

XVII. *On Colour-Blindness.* By WILLIAM POLE, *F.R.A.S., F.G.S., Mem. Inst. C.E., Professor of Civil Engineering, University College, London.* Communicated by CHARLES MANBY, *F.R.S.*

Received March 24,—Read April 7, 1859*.

1. MY object in this paper is to state my own case of Colour-Blindness, which I believe to be one of the most decided on record; and to show that the general phenomena attending this defect of vision are more simple, uniform, and consistent than is generally supposed.

2. Some apology is perhaps necessary for a colour-blind person undertaking to treat, even indirectly, of the subject of colours; on which the views formed from his own experience must necessarily be very limited. It is not, however, my intention to trespass upon the province of the normal-eyed. All I wish to do is to give a statement, as explicit and accurate as I can, of the facts connected with the sensations of myself and others similarly situated, leaving these facts to be discussed by others more competent to deal with them.

And as far as the correct determination of these facts is concerned, it seems to me that we, the colour-blind, are really in a better position for investigating their nature than the normal-eyed.

Such an investigation must be based entirely on a comparison of the impressions experienced respectively by two distinct classes of individuals. The normal-eyed person experiences one set of sensations, the colour-blind person a set entirely different; neither can see what the other sees; and each must therefore draw his ideas of the other's impressions solely from the description communicated to him.

Now in such case, supposing it is necessary for one of the parties so far to understand both sets of phenomena as to describe faithfully the difference between them, it is evident that he will be most favourably situated who can procure the best testimony from the other side; and this is certainly the position of the colour-blind. The greatest difficulty in dealing with the subject has been hitherto, and still is, the limited and imperfect nature of the evidence obtainable from those labouring under the defect; and this is natural for several reasons. In the first place the number of persons afflicted is very small, only (as far as can at present be computed) about two or three in every

* This paper is in the main identical with a former paper by the author, received June 7 and read June 19, 1856 (see 'Proceedings,' vol. viii. p. 172), which is here presented in an abridged and modified form, with the addition of the results of some experiments with Professor MAXWELL'S colour-top, made by the author in the interval.

hundred. Of these again but a small proportion know of their defect; still fewer have cared to examine themselves upon it; and there are only a much smaller minority still, who, being accessible, have qualified themselves to explain their views in such a manner as to represent them faithfully. For it is important to consider that it is by no means an easy thing for a colour-blind person to explain his impressions to a normal-eyed one in language free from misapprehension; and I shall hereafter have occasion to show that for this reason erroneous inferences may often be drawn from perfectly honest testimony.

But let him be the inquirer instead of the witness, and the case is wholly reversed; he may collect evidence about colours in every possible shape, from the scientific investigations of the philosopher to the artless remarks of the child; he need not go far for an answer to any question he may choose to put, however abstruse; and as to common facts, almost every one he meets is a competent witness from whom he may gather them.

I conceive, therefore, that the careful and patient investigation by any colour-blind person of his own case, supposing him to embrace the opportunities open to him for ascertaining clearly and fully the ordinary facts and impressions regarding colour in general, is likely to lead to a more faithful representation of the phenomena, than when, as is usually the case, the comparison is undertaken by the normal-eyed.

3. It is not necessary for me to enter into the optical theory of colours generally. I only require the means of illustrating, in the simplest manner possible, the facts I have to bring forward; and this, I conceive, may be sufficiently done by reference to well-known colours in ordinary use. And as it is convenient to adhere to some definite system of colour-nomenclature, I propose to adopt, for the purposes of the paper, the popular hypothesis that there are three primary colours, red, blue, and yellow, by combinations of which all hues in nature may be supposed to be formed.

4. The existence of a defect in the eye, which gives rise to an abnormal vision of colours, is now well established. Its nature has been discussed, and descriptions of cases have been published, within the last few years, by various writers; but it will be sufficient here to refer to the latest and most complete work on the subject, namely, that by Professor WILSON of Edinburgh*, who has made this defect his particular study.

5. Dr. WILSON considers colour-blindness, existing in eyes otherwise normal, as of three kinds:—

A. Inability to discern any colour, properly so called; so that black and white, *i. e.* light and shade, are the only variations of tint perceived. Cases of this total blindness to colour are very rare.

B. Inability to discriminate the nicer shades (hues) of the more composite colours. This is so frequent as to be apparently rather the rule than the exception; and more than one of our most eminent artists have expressed to me their conviction that there are very few people who have a perfect appreciation of the nicer distinctions of colour. It is, however, probable that this often arises rather from want of education of the eye, or want of ability to describe the impressions perceived, or both combined, than from

* *Researches on Colour-Blindness.* By GEORGE WILSON, M.D., F.R.S.E. &c. Edinburgh, 1855.

any physical defect of the visual organs. My own eyesight is very sensitive to minute differences of tone or hue*, in regard to those colours which I can see.

C. The third variety is the only one with which we have now to do. It is a real physical defect in vision, of a milder character than the first kind, but much more common; and its outward manifestation is a natural inability to distinguish between many of the colours most marked and distinct to normal eyes. It is yet an open question what degrees of severity may exist in this defect; but its most complete form is that called *dichromic* vision, of which my own case is a very perfect example.

6. I was born in 1814. My eyesight, in every other respect but that of colour, is remarkably good. I am very fond of bright colours, and of scenes and pictures that contain them.

