REMARKS

ON

COLOURS AND COLOUR-BLINDNESS:

Being an Introduction to a Discussion in the Section of Ophthalmology at the Annual Meeting of the British Medical Association in Cambridge, August 1880.

By F. C. DONDERS, M.D., LL.D., F.R.S.,
Professor of Physiology in the University of Utrecht.

You know, Mr. President, that it is in accordance with your own kindly expressed wish, that I have the honour of being here on this occasion, and in this place. What I am going to say about the sensation of colours and colour-blindness has no pretension to be an address. It will be merely an introduction to the subject. I think an historical sketch will give the clearest understanding of the different questions to be touched on.

I. THEORY OF COLOUR-PERCEPTION.—Besides white, Wt., and black, Bk., we distinguish a great variety of Colours. These admit of being all arranged side by side, raywise, in a closed circle, but only in one certain order, not in any other. Starting from green, G, we come on the one hand through yellow, Y, to red, R; on the other hand through blue, Bl., to violet, V; and R and V meet in crimson, Cr. Proceeding quite empirically, selecting all the tints or hues which it was possible for a perfect sight to distinguish one from another by the slightest well appreciable gradations, I arrived at the number of one hundred; and it is remarkable that when these hundred are arranged with equal areas radially in their due order in a circle, those standing diametrically opposite to each other are, within narrow limits, the complementary ones. Chevreul, starting from three colours, R, Y, and Bl, as equidistant in the circle, was obliged to make very unequal stages from tint to tint, and did not obtain the complementaries opposite to each other.

Each tint or hue (nuance) has its various shades of saturation, and every shade its various degrees of luminosity (or tones).

This three-dimensional system of colour-sensations is quite adequate to the needs of common life, of art and industry. But the task of physiology extends further. It has to show the relations between light and sensation, and to examine the action in the retina, the conduction in the nerve, and the corresponding processes in the brain.

The first and the greatest step was Newton's discovery of the relation between refrangibility and colour, which he "found very precise and strict". Newton also examined the mixture of different rays. The mixture of all the rays forming Wt, he found "most surprising and wonderful". If not too far from each other, two colours form the intermediate. Whether Wt can be produced by only two sorts of light he never decided: "it was to be tried again". Even more than a century afterwards this was not yet done.

As to the action of the light on the retina, Newton considers that the rays "impinging upon the ends of the optic nerve" excite "vibrations", which will run through the optic nerve to the sensorium. Here they are supposed to affect the sense with various colours "according to their bigness and nature".

In reference to this hypothesis, Thomas Young remarks "that the frequency of these vibrations must be dependent on the constitution of the substance of the retina." And as it is almost impossible that every sensitive point should have an infinite number of different particles, it becomes necessary to suppose the number limited, for instance, to the three principal colours, R, Y, and Bl, and put in motion more or less forcibly by undulations differing, more or less, from a perfect unison. Each sensitive filament of the nerve may consist of three portions, one for each principal colour. Afterwards Young came to R, G, and V.

Clerk Maxwell and Helmholtz adopted the theory of Young. As to the fundamental colours, the former came to R, G, and Bl; the latter, after the experiments of J. J. Müller, who found that the (saturated) violet of the spectrum cannot be produced by blue and red, returned to the colours of Young.—To each fundamental colour seems to correspond not only a specific molecular action, but also a morphological element, of the retina. Helmholtz found the colours of the spectrum to be not saturated: he therefore concludes that all the luminous rays act on the three elements in the retina.

In this form, the theory presents some difficulty. The action of the light on the retina is to be considered as photo-chemical. Beyond the red, no action at all manifests itself. The theory requires three different actions on three different elements. Now it seems to be unintelligible, either from a chemical or from a genetical point of view, that two, or even three, actions, should begin just at the same wave-length. Each action must be supposed to be a special function of the wave-length, as it has its own maximum. According to this statement, R and V must be two fundamental colours, corresponding to the beginning and the end of the spectrum. With R and V, G alone suffices as the third fundamental colour; Y does not. Now G of the spectrum cannot be saturated, because the same rays excite necessarily red and violet. But the want of saturation of the extreme red and violet (omitting fluorescence) must have another cause.

