REPORT

OF THE

COMMITTEE ON COLOUR-VISION.

Presented to both Houses of Parliament by Command of Her Majesty.
June, 1892.

LONDON:
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COMMITTEE ON COLOUR-VISION.

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REPORT OF THE COMMITTEE ON COLOUR-VISION.

The Committee on Colour-Vision appointed by the Council of the Royal Society on March 20, 1890, and consisting of the following members:—The Lord Rayleigh, Sec. R.S., *Chairman;* The Lord Kelvin, Pres. R.S.; Mr. R. Brudenell Carter; Prof. A. H. Church, F.R.S.; Mr. J. Evans, Treas. R.S.; Dr. R. Farquharson, M.P.; Prof. M. Foster, Sec. R.S.; Mr. F. Galton, F.R.S.; Dr. W. Pole, F.R.S.; Sir G. G. Stokes, Bart, M.P., F.R.S.; and Captain W. de W. Abney, C.B., F.R.S., *Secretary*, now submit their Report, with Minutes of the Evidence taken.

The Committee have held 30 meetings, and have examined more than 500 individuals as to their colour-vision. They have tried various methods and apparatus, including Holmgren's wool-test with Dr. Jeaffreson's and Dr. Thomson's modifications, Lord Rayleigh's colour-mixing apparatus and that of Captain Abney, Dr. Karl Grossmann's system, the lantern devised by Mr. F. Galton, and Mr. Lovibond's tintometer. They have taken the evidence of Captain Steele, of the Board of Trade; Mr. Rosser, a private instructor in navigation; Messrs. J. J. Hanbury, A. S. H. Wadden, and Bambridge, connected with the colour-testing departments of certain railways; Captain Macnab, of the Liverpool Board of Trade; Captain Angove, of the Peninsular and Oriental Steamship Company; and the following surgeons and experts in colour-vision testing:—Mr. Priestley Smith, Mr. T. H. Bickerton, Mr. E. Nettleship, Staff-Surgeon T. J. Preston, Dr. G. Lindsay Johnson, and Dr. Edridge Green. The Committee are under great obligations to Captain Abney, not only for having officiated as Secretary, but also for his very considerable labour in the determination of colour-constants, the registration of colours, and the examination, by spectral methods, of particular cases of defective colour-vision.

After weighing the evidence which they have obtained, the Committee have unanimously agreed upon the following recommendations:—

1. That the Board of Trade, or some other central authority, should schedule certain employments in the mercantile marine and on railways, the filling of which by persons whose vision is defective either for colour or form, or who are ignorant of the names of colours, would involve danger to life and property.
2. That the proper testing, both for colour and form, of all candidates for such employments should be compulsory.

3. That the testing should be entrusted to examiners certificated by the central authority.
4. That the test for colour-vision should be that of Holmgren, the sets of wools being approved by the central authority before use, especially as to the correctness of the three test colours, and also of the confusion colours. If the test be satisfactorily passed, it should be followed by the candidate being required to name without hesitation the colours which are employed as signals or lights, and also white light.
5. That the tests for form should be those of Snellen, and that they should be carried out as laid down in Appendix VI. It would probably, in most cases, suffice if half normal vision in each eye were required.
6. That a candidate rejected for any of the specified employments should have a right of appeal to an expert approved by the central authority, whose decision should be final.
7. That a candidate who is rejected for naming colours wrongly, but who has been proved to possess normal colour-vision, should be allowed to be re-examined after a proper interval of time.
8. That a certificate of the candidate's colour-vision and form-vision according to the appointed tests, and his capacity for naming the signal colours, should be given by the examiner; and that a schedule of persons examined, showing the results, together with the nature of the employments for which examinations were held, should be sent annually to the central authority.
9. That every third year, or oftener, persons filling the scheduled employments should be examined for form-vision.
10. That the tests in use, and the mode of conducting examinations at the different testing stations, should be inspected periodically by a scientific expert, appointed for that purpose by the central authority.
11. That the colours used for lights on board ship, and for lamp signals on railways, should, so far as possible, be uniform, and that glasses of the same colour as the green and red sealed pattern glasses of the Royal Navy, should be generally adopted.
12. That in case of judicial inquiries as to collisions or accidents, witnesses giving evidence as to the nature or position of coloured signals or lights should be themselves tested for colour- and form-vision.