I believe I was about eight or ten years old when the mistaking of a piece of red cloth for a green leaf betrayed the existence of some peculiarity in my ideas of colour; and as I grew older, continued errors of a similar nature led my friends to suspect that my eyesight was defective; but I myself could not comprehend this, insisting that I saw colours clearly enough, and only mistook their names.

I was articled to a civil engineer, and had to go through many years' practice in making drawings of the kind connected with this profession. These are frequently coloured, and I recollect often being obliged to ask, in copying a drawing, what colours I ought to use; but these difficulties left no permanent impression, and up to a mature age I had no suspicion that my vision was different from that of other people. I frequently made mistakes, and noticed many circumstances in regard to colours which temporarily perplexed me†; but I still adhered to my first opinion, that I was only at fault in regard to the names of colours, and not as to the ideas of them; and this opinion was strengthened by observing that the persons who were attempting to point out my mistakes, often disputed among themselves as to what certain hues of colour ought to be called.

I was nearly thirty years of age, when a glaring blunder, persisted in by me in opposition to the positive evidence of others, led me seriously to suspect that my vision of colours must be defective; and this suspicion once admitted, it was soon confirmed and strengthened by further observation. I cannot recollect what process of investigation I followed, but I succeeded in determining, from my own case, the general facts now known to characterize the defect, and made out its principal feature to be an insensibility to one of the primary colours. I subsequently became acquainted with the

* I use the word *hue* always to denote a distinct variety of colour. The variations in illumination or shade which may be given to any hue by its mixture with white or black, I call *tones*. The light tones produced by diluting it with white are technically called "tints;" the dark ones formed by darkening it with black are called "shades." Thus the addition, to any pigment, of white or black will only alter its *tone*; the addition of any other colour will alter its *hue*.

† I recollect in particular, having wondered why the beautiful rose light of sunset on the Alps, which threw my friends into raptures, seemed all a delusion to me.

accounts of similar cases, and have now the advantage of a large fund of information collected on the subject, which enables me to analyse and express my sensations in a much more complete way than I could have done a few years ago.

It will be convenient first to describe what I may call the *symptoms* of the malady, or the effects it produces on my judgment of colours; and then to endeavour to trace more accurately how these effects arise.

7. The symptoms of my colour-blindness, as manifested by the errors I commit in judging of colours, are so varied and heterogeneous in character, that it would be an endless task to follow the usual practice of particularizing the mistakes to which they have led me. I therefore prefer stating them in a generalized list, such as it might be supposed a careful normal-eyed person would prepare, who had been examining me fully, and had reduced the result of his observations into the most condensed form.

Symptoms of Colour-Blindness.

A. Blue and yellow are always perfectly distinguished, even in their lightest or darkest tones, and are never confounded with each other.

B. Only these two colours are seen in the spectrum, the blue corresponding to the more, and the yellow to the less refrangible rays. The red space is seen as yellow.

C. Red is often confounded with black, or more properly grey.

D. It is also confounded with orange, and (E.) with yellow.

F. Also with green. This is the most common symptom of all.

G. Also with brown, (H.) with blue, and (I.) with violet.

K. Crimson and pink appear to have no relation to the idea of red derived from vermilion or a soldier's coat.

L. Red is frequently identified, when of a full tone, and when the hue is scarlet, or some other tending towards orange.

M. Green is a colour most perplexing to the patient, who cannot be said generally to manifest any definite sensation about it at all.

N. It is not only confounded with red, but also with black, white, or grey.

O. Also with orange; (P.) with yellow; (Q.) with blue; (R.) with violet; and (S.) with brown.

T. Orange is confounded with yellow.

V. Violet is confounded with black or grey, and (W.) with blue.

X. Light or dark tones of certain colours are more liable to mistake than full tones.

8. Symptoms such as these, in their apparently hopeless complexity, furnish all the information usually obtained from a colour-blind witness under his examination by a normal-eyed investigator. I propose, however, now to go further, and to state, in a more definite and logical manner, what my sensations of colour really are, and how they may be made to explain and reconcile the anomalous effects above alluded to.

In doing this it is necessary to have some standard specimens to refer to, and the most

convenient for the purpose I have yet met with are the "Cercles Chromatiques" and "Gammes Chromatiques" lately brought out by M. CHEVREUL*.

The former consist of ten graduated colour-circles, one representing the full colours, the rest the same colours in different darkened shades. We require only the first circle, which is divided into seventy-two radial sectors, each coloured with a different graduated hue. Three of these sectors, at 120° apart, contain the full primary colours, yellow, blue, and red, and half-way between them are the three secondary compounds, green, violet, and orange. The intermediate spaces are filled with different gradations, and the diagram, therefore, presents a complete re-entrant circle of hues, of great variety, and capable of identification with great exactitude.

For the representation of toned colours, M. CHEVREUL has prepared a series of what he calls "Gammes Chromatiques," each consisting of twenty-two oblong divisions ranged one over the other. One division, about the middle of the row, contains a certain full colour, which is toned upwards in various shades to black, and downwards in various tints to white. The Gamme thus represents twenty different *tones* of the given colour, from the lightest tint to the darkest shade.

I shall also have occasion to refer to Mr. MAXWELL'S method of representing colour-sensations in a mathematical form, by the aid of his ingenious "Colour-Top," described in the Transactions of the Royal Society of Edinburgh, vol. xxi. art. xviii.

9. I have already stated that my vision is perfectly *dichromic*; *i. e.* while that of normal-eyed persons is compounded of *three* primary colour-sensations, mine is formed of only *two*.

