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II. *Further Data on Colour-Blindness.*—No. II.
By Dr. WILLIAM POLE, F.R.S.*

IN the July number of the Phil. Mag., seeing the importance that had been attached to the subject of Colour-blindness, I contributed some data as to certain early investigations of my own. Since that time the interest in the matter has been much increased by the prominence given to it at the late meeting of the British Association in Edinburgh, and by criticisms made on some of the views still held on it in this country. It may therefore be useful to invite more attention than has yet been given, to opinions expressed on it by foreign writers of eminence and authority who have made it their special study ; and I propose to add some notes with this object.

I will begin with a writer whose reputation as physicist, physiologist, and practical oculist was second to none,—the late Professor F. C. Donders of Utrecht. He took great interest in Colour-blindness, made many valuable investigations, and wrote much thereupon. The position he took was peculiarly independent. He embraced and strongly advocated Young's trichromic theory, but entirely dissented from the application of it so commonly made to dichromic vision. At the same time, though he agreed with some of Hering's fundamental principles, he opposed his colour theory. And, consistently enough, having objected to the current explanations, he brought forward a hypothesis of his own, remarkable for its originality and its consonance with modern biological science.

Professor Donders came over to the meeting of the British Medical Association at Cambridge in August 1880, and gave there an able lecture on Colour ; but his views are still but little known here. They are contained chiefly in two elaborate articles, namely :—

“ Ueber Farbensysteme,” in Graefe's *Archiv für Ophthalmologie*, vol. xxvii. part i. 1881.

“ Noch einmal die Farbensysteme,” *Ibid.* vol. xxx. part i. 1884.

In giving his ideas about Normal Vision, he considers that our natural impressions point to four “ simple ” colours—red, yellow, green, and blue (which is one of the starting-points of Hering's theory) ; but he believes these sensations are caused by the combinations of three more-highly satu-

* Communicated by the Author.

rated "fundamental" energies, corresponding to red, green, and violet, which is essentially the Young-Helmholtz doctrine.

He describes the phenomena of dichromic vision, according to the testimony of patients (laying some stress on my own case), confirmed by his own experiments and observations. But he prefers to denote the contrasting colours as "warm" and "cold" respectively.

He then discusses at some length (what is the most important part of his work for our purpose here, namely), "The connexion between the Normal and the Abnormal Systems," and he puts the question thus :—

Is one of the energies belonging to the normal system wanting in the dichromic system? Or, in other words, Does every dichromic system consist of two of the energies of the trichromic system?

Maxwell and Helmholtz assumed this ;—and they believed they found it so.

After discussing at some length the reasonings and calculations of Maxwell and Helmholtz, the author continues :—

Now do these facts prove that the colour wanting in colour-blindness is generally one of the fundamental colours?

We call those colours fundamental which do not spring from others, but are necessary to form others. We assume that every fundamental colour shall base its specific process in definite retinal elements, and in order to characterize it more closely, we determine its subjective luminosity as a function of the wave-length, inasmuch as we presuppose that this will coincide with the intensity of the retina-process. Without regard to colour-blindness we come to the result that the terminal colours of the spectrum, red and violet, and the central, green, are the fundamental colours, as Young had already shown.

Now it happens that in Red-blindness the wanting colour is not the spectral red, but a red which approaches to carmine, *i. e.* a red which does not appear in the spectrum, and is only to be obtained by a mixture of two spectral colours, red and violet.

With Green-blind patients there is reason enough to look for the wanting colour in their neutral spot; but this by no means decides that the bluish green which corresponds to this neutral must be one of the fundamental colours of the normal system.

The final result of this, therefore, is that we have no right to consider the colours wanting in the various forms of colour-blindness as the fundamental ones of the normal system.

He adds elsewhere :—

In a theoretical point of view the simple falling away of one of the energies is inadmissible. It does not harmonize with our idea of the origin of things, that, of three activities which develop themselves in a reciprocal relation as an organic whole, one should

be absent without the defect having an influence on the other two.

Edmund Rose was the first to point out this difficulty in the application of Young's theory, but he was, in my opinion, quite wrong in inferring that this was fatal to the theory. The retina is not a thing formed by human hands. It is not an instrument with three strings, one of which is broken for the colour-blind. It is a living instrument—*genitum non factum*—whose three differently-tuned strings have developed themselves in combination with each other. If one is absent, then the tuning of both the others is certainly not what it would have been under a regular development of the whole.

We have also to consider the subjective sensations of the colour-blind.

I presuppose that they see the ordinary daylight as the normal eyes see it, *i. e.* neutral, colourless. Herschel, in his remarkable letter to Dalton, says, "when your two colours are in equilibrium, they form your white;" and in the case of Mr. Pole also he says he "is strongly disposed to believe that he (Mr. Pole) sees white as we do."