(Signed) RAYLEIGH,
Chairman.

April 28, 1892.

The reasons on which the Committee have based these recommendations are set forth in the following pages.

Introductory.

The subject of colour-sense and its imperfections is one which is necessarily of great scientific interest; but it also has a practical importance, as it affects a definite proportion of the men who are engaged in the two great industries of railway traffic and of navigation. Amongst railway men, at least, if not also amongst sailors, a suspicion has been excited that the methods adopted for testing colour-sense are not entirely trustworthy, and have had the effect of excluding some individuals from employments, the duties of which they were well qualified to discharge. On this ground alone, if on no other, it has seemed advisable to the Committee that the reasons for their recommendations should be so stated as to be intelligible, as far as possible, to all those who are interested in the matter.

Every colour, and among colours for convenience sake are included black and white, can be defined by three qualities:—1st, its hue—thus we talk of red, green, violet; 2nd, its purity, or the measure of its freedom from admixture with white—which is expressed by such terms as "deep" or "pale;" and 3rd, its brightness or luminosity—thus we say a colour is "bright," or "dark." Two colours are identical only when they can be defined as possessing the same three colour qualities, or constants as they are called, and if they differ in any one they are no longer the same. When two objects are compared together for colour, the large majority of persons will agree as to their identity or difference. Their verbal descriptions of the difference may vary slightly, but practical tests show that in reality they recognize the same variations, and hence their vision is termed *normal vision*. There is, however, not an inconsiderable minority, as will presently be shown, whose perception of colour differs very widely from that of the majority, and, for want of a better term, members of this minority are called "*colour-blind*." By this term it is not intended to convey the idea that there is absolute insensibility of vision, or even of colour-vision, but merely that the ordinary distinction between certain colours is defective The variations in the amount of this deficiency in colour-perception are numerous, and when small, are often exceedingly difficult to classify.

We have to regard these deviations from normal vision more from a practical than from a theoretical standpoint, and in testing for them we have to take the broad view that the colour-blindness which has to be detected is that which may be dangerous to the public in the industries already mentioned.