This is the usual theoretical manner of defining the defect; but in a practical point of view it may be desirable somewhat to modify the definition. The more important colour-compounds may be practically considered as giving distinct impressions, and on this principle we may say, that while normal-eyed persons have *seven* colour-ideas (red, blue, yellow, green, orange, violet, and white), the dichromically colour-blind have only *three*, namely, two primary colours, and the secondary one produced by their combination.

The first mention of the dichromic explanation of colour-blindness is in a letter from Sir JOHN HERSCHEL to Dr. DALTON, which, though dated 2nd of May, 1833, was only published in HENRY'S 'Life of DALTON' in 1854. I have little more to do than to show the application, to my own case, of the theory there so simply and admirably laid down, and which I believe has never yet been followed out so completely as is necessary to explain the varying phenomena observed.

10. The first and most positive fact I am cognizant of is, that there are two distinct colours which I really do see, and which I can at once identify with those called, by the normal-eyed, *blue* and *yellow*. The pigments ultramarine and chrome-yellow, or the parts of the solar spectrum near the lines D and F of FRAUNHOFER, excite the colour-

* Paris, chez Digeon, Rue Galande, No. 65, 1855. M. CHEVREUL guarantees the perfectly similar reproduction of the colours in all copies.

sensations I am capable of, most fully and completely, and form with each other the strongest contrast it is possible for me to conceive.

I can, of course, never know whether my abstract sensations of these colours are the same as those of the normal-eyed; but this is of no moment, for we can only judge of our ideas by their manifestation; and if I find that I can understand and agree in all that is said of blue and yellow by the world in general, and that they can also understand and agree in all that my impressions lead *me* to say about blue and yellow, I have a sufficient proof that I see these colours as others do. This experience is general among the colour-blind, who one and all identify blue and yellow as the colours about which they are most certain, and which they never run the slightest risk of confounding with each other.

11. The fact next in importance is, that my ideas of the third primary colour, *red*, do not agree with those of the normal-eyed.

The term red is so indefinite, in ordinary language, that I have had much trouble to find out by an example, what is usually considered the pure colour, free from yellow on the one hand, or blue on the other. Many well-educated persons differ much on this point, and I have myself often detected considerable variation between examples of red which normal-eyed people have declared to correspond. I believe, however, that the pigment *carmine* is usually understood to be the best artificial representation that can be had of the true unmixed colour.

Now this red is by no means invisible to me; it conveys a very marked sensation of colour, by which I am perfectly able to identify, in a great number of instances, bodies of this hue. If therefore my testimony ended here, there would be no reason for inferring that I am blind to red, or have much defect in my vision regarding it. But when I examine more closely what I do really see in the cases referred to, I am obliged to come to the conclusion that the sensation I perceive is not one that I can identify separately, but is simply a modification of one of my other sensations, namely *yellow*. It is in fact yellow shaded with black or grey—a dark yellow.

This I can prove to myself in several ways. First, I find that among the various tones in the gamme of yellow, there is one, namely that numbered 16, which perfectly matches, to my eye, the “rouge” in the circle. Secondly, I can make very nearly this appearance of red to my eye, by mixing 1 part by measure of lampblack with 5 or 6* of chrome-yellow powder, so as to darken it to the required tone. And thirdly, I can produce, on Mr. MAXWELL’S colour-top, a tolerable match to the carmine card, by a combination of about 90 parts black with 10 parts chrome.

12. It may be safely stated, therefore, that what is ordinarily called red, is distinctly visible to my colour-blind eye, not as an individual colour, but as a shade of yellow.

* These quantities are only given approximately to illustrate the fact; they are very difficult to get accurately. The proportions by mixing powders are very different to those required by rotation to produce the same hue; and even when this has been tolerably arrived at, the quality of the pigments has much influence on the appearance of the match.

Now if I follow the Chevreul circle, starting from red, and going round, in the direction of a watch-hand, towards blue, in every division which I pass, the sensation of yellow becomes fainter and fainter, and at the same time the darkening shade becomes more and more powerful, until very soon the yellow disappears altogether, and nothing but a dark grey or perfectly colourless hue remains. This point is still within the limit of what may be called *red*; and thus I arrive at the fact that there *is* a hue of red which, to me, is, as a colour, absolutely invisible. It is a well-defined crimson, not much differing from crimson-lake; and its place on the circle is very near the division called "red-violet," probably the one marked 5 immediately beyond it; and it is perfectly matched to my eye by the division 17 on the gamme of neutral grey. I can also imitate it by mixing about $3\frac{1}{2}$ or 4 parts of carmine powder with 1 of ultramarine; or on the colour-top, 86 parts of carmine combined with 14 of ultramarine will about match a grey compound of 7 white and 93 black.

This, to me, neutral hue of red is not contained in the spectrum, but lies among the hues which are wanting to connect the red and violet ends together, and make the image re-entrant. The red end conveys to me a decided sensation of yellow, and the violet end a decided sensation of blue.

13. I can now easily fill up my description of that portion of the circular diagram lying between red-violet and yellow. The appearance to my eye of the whole of this, simply corresponds with that of the upper part of the yellow gamme, *i. e.* it presents a series of successive *shades* of yellow, commencing with the full colour, and gradually darkening down, by the abstraction of yellow and the addition of black, till it arrives at the colourless limit before described. Thus, "yellow-orange" appears yellow slightly darkened; "red-orange" or scarlet, still more; carmine-red, again more; and red-violet or crimson is all darkness with no yellow at all. The gradations of *hue* visible to the normal eye, are to my vision represented by gradations of *shade* only, the element of red acting, not as a chromatic agent, but simply as a darkening power*.

