REMARKS

ON THE

EXAMINATION AND CLASSIFICATION

OF

CASES OF COLOUR-BLINDNESS.

BY

GEORGE A. BERRY, M.B.

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EXAMINATION AND CLASSIFICATION OF CASES OF COLOUR-BLINDNESS.

Since the publication of Holmgren's excellent work on colour-blindness,[1] a great deal of attention has been paid, not only in Sweden, but also in most European countries and America, to this curious physiological anomaly. The comparative frequency of defects of colour-vision has directed attention to the possible dangers which might result from the employment in our railways and mercantile fleet of individuals unable to distinguish with normal certainty between the colours universally used as signals, viz., red and green.

Although we cannot but think that accidents directly traceable to mistakes arising from colour-blindness must be of extremely rare occurrence, and that the possible dangers have been considerably exaggerated, still we have little doubt that our Government will sooner or later follow the example of others, and demand a systematic examination of the colour-vision of all persons entering such services. This examination will no doubt, to some extent at least, have to be conducted by medical men, and it is on this account that we feel justified in publishing our views as to the nature of colour-blindness in a journal devoted more especially to papers on practical medicine and surgery, rather than in one of the physiological journals, for which they might otherwise be more suitable.

After having recognised the possible dangers above referred to in connexion with colour-blindness, it naturally became of the utmost importance to discover a means whereby any trace of this anomaly could be speedily detected. Holmgren has undoubtedly the merit of being the first to devise and employ a method which has shown itself to be thoroughly practical and expeditious. For the benefit of those of our readers who may not yet be acquainted with this method, it may be as well, in as few words as possible, to describe it. It is a well-known fact that a high degree of achro-

[1] *Om Färgblindheten i dess förhaallande till Jernvägstrafiken och Sjöväsendet.* Upsala, 1877.

matopsia may co-exist with a tolerably perfect power of naming colours, from which it is evident that any system based on the statements made by individuals as to the names of colours presented to them must be rejected as impracticable. Holmgren has therefore adopted the method of *comparison* between colours which to the normal eye are different, a method which, in a less perfect manner, inasmuch as the time required for examination is much longer, was used by Maxwell[1] and Seebeck.[2] Holmgren's method is, in fact, a modification of Seebeck's: the individual examined is asked to pick out from amongst a large number of differently coloured wools those which appear most like one particular shade placed before him. The reasons for choosing wool instead of coloured glass, paper pigments, etc., are, that all colours and shades of wool are easily obtained in any shop;[3] that it can be used without any preparation as obtained; that, having the same colour on all sides, it is easily recognised amongst a lot of other coloured objects; that as its surface is rough, no difficulty is caused by reflexion; and finally, that it is easily packed and carried about.

From the way in which this test is executed by different individuals it can at once be seen whether they are colour-blind or not: those with normal vision, provided they are possessed of a certain amount of intelligence, are not long in selecting the few shades which most nearly resemble the pattern given them to match; and a colour-blind individual soon commits a sufficient number of mistakes to amply reveal his defect. In order, however, at once to obtain some idea as to the nature of his colour-blindness, it is advisable to choose certain colours as patterns. Holmgren begins with light green, and, when mistakes are made with this, proceeds with some shade of rose or purple, which, owing to its position in the scale of colour perceptions,—viz., between red and blue,—is very well suited for this purpose, as it can at once be seen from the colours with which it is confounded, or, in other words, with which it is pseudo-isochromatic, in which direction the defect lies. Several subsequent investigators, more particularly Cohn[4] (who has lately examined a great number of cases of colour-blindness from the various schools in Breslau, and whose work on this subject is one of the most valuable of the more recent publications, inasmuch as he has, with the utmost impartiality, employed most of the methods of examination, and fully recorded the result in each case), have rejected as superfluous the preliminary examination with light green, and begun at once with rose. This, we think, is a mistake, as although rose probably suffices as a test for all forms of colour-blindness when com-

[1] *Trans. Roy. Soc. Edin.*, 1855.

[2] "Mangel an Farbensinn," *Pogg. Ann.*, 1837.

[3] We procured ours, exactly as used by Holmgren, from Betty Oldberg, Upsala, for 5 kr. (5s. 8d.)

[4] *Studien ueber angeboren Farbenblindheit.* Breslau, 1879.

plete, yet slight anomalies of colour-vision are most easily detected by using light green. Holmgren gives, as the result of examination by his method, the following classification of all cases of defects of colour-vision:—

I. *Total Colour-blindness.*—In these cases colour hues are not distinguished from each other as such, but only according to their relative brightness (very much in the same way as the normal eye would distinguish coloured objects illumined by a sodium flame alone).