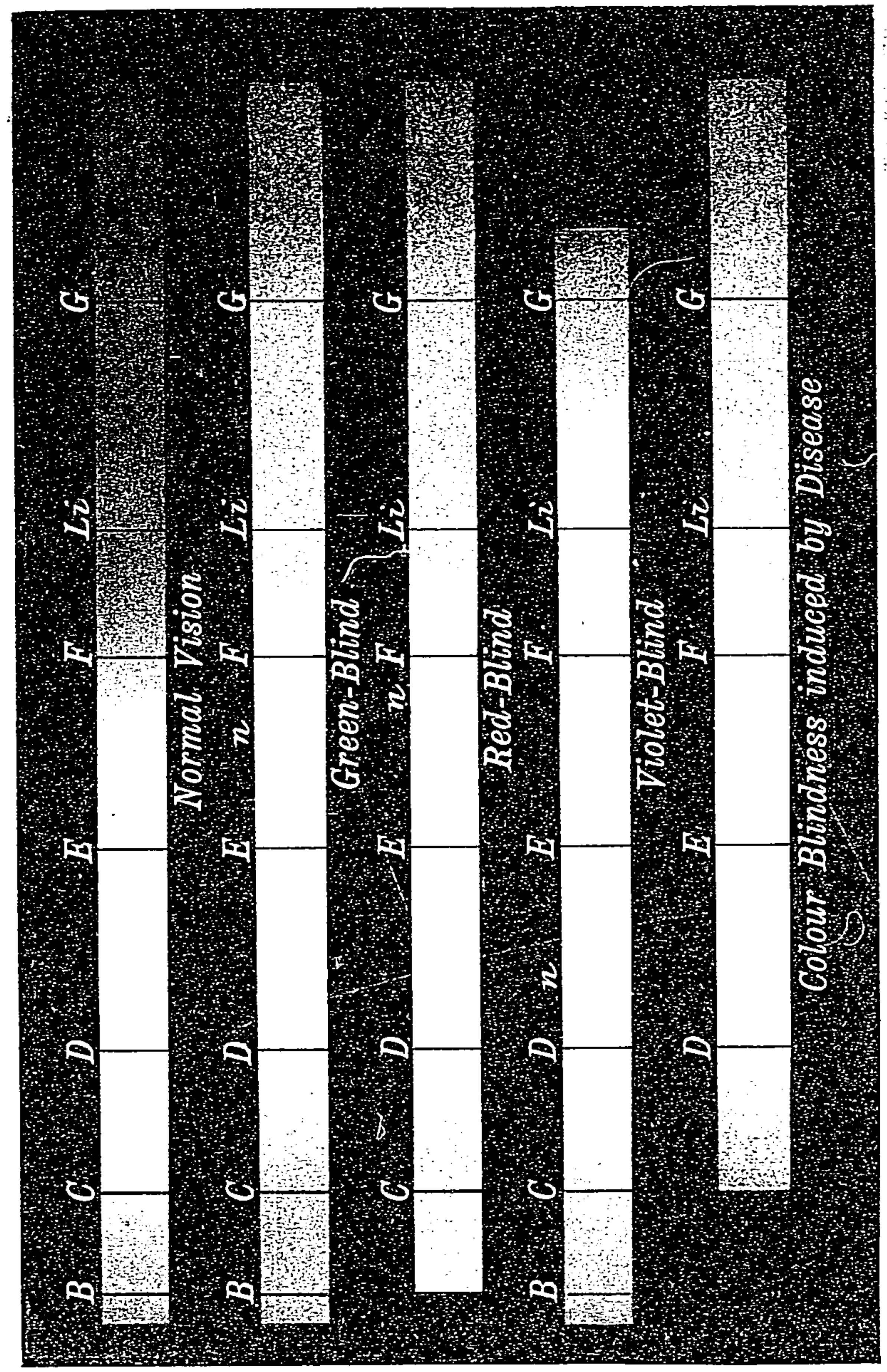
Character of colour-blindness.

There are some few people who fail to distinguish blue from green, and others, equally few, who only see in monochrome, but the colour-blindness which is most common, and therefore, most dangerous, is the so-called *red-green blindness*, in which there is a failure to distinguish between red and green; that is to say, a red-green blind person will regard a certain hue of green as identical in colour with some hue of red, another of green as identical with white, and some will also fail to see red at all of another particular hue. When it is considered that on our railways white, green, and red lights are used as safety and danger signals at night, and that the same colours are not unfrequently used for a similar purpose by day, it is very obvious that to place persons who are red-green blind in positions where the colours ought to be correctly recognised may be the cause of disasters. The same objection to the employment of persons with defective colour-vision applies also to navigation, for at night the presence of a green or red light on the port or starboard side indicates the course that a vessel is taking, and if either those in charge, or on the look-out, are colour-blind, serious risks of collisions are run.

Description of the spectrum.

It is proposed to enter somewhat minutely into the characteristics of red-green blindness, showing how it may be divided into two species. For this purpose it is necessary to appeal to the spectrum. When a thin slice of white light falls on one or more prisms, or on what is known as a diffraction grating, it is decomposed into a parti-coloured band which we call the spectrum, the principal colours, as given by Newton, being red, orange, yellow, green, blue, indigo and violet. If the light be that from the sun innumerable black lines will be seen interrupting this series of colours, some more marked than others. It is found that these lines always occupy the same position as regards the colour in which they are situated, and hence the more pronounced ones will act to the spectrum as milestones do to a road. Different coloured rays have different lengths of undulations in the all-pervading medium which is called ether, and the *wave lengths* of the coloured rays which, if present, would occupy the place of the principal black lines have, notwithstanding their minuteness, been determined with extreme accuracy, and this enables the position of any particular hue of spectrum colour to be numerically fixed by a reference to the wave lengths of these lines. We have said that the principal spectrum colours are those stated above, but it must be understood that they are only fully recognized by persons possessing normal vision; for the spectrum would be described by a colour-blind person in very different terms. For instance, some red-green blind would say that the red, orange, and yellow were all yellow; red would be described as dark yellow, orange as less dark, and yellow as bright yellow, whilst the green part of the spectrum bordering on the yellow would be described as yellow diluted with white. In the pure green would be pointed out a white or grey band, and the blue-green would be described as blue diluted with white; whilst the blue would be called light blue, and the violet dark blue (*see* No. 2, Plate I). Others, again, whilst similarly describing the blue and violet part of the spectrum would substitute green