We find this in the sensorium. Where the extreme red fails (in red-blindness) in the spectrum, there white fails. By this fact, white is excluded as a special energy (*contra* Hering). It ought to be considered as a simultaneous production with every other colour in the sensorium. And it may be produced there, where white is produced by combination of several impulses, i.e., in the cells of the cortical substance corresponding to the retina (Ferrier, Munck). The complete molecular action in these cells may correspond to white; some incomplete, or partial, action to different colours. One action in the retina is supposed to excite a partial, and, in some degree, a complete action in these cells, producing a specific, but not saturated colour. Different actions are here combined: those of red and green to that of yellow; those of green and violet to that of blue (both less saturated than the fundamental); those of red, green, and violet, or of blue and yellow, to white (saturation = 0).

The resulting molecular action is not simply a compound of two or more, nor is the corresponding colour: the resulting process and colour both can be characteristic, as we find in white, yellow, and blue. In Cr we see R and V: simply a compound, both existing together. In Wt we do not see R, G and V; nor, in Y, R and G; nor, in Bl, G and V; the combination is not simply a compound; it is an action *sui generis*, produced by simultaneous action of the two or three, but different from these, specific.

In other combinations we do really distinguish the component colours in their resultant, e.g., in the combination of white with every colour, in that of yellow with each of its component energies, R and G, in that of blue with each of its component energies, G and V. Here also the two actions may co-exist, the one beside the other.

These combinations explain the gradual transitions in the spectrum and in the circle of colours.

The difference in the notion of simple colour and of fundamental colour (energy) also clearly appears.

In the same cells of the centrum (cortical substance) we suppose the seat to exist of the simultaneous contrast and the induction of light, partially too of the successive contrast and the secondary images.

The action of peripheric cells can only manifest itself by an uniform effect on nerve-fibres; the central cells may, in diversity of action, directly represent every diversity of sensation.

II. COLOUR-BLINDNESS.—Dalton's case (1794) excited great interest. "I see", he says, "in the spectrum only two (or at most three) distinctions. These I should call yellow and blue (or yellow, blue, and purple). My yellow comprehends the red, orange, yellow, and green of others; and my blue coincides with theirs. That part of the image which others call red, appears to me little more than a shade, or defect of light: after that the orange, yellow, and green seem one colour, which descends pretty uniformly from an intense to a rare yellow, making what I should call different shades of yellow." Green and blue "are strongly contrasted"; "the purple appears to be blue much darkened and condensed." Dalton's defect was what is now called red-blindness. He drew no distinction between the cases he saw.

Seebeck distinguished two classes of colour-blindness; his second class is characterised by defect of light in the red, as in Dalton's case; his first class has no defect of light in the red. This class has been supposed to be, and has been called, green-blindness, according to the theory of Young.

Sir John Herschel supposed, and Clerk Maxwell proved, that the colour-blind see only two colours: they have a dichromatic system (Herschel, 1832). In the spectrum, they see only two colours: that on the red side we call the warm, W; that on the blue side we call the cold, C. They see a grey stripe, N, between them, there, where

$$\frac{dW}{W} = \frac{dC}{C}$$

Green, yellow, orange, and red belong to W; blue and violet to C. W and C they distinguish easily. But the different colours belonging to W, or to C, are confused by the colour-blind: such differences as

they do distinguish between these are differences of saturation and of intensity.

Trying to apply our words to their sensations, their W they call *red*, if much saturated (and brilliant); *yellow*, if intense and moderately saturated; *green*, if pale. And they often decide rightly. But red may be pale, yellow dark, green much saturated; and then confusion is inevitable. With the different colours belonging to C they have no success at all; they call them all *bluish*, or *blue*.

The stripe N produces a second series of confusions. It is found, as we saw, in the bluish green. Now, pink is another neutral colour, producing the same equilibrium of W and C; so that it also is seen grey. Bluish green, pink, and grey are therefore the same, all grey. But the least predominance of W or C is recognised.

All this holds good as well for red-blindness as for green-blindness. It is inherent in the dichromic system. But there are differences. C seems the same for both; but W is not. In the green-blind, W, in its curve of intensity, scarcely differs from our red; but in the red-blind it approaches green, and in some cases reaches it. Here the spectrum is darker and shortened at the red end; the maximum of intensity is much farther off, and N is nearer to the blue.

Hence many differences as to the confusion of colours. The red-blind person sees as black the dark-red brown of the green-blind. The same red and orange correspond to a dark yellow or green in the former, to a light in the latter, etc. Moreover, most remarkable differences occur in regard to the stripe N: that of the green-blind is W for the red-blind; that of the red-blind is C for the green-blind; and also there is a pink, which is blue for the former, red for the latter.