II. *Partial Colour-blindness.*—This may be (*a*) complete or (*b*) incomplete.

Complete partial colour-blindness he divides into (α) red-blindness, (β) green-blindness, and (γ) violet-blindness. Although most writers are agreed as to the great superiority of the above described method for the rapid determination of colour-blindness, there is a most extraordinary, and at first sight apparently inexplicable, want of unanimity with regard to the classification of cases of complete partial colour-blindness; some, amongst whom are Hering,[1] Cohn,[2] Stilling,[3] etc., contending that there is no difference between red and green blindness, and between blue and yellow blindness, whilst others—Donders,[4] Raehlmann,[5] Magnus,[6] etc.,—follow Holmgren's classification, which is based on the Young-Helmholtz theory of colour perception. Those, again, who adopt the first classification see in the phenomena of colour-blindness a strong support for Hering's theory. We shall endeavour to explain how it is that the same phenomena appear to support both theories; but first let us consider the theories themselves. The theory of Thomas Young,[7] which, revived and extended by Helmholtz, is now generally known as the Young-Helmholtz theory, was until recently, and since the publication of Helmholtz's great work on physiological optics,[8] the one generally adopted to explain the nature of our colour perception. It supposes that there exist in the eye three different kinds of nerve-fibres, which, when thrown independently into a state of functional activity, give rise respectively to the sensations red, green, and violet, which have received the name of the three fundamental colour sensations, so that light of different wave lengths, although acting as an excitant to all three, produces unlike effects on each, according to the

[1] *Sitzungsbericht der Wien-Akad.*, vol. lxix.

[2] *Loc. cit.*

[3] "Beiträge zur Lehre v. den Farbenempfindungen" (*Zehender*, 1875-76, extra vol.)

[4] "Des systèmes dichromatiques" (*Annales d'oculistique*, 1879, p. 7).

[5] "Beiträge z. Lehre v. Daltonismus u. seiner Bedeutung f. die Young'sche Farbentheorie" (*Graefe's Archiv*, vol. xix.)

[6] "Beiträge z. Kenntniss der Physiologischen Farbenblindheit" (*Graefe's Archiv*, vol. xxiv.)

[7] *Lectures on Natural Philosophy.* London, 1807.

[8] *Handbuch der Physiologischen Optik.* Leipzig, 1867.

length of the undulations. Thus the red-perceiving elements are most strongly excited by the longest light waves, and the violet by the shortest, whilst undulations of medium length produce the greatest effect on the green elements. The sensation of *red* is therefore, according to this theory, produced by a strong excitation of the red-perceiving elements, together with a weak excitation of the green and violet. *Yellow*, again, must be imagined as produced by a moderate excitation of the red and green, and a weak excitation of the violet elements; *green*, by a strong excitation of the green, and a weak excitation of the two others; and *blue*, by a moderately powerful excitation of the green and violet elements, and a weak excitation of the red. This is represented diagrammatically in the accompanying figure taken from Helmholtz, where the colours of the spectrum are supposed arranged in order horizontally, whilst the three superimposed curves are taken to represent, more or less exactly, the irritability of the three kinds of fibres for each part of the spectrum.

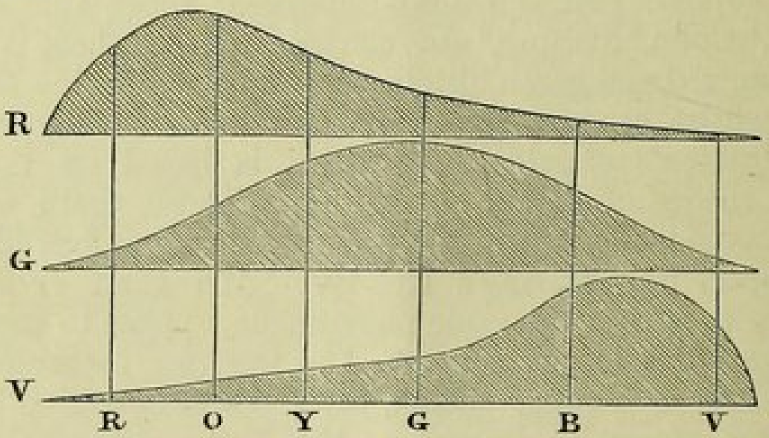

Fig. 1. (After Helmholtz.)

As we shall elsewhere consider in detail the arguments for and against the Young-Helmholtz theory, we have at present merely to state that, although its supporters imagine that they see in colour-blindness the strongest arguments in its favour, we doubt whether it or any other theory based on the assumption of a limited number of principal or fundamental colour perceptions is borne out by the phenomena which that condition presents.

We are now in a position to understand Holmgren's classification. Red-blindness is, according to the theory of Young and Helmholtz, the result of an absence or paralysis of the red-perceiving elements: a red-blind individual's colour perceptions must, therefore, be made up of a combination of two instead of three fundamental sensations—green and violet. In green-blindness, again, a different fundamental colour perception is wanting, and the remaining colours arise from combinations of red and violet alone; finally, violet-blindness will be due to a loss of the fundamental colour sensation which remained in the two preceding cases, and all colours will be made up of a simultaneous perception of red and green in different proportions.

Let us see if we can now imagine in what colours the spectrum must appear to any one supposed to have but two of the three fundamental sensations of colour. We shall then be able to see how this supposition can explain the actual mistakes in colour comparison made by the colour-blind. Let us take *green-blindness;* here absence of the green-perceiving elements will give rise, according to Holmgren, to the following:—"Spectral red, which excites strongly the red-perceiving organs, but scarcely at all the violet, must appear as a red somewhat weaker but much more saturated than normal red, which is relatively more yellowish owing to mixture with green. Yellow is certainly a stronger but at the same time a more whitish red than spectral red, as a considerable amount of the other primary colour perception is excited. Green, with its hues in the direction of yellow and blue, should be a saturated and tolerably strong purple, but is, at the same time, the green-blind individual's white (gray), as the two primary colours enter in tolerably equal proportions. Blue is a strong but somewhat less saturated blue than indigo, which is also stronger; and violet a somewhat weaker but more saturated violet than the normal.