PLATE I.

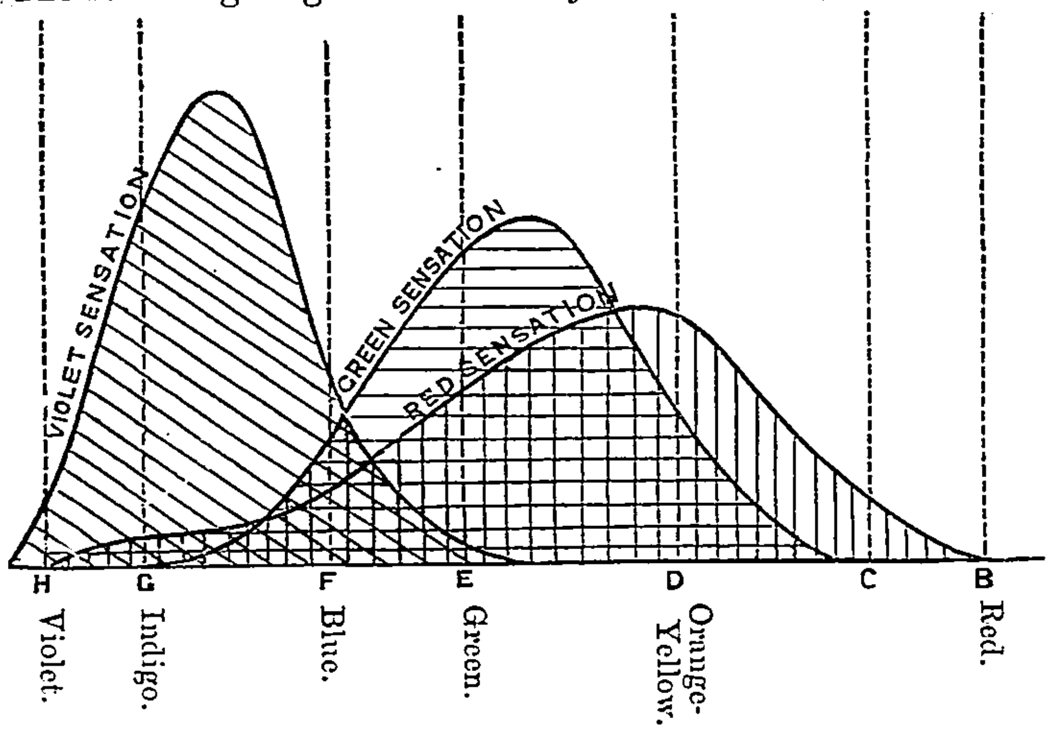


for yellow in the above description of red, orange, yellow, and yellow-green, the brightest red would be called dark green, and they would fail to see at all in the extreme red, the spectrum being shortened. These latter would also recognize a white or grey band, but it would be in a position rather nearer the blue of the spectrum than in the first case (*see* No. 3, Plate I). It is needless to say that to normal vision this white or grey band is non-existent, and whenever a person under examination sees such a band the evidence is conclusive that he is colour-blind. These differing descriptions of the spectrum show that this form of colour-blindness may be divided into two classes, which for convenience sake may be termed green- and red-blindness. Another point of difference between them is the part of the spectrum that appears brightest. To the normal eye it is the yellow, and to the green-blind it is nearly at the same place, but to the red-blind it is the green. This, perhaps, may give a clue to the designation of the spectrum colours by these two classes. To the green-blind, red and yellow are the same colour, but the yellow being the brighter he looks on red as degraded or darkened yellow. On the other hand, to the red-blind green is brighter than yellow or orange, and these appear as degraded green.

