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A DIFFICULTY IN ACCEPTING THE YOUNG-HELMHOLTZ THEORY

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NOT very long ago* I discussed at some length the question of colour vision, but without reference to hypotheses or theories. As the subject has been recently before the readers of the BRITISH JOURNAL OF OPHTHALMOLOGY, I venture to call attention now to what, to my mind, is the weak point of the Young-Helmholtz theory.

Our present position with regard to inferences to be drawn from experimental data must, I take it, be to ascribe to the retinal rods an end-organ function in connection with neutral, non-coloured, light impressions and to the cones a similar end-organ function, but in addition a functional relationship to qualitative light or colour sensations. This latter function alone, presents, as one of its essential features, the phenomenon of antagonism. What the explanation of this phenomenon may be, whether the antagonism takes place in the end-organs or in the visual centres, is one of the puzzles which remains to be solved. Popularly, we talk of one colour destroying another. In point of fact, all colour impressions when superimposed, destroy each other in some degree. The

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actual degree varies from slight, in the case of impressions which are nearly alike, to complete destruction in those which are dissimilar to the extent of being complementary. These latter are often indeed referred to as "antagonistic." The full extent of antagonism, though present, is only noticeable when the super-imposed colours are of equal "strength."

The problem of explaining colour vision is one that has for long been attractive both to the physiologist and the mathematician. Unfortunately it is rare that the mathematician who attacks the problem has a sufficient knowledge of physiology quite to appreciate the difficulties which call for solution. On the other hand, it is not uncommon to find a physiologist to whom the subject is specially interesting, unable fully to understand the mathematician's point of view. Helmholtz was both a physiologist and a mathematician and the same applies to Thomas Young, though in his day physiology was a somewhat rudimentary science.

It is really preponderatingly a physiological problem. And much of the confusion that exists comes from the uncertainty as to whether some element in the chain of events leading to colour perception is retinal or central. It seems doubtful whether the great mathematical development that the colour problem has received from Helmholtz and his pupils and others, though highly suggestive and research stimulating, has really been necessary. Because, the attempt to explain at the same time both colourless and coloured impressions by the interaction of the same postulated variables is inconsistent with what is known of the physiology and pathology of colour vision.

The idea of the complete causative interdependence of the two kinds of sensation probably originated with Newton 250 years ago. Newton suggested that the impingement of light on the refracting surfaces of the retina sets up vibrations of different sizes which run along the optic nerve fibres to the sensorium, causing different colour sensations according to their size, "while a confusion of all caused white."

Of course this is not consistent with what is now known of a specific nerve energy. But it was the consideration of this suggestion that led Thomas Young to propound the view that "each sensitive filament of the nerve may consist of three portions, one for each principal colour." And 50 years afterwards, now nearly 70 years ago, Helmholtz, when he resuscitated and elaborated the hypothesis of Young, retained this conception of Newton's as an essential part of the hypothesis which is now known as the Young-Helmholtz theory.

Helmholtz, however, made an important modification in the hypothesis. The three postulated receptors were retained, but only in a general sense, without any assumption as to their nature, such

as distinct nerve fibres, three different chemical or electrical changes, &c.

In this general sense the hypothesis lends itself to mathematical treatment. At the same time it becomes, so to speak, more elastic. The elasticity is necessary to explain and correlate abnormal conditions of the colour sense and other phenomena with normal colour vision. But is this elasticity not of itself a little suspicious?

We can probably never hope to understand the cerebral psychical processes which result in the extraordinary number of separate colour impressions which we can perceive. The only question that might, and possibly eventually will be elucidated, is the discovery of the nature of the provision that exists for the retinal reception of the "light" stimuli, and their transformation into nerve energy, which finally elicits these sensations.