"In this case, then, the same elements are excited by both red and green spectral light. Red and green produce, therefore, the same sensation for a green-blind individual. In those cases in which he can distinguish between them, he does so owing to the difference in their brightness (shade). In this case, though, as far as brightness goes, the conditions are exactly the opposite from those seen in red-blindness, a green *nuance* which is to appear to the green-blind exactly like a red, must be such as to the normal eye appear decidedly lighter than the red."

Following the same theory, red and green must also appear of the same colour to the red-blind; green objects, however, which give rise to the same impressions as red, must be such as to the normal eye appear darker and weaker.

The whole difference between the conditions which are thus distinguished as red and green blindness is that in the first case red appears isochromatic with dark green, in the second with light green.

Such a difference is actually found to exist in testing by Holmgren's method. Thus one set of colour-blind individuals will place along with a bright red wool darkish shades of green and brown, and along with the purple or rose-colour test which Holmgren recommends, some shade of blue; whilst others compare the red pattern with lighter shades of green and with yellowish-brown, and the rose-coloured one with green or gray. There is, therefore, an undoubted difference between these two cases, although, as will afterwards be seen, we shall have occasion to question the correctness of the distinction into red and green blindness.

Holmgren has lately devised[1] what seems to be a very good

[1] "Om de färgade Skuggorna och färgblindheten" (*Upsala Läkareförenings Forhandl.*, vol. xiii. p. 456).

way of distinguishing between his cases of red and green blindness. It is based on the principle of *simultaneous contrast.* When a colourless surface is simultaneously illuminated by a coloured and a white light, the two shadows thrown by an object lying between the sources of light and the surface appear, the one in the colour of the coloured light, the other in its complementary colour. Now, suppose a red and a white light be used for casting the two shadows from the same object, that cast by the white light will be illumined by the red light alone, and will appear red, and that cast by the red and illumined by the white alone will appear green. Red or green blind individuals, not receiving the normal impression from the one coloured shadow, do not see the other shadow in its true complement, and distinguish the shadows more from their relative darkness than from their difference in hue. For the purpose of being able to vary the strength of these shadows to a measurable extent, Holmgren has constructed his *chromatoskiameter,* which he thus shortly describes in an abstract of his own paper:[1]—"It consists of a stand specially adapted, bearing in the centre an ordinary petroleum lamp; two wooden arms, about a metre in length, proceed from its centre, movable in a horizontal plane round it: these support the other parts of the apparatus. On the one arm the coloured glass, the shadow-throwing body, and the screen are given a fixed position at a definite distance from the lamp, whilst a mirror reflecting the light of the lamp on the screen is movable back and forward on the other arm, on which the position given to it in any experiment can be read off in a millimetre scale."

Two differently coloured glasses were used for these investigations—a *red,* which only transmitted red spectral light, and a *green,* which, besides transmitting all the green light of the spectrum, also permitted of the passage to a small extent of other rays, but entirely excluded red.

The chromatoskiameter has first to be graduated for normal colour-vision—that is to say, the distance found for each glass at which both shadows appear of equal strength, each in its own colour. Holmgren found for himself:—

For the red glass,	= 40 cm.
„ green „	= 35 cm.
Difference (R.-Gr.), =	5 cm.

He says that it is, as a rule, much easier for the colour-blind to find such a position for the mirror, for this reason, that they generally find the shadows identical in colour when the mirror has attained the position at which they appear of equal strength. This placing of the mirror in the required position is so characteristic that it reveals the nature of the colour-vision. It varies much in

[1] *Nordiskt Medicinskt Arkiv,* vol. xi. No. 6.

different cases, but all the cases examined "could, from the method of executing this test, be arranged in two well-defined groups, which correspond to two kinds of complete colour-blindness, red and green blindness."

The distance of the mirror averaged, for 25 cases of red-blindness :—

For the red glass,	= 73·2 cm.
„ green „	= 27·6 cm.
Difference (R.-Gr.),	= 45·6 cm.

And for 35 cases of green-blindness :—

For the red glass,	= 28·7 cm.
„ green „	= 48·5 cm.
Difference (Gr.-R.),	= 19·8 cm.

This method, although a capital one for the control of cases examined by the coloured wools, is admitted by Holmgren himself to be much inferior to the wool method for the primary detection of anomalies of colour-vision.

Let us now turn our attention to the other classification of colour-blindness into red-green-blindness and blue-yellow-blindness. A considerable number, and, as it appears to us, a constantly increasing number of ophthalmologists are inclined to adopt Hering's theory, and classify as above. According to Hering, "all our colour sensations must be ascribed to four fundamental or primary sensations—red, green, blue, and yellow," and "the sensations red and green on the one hand, and blue and yellow on the other, are antagonistic and neutralizing." There is no such thing as reddish-green, greenish-red, bluish-yellow, or yellowish-blue. Further, he assumes the existence of two more fundamental sensations of a different order—black and white ; the latter being the consciousness of material changes in the central visual apparatus produced by objective light, the former the consciousness of nature's reparation. The one he calls dissimilation (D), the other assimilation (A). When D = A we have the sensation of a medium gray. This black-white series of sensations is at the same time called into action by all light rays. We are consequently unable to perceive any colour absolutely pure.