Experiment has shown that every colour in nature, as seen by a normal eye, can be expressed as a mixture of three, so that normal vision is tri-chromatic. In a similar sense the more pronounced types of ordinary colour-blind vision are di-chromatic. These colour relations must be regarded as purely subjective, for enough is now known of the nature of light to exclude the possibility of a three-fold physical constitution. In the theory of Young, subsequently, and independently, brought forward and developed by Helmholtz, light is supposed to be capable of exciting three distinct primary sensations, combined in varying proportions, and dependent upon the quality of the light. As to the character of the three sensations, Young identified them with red, green, and violet; and no widely-differing choice is possible, unless upon the supposition that the primary sensations, in their purity, are quite outside the range of our experience. The yellow of the spectrum, for example, cannot be primary, for it is capable of being matched by a suitable mixture of red and green. According to this view each primary sensation is excited in some degree by almost every ray of the spectrum; but the maxima occur at different places, and the stimulation in each case diminishes in both directions, as the position of maximum is receded from.

The Young-Helmholtz theory of colour-vision.

The following diagram will convey the idea of this theory :—



The lines with the letters B, C, D, &c., below the curves indicate certain fixed lines in the solar spectrum whose wave-lengths have been determined.

The different degrees of the stimulation given to each of the three sensations by every part of the spectrum is shown in the diagram by the heights of the curves above the horizontal base line. Thus in the middle of the spectrum, near E, each of the curves is to be found of a different height, and these degrees of stimulation of the three sensations, combined together, give the sensation of spectral green. It may be remarked that, on the scale adopted, the three sensations are supposed to be equally stimulated when white light is perceived. The areas of the three curves are therefore equal, and at the places in the spectrum where the curves are of the same height, the stimulation of the sensations is also the same. At the extreme red and extreme violet of the spectrum the curves of the red and violet sensations are alone to be found, hence at those parts the sensations are simple.

According to this theory, the two types of complete red-green-blindness are attributed to the absence of either the red, or else of the green sensation, the absence of the former corresponding to red-blindness, and of the latter to green-blindness. Where the violet and green curves cut, the red-blind person will see what to him is white, and where the red and violet curves cut the green-blind will also similarly describe his sensation of colour. To the normal eye these parts of the spectrum appear as bluish-green and green, as there is a stimulation of the green and violet sensations, or of the green alone, over and above that necessary to produce with the red sensation the mixed sensation of white.

In considering the question as to how far red-green blindness can be regarded as a *mere deficiency* in colour-perception, it is important to bear in mind that, according to recent observation, considerable deviations from the normal type may occur without any approach to colour-blindness. If we imagine a di-chromatic system be derived from an abnormal tri-chromatic system by the suppression of one sensation, it will differ from a di-chromatic system similarly derived from a normal system of colour-vision.

Violet colour-blindness.

Blindness to violet, and shortening of the violet end of the spectrum, have been described, but the instances are very few. One case of apparent violet-blindness of which the Committee have cognizance answers accurately to the Young-Helmholtz theory, on the supposition that the violet sensation is absent (*see* No. 4, Plate I).

Three other cases of congenital colour-blindness investigated by the Committee deserve special mention; two (brothers) in which there was but one sensation, answering probably to the violet sensation of the Young-Helmholtz theory, and the third in which the principal sensation was a pure green with perception of white and probably a slight trace of red. As these were all cases of congenital colour-blindness, they are mentioned as in some measure confirming the theory in question (*see* Note *a*).

Hering's theory of colour-vision.

