walk", and rode about the neighbourhood on a stout cob. After early manhood he smoked only occasionally. He became a regular snuff taker, but in order to keep the habit in abeyance kept his snuff jars in the hall, so that when desiring a pinch he had to rise and leave the room.