Physiologically there is a very complete similarity between the black-white series of impressions and the colour series. Black and white are just as definite specific sensations as red or blue or any other colour. And the relation between black and white appears to be exactly the same, physiologically, as that between any pair of complementary colours. Black, physiologically, is the complement or antagonist of white. Like any objectively elicited colour sensation which is always capable of being heightened in its saturation by a purely subjective addition, the black and white sensations are similarly subjectively intensified. This is very striking as regards black.

"White" is more or less a relative sensation, produced by an illuminated object or surface devoid of colour. But it is possible to approximate to, and easy to imagine, an absolutely pure white. Any colourless impression, from white to very dark grey, may, under special conditions of illumination, of contrast and of retinal adaptation, appear to be white. And however pure the white of a surface may appear, it is always possible to elicit the sensation of a still purer white. An increased sensation of white is got by screening off a portion of a white surface for a few seconds by interposing a grey or black object. On removing the screen the portion which it covered appears then more brilliantly, more saturatedly white, than the rest of the surface. That fatigue is not the only factor in causing this increased saturation is shown by making the same experiment with black. "Black" is also under most conditions a relative sensation. But it is possible to obtain a practically absolute black, i.e., it is possible to present to the retina a surface from which no light at all is reflected. Yet this, which one might call a physical black, is not as black a black as it is possible to experience. It is not a fundamental 'black' in the physiological sense. The retinal image of a hole in the middle of a box, the inside of which is darkened with mat lamp-black, provides

an absolute, or very nearly absolute, physical black. If over a portion of such a hole we hold a screen of white paper for a few seconds, the area covered appears, on the withdrawal of the screen, a great deal blacker than the rest of the hole. Here there can hardly be any question of fatigue.

The simultaneous effect of objective conditions capable, separately, of giving rise to two equally strong and exactly complementary impressions is to cause a colourless impression. And this has its analogy in the grey that results from mixing black and white. Just, too, as we can imagine an absolute white and an absolute black perception, so we can conceive some definite grey sensation which would result from conditions tending to elicit equal and simultaneous pure black and pure white sensations.

There is, therefore, this close analogy between the colourless and the coloured series of light impressions. But there are also differences. In the first place, the black-white series is one, which, though quite independent of the absolute amount of light, passes from darkness to light—from the absence of any light sensation at all to a greater and greater sensation of light. The neutral line in any concrete case corresponds to the impression of some definite grey. So far, then, as the end-organ excitation which originates these impressions goes, it can only be imagined as taking place for the one end, the white of the series.

In the case of two-colour impressions having the same relationship to each other as black and white have to each other, i.e., qualitative impressions which are mutually complementary or antagonistic, there is light at both ends of the series, because there can be no colour without light, though there may be light without colour. The result of this is that the neutral line or division between the two impressions, which is, as before, uncoloured, is, so far as light goes, brighter than would be the impression produced by one of the colours alone. There is, in fact, a summation of the two lights, with, at the same time, a destruction of qualitative impressions—the colour of each. There is, therefore, presumably end-organ stimulation at both ends of the series. Combination of any two colours produces an intermediate colour whose brightness is the sum of that of the components. This is the case whatever be the qualitative character of the resultant. Abney has shown that “within the limits of error of observation, the luminosity of the combined spectrum, measured as white, is equal to the luminosity of spectrum colours measured separately.”

The black-white grey, therefore, though the same psychically as that resulting from combining two equally strong complementary colours, has a different relation to that of its components. The concomitance of the two conditions which would cause the two sensations black and white, results in a sensation which differs from

either, but yet is one which for varying proportional activities of its two components has always the same character.

How is the neutral effect of simultaneously superimposed stimuli which would, separately, cause impressions of two complementary colours, or of many colours suitably selected to produce this effect, to be explained? It seems generally to have been inferred since Newton, that they make "white," i.e., a non-coloured light sensation. It is surely more consistent with what we now know to say that the stimuli to colour impressions destroy each other and "leave" white. Antagonism of action is a common and necessary physiological process. How far antagonism may take place in the end-organ response to simultaneous stimuli is not known. Probably it takes place elsewhere.