14. The appearance to me of the *violet* division of the diagram, or the part lying between blue and red-violet, is perfectly analogous to that of the part just described. The blue I see perfectly, but the various tints of violet are to me only darkened blue; for example, the "violet" division of the Chevreul circle perfectly corresponds with No. 18 of the blue gamme, which is simply blue+black; and I can make by mixtures of powders, or by rotation of the coloured disks, combinations of blue and black which shall exactly match others of blue and red. And this of course may be expected to be so; for since I have described the effect of pigmental red as only that of a darkening

* This expression must of course be only understood as regards the effect obtained in the pigments; what the intensity of direct light, of my red neutral hue, would be, I cannot say. It is probable that in regard to the degree of illumination generally, my sensations are normal. To an ordinary observer a crimson pigment conveys much less light than a yellow one; I appreciate the loss of light, but fail to see the accompanying effect of colour; hence what may be to him redness and darkness combined, is to me darkness only.

agent, its action, when added to blue, will not be to alter the hue, but only the shade. Thus, in the diagram, beginning from the vivid blue and going towards the red, I see the blue gradually diminish, and the shade gradually increase, till it meets the red-violet, as before, at which point all colour is gone.

15. I have now gone over two-thirds of the colour-circle, namely, from yellow round through red to blue; the remaining third comprising the hues which to the normal-eyed are known as *green*. The appearances this division presents to the colour-blind eye are very simple.

Starting from the vivid blue, and passing round in the direction of a watch-hand, I find the sensation of colour gradually diminish, and an impression of darkness gradually increase, until, at about the second or third division beyond "bleu vert," the blue has entirely disappeared, and nothing is left but a neutral grey, which matches, to me, No. 18 on the grey gamme. Beyond this the illumination begins to increase again, and at the same time a sensation of *yellow* begins to enter; the light and the colour both gradually heightening as I advance, until at the division "jaune" the darkening influence has entirely disappeared, and the full normal yellow hue is obtained.

Thus the appearance, to me, of the green division of the diagram corresponds exactly with that of the red or opposite one. First, I find one particular hue (full green to the normal-eyed), which to me is entirely neutral and colourless, and visible only as a dark grey; secondly, all the greens on the blue side of this neutral are represented to me by shades of blue, and can be matched to my eye by blue *plus* black; and thirdly, all the greens on the yellow side are simply shades of yellow, and can be perfectly imitated by darkening this colour. I am, in fact, as totally blind to green as to red; an element of the malady which, I think, has not hitherto received the attention it deserves.

16. But here a curious question arises, whether these two kinds of blindness have any connexion with each other? We have seen that insensibility to red induces also a want of perception of its compounds, orange and violet; but can this in any way affect the vision of green, a colour into which red can scarcely be supposed to enter?

It is difficult to answer the question without assuming something in regard to the nature of the colour green. If, according to the popular theory, it be supposed to be a combination of blue and yellow, our white, which must, as Sir JOHN HERSCHEL has observed in his letter to DALTON, be produced by the equilibrium of the two colours we see, is not in reality white at all, but *green*! Now green is only a *colour* to the normal-eyed, inasmuch as it is contrasted with their white light; but since we know no such contrast, we have no perception of green as a distinct colour, and our green, white, and grey become synonymous terms.

It is certainly rather a startling thought that, if this explanation be true, a portion of mankind exist all their lives in an atmosphere of green without knowing it; that their sunlight is green, their snow green, their grey green; everything in short about them green which is not blue or yellow; and the invisibility of white is no doubt a harder lesson to be learned than that of red. But this is no argument against the fact; we are

in no more anomalous position than any man would be if shut up from his birth in a room with green windows; he could form of himself no idea that the light outside his prison was of a different hue from that within; he would call it white if he heard others do so; and if it were as practicable to open our eyes as it would be his to the true aspect of nature, no doubt we should be quite as much astonished as he could be, at what had remained so long unseen.

17. If, however, we ought to consider, according to a doctrine now strongly supported, that blue and yellow combined properly make white, and that green is an independent colour, we can only accept the fact as it stands, that the colour-blind must be insensible to *two* primary or independent colour-sensations, red and green, instead of to one only, as has been generally supposed.

But since it is very difficult for me to conceive that my two colours, blue and yellow, are not also independent sensations, the idea would seem to suggest itself of a *tetra*-chromatism in the formation of the normal colour-scale; or at least that *four* standard colours must be selected in order to enable us to describe all other colours as mixtures of them. This question, however, it is out of my province to discuss further.

18. To recapitulate, in a brief form, the appearance to my eyes of CHEVREUL'S colour-circle, I may describe it as having one point full yellow, another full blue, two points colourless grey, and all the rest simply different tones of blue or yellow. The following diagrams will explain this even to those who have not the colour-circle itself to refer to. (See next page.)

And thus I come back to the statement, that I have only three sensations of colour, namely, yellow, blue, and that produced by their combination.

19. It may be serviceable to those who may wish to compare my case with others, to state still more definitely my perceptions of colour according to the mathematical system of Mr. MAXWELL, before alluded to.