The two colour-pairs, red-green and blue-yellow, are supposed to stand in the same relation of dissimilation and assimilation to each other. Thus, if by the dissimilation of some substance we perceive red, assimilation of the same substance gives rise to the sensation of green. In this way is explained the appearance of after-images in the complementary colour. But if red be produced objectively by dissimilation, it appears to us very unreasonable to suppose, as this theory would have us do, that the objective sensation of green arises from assimilation—assimilation produced directly by rays of light! It would coincide better with our views on physiology in general were we to assume that dissimilation in the green-perceiving elements produced the same effect on our sensorium as assimilation in the red, and *vice versâ*. Objective sensations, whether white or coloured, would then all arise from dissimilation, whilst all subjective colour sensations would owe their origin to assimilation.[1]

We are now in a position to understand why those who embrace this theory do not believe in the separate existence of red and green blindness. Green and red objects are mistaken *inter se* because they are both uncoloured, as, when we are unable to see red as such, we must also be blind for green. The supporters of Young's theory, on the other hand, imagine that the confusion is made by a green-blind individual because he sees green objects red as well as those which, to the normal eye, appear red, and by a red-blind individual because he sees both green and red objects green.

Now, it is more difficult than it would *a priori* be imagined to tell how a colour-blind individual actually sees a certain colour, because, having been influenced all his life by the names given to the colours of surrounding objects by his more fortunate companions, he may have so associated definite shades of gray, seen in certain relations, with certain colours, that when a gray object having that particular *nuance* is placed before him, he does not hesitate to call it by the name of the colour for which he is blind, and which gives him the same impression. Thus it is that of two colour-blind individuals whose defects appear otherwise to be similar, one will be found to call a certain shade of gray green or red, whereas the other defines it rightly. But—and this is a point of great importance—he does not make the mistake with all shades of gray; he does not, for instance, call all light grays light red or light green, and all dark grays dark red or dark green.

We have now to consider what is the actual condition of the sense of colour in those who are colour-blind; and if in the phenomena of colour-blindness itself there is nothing which might form a basis for classification, independent of any theory we may embrace as to the perception of colour. In the first place, we think there can be no doubt that an individual who is blind for one particular colour hue is at the same time blind for its complement. That this is the case is shown by the following facts:—It is possible, as is well known, by rapid rotation on a Maxwell's disc, to obtain from three or more suitable coloured sectors an impression which is identical with that of a mixture of white and black produced in the same way: the colours, taken in certain proportions, can be got to neutralize each other, so that the resulting impres-

[1] That a similar explanation may be conceived without the assumption of fundamental sensations will be seen by reference to p. 17, where will also be found a diagrammatic representation of the theories of four fundamental colour sensations.

sion is colourless. The slightest change, however, made in the proportion of each colour, or the removal of any portion of one of the colours entering into the combination, can at once be detected, and some colour sensation is the result. If, on the other hand, the disc should contain two sectors of exactly complementary colours, their simultaneous removal would not destroy the colourless effect ; the remaining colours would continue to neutralize each other, so that the impressions they give rise to, following each other in rapid succession, would resolve themselves into gray. Now, it is found that the same mixture which to a normal individual appears similar to a mixture of black and white, appears also to the colour-blind identical with the same gray thus produced; whence it follows, as they are known to be blind for one colour, that they must either be insensitive to two complementary hues in both discs, or to only one in each. If they only fail to perceive one, both discs must appear to them coloured; but this is unlikely, because then all objects which appear to the normal eye colourless must appear to them coloured, which there is no reason to suppose is the case. But there is another reason for believing that this cannot be the case, viz., the analogy which exists between physiological colour-blindness on the one hand, and the normal colour-sense at the periphere of the retina and pathological colour-blindness on the other. Although we believe, for reasons which need not here be stated, that the colour-blindness existing for the peripheral parts of the field of vision is only partial, still the fact remains that there a very similar colour confusion exists as in the colour-blind. Thus a red or green object will appear, when viewed peripherically, yellow, gray, or blue, according to the hue taken ; yet a white or gray object does not become coloured by being moved from the centre to the periphere of the field of vision, which, as a white surface reflects all rays equally, or at any rate nothing but rays which neutralize each other, would necessarily be the case if certain parts of our retina were insensitive only to particular and non-complementary homogeneous rays.

Again, if a certain colour appear colourless to a colour-blind individual, its after-image appears also colourless, and one which fails to produce the normal impression also gives rise to an after-image which is exactly complementary to the impression received, and not to that which would be seen by any one whose colour-sense was not defective. There is no reason, however, why rays which, although colourless, are yet visible, should fail to produce in us the usual successive or simultaneous contrast, unless we are at the same time insensitive to those which give rise to the complementary impression ; indeed, if we have not the power of evoking the normal impression subjectively, we cannot expect to do so objectively.