One of the main difficulties in accepting the Young-Helmholtz theory is just this assumption on which it is based, that stimuli which acting alone would cause the sensation of colour may, when combined, "make" white.

Some of the differences between neutral and coloured sensations may be noted. In the first place, a physical stimulus, which otherwise would give rise to a sensation of colour, produces a neutral sensation alone, when insufficiently strong. It is a familiar experience that when the light is sufficiently dim colours are unrecognizable, and only the white-black series of impressions are elicited. Snow gives rise to the sensation "white" even when the illumination is insufficient for the recognition of any colours. "Bei Nacht sind alle Katzen grau."

There is for all colours an interval between the general (light) and the specific (colour) thresholds. The magnitude of this interval (the photo-chromatic interval) varies with the different parts of the spectrum. It varies, too, according as the colour is seen by the centre or the periphery of the retina, being in fact barely perceptible for the fovea. It varies with the state of retinal adaptation. Still more strangely the relative brightness of the spectral hues varies with the absolute illumination.

Again, when the stimulus is too intense the colour impression which it would otherwise produce is lost. All colours tend towards white when light is intense.

Further, neutral light perception exists equally all over the retina, being dependent, in the first place, upon changes which occur by the action of light on the hexagonal pigment cells. This pigment cell layer is the only one that is continuous throughout the retina.

Again, colour perception varies, both quantitatively and qualitatively for different parts of the retina. And, it is the specifically coloured factor of the complex sensation that varies—the black-white factor remains constant.

Pathological conditions show too, a certain independence between the neutral light sense and the colour sense.

All these facts, as well as others, appear to indicate that there is some sort of differentiated origin for the two series of sensations. As the same light stimulus originates only non-colour impressions when acting through the rods, but both colour and non-colour impressions for cone excitation, from which the resulting sensations are always more or less mixed, the independence of the two sensations is subject to limitation.

Whilst then the same energy provides the physical stimulus for eliciting both neutral and coloured visual sensations, and although there is a close analogy and similarity between many of the physiological effects of the stimulus in the two cases, it surely does not follow that the one is strictly speaking dependent upon the other. Physiologically the effects of both responses to the stimulation are inseparably associated in the final character of the sensation. In addition to colour hue there is always some admixture of uncoloured light sensation, the effect of which is to add a practically limitless series of shades and tints. In the case of the spectrum colours it is no doubt difficult to detect the presence of an uncoloured element. But it is there all the same, and it is this element which accounts for luminosity apart from colour saturation. It has received the name of "white valency."

Just as black, though a definite sensation, has no physical counterpart, so no relation has been found between changes in the wave lengths of luminous energy and colour sensations. In fact, the rate at which change in perceivable hue takes place for different wave length varies within very wide limits. It varies too, in an altogether intermittent manner. Our colour sensations form a complete re-entrant curve. The spectrum, on the other hand, leaves a not inconsiderable gap. It does not elicit all the pure colour sensations which we normally receive.

Our idea of primary or fundamental colour sensations, if such exist at all, must be a purely physiological one. It cannot be based on the colours found in the spectrum. Beginning with Thomas Young himself there has been much speculation, based upon experimental data, as to the three hues to be selected as fundamental. Even the exact wave lengths of these have been postulated. But the selection has always been made on the assumption that one response to all compound colour stimuli must be the "making" of white.

It may, perhaps, be admitted that the inference that separate receptors of some nature exist—but in connection with qualitative light sensations alone—is one to which one seems almost forced by the known facts of colour mixture. It is also easy enough—if we exclude the "making" of white light at the same time—to imagine

a system of a limited number of fundamental sensations which would suffice to explain symbolically both normal and abnormal colour vision. But this is not the Young-Helmholtz theory.