Proceeding on the principle that all my colour-sensations are compounded of two elements, blue and yellow, I take cards coloured with the most perfect examples of these I can find, namely, ultramarine and "pale or lemon chrome*," and form with them one of the circles of the colour-top, while in the other circle I place the colour to be matched. I find in this way I can match every colour on the set of cards, by simply varying the proportions of blue and yellow; only, since the *intensity* of the blue and yellow combination is generally different from that of the matched colour, white or black must be used in addition, to make the resemblance perfect. The colour-circle I suppose to be divided into 100 parts.

The neutral combination of blue and yellow is, to my vision, as follows:—

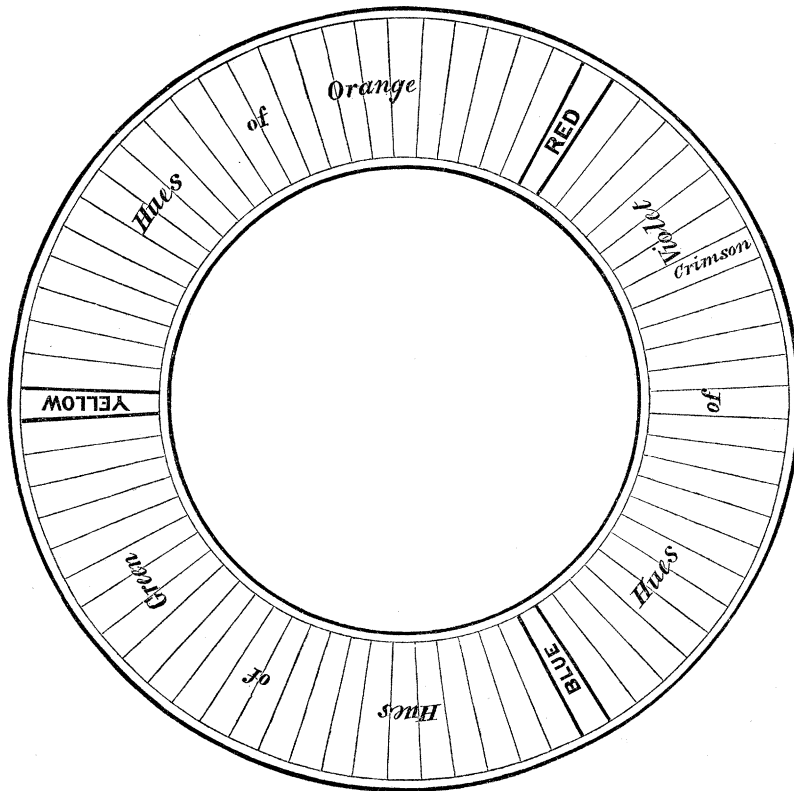
$$(I.) \quad 38\frac{1}{2} \text{ Y.} + 61\frac{1}{2} \text{ Ult.} = 64 \text{ Black} + 36 \text{ White.}$$

The combinations for other colours are—

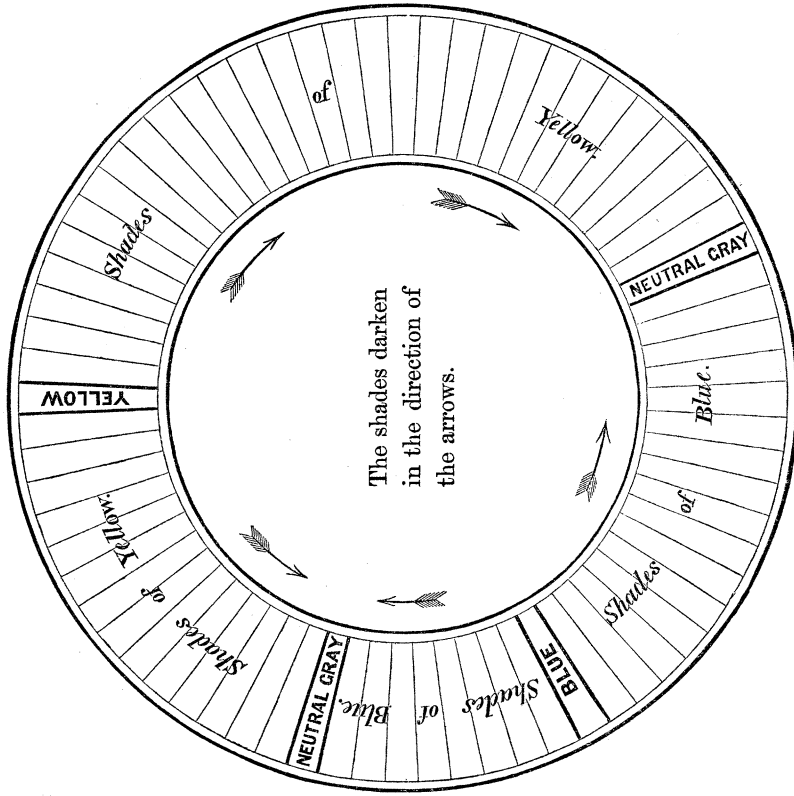
* These experiments were tried in December 1858, with a colour-top and cards prepared by Mr. BRYSON, Optician, Edinburgh.

DIAGRAMS OF CHEVREUL'S COLOUR-CIRCLE.

As it appears to the Normal-eyed.



As it appears to the Colour-blind.



Yellow side of the Neutral.