The reason why, according to my view, the white of the colour-blind should correspond with that of the normal-eyed, lies deeper. What the total light brings forth must necessarily be the manifestation of the total process, and according to the nature of things this is, in opposition to the partial process, neutral, or it would become so, if it were not so already. Colour-blind people who have due regard to their sensations, see in white no third colour, but only the negation of the other two, something neutral. Mixed with either of these, it leaves the colour unchanged, and only reduces the saturation. Nobody can believe that the white to the Green-blind should be a purple, such as for the normal eye is formed out of red and violet, and no one has ever believed it.

According to the assumption that the white light of the colour-blind is neutral, colourless, I consider their fundamental colours as complementary.

In common with the declarations of intelligent colour-blind persons, I have assumed that the Red-blind must have for their warm colour a yellow, leaning towards green, and the Green-blind a yellow leaning towards red; and that blue or violet, as cold colours, will correspond with these. And I consider these assumptions as already, to a certain extent, proved by the revelations of one-eyed colour-blindness.

In the lecture given at Cambridge, 1881, Donders repeats this opinion: he says:—

The warm and cold must be considered as complementary colours; to which of our sensations they correspond cannot well be told, probably the cold colour is blue or violet, and the warm one is yellow, approaching to red or green.

From these extracts it is clear that he agrees in the view, drawn from observation, that the colours seen in dichromic vision are, generally speaking, yellow and blue, and he does not consider that there is any such connexion between the dichromic and the normal vision as should require them to be otherwise.

But he goes farther, and puts forward a view of his own, which he believes may explain Colour-blindness without interfering with the Young-Helmholtz theory. He considers dichromic vision may be a step in the evolution of the colour-sense, anterior and introductory to the present normal vision.

He appears to have been led to this by the analogy of the remarkable variation of colour-perception in the different parts of the human retina. He describes this at some length, shows how practically to examine and test it, and notices the remarkable arrangement of full normal colour-perception in the central portion, dichromatism in a surrounding ring, and total colour-blindness in the outer periphery.

The Young-Helmholtz theorists had tried to explain this, as they did dichromatism, by the falling away of one or two of their fundamental sensations ; but Fick had shown the unsatisfactory nature of this explanation, in which opinion Donders entirely concurs.

His view is that this structure of the eye points to a gradual development of colour-seeing power. In the first instance, the whole eye was in the state that its exterior ring is now, namely, having a power of vision of light and shade without colour.

That afterwards an improved state set in, with two colour-sensations, which, beginning in the centre, gradually extended to a certain diameter over the retina. This was the state corresponding to the present colour-blind or dichromic vision.

That, thirdly and lastly, a still further improvement set in, extending to a smaller circle, and giving the present normal vision. And all these states, be it observed, still remain in the human eye.

Now if we call in the well-known phenomenon of *atavism*, an exceptional return in certain individuals to a former inferior state of development, the whole explanation lies open before us. In some few cases the inner circle of the three-colour sensation is absent, and the dichromic ring extends, as in former ages, to the centre. These are the cases of dichromic vision. In some cases, rarer still, the structure reverts to the still earlier type, where both the trichromic and dichromic

states are absent, and these are the very rare people with vision of light and shade only.

Donders even thinks that he can trace, within the ocular area, a vestige of a difference of the kind existing between red and green blindness, the former having a shortened spectrum, and the latter being a stage nearer perfect vision, which, if it were established, would be an additional element in the analogy. The idea of a complete system of evolution for colours might then be sketched out somewhat as follows :—

1. Achromic vision (light and shade only).
2. Dichromic imperfect vision (called “Red-blindness” : short spectrum, low sensitiveness to the long-waved rays).
3. Dichromic perfect vision (called “Green-blindness” : longer spectrum, full sensitiveness to the long-waved rays).
4. Trichromic imperfect vision (as pointed out by Lord Rayleigh), with low sensitiveness to certain colours.
5. Trichromic perfect vision.

These classes would be subject to intermediate gradations, as in other evolutionary development.

Looked upon in this way, colour-blindness would be only an imperfect development of normal vision, not springing out of it, as the Young-Helmholtz explanation would suggest, but antecedent to it. It would be a system whose two energies resulted independently from the decomposition of white light, and, therefore, would be complementary to each other.

Donders also cites, as favouring this view, the peculiar mode of hereditary transmission of the defect, according to the unanimous testimony of experts. A patient transmits it, not to his sons, but to his grandsons through a daughter, who is free from it herself : thus causing it to skip over one generation.

Athenæum Club, S.W.
October, 1892.

LII. *On Graphic Solution of Dynamical Problems.*
By LORD KELVIN*.

THE method of drawing meridional curves of capillary surfaces of revolution, described in ‘Popular Lectures and Addresses,’ vol. i., 2nd edition, pp. 31–42, and illustrated by woodcuts made from large scale curves, worked out according to it with great care and success by Professor Perry when a student in the Natural Philosophy Class of Glasgow

* Communicated by the Author.