In the theory as it stands the condition of peripheral colour vision is explained in a way which is inconsistent with facts. For the periphery of the normal field of vision there is no difference in kind between the non-coloured impressions and those got on direct fixation. Nor is there any qualitative difference in the two cases for certain hues of blue and yellow, although reds and greens appear at the periphery of a dirty yellowish or dirty blueish hue or altogether uncoloured, according to what may be the actual hue impression that they produce when seen directly. As the black-white perceptions are unimpaired, so also are their combinations with blue and yellow. Thus, a yellow brown and a light blue are not materially altered on peripheral fixation.

The phenomena of peripheral colour vision show that if the power of correctly perceiving any hue is lost, that of perceiving the complement to that hue must also be wanting. If this were not so, then a white object would change in the impression to which it gives rise when passing from the centre to the periphery of the field of vision, or vice versa. That it does not do so is readily observed. Possessing the power of perceiving colour, we should surely at once notice if the peripheral impression were a coloured and not an uncoloured one.

There is nothing to indicate that there is any very radical difference between normal peripheral colour blindness and congenital colour blindness. When the supporters of the Young-Helmholtz theory, as modified to explain congenital colour blindness, assume that the white of the colour blind is different from the normal white, they are led to this quite untenable conclusion by carrying through the same idea as to the making of white. I am not aware whether it has ever been suggested that the colour blind's peripheral white is different from what is normally the case, or that the central white and peripheral white are two distinct impressions. Either assumption would, as it appears to me, be equally absurd, and it is doubtful if even the elasticity of the theory could be stretched so as to meet the second supposition.

If we infer that colour vision is induced by excitation of different end-organs or different elements of the same end-organs or different central connections, some of the preliminary, though only the preliminary, difficulties in understanding the colour sense are overcome. It has to be remembered that the analogy between colourless and coloured sensations lies mainly in the manner of their central production. It is a physiological analogy. The fact that white light is associated with every—even pure—colour sensation, the difference in the general and the specifically

chromatic thresholds, where these differences can be measured, and the differences in retinal distribution of the means whereby colourless and coloured impressions are evoked, all seem to point to a separate or differentiated origin of the two series of sensations. An additional reason for drawing the same inference is the absence of purely light-sense defects in congenital dichromatic vision. Still another is the retention of normal colour vision in some of the pathological conditions in which the light-sense is impaired.

We may represent by analogy, in a simple though perhaps rather crude way, associated and yet independent response to a single force, such as the facts of the excitation to coloured and non-coloured vision by the physical energy, which evokes any sense of light at all, suggest. Take, e.g., a body of any kind, capable of freely gliding, or rolling on wheels, along a horizontal surface. Suppose that attached to this body, and therefore constrained to move with it, there is a vane similar to that pushed along at the end of a stick by children, the whole forming a sort of wind-mill on wheels or gliders. Suppose that a current of air plays against the surface of the body and at the same time directly on the vane. If the air current is sufficiently strong it will cause the body to move along the surface, and at the same time cause the vane to rotate. Let us suppose, further, that the friction which tends to prevent the body as a whole from being put in motion is less than that which would resist the rotation of the vane. The movement of the whole body may be taken to symbolize the non-coloured response to the energy which is the physical basis of light, the rotation of the vane standing for the colour sensation response and the air current for the light energy. The possible adjustments which might be imagined in the relative kinetic responses of body and vane to the air current would take the place, in this analogy, of the differences which characterise the photo-chromatic interval. If the air current, again, was supposed to be very strong, the movement of the body as a whole would be relatively more rapid than that of the vane, a condition which might be taken as representing some analogy to the whitening of very strong colour excitations.