Another point of importance in connexion with the vision of the colour-blind is, that although they fail to distinguish between many different colours, yet they are only actually blind for two particular hues which are complementary, and the slightest change in which is capable of giving rise to a colour impression. Thus most see a continuous spectrum, or one in which the two hues of which it is composed are only separated by a narrow band of gray, which band diminishes in breadth according as the intensity of the illumination increases. These *neutral* points appear, however, to differ in different cases of colour-blindness, which, nevertheless, are included under the same class. If, therefore, we could imagine all our possible colour hue perceptions so disposed round the periphere of a circle that those which are complementary were exactly opposite each other, we should find that the directions of the diameter representing the exact hues for which different individuals were blind differ. Such a circle would necessarily include not only all the different homogeneous light rays which we are capable of distinguishing as different hues,—in other words, all the colours of the spectrum,—but also such complements to these colours as are not contained in the spectrum, which for some reason or other we are not able to see as homogeneous light, although we can do so subjectively, or by mixing other spectral colours. We refer to all the different hues of purple. The reason why only one neutral line is to be found in the colour-blind spectrum is, that in the immense majority of cases the diameter representing the hues for which they are insensitive passes from some part of the green to some part of the purple. The position of this colour-blind diameter *has an influence on the perception of all the colours of the spectrum*, and constitutes a difference—at one time small, at another time considerable—between two cases of colour-blindness, so that if in one case the diameter lie between bright green and purple, the colour confusion will differ from that presented by a case where it lies between a more bluish green and a more reddish purple or rose colour. This, we believe, is the true explanation of the difference between green and red blindness of some others. What we usually call green is not exactly complementary to red, but to purple. Although many observers have noticed this difference in the exact hue for which individual cases are blind, they have either ascribed no importance to it or given some other explanation; as, for instance, this one of Stilling's:[1]—" Let us suppose a certain rose-colour to be made up of three parts of red and two of blue. To a colour-blind eye with normal acuteness of vision (V) for red, this red appears yellow, and the rose for such an eye must be made up of three parts of yellow and two of blue, and must therefore be seen as a yellowish gray. A second red-green blind eye may have V for red diminished to such an extent that the yellow impression to which the red gives rise is exactly sufficient to neutralize the blue. To such an eye the rose-colour must appear gray. For a third red-green blind eye there is, let us say, a con-

[1] " Ueber den Stand der Farbenfrage " (*Archiv. f. Augenh.*, vol. viii.)

siderable shortening of the left end of the spectrum: it scarcely, if at all, sees the red, so that in any case the blue impression predominates. For such an eye the rose-colour is blue. In this way it is easily explained how different hues are confounded with gray." Now, in the first place, Stilling, along with so many others, talks of red, yellow, green, and blue as if there were only one red, one yellow, etc. (whereas it is impossible for us to point out four exact spots in the spectrum which appear to us more red or more yellow, more green or more blue, than the parts immediately contiguous). Thus he has in another paper,[1] in describing a method of arriving at the exact colourless hue in his testing of colour-blindness by means of coloured shadow contrasts, come to the conclusion that, although he is unable with a prism to detect any yellow rays in the light passing through a certain combination of blue and red glasses, yet, as it appears yellow in some cases of colour-blindness, it must nevertheless contain yellow rays; and therefore, although it appears to the normal eye purple, it must contain, besides blue and red, also yellow rays, which for the colour-blind eye (although not for the normal!) are sufficient to neutralize the blue, leaving the red, for which he is blind. He says—" Even if objective red light had the property of exciting simultaneously both the red and yellow perceiving elements of our eye, yet this does not explain why a candle flame appearing to the normal eye of a deep reddish purple should appear to the colour-blind eye colourless through three blue glasses and one red, and yellow through two blue and one red. The addition of blue glasses can plainly have no other effect than that of absorbing the yellow rays passing through the red glass; consequently even the deepest spectral red must still be mixed with objective yellow." Again, Stilling considers shortening of the left end of the spectrum as affording an explanation for the different hues perceived as gray in different cases. This actual blindness for the less refrangible rays of the spectrum we should feel more inclined to look upon as something similar to the normal blindness for homogeneous purple rays, to which we have already referred, in which case it is improbable that it can have anything to do with what we call colour-blindness, which, as we have seen, principally exhibits itself in a want of power of distinguishing between different colours. It is found in about 2 per cent. of colour-blind individuals. We should like, therefore, to know the result of the examination of the spectra of a number of individuals possessing the normal power of distinguishing between different colours before ascribing to it even a secondary importance in the phenomena of colour-blindness.

Stilling's second case, which takes into consideration diminished V existing in some cases for red rays, would, we must admit, offer a very satisfactory explanation if he could have shown that the exact neutral hue varied only when there existed, and in propor-

[1] *Loc. cit. ant.*

tion to, a diminution of V for such rays. Supposing we were to take a blue and yellow hue which were exactly complementary, it is quite evident that, by mixing them in any proportion we pleased, we should not be able to destroy the sensation of colour to which the combination would give rise, unless we happened just to hit upon the exact proportions in which the relative intensities and proportionate quantities were in equilibrium. If, therefore, the red component of a blue and red mixture gave rise in one case to only a feeble sensation of yellow, whereas in another the sensation was much more intense, it is quite clear that in the first case the amount of blue required to be added to the red in order to produce a neutral sensation would be less than in the second case; or, in other words, the purple of the first case would be more reddish than that of the second. Yet the mere probability of the red colour taken appearing in one case more strongly of some particular yellow hue than in another, lies for us in the different positions which the neutral diameter in one colour-perception circle has in different cases, which, as we before remarked, alters the perception of all other colours; but a diminution in the distance at which certain colour hues can be distinguished is said by Donders[1] to be commoner than supposed, although absolute colour-blindness is rare. He says—"On approaching a small coloured object the normal eye distinguishes its colour, but very shortly after perceiving it at all; one does not require to search long in order to find people who begin to see the colour of the object much later than the light it reflects."