- (II.) 62 Y. + 38 Ult. = 78 Orange chrome + 22 White.
 (III.) 51 Y. + 49 Ult. = 88 Emerald green + 12 Wh.
 (IV.) $48\frac{1}{2}$ Y. + $51\frac{1}{2}$ Ult. = 70 Vermilion + 30 Wh.
 (V.) $42\frac{1}{2}$ Y. + $57\frac{1}{2}$ Ult. = 66 Carmine + 34 Wh.
 (VI.) $42\frac{1}{2}$ Y. + $57\frac{1}{2}$ Ult. = $68\frac{1}{2}$ Brunswick gr. + $31\frac{1}{2}$ Wh.
 (yellow shade)

Blue side of the Neutral.

- (VII.) 20 Y. + 80 Ult. = 65 Blue verditer + 35 Black.

Now as all colours on the yellow side of the neutral are to me only shades of yellow, it follows that they may all be matched more directly by yellow only, darkened with black or grey as the match of intensity may require. The following are the equations thus produced:—

- (VIII.) 50 Y. + 50 Blk. = 100 Orange chrome.
 (IX.) 23 Y. + 58 Blk. + 19 Wh. = 100 Emerald green.
 (X.) $23\frac{1}{2}$ Y. + $76\frac{1}{2}$ Blk. = 100 Vermilion.
 (XI.) 10 Y. + 90 Blk. = 99 Carmine + 1 White.
 (XII.) $9\frac{1}{2}$ Y. + $87\frac{1}{2}$ Blk. + 3 Wh. = 100 Brunswick green.

And similarly for the blue:—

- (XIII.) 70 Ult. + 30 Wh. = 100 Blue verditer.

All the yellow colours may be neutralized by adding blue, and the blue ones by adding yellow. The following are the equations:—

- (XIV.) 73 Emerald gr. + 27 Ult. = $70\frac{1}{2}$ Black + $29\frac{1}{2}$ White.
 (XV.) 73 Vermilion + 27 Ult. = $83\frac{1}{2}$ Blk. + $16\frac{1}{2}$ Wh.
 (XVI.) 86 Carmine + 14 Ult. = 93 Blk. + 7 Wh.
 (XVII.) 87 Brunswick gr. + 13 Ult. = 90 Blk. + 10 Wh.
 (XVIII.) 68 Blue verditer + 32 Yellow = 51 Blk. + 49 Wh.

The following are some equations of red and green matched with each other:—

- (XIX.) 84 Vermilion + 16 White = 85 Emerald gr. + 15 Blk.
 (XX.) 75 Carmine + 10 Y. + 15 Wh. = 76 Emerald gr. + 24 Blk.
 (XXI.) 96 Carmine + 4 White = 100 Brunsw. gr. (nearly).

The different classes of equations above given may be compared theoretically with each other. An example will best show how this is done.

Take equation (III.) for emerald green, and add to both sides as much yellow as will neutralize the 49 parts of ultramarine, which, from equation (I.), is found = about 31 parts. Then

$$51 \text{ Y.} + 49 \text{ Ult.} + 31 \text{ Y.} = 88 \text{ Em. gr.} + 12 \text{ Wh.} + 31 \text{ Y.}$$

But by equation (I.),

$$49 \text{ Ult.} + 31 \text{ Y.} = 51 \text{ Blk.} + 29 \text{ Wh.};$$

$$\therefore 20 \text{ Y.} + 51 \text{ Blk.} + 17 \text{ Wh.} = 88 \text{ Em. gr.};$$

or, which is the same thing,

$$23 \text{ Y.} + 58 \text{ Blk.} + 19 \text{ Wh.} = 100 \text{ Em. gr.},$$

which is equation (IX.).

I have in this way tested the whole of the equations both by theory and observation, and the correspondence of the two is very satisfactory.

20. I may now point out how easily and perfectly the simple fact of dichromic vision may be made to explain all the phenomena, or as I have called them symptoms, collected in art. 7, and which appear, when considered alone, so anomalous and contradictory.

A. See art. 10.

B. The explanation of the appearance of the spectrum is precisely analogous to that of the colour-circle. The division between the yellow and blue colours I believe to be about half-way between the lines *b* and F of FRAUNHOFER.

C, N. The neutral hues of red and green appear grey.

D, E, F, G, O, P, S, T. Since certain hues of both red and green, as well as all kinds of orange and brown, appear shades of yellow, these five colours are confounded with each other. Red and green are the two most common colours in nature, and as the hues of both most frequently met with, lie on the yellow side of the neutral, the mistaking of red and green is such a universal symptom of colour-blindness as to constitute the "shibboleth" of the disorder. Bright grass-green and scarlet may be taken as perhaps the most common representatives of the two colours, and these, to me at least, present almost the same identical shade of yellow.

H. The red which is confounded with blue is always crimson, or its light tint pink, never any of the scarlet or orange varieties; and it is obvious that any of the red hues on the blue side of the neutral will be seen by the colour-blind only as blue. With regard to pinks, it would appear that diluted or thinly applied crimson dyes give generally a bluer impression than the full colours. For example, taking the gamme of red-violet, and comparing it with that of grey, I find that No. 8 of the former will perfectly match No. 10 of the latter, *i. e.* No. 8 of the crimson scale is to me neutral and colourless. But all above 8, *i. e.* all the fuller tones, decidedly incline to yellow, and all below, *i. e.* all lighter tints, as decidedly to blue; so that, seeing Nos. 2 or 3 alone, I should have no hesitation in calling them blue, though of a very dull and imperfect kind. And it must be observed that the blue for which the colour-blind mistake crimson and pink, is always described by them as dirty and faded; never so decided as to stand comparison with the pure colour, even diluted. I am told that the circumstance of certain coloured substances appearing to change in *hue* when reduced in thickness or diluted, is one familiar to the normal-eyed.