Because it may be more consistent with facts to hold that the energies which would evoke, when separately active, a pair of complementary colour sensations, or three or more colour sensations, or the whole spectrum, when simultaneously active and superimposed, "leave" rather than "make" white light, this does not exclude as altogether inapplicable the conception of three fundamental receptors for qualitative impressions alone. I am not prepared to admit that even when modified to this extent, what remains of the theory gives a satisfactory explanation, so far as any explanation is possible at all, of all colour phenomena. It may be that the whole idea of a limited number of primary colour sensations is wrong,

notwithstanding the cogent indications suggested by the facts of colour mixing. No one, I hold, can say of any colour that it is consciously more primary than are the hues in its immediate neighbourhood in the spectrum. For instance, the statement, so often made, that in orange one is conscious of seeing a compound, as opposed to a simple, colour, and conscious, moreover, of the presence in the orange sensation of yellow and red, it is to me quite unintelligible. An analysis of my own sensations of colour, unbiassed by theory, causes me to regard orange, as indeed any other colour, as a colour entity.

In any case the Young-Helmholtz theory has to assume that its postulated primary sensations can only be approximately similar to, not identical with, those obtained by the stimulation respectively of three specialised end-organs. Because it assumes that no kind of light stimulates one alone of the terminal receptors. Every colour, it assumes, must be the result of a triple stimulation, though these hues which are most nearly primary arise from a preponderating response of one of the receptors. Though such an assumption is not unimaginable, it does seem to demand considerable modification in our conception of specific nerve energies.

On the other hand, as has already been said, it is quite a reasonable inference to make that separate receptors of some nature exist in connection with qualitative light sensations alone. Admitting this, for the sake of argument, why should three such terminals be selected and not four or any greater number? Obviously the same combinations could be made with four selected primaries as with three. As the whole matter is so conjectural there can be no absolutely convincing argument adduced in favour of only three. But the physiology of the other special senses offers no analogy for the assumption, in regard to them, of even as many as three independent subdivisions of their respective end-organs. Consequently, as for vision, three would be enough, just as a circle is fixed by three points, there is a natural objection to assuming a greater number of divisions. Even Hering's theory, the other of many theories of colour vision which has the greatest number of adherents amongst physiologists, although postulating four so-called, primary colours, derives the whole gamut of coloured and uncoloured impressions from the stimulation of three specialised receptors, i.e., of three substances each capable of katabolic and anabolic changes.

Again, when we exclude the necessity for considering the white element, or white valency, of every colour impression it is easier to account, by a three-fold stimulation in varying degrees and combinations, for the complete qualitative series of impressions which it is possible to receive. With this limitation it is no longer

necessary to represent graphically these impressions as points on a curve of the form given by Helmholtz. A simple re-entrant curve, say a circle, as Newton imagined, seems most consistent with observed facts. And such a circle, though it cannot be completed by points representing visible spectral hues, which do not form a complete re-entrant series, can be completed to represent all the colour hues that we can otherwise perceive. That is to say, that, so far as colour hue sensations go, we can begin with one colour and pass on through others till we come to the first again. And this relationship and order of arrangement is one of which every individual possessed of a normal colour sense is more or less intuitively conscious.

In arranging round a circle points to represent the 150 or so hues which may possibly be distinguished in the spectrum, it has to be remembered that the arrangement to be representative of our re-entrant colour sense must be according to hue and not to wave length. It must be a physiological, not a physical arrangement. The reason of this is that the rate at which perceptible change in hue takes place for different wave lengths varies within very wide limits and in an altogether intermittent manner.

But it is not necessary to pursue such a speculative matter as the selection of the three points in the colour circle to represent symbolically the so-called primary sensations. The selection could not be purely arbitrary; it would be conditioned by being brought into accordance with such phenomena as the known effect of mixing colours, the existence of complementary colours, dichromatism, etc. But the three points being merely symbolic, when the idea of selecting them to represent such spectral colours as "make" white is rejected, need not necessarily be denoted otherwise than by letters or numbers.

THE LATE EFFECT OF TAR POISONING ON FISH

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THE question of river pollution by road tar or its bases has not received much investigation, but at the present time the subject of tar pollution and its effects upon fish is being considered by the joint committee appointed by the Board of Agriculture and Fisheries and the Ministry of Transport to enquire into it, and carry out experiments as to its poisonous effects. The following case which illustrates the late effect of tar poisoning, is therefore, we think, of some interest.