THEORIES OF COLOR-PERCEPTION

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Compliments

BY

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THEORIES OF COLOUR-PERCEPTION.

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It is a well-established principle of scientific philosophy, that, in the explanation of natural phenomena, that theory should stand nearest to acceptance which is most in keeping with laws that have been fully demonstrated, or that present some approach to harmony with authenticated facts of an analogous character. That a theory *can* account for phenomena is not a sufficient reason for its unequivocal acceptance; it must account for them in accordance with the laws that have been found to govern all phenomena of like nature.

When the action of such laws is obscure and not clearly understood, and when there are no closely allied facts to fall back on in the construction of a theory, then we are permitted to indulge in speculations, which can be provisionally accepted until other theories, better substantiated by newly discovered facts, arise to take their places; and as the laws controlling any manifestation of nature are not yet, and from the necessity of the case probably never will be, fully understood, no theory concerning any phenomenon can be considered as fixed. The truly scientific mind, therefore, always holds itself in readiness to change its attitude towards any of the workings of nature as our constantly increasing knowledge may demand.

The question of colour-perception is one which opens a very wide field for the display of speculation, and yet the theories on the subject have been, considering this fact, wonderfully few. As we only came on to anything like accurate knowledge concerning the properties of light with Newton, we are justified in regarding the truly scientific ideas concerning the perception of colour as beginning with him.

Theories of Newton and Young.—Since Newton looked upon light as the result of the action on the eye of corpuscles of a material kind emanating from luminous bodies, it was natural for him to suppose that the size of these corpuscles or the velocity with which they travelled, had something to do with the perception of colour, since it was on these qualities of the emitted particles that he accounted for the physical constitution of light, and for its decomposition into the solar spectrum. We accordingly find him adopting the theory that the particles of light excite the retina according to their nature and bigness, and thus give rise to different sensations of colour. His views on the subject may be inferred from the following extract from the fourth edition of his *Opticks* (1730) pp. 318–319. They are in the form of questions which he appended to Book III. of the third edition, the last which had revision at his hands.

"*Qu.* 12. Do not the rays of light in falling upon the bottom of the eye excite vibrations in the *Tunica Retina?* Which vibrations being propagated along the solid fibres of the optic nerves into the brain, cause the sense of seeing. For because dense bodies conserve their heat[1] for a long time and the densest bodies conserve their heat the longest, the vibrations of their parts are of a lasting nature, and, therefore, may be propagated along solid fibres of uniform dense matter to a great distance, for conveying into the brain the impressions made upon all the organs of sense. For that motion which can continue long in one and the same part of a body, can be propagated a long way from one part to another, supposing the body homogeneal, so that the motion may not be reflected, refracted, interrupted, or disordered by any unevenness of the body.

"*Qu.* 13. Do not several sorts of rays make vibrations of several bignesses, which, according to their bignesses, excite sensations of several colours, much after the manner that the vibration of air, according to their several bignesses excite sensations of several sounds? And particularly do not the most refrangible rays excite the shortest vibrations making a sensation of deep violet, the least refrangible the longest for making a sensation of deep red, and the several intermediate sorts of rays, vibrations of several intermediate bignesses to make sensations of the several intermediate colours?

"*Qu.* 14. May not the harmony and discord of colours arise from the proportions of the vibrations propagated through the fibres of the optic nerves into the brain, as the harmony and discord of sounds arise from the proportions of the vibrations of the air? For some colours if they be viewed together, are agreeable to one another, as those of gold and indigo, and others disagree."

Essentially the same ideas were expressed by the eminent physiologist and physician, Wm. Poterfield, in his *Treatise on the Eye, the Manner and Phenomena of Vision*, in two volumes, Edinburgh, 1759. We find in vol. 2, pp. 342–343, the following paragraph:—

"§ 5. The third manner in which colours may be considered is the passion of our organ of sight, that is, the motions or vibrations excited in the fibres of the retina by the impulse or stroke received from the rays of light; which motions or vibrations being propagated along the solid fibres of the optic nerves into the brain, cause the sensation of colours. For the rays of light being corpuscles of different magnitudes, will, by striking the retina, excite vibrations of different bignesses, which, according to their bignesses must excite sensations of several colours, much after the manner of the vibrations of air, according to their several bignesses excite sensations of several sounds; and particularly the shortest or most refrangible rays will excite the shortest and weakest vibrations for making a sensation of deep violet, the largest or least refrangible, the largest and strongest vibrations for making the sensation of deep red, and the several intermediate sorts of rays, vibrations of several intermediate bignesses to make sensations of the several intermediate prismatic colours; but when the several heterogeneal rays are blended together promiscuously, they must then, in falling upon the *retina*, excite several other different sorts of vibrations for making the sensations of the several compound colours, which will, therefore, differ among themselves according as the light is composed of more or fewer of the different coloured rays or as they are mixed in various proportions."

[1] It will be observed that Newton in the discussion of this question recognizes the analogy or identity of light and heat.