All the colours of our circle, as the red-blind or the green-blind see them, can be made up by yellow and blue with black and white. The differences are seen at once if represented, as in the diagram before you, on two circles inside the circle of our colours. In both the same tones recur twice, and twice the neutral stripe N—once between W and C in the greenish-blue, and once between W and C in the pink. But to the red corresponds a much darker yellow in the red-blind, to the bluish-green a darker blue in the green-blind. W and C must be considered as complementary colours. To which of our sensations they correspond cannot well be told: probably C is blue or violet, W is yellow, approaching to red in green-blindness, to green in red-blindness.

As to the *methods of investigating or testing*, many may be recommended, all rather satisfactory. The general principle in all is *comparison*:

- a. Of *Similar* (Seebeck, Holmgren);
- b. Of *Identical* pseudo-isochromatic colours (Maxwell, Rosen, Stilling, Cohn, Donders).

Holmgren's ingenious method is well known and much employed. Maxwell gave equations on the disc and with spectrum light; Rosen's colorimeter gives equations of the two neutral colours; Stilling used pseudo-isochromatic letters, Donders pseudo-isochromatic woollen stripes. The double spectroscope enables us to compare colour, saturation, and intensity for each length of waves. This is what we want for scientific purposes.

Differences between green-blindness and red-blindness are also detected by some of these methods; by those of Holmgren, Maxwell (chiefly used for scientific purposes), Rosen, Stilling (last plates 1880), by the stripes of Donders, and, with great accuracy, by the double spectroscope.

For practical use should be recommended:

1. The sorting out from a series of *blue* and *violet* woollens of different degrees of saturation. It shows the slightest degrees both of red-blindness and of green-blindness.
2. The *woollen stripes*. These enable us to distinguish between the typical cases of red-blindness and green-blindness.
3. The *double spectroscope*.

The various methods of investigation confirm the view that the two categories of colour-blindness should be distinguished, now generally called red-blindness and green-blindness. Though transitions are met with, the large majority of cases may be referred either to the first or the second class, thus showing that there are two classes; for, if all the cases represented, or belonged to, a single class, the majority would hold the middle place.

Another question is this: Are the two energies, in red-blindness and green-blindness respectively, the green and violet, and the red and violet, of the normal eye? As to the sensations, no answer can be given. As to the intensities and saturations, as functions of the wave-length, for W and C, we find C, in both, to be rather equal to the violet of the normal eye, and W, in the green-blind, to be rather equal to the red of the normal eye. But, in the red-blind, we find W very different. In the ordinary cases, certainly W does not descend so far as green; but, in rare cases, it may even go beyond.

We could not expect that the two energies of the dichromic system would exactly correspond to two of the energies of the normal trichromic. This result does not conflict with the theory of Thomas Young.

Violet-blindness.—Besides red-blindness and green-blindness, a few cases of violet-blindness have been observed. I examined one with great care. The spectrum is much shortened at the violet, somewhat at the red, end. The maximum of intensity is in the yellowish-green (about 560 millionths mm wave-length). A greyish band, very broad (one-third of the spectrum) in feeble light, separates the two colours in the spectrum. The middle of that band is about the yellow. W, which the violet-blind person calls red, is not intense, but rather saturated; C, which he calls blue, is more intense, but little saturated.

Now yellow objects appear colourless, pale green and pale blue also colourless; the blue of the sky is grey. Saturated blue and green look alike, but the blue looks darker. Blue and violet woollens of very different degrees of saturation are correctly sorted apart, though very slowly.

The sensibility for light, which does not differ from the normal in green-blindness and in red-blindness, is much diminished in violet-blindness; and the sensibility for colour still more so. The acuity of vision is normal. No pathological changes are visible in the eye-ground.

Complete Colour-blindness.—There are also rare instances in which the perception is reduced to white, black, and the intermediate shades of grey. The cases I have seen are still more pathological than those of violet-blindness.

Imperfect Forms of Colour-blindness.—In some cases, there is only a difficulty in distinguishing very pale colours, and in sorting out blue and violet. This may depend on unproportionate development or saturation of the three energies.

The general formula for colour-perception is this: The number of energies is from one to three; and each energy is, as to its intensity and its saturation, a rather variable function of the wave-length. It is very desirable that these functions should be determined accurately in a large number of cases of *imperfect* colour-blindness, in order to characterise some types of this, as has been done for *perfect* colour-blindness.