Adamük and Woinow[2] have found that the colour mixtures which appear gray at certain parts of the periphere of the retina vary according to the intensity of the illumination; and, according to Donders and Landolt,[3] the peripheral colour impressions do not differ from the central if the intensity of illumination be increased. Such cases, then, for which Stilling's last explanation would apply are probably only those in which the colour-blindness is incomplete.

Donders determined numerically the acuteness of vision for colours of 2300 railway employés, from amongst whom he selected 152 for further examination. He determined V both for reflected and transmitted coloured light. For reflected light he used small portions of the signal-flags of different sizes, pressed into black velvet; and for transmitted light a candle placed at measurable distance behind the coloured glasses used for signalling, in front of which was a dark screen into which was let a piece of obscured glass, the size of which could be regulated by

[1] "Die Quantitative Bestimmung des Farbenunterscheidungsvermögens" (*Arch. f. Ophth.*, xxiii. 4, p. 282).

[2] "Beiträge zur Lehre von den negativen Nachbildern" (*Arch. f. Ophth.*, xvii. 1, p. 135).

[3] *Klinische Monatsblätter*, 1873, p. 356.

means of a diaphragm with holes of different sizes. The distinguishing power K he calculates by the following formula:—

$$K = \frac{1}{m^2} \cdot \frac{d^2}{D^2},$$

where $1 = 1$ sq. mm.; $m^2 =$ size of object (in square millimetres) for eye tested; $D =$ distance at which normal eye sees 1 sq. mm.; and $d =$ distance at which the tested eye discerns the colour.

As the perception of colour depends very much on the amount of illumination, D has to be determined for one's self at each examination. With transmitted light, where it is possible to regulate the illumination by the distance of the candle behind the screen, the formula used was—

$$K = \frac{1}{m^2} \cdot \frac{d^2}{D^2} \cdot \frac{a^2}{A^2},$$

where $A =$ the distance of candle when $D = 5$ metres. Although we have said that there are only two colour hues from which a colour-blind individual fails to receive any colour sensation, and therefore confounds with gray, we do not wish to be misunderstood, our statement having reference only to saturated colours, one of which forms the neutral line seen by some in the spectrum. The other, which in the great majority, if not in all cases, not being contained in the spectrum, cannot be evoked other than subjectively, as a mixture of two homogeneous rays, especially such corresponding to such widely apart colour perceptions as the violet and red of the spectrum, is far from being saturated. The colour-blind can, indeed, receive many impressions of gray corresponding in each case to different proportions of black and white, by mixtures with blue in different proportions of all colours from red to green. This is a natural consequence of their dichromatic spectrum and of the two colours seen being only saturated at two definite points.

Most investigators describe the spectrum of the colour-blind as continuous, although usually only containing two colours, no portion appearing gray. This is due, we believe, to the way in which they have conducted their examination. If a very luminous spectrum be used, and if we are right in supposing that the blindness is for one colour sensation alone, then it is not improbable, when we take into consideration our extraordinary power of distinguishing rays of different degrees of refraction as different colour hues,[1] that the images of the slit in the rays lying on each side of the one giving rise to the exact neutral hue might so overlap each other as to cover the image formed by these colourless rays. A less luminous spectrum, by so diminishing the colour sensations produced on each side of the neutral line, which in all cases are described as feeble, would give rise to the impression of a gray line separating the two colours composing the spec-

[1] See Mandelstamm (*Arch. f. Ophth.*, xiii. 2, p. 399), and Dobrowolsky (*Ibid.*, vol. xviii. 1, p. 66).

trum. Other cases, again, in which no neutral line is observed may be cases of incomplete colour-blindness, which, there is reason to believe, are not infrequent and of very different degrees.

All our possible colour hue perceptions form a continuous ring, as, although there is a break in those produced by homogeneous light between the extreme red and violet of the spectrum, still for every colour in the spectrum we have a complementary sensation, either contained in it or occupying a position between the two ends, exactly analogous to that which it would occupy did the spectrum itself complete the circle, and which we can evoke subjectively or objectively by a mixture of heterogeneous light. If, therefore, adopting the supposition of Hering and others that all these various sensations are derived from four fundamental sensations, we wished to ascribe to these fundamental sensations definite positions in our colour circle, they would have to occupy diameters which in the first place corresponded to but two complementary sensations. By merely calling the one red and the others yellow, green, and blue, as so many writers do, we should, owing to the paucity of names for the many hundred distinct impressions produced by light of different wave lengths, apply names given to about three-tenths, one-fiftieth, one-tenth, and one-twelfth respectively of the whole spectrum to sensations which are supposed to be fundamental! As, according to this view of the nature of colour-blindness, that condition is due to the absence of two of the four fundamental sensations, the