J. Violet being to us only dark dull blue, its confusion with crimson, and that of its tint lilac with pink, come under the explanation above given.

K. The remark, first made by DALTON, that crimson and pink appear to have no relation to the idea of red derived from vermilion or a soldier's coat, must now be perfectly intelligible. Crimson appears dark grey, pink dirty blue, but scarlet is a very decided yellow, and these are therefore as unrelated to each other as the yellow to grey of normal eyes.

L. All scarlet hues of red are very distinctly visible as dark yellow.

M. The hopeless perplexity into which the colour-blind are thrown in regard to green may be easily inferred from art. 15. It is to them what white or grey is to the normal-eyed, *i. e.* it represents no colour at all. The only cases therefore where it becomes visible as a colour, are those where it has a preponderance of yellow or blue in its composition.

Q, R, W. All violets, and all greens on the blue side of the neutral, appear dark blue.

V. If the red element in violet is much stronger than the blue, the latter may be overlooked, and the hue will then appear colourless or grey.

X. This only applies to compound hues, in which the blue or yellow element (which alone gives the appearance of colour to our eyes) is often present in quantities so small as scarcely to bear toning without becoming imperceptible. With the simple colours blue and yellow, I believe our vision is quite as acute as that of the normal-eyed, even for the faintest or the darkest tones.

21. Having now described my own case, the question arises how far this conforms with other instances of colour-blindness, and to what extent it may be considered as a type of the defect in general.

It will be impossible for any one to examine the various cases on record without noticing many points of strong resemblance to the characteristics of my own vision, as enumerated in art. 7; but I am not aware that, till now, the whole of these varied and apparently incongruous symptoms have ever been represented as combining in one person. Each individual has contributed his portion to the list, by telling the story of his own experience; but I scarcely suppose it has been conceived possible that any case should exist which would comprehend them all together, or that phenomena so different could be brought under any simple law. Hence an opinion has prevailed that there are many varieties of colour-blindness, differing much in character as well as in severity, each being denoted by its own peculiar symptoms, and each therefore requiring special classification.

Professor ELIE WARTMANN of Lausanne, in a paper on Colour-Blindness, translated in TAYLOR'S Scientific Memoirs for 1846, after enumerating several different classifications of the disease given by different continental authorities, appears himself to be of the opinion that there are as many varieties of the defect as of individuals who are affected with it, so that, as he expresses it, no classification is possible.

Dr. WILSON does not go to this length, but he appears to consider his cases as varying

much in severity, and inclines strongly to the opinion that the number of instances where the vision is perfectly dichromic, *i. e.* where the true sensation of red is altogether imperceptible, are very few.

It is with diffidence I would dissent from the opinion of such an authority; but as this is a point confessedly obscure, I do not hesitate to record my own impression that the cases of perfect dichromatism are much more common than Dr. WILSON supposes, and that, in fact, the majority of cases where well-defined symptoms occur, may be, and probably are, purely dichromic.

22. The opinion in favour of the varied character of the disorder is doubtless suggested by the nature of the testimony; for on examining it closely we discover differences in the descriptions which would seem to indicate considerable variety between the sensations of different parties. But granting, without hesitation, that each individual may have faithfully described what he thinks he sees, there are some considerations which must ever render it necessary to use great caution in interpreting the testimony of the colour-blind, and which, if not allowed for, may lead to the deduction of very erroneous inferences from what they say.

23. In the first place they must be very liable to associate, almost indissolubly, the true normal name of a colour with the sensation it conveys to their minds, *whatever that sensation may be*; and they may therefore easily be led to speak of that colour as if they saw it like other people, although the sensation they refer to may be really of quite a different nature to that which the name implies. A colour-blind person will be especially loth to believe that certain colours, which he hears about and talks about every hour of the day, can be invisible to him. Objects of these hues will probably present to his mind *some* ideas of colour (though not the true ones), and he may naturally imagine therefore that he does see them, and may give his description accordingly.

And this source of error is very much enhanced by the fact that it is not an easy matter always to refer different *tones* of any one colour to the same colour-sensation; so that a modification of tone, if considerable, may be easily supposed to be a different colour. The sensations excited by the higher, the middle, and the lower divisions of any one of the "gammes chromatiques" are so different from each other, that it requires no small degree of reflection and judgment to be able to identify the difference as due to black or white only, independent of any other colouring agent.

I believe this difficulty is also felt by the normal-eyed, and the popular nomenclature of colours furnishes illustrations of the fact, different tones of the same colour having often different names, and being treated as separate colours. Pink and crimson, lilac and violet, are well-acknowledged examples of this; and a dark shade of orange is called brown, which generally passes for a separate colour. Persons not well versed in the principles of colour, are often reluctant to admit that these variations of tone are really the same hue. Hence we may easily see what a great probability there is that the colour-blind may acquire the habit of attaching the names of different colours to what are in reality only varieties of the same sensation; and as this habit dates from

their infancy, and is encouraged by their every-day communication with the world, it is much more difficult to get rid of than might be supposed. The sufferer may find himself continually blundering, but he must go through a very rigid self-examination before he can trace this to the fact that some of the principal ideas he has all his life held upon colour are mere delusions.