On the present occasion, I must confine myself to the mode of measuring the faculty of distinguishing colours in cases of imperfect colour-blindness for a practical purpose (railway service). The principle of the method has been to measure the angle of vision under which colours, chiefly red, green, and grey or white, could be distinguished *quickly* and *with certainty*. I used a light, behind a disc furnished with openings of different sizes, able to show each colour under different angles of vision, and in different degrees of luminosity. The disc contains several glasses, some colourless, others coloured, to resemble those used as signal-lights on railways. It had been previously determined at what distances of the light behind the disc the normal eye was able to distinguish each of the colours when applied to an opening of one millimetre, at a distance of five metres. Now, in cases of *imperfect* faculty, I determined the distance and the size of the opening required to distinguish the same. In this way, the relative faculty of distinguishing was found for every colour.

The light could be made to approach or recede from the disc, in order to vary the degree of luminosity, by which the colour-blind are in the habit of forming their judgments about colours.

The same principle was applied by using reflected daylight; but, as this varies much in intensity, comparative determination with a normal eye is always required. The method is also of use in detecting colour-blind central scotoma, in some forms of amblyopia.

III. THEORY OF HERING.—In different quarters, and for a long time, objections have been alleged against the theory of Young. It was said not to account for some facts of normal vision, and to explain only in a forced way some facts relating to colour-blindness.

A few years ago, Ewald Hering altogether rejected Young's theory, in which he found little to praise, and he substituted a new one of his own in its stead. Consulting his sensations, Hering found, besides white, Wt, and black, Bk, four simple colours: R, G, Y, and Bl. These he combined into three pairs: Wt and Bk, R and G, Y and Bl. These three pairs are his six *variables*, determining every sensation of light and colour.

Wt and Bk he considers as corresponding respectively to *dissimilation*, D, and *assimilation*, A. R and G, Y and Bl, are supposed to be in the same relation to D and A. Which of each pair corresponds to D, and which to A, he does not decide.

Now the two colours of the same pair are said to annihilate each other; they are not regarded as complementary colours, combining into white, but as antagonistic colours (*Gegenfarben*).

In connection with his psycho-physical law, Hering develops his theory in a mathematical form, which may be omitted here.

The theory of Hering has not the same wide bearing as that of Young and Helmholtz. It relates exclusively to the central processes. These are supposed to correspond to the sensations, to which we readily agree. No attempt is made to find out what is going on in the retina, under the influence of light; no attempt to follow the retinal processes up to the brain; even no attempt to point out the relation between light and sensation. The whole theory is based upon the sensations, and on the supposed corresponding processes (of D and A) in what is called, in the most general sense, *optic substance* (*Seh-substanz*).

I consider, therefore, that the theory is incomplete. Still, having been set forth in lucid terms, and logically developed; being also simple in its conception, and easy of comprehension, it has been received with assent by some physiologists, but chiefly by ophthalmologists.

At first sight, it appears to account in a nice and simple way for every form of colour-blindness. Where R and G could not be distinguished, they might be regarded as absent. It was simply *red-green blindness*, as they call it, neglecting every difference between red-blindness and green-blindness. Yellow and blue would be the only remaining sensations.

But we have seen that this is quite a mistake. A slight notice of the degrees of saturation and intensity of the colours in the different parts of the spectrum would have prevented it. R and G are confounded, not because they are absent, but because they belong to the same colour, W, of the dichromic system, being at the same side of the neutral stripe N; and Y, belonging quite as much to W, is not any better distinguished from red or green, provided they acquire the same saturation and intensity (e.g., on the revolving disc, by adding the required black or white). There cannot be a question of Y remaining, and of R and G being absent. For all of them, it is the same sensation, most likely approaching more to the red in green-blindness, more to the yellowish-green in red-blindness. To suppose that green and red are simply absent where they are confounded, is quite the same as to declare blue and violet absent because they cannot be distinguished the one from the other.

Objections have been advanced against Hering's theory, either directly or indirectly, by Bruecke, Von Kries, Küster, Kitto, Fick. In my own opinion, also, Hering has not succeeded either in his contention against Young and Helmholtz, or in making good his own theory.

My chief objections are these.

1. Wt and Bk may (generally speaking) be opposed to each other, as D and A; but there is no reason for opposing in the same way R and G, Y and Bl. Even Hering does not try to determine which of each pair should correspond to D, which to A. In fact, they all four are active in their specific line; all are in the same relation to D and A. Each of them is opposed to A, corresponding to Bk, the negative of Wt, and of every colour.

2. The simple colours are not *complementary*, as Hering's theory asserts. The complementary of R is not G, but bluish-green; that of Y is not Bl, but violet-blue. How, then, can they be considered antagonistic, as in Hering's theory they are?