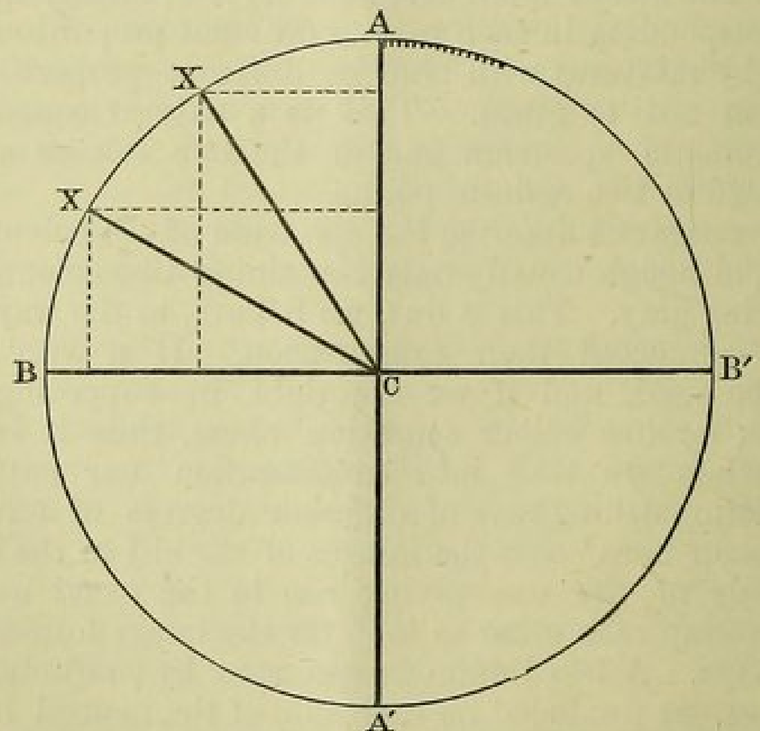

Fig. 2.

exact colours for which blindness exists must correspond to two of these fundamental sensations: let us represent them by the diameter A A′ (Fig. 2). In the second place, as the colours remaining occupy a position midway between those which are wanting, our second diameter may be drawn at right angles to the first, BB′, in the figure.

Now let any other sensation, X, occupy a position between A and B. According to the theory this sensation, whether produced by homogeneous light or occupying the position it does in our series of colour perceptions as the resultant of any number of combined impressions, gives rise to a definite colour sensation owing to the proportion in which the simultaneous impressions of the fundamental sensations A and B enter, so that a colour sensation lying midway between the two would result from an equal impression on both, whilst those lying nearer B and those lying nearer A would arise from stronger impressions of B than A, or of A than B. If we call the angle A C X, α, and the angle B C X, β, the proportionate impressions of A and B giving rise to the compound sensation X will be as cos. α to cos. β.

We have introduced the above method of demonstrating diagrammatically the way in which four fundamental sensations may suffice for the perception of any number of hues, as it has a certain bearing on a suggestion lately thrown out by Krenchel. Krenchel seems to start from the idea that if it is possible to imagine any way (consistent, of course, with the state of our knowledge of normal and abnormal colour sensations) in which such could arise without calling in the aid of a limited number of fundamental colour sensations, hypotheses based upon the assumption of such must necessarily lose half their weight. Krenchel's paper contains, therefore, more a refutation of the existing theories than a new theory ; and herein, we venture to say, lies its merit, as nothing has, to our mind, so trammelled researches in this branch of physiology as the blind adherence to such theories. According to Krenchel, we can imagine a molecule movable in all directions about its centre, and also capable of displacement in a vertical direction—such as a hemisphere floating in water. If we, at the same time, imagine that any displacement brings about a condition of unstable equilibrium, there would always be a tendency to regain the position of rest taking place in the opposite direction to the force causing the displacement. Let us imagine, again, that the number of appreciably different motions of this molecule corresponded to the total number of our colour sensations. If, then, A C (Fig. 3) represent the direction of the displacement corresponding to a certain colour, and the depression taking place at the same time at C represent the amount of white light we perceive along with the colour, then, on the close of the objective stimulus producing these displacements, there will be a return of the molecule to rest, the colour and shade of which will be complementary to A, and be represented in hue by the line A′ C. The same holds good for any sensation represented by B C, Y C, etc.

The nearer the force causing displacement acts to the centre of the molecule, the greater will, of course, be the proportion of depression to rotation, and therefore the greater the admixture of the sensation of white light. Thus, if the sensation represented by A C arose from two simultaneous impressions of equal strength, the resulting impression would correspond to that produced by a force acting at the point *a*—*i.e.*, would contain a greater proportion of white light. This is actually found to be the case, as the farther apart two spectral colours are taken, provided they are not so far distant as to be complementary, the whiter is the mixture, although always midway between. As we cannot receive the sensation of purple from a homogeneous impression, the mixtures giving rise to the resultant molecular movement must, according to the figure, produce more whitish, less saturated purples than those which we can evoke subjectively by the after-images from saturated green hues. That this is actually the case will be evident to any one who makes the experiment.