Accepting the theory of light as promulgated by Newton, nothing could be simpler or more satisfactory than this hypothesis, and it is wrought out in that direct manner characteristic of the great philosopher. No other important explanation of the phenomena of colour-perception, so far as my knowledge extends, was advanced until the overthrow of Newton's emission theory of light and the adoption of the undulatory hypothesis. As is well known, the man who was mainly instrumental in this revolution of opinion was Thomas Young, another of England's great scientific geniuses. He was not content with substituting the undulatory for the emission theory, but deemed it necessary to do away with Newton's simple explanation of coloured vision and put forth one which, in its attempt at simplicity, becomes involved in a series of complexities and inconsistencies which is rarely met with in the history of science. Young believed it impossible for as many vibrations as answered to the chief colours of the spectrum to take place at one and the same point of the retina at one and the same time. This, so far as I am able to learn, was the sole cause for his refusal to accept Newton's theory and for the adoption of the one which is now known by his name and has had an accepted place in the scientific world for eighty years.

Since all the vibrations could not be reproduced at the same point of the retina at the same time, he considered it necessary to reduce the spectrum to a few fundamental colours and make the others but a combination of these. He accordingly fixed upon three colours, which he called primary, and supposed that there existed in the retina three fibres which responded to the vibrations representing them. The three colours he chose as primary were red, green, and violet. White light was the sensation produced by an affection in a certain degree of all three fibres, and the secondary colours came from a combination in varying proportions of two or more of the fundamentals. The ingeniousness of the theory was very captivating, and in one way or another nearly all of the phenomena of coloured vision could be accounted for by it; so that, until within a very few years, it held sway over the scientific mind of the whole world, particularly after it had received the sanction of so eminent an authority as Helmholtz.

Objections to Young's Hypothesis on Physical Grounds.—In the first place, the retina, in addition to its function as a receiving and transmitting organ, is made by this theory into a differentiating apparatus as well. This is rendered necessary because of Young's disbelief in the capacity of the retina to act as a receptacle for vibrations after the manner of simple bodies. There is something remarkable in a kind of hitch we sometimes find in the intellectual workings of even our greatest men. It has always been a wonder to scientists that Newton, with a mental power capable of originating so far-reaching a theory as the law of gravitation, should pass by the undulatory theory of Huygens as not capable of explaining phenomena of light.[1]

And it is equally astonishing that Young and all those who have accepted his theory should have overlooked one fact which must have been apparent upon a moment's reflection.

Since the emission theory had to go to the wall, it became necessary to search for some origin of the vibrations of the ether, and this was most naturally found in the substance of the luminous body itself. Researches in the domain of molecular physics seem to leave no doubt that when bodies are heated up to the point of luminosity (or when heated at all, for that matter), the ultimate molecules of which they are composed are put into a state of vibration, and it is this vibration which, communicated to the ether, is the first link in the chain of phenomena which finally ends in the sensation of light. It must be accepted as a fact, therefore, that all the vibrations found in the ether must have had their existence primarily in the molecules of the luminous body. When a body is brought to a white heat, for example, the molecules of which it is composed must make all those phases of vibrations which correspond to every colour into which white light may be decomposed, and must make them at one and the same time. In no other way is it possible to explain satisfactorily and consistently the various vibrations of the ether and the manner in which they are brought about.

Now, Young must have known this, for he could hardly have supposed that there were three separate and distinct fibres in all luminous bodies giving out white light, particularly in those bodies which so far as it is possible to ascertain are strictly homogeneous and simple. If this is true of the originating body, why should it not be true of the body receiving and transmitting the vibrations? Why is it necessary to assume the existence of three separate fibres in the retina whose office it is to receive the vibrations,

[1] The position of Newton in regard to an ether was a peculiar one, and deserves notice here, since it has a bearing on the subject in hand. He by no means denied its existence, but on the contrary believed in it strongly, and even went further in the applications of its use than is contended for now. Thus he says in his *Opticks*, p. 328 :—

"*Qu.* 23. Is not vision performed chiefly by the vibrations of this medium excited in the bottom of the eye by the rays of light and propagated through the solid, pellucid, and uniform capillamenta of the optick nerves into the place of sensation? And is not hearing performed by the vibrations either of this or some other medium excited in the auditory nerves by the tremors of air and propagated through the pellucid and uniform capillamenta of those nerves into the place of sensation? And so of the other senses.

"*Qu.* 24. Is not animal motion performed by the vibrations of this medium, excited in the brain by the power of the will, and propagated from thence through the solid, pellucid, and uniform capillamenta of the nerves into the muscles for contracting and dilating them? I suppose that the capillamenta of the nerves are each of them solid and uniform, that the vibrating motion of the ethereal medium may be propagated along them from one end to the other uniformly and without interruption; for obstruction in the nerves causes palsies."