3. The complementary colours (and the two colours of Hering's pairs) do not annihilate each other, but combine into white. This is proved by mixture. E.g., in the double spectroscopic violet (a saturated colour) and intense yellow, covering each other halfway, produce a white manifestly more intense than the yellow. Another yellow, equal in luminosity to the violet used, joined to the same intense yellow, does not produce a yellow intenser than the white resulting in the first experiment. Now, according to Hering's theory, the luminosity should be the sum in the last, the difference in the first; but manifestly it is the same in both.

Two complementary spectrum-colours, s and s' , pass through two slits illuminating the fundus of a dark chamber; I found, if $s = s'$, also $\frac{s+s'}{2} = s = s'$. I tried, also, to compare the acuity of vision at $\frac{s+s'}{2}$ and s or s' . The experiment presented a difficulty: in violet, blue, and even in green light, the retina, after being allowed to become sensitive by repose in darkness, presents a great central scotoma, occupying the yellow spot, and making it impossible to distinguish any letter at a luminosity under which, in red light, reading is extremely easy. Here we were reduced to experiments with indirect vision. Of this, the acuity was found equally good at $\frac{s+s'}{2}$ as at s or s' .

The scotoma mentioned I do not venture to explain. One of my assistants, Dr. Waelehl, is pursuing these interesting phenomena with the greatest care and industry.

4. White is not a direct, independent sensation: it is absent in the spectrum, where, in red-blindness or violet-blindness, the specific colour is absent.

5. The theory of Hering is quite insufficient to account for the different forms of colour-blindness.

AN ADDRESS ON THE STUDY OF PHYSIOLOGY IN RELATION TO MEDICINE.

*Delivered at the opening of the New Physiological Institute,
Trinity College, Dublin, November 1st, 1880.*

By J. M. PURSER, M.D.,
King's Professor of the Institutes of Medicine.

ALTHOUGH the delivery, at the commencement of the session, of a formal introductory lecture has been wisely discontinued at this, as at most of the other Dublin schools, yet, on an occasion like the present, I feel it would be ungracious to you, and ungrateful towards my colleagues and the heads of the college, were I at once to plunge into the subject of our course without first bidding you welcome to this new building, and trying to present to you, as it were, a programme of the studies to be here followed, and without expressing publicly my sense of the wise and far-sighted liberality of the Board, who have, even at a time when money is not plentiful, supplied the necessary funds for the erection, furnishing, and maintaining of this institute. In this matter, I feel I may express your gratitude as well as my own; for, although my facilities for teaching are much advanced by the convenience which this place will afford, it is for your sake that the work has been done, and it is you who will benefit by the advantages which the ample space and appliances of this place offer. In this, as in most of the improvements in this school, the chief credit lies with Dr. Haughton, who, with the committee of which he is chairman, has in the kindest manner fallen in with all my suggestions, and in every way facilitated the carrying out of my wishes.

[Professor Purser, having contrasted the difficulties under which former courses of his lectures were conducted, in consequence of the ill-suited accommodation available, with the facilities which would now be at his disposal, to the great advantage of both student and professor, continued as follows.]

And now, gentlemen, I should like to endeavour to point out to you the position which the studies you have to pursue in this place occupy in regard to the whole course of your medical studies. It is too much the opinion among students, that each subject which they take up is distinct in itself, and has no relation to the other subjects in the course; that the chief object of anatomy is to pass the half, and that, once this is done, anatomy has served its purpose, and may be dismissed from the mind, in order to make way for those subjects whose utility will appear at the M.B. And I think we professors do not take sufficient pains to point out to you the connection which the different subjects we teach have with one another. I know that I am not singular in feeling that we take too little cognisance each of what the other is teaching; and that we endeavour too little to make our lectures and courses of practical instruction complementary one of the other, and continually to point out the unity of the whole medical curriculum. The ground which has to be traversed by a medical student in four years is enormous; and it is only by seeing clearly from the outset the whole lie of the country, and the course of the roads, that he will be able to make a straight and successful journey, avoiding false turns which may lead him altogether astray, or compel him to traverse the same part of the road twice over, and thus involve loss of time and energy.

The main point, I think, for students and teachers to bear in mind, is this: that you came here to learn medicine and surgery, not to be made anatomists, chemists, or physiologists; and that, if it were possible to teach you medicine and surgery as these should be taught, without teaching you anatomy, chemistry, and physiology, it would be dishonest on the part of the College to compel you to study these sciences, which are sometimes called accessory, but which I would call fundamental with regard to medicine. But this University does not believe this possible, and the smallest consideration will show the justice of this opinion.