Taking red as an example; it is in the highest degree natural that persons who are continually seeing this colour under the appearance of dark yellow, should imagine that the latter sensation (which is certainly very distinct from that of full yellow) is what corresponds to the term red, and the notion that they cannot really see red at all is one they may have the greatest difficulty in comprehending. Hence the very general assertion by the colour-blind that they *do* see red, an assertion which I think has been far more readily accepted than it ought to be*.

My own experience is very decided on this point. It is only after long and careful investigation I have come to the conclusion that my sensations of colour are limited to blue and yellow. But before I found this out, that is, for nearly thirty years of my life, I firmly believed that what I now know to be only differences in tone of one or other of these, were different colours, and hence I was in the habit of talking of red, crimson, scarlet, green, brown, purple, pink, orange, &c., not of course with the confidence of the normal-eyed, but still with a full belief that I *saw* them. If therefore at that time any scientific man had examined me, I should have given him a description of my case which I now, after more careful study, know would have been entirely wrong. I should have told him, among other incorrect statements, that I saw red objects of a full tone, such as vermilion, soldiers' coats, &c., perfectly well; and I could, if necessary, have supported my assertion by naming correctly a great variety of bodies having this colour, which indeed I am in the habit of doing every day. It would have been inferred, with great appearance of truth, that I was really impressible with the red sensation; but I now see what an erroneous inference this would have been.

24. Another source of confusion in interpreting the descriptions of the colour-blind, is the want of due appreciation of the different sensations that may be produced on their minds by modified *hues* of the same general colour. The normal-eyed person considers green, for example, as always green, whether it be yellow-green, neutral green, or blue-green; whatever the particular "shade of green," as it is called, it still has in his eye the distinguishing character of *greenness*, which cannot be hidden or disguised by any predominance of blue or yellow it may contain. But with the colour-blind this identifying characteristic of greenness is wanting; and hence several patients, speaking of green, may, by each having reference in his own mind to some different hue of the colour, describe it in the most contradictory terms. One may say, with perfect sincerity, that green appears to him like red, another that it looks yellow, a third blue,

* Red is a more common colour than dark yellow, and hence the preference, by the colour-blind, of the former name for the common sensation. A great variety of bodies are known to be red by habit and association, and are for this reason often named correctly.

a fourth black, a fifth orange, a sixth violet;—from which the normal-eyed examiner, impressed with the unity of greenness, may naturally infer that each person is suffering under a different species of the disorder; while by proper interpretation these anomalous descriptions would only convey the expression of one consistent truth, and one perfectly uniform defect of vision.

25. Guided by these considerations, as arising out of my own experience, I have carefully examined all the published cases accessible to me, and I generally find that I can understand and enter fully into the feelings of the witnesses; can put myself in their places, and see, as it were, with their eyes; and, recollecting what my ideas of my own sensations once were, I feel I can adopt by far the greater part of the testimony as my own. The explanation of my case comprehends and accounts for, with trifling exceptions, the whole varied range of symptoms described by others; and I think there are fair grounds for believing that the few discrepancies that exist are but apparent, and admit of being satisfactorily explained away, on the grounds above alluded to. It appears to me, therefore, a reasonable inference, that the great majority of cases of colour-blindness hitherto described, correspond in general nature with my own.

26. And I think there must be great difficulty in finding any hypothesis, except that of perfect dichromic vision, which will satisfactorily account for the facts observed. Take for instance the most common symptom, the confounding of red and green. If it be assumed that *either* of the colours presents its proper sensation to the colour-blind, it is difficult to avoid the inference that this colour ought always to be recognized; but this is not so, red and green being generally *both* mistaken.

It has been sometimes thought that red may be visible only in a partial degree; but I can scarcely conceive what a partial vision of red can mean, or what mistakes of colour it ought to give rise to; for it would be only a perversion of language to say that red is partially visible when it appears yellow, green, or grey. If red is really the most positive and individual of all colours, as it is usually described, one would think that *any* perception of its true sensation should lead to a much more perfect and consistent identification of it than is generally found in the colour-blind. I am not only sure of my own insensibility to red, but I cannot see, in the testimony of other colour-blind persons, any satisfactory evidence that the true sensation of the colour is really perceptible to them.

It has also been imagined that though *full* colours may be properly discriminated, they may lose their individuality in their light or dark tones; but I cannot see any proof of this supposition, or that, if admitted, it would afford any sufficient explanation of the phenomena.

It would be desirable to direct further inquiries to this part of the subject, in order to discover whether the apparent varieties in the cases are merely due to the nature of the testimony, or whether they really indicate true variations in the character of the vision. If the latter, it would surely not be difficult to reduce them to some kind of consistent classification, and to determine, with more precision than hitherto, what are the real chromatic perceptions causing the different classes of symptoms observed.

POSTSCRIPT.

Since the foregoing paper was written, I have had the opportunity of examining three colour-blind persons, and have found that the vision of each is perfectly dichromic, corresponding precisely in general character with my own. But the remarkable feature has presented itself, that the *coefficients* of the colour-top equations vary considerably in the different cases. Thus, for example, although my equation XV. will always hold in its *general* form,

$$m \text{ Vermilion} + n \text{ Ult.} = p \text{ Black} + q \text{ White,}$$

yet the values of m , n , p , and q will vary for different individuals.

I have also found reason to suspect that the values of the coefficients may vary to some extent, even in the *same* individual, at different times.

I hope to investigate both these points more fully.

October 1859.