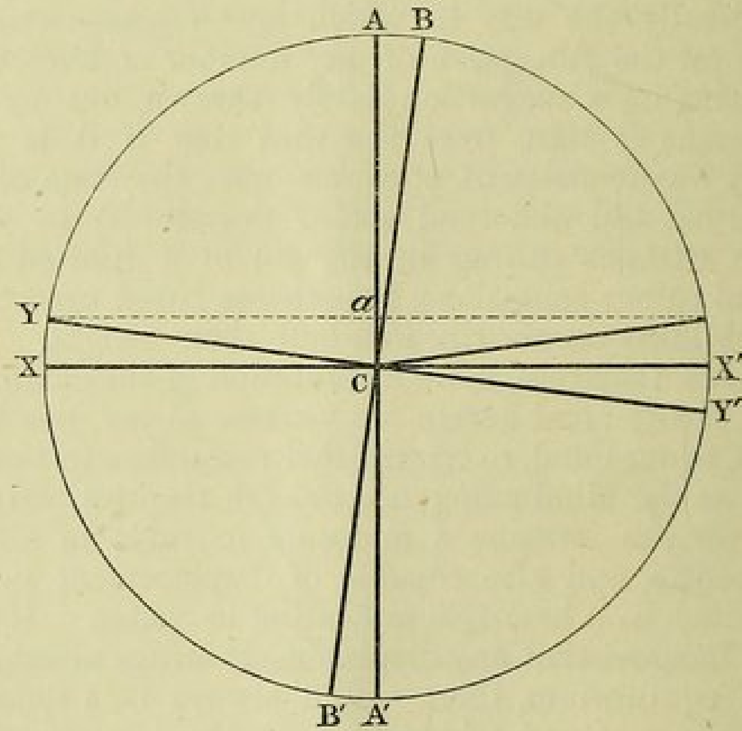

FIG. 3.

If, now, we imagine the rotatory molecular movement rendered impossible in any one direction represented by any of the diameters in the figure, our molecule can only retain this motion in one direction at right angles to the exact one for which it is abolished ; but the movement up and down will not be affected. Now we have it in a condition which can explain all the phenomena of complete colour-blindness. In the first place, it explains why there are only two hues in the colour-blind spectrum lying midway between the neutral hues, and which, therefore, alter in position with the latter. It explains, also, how the colours passing from the position of the diameter representing the direction of possible movement to that at right angles gradually becomes less and less saturated, till they fail to produce any sensation of colour at all.

It must be remembered that this demonstration is only diagrammatic, and not put forth as a theory; but it appears to us that a point is gained when we can explain the same phenomena as well, if not better, without assuming the existence of primary sensations, about which we can know nothing. We could carry out the same train of thought still further, and show where and how such molecular motion could be imagined to be produced, but we should then depart still further from the original intention of this paper, which was to point out how the different classifications of cases of colour-blindness arose, and how far the actual facts supported the theories which formed the bases of their classification.

We have now explained how it is that many different colour mixtures may be found which to the same colour-blind individual appear gray, and that this is a natural consequence of their dichromatic spectrum, and consistent with the belief that there exists blindness for but one pure colour hue. Cases of colour-blindness for yellow and blue hues have not been examined, as far as we know, for their neutral impressions; indeed, it appears extremely doubtful if such cases exist independently of the usual form of red and green blindness. The whole literature on the subject of colour-vision contains, so far as we are aware, only a few supposed cases examined by Stilling and Cohn, and those of the former, from the method of examination used, may be entirely disregarded.

If we take any red, orange, yellow, or green sector, and combine the impression received from it with that from a blue pigment, we shall find that the proportions of any of these with the blue, which is found necessary to produce a neutral colour sensation, varies in different cases of colour-blindness, that is to say, different cases are blind for different non-saturated hues—hues which owing to their mixture with white light are impure, and owing to the absorption of light by the pigments are wanting in brightness. It will be gathered from what has preceded that the explanation for this fact may be sought either in a difference in the acuteness of vision for one of the component colours, whilst the particular neutral hue remains the same, as Stilling suggests, or in the alteration of the strength of the impression arising from that component, owing to the altered position of the neutral diameter in the circle taken as diagrammatic of our pure colour sensations. We feel convinced that the proper solution of this point will be more conducive to the clearing up of the difficulties which still remain as to the nature of colour-blindness, than the efforts made by many investigators to explain all their observed facts by taking advantage of the natural elasticity of the theory of Young and Helmholtz.

To recapitulate.—There is no blindness for any colour hue without a simultaneous insensitiveness to its complement. In all probability there are a great number of forms of complete colour-blindness corresponding in general to blindness for certain rose and green hues; and although we prefer the classification into red-green-blindness and blue-yellow-blindness to that based on the theory of three fundamental sensations, still there can be little doubt that a more accurate one might be taken from the hues representing neutral sensations.

In conclusion, we would recommend the following systematic method of examination:—

1. Holmgren's wools for detection.
2. Position of neutral line in spectrum.
3. The examination with Maxwell's disc (using the same two pigments for every case, and taking care to select such as were unaffected by exposure to light).
4. Determination of V for colours.

We hope shortly to record the results obtained by the examination of a number of cases in the above manner.

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