It will be seen from this extract that he considered the ethereal medium to pervade solid bodies and to take part in the phenomena of light, but it was a secondary part.

when the body giving rise to these vibrations is simple, and with its molecules so arranged that they can vibrate at one and the same time in the different phases corresponding to the different wave-lengths representing the various colours? This, it seems to me, is a death-blow to the sole objection advanced against the adaptation of Newton's views to the undulatory theory.

Neither is there any support for Young's theory from analogy. Certainly it is not to be found in the sense of hearing which has always been considered as most closely allied to that of vision. On the contrary, it seems the rather to offer evidence against it. Take the membrana tympani, for example. It is a simple membrane, and as far as regards any action of sound-waves homogeneous in structure, and yet it can take up and carry to the chain of small bones, correctly and without any alteration in character, an infinite number of different aerial vibrations at the same time. In an orchestra composed of 100 pieces the trained ear of the leader can often detect a single false note, and yet this is only one of many hundreds of thousands of tones and over-tones which are simultaneously taken up by this small membrane and faithfully transmitted to the ossicles and thence to the auditory nerve. And even when we reach the labyrinth which bears a still closer analogy to the retina in function we find there nothing which would substantiate Young's theory. Even if the organ of Corti were the finally differentiating organ, which no one will, I presume, assert, there is a cord for every tone, and three are not called upon to do the service of hundreds or thousands.

And again, if a fibre is so constructed as to be in harmony with waves of a certain length, it becomes thereby physically incapacitated from responding to waves of other lengths. This is one of the fundamental laws of wave-motion, and its greatest beauty is shown when it comes to be applied in the domain of molecular physics. This law finds no exact application in the theory of Young. He assumes three retinal fibres, red, green, and violet, which are attuned in harmony with the red, green, and violet waves. Now in accordance with this law these fibres should respond only when acted on by wave-lengths corresponding to the colours they represent. If the red fibre is accurately attuned to red rays, it should not be affected by the green or violet, nor the green by the red and violet. Still for a satisfactory explanation of some of the phenomena of coloured vision Young was obliged to suppose that all the fibres were affected by the rays of each of the other two colours, though in varying degrees; and not only that, but they must respond to wave lengths not peculiar to any one of the three. Thus yellow, which is not considered a primary colour, but a combination of red and green, has a distinct wave-length of its own, being about $\frac{1}{43,816}$ of an inch (5,808/10,000,000 mm.).

The "rays of light" were solid bodies which coming in contact with the ether contained in the retina set it in vibration; which vibration was conveyed along the "solid and pellucid" optic nerve to the brain.

There is no fibre corresponding to this, but for the perception of yellow there must be an affection of the red fibre $\frac{1}{37,640}$ of an inch (7,000/10,000,000 mm.) wave-length, and the green fibre $\frac{1}{48,200}$ of an inch wave-length (5,271/10,000,000 mm.). So that for the perception of yellow it is necessary for its corresponding wave to affect, not a fibre attuned to its own length, but two others which are adapted to phases of vibration different from its own and different from each other, a state of affairs which the molecular physicist must look upon as absurd. We have, moreover, direct proof that yellow is not a compound colour, for in Hippel's case of unilateral colour-blindness (Gräfe's *Archiv*, xxvi. 3) the yellow as seen by the affected eye had no difference as regards intensity or tone from that seen by the unaffected eye; showing that yellow cannot be composed of red and green, or at least that it can be produced independently. If it were a compound colour, in green-blindness it would appear according to the three-fibre theory as red, in red-blindness as green.

Besides, in giving this amount of forced latitude to his theory, Young destroyed the cause for its existence, since he plainly failed to get rid of the very thing he wished to avoid, namely, the action of a number of wave-lengths on the retina at the same place and at the same time.

The Theory of Prof. Hering.—The theory first advanced by Prof. Hering of Prague[1] differs in many important details from that of Young, though they have this in common, that they require the presence of three peculiar anatomical elements in the retina. In Young's, as we have seen, they are fibres. In Hering's they are chemical substances, which he designates as the *white-black*, the *red-green*, and the *blue-yellow*. Hering supposes that these substances are acted upon by light in a peculiar manner. The red-green substance is affected by no colours but red and green, and these act upon it in opposite ways. Red light, for example, acts in a decomposing or dissimilating (D) manner on this substance and produces the sensation of red; green light acts in a regenerating or assimilating (A) manner on it causing the sensation of green. Blue has an A-action on the blue-yellow substance; yellow a D-action. It will be seen that he recognizes four fundamental colours instead of three, which are divided into two pair, the components of each pair being antagonistic; for when the A- and D-action on any substance are equal the effect is neutral, and no sensation is the result. On the third substance, the black-white, white light acts in a dissimilating manner, while black causes an assimilating action. Moreover, both the other substances are affected in an A- and D- manner by means of white and black.

The peculiarities of this theory are, that it makes the perception of black a positive action instead of a simple absence of sensation, the so-called complementary colours, antagonistic, and the white resulting from

[1] Lehre von Lichtsinne, Vienna, 1878.