Another theory, that of Hering, starts from the observation that when we examine our own sensations of light we find that certain of these seem to be quite distinct in nature from each other, so that each is something *sui generis*, whereas we easily recognise all other colour sensations as various mixtures of these. Thus, the sensation of red and the sensation of yellow are to us quite distinct: we do not recognise anything common to the two; but orange is obviously a mixture of red and yellow. Green and blue are equally distinct from each other and from red and yellow, but in violet and purple we recognise a mixture of red and blue. White again is quite distinct from all the colours in the narrower sense of that word, and black which we must accept as a sensation, as an affection of consciousness, even if we regard it as the absence of sensation from the field of vision, is again distinct from everything else. Hence the sensations, caused by different kinds of light or by the absence of light, which thus appear to us distinct, and which we may speak of as "native" or "fundamental" sensations, are white, black, red, yellow, green, blue. Each of these seems to us to have nothing in common with any of the others, whereas in all other colours we can recognise a mixture of two or more of these.

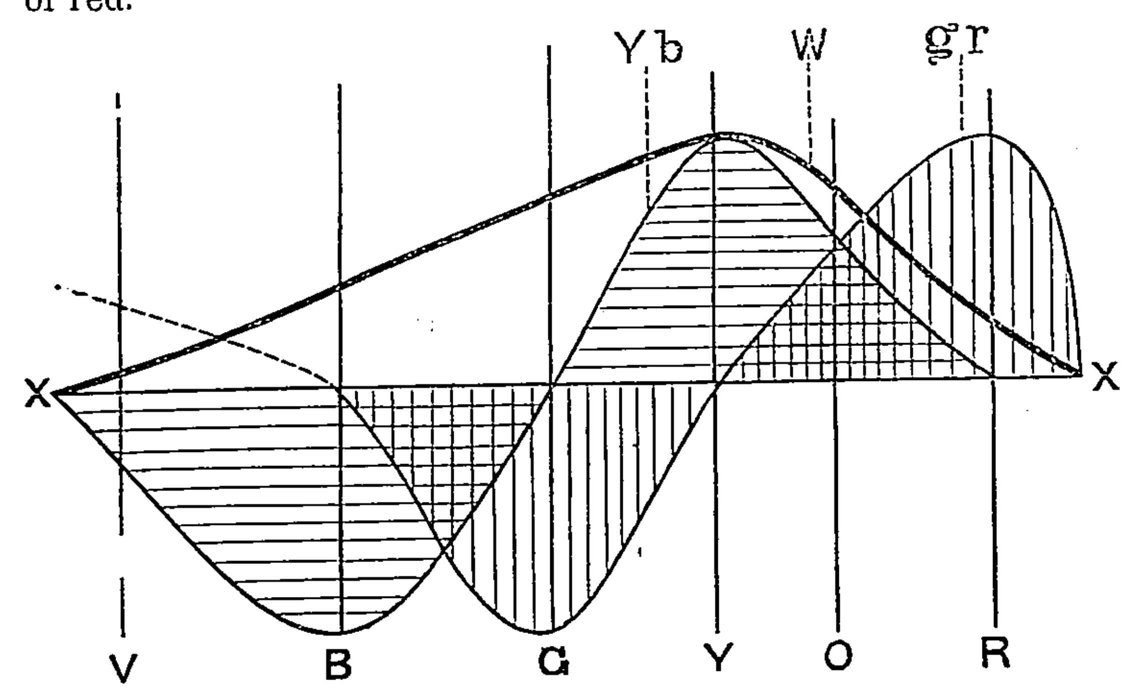
This result of common experience suggests the idea that these fundamental sensations are the primary sensations, concerning which we are inquiring. And Hering's theory attempts to reconcile, in some such way as follows, the various facts of colour-vision with the supposition that we possess these six fundamental sensations. The six sensations readily fall into three pairs, the members of each pair having analogous relations to each other. In each pair the one colour is complementary to the other; white to black, red to green, and yellow to blue.

Now, in the chemical changes undergone by living substances, we may recognise two main phases, an upward constructive phase in which matter previously not living becomes living, and a downward destructive phase in which living matter breaks down into dead or less living matter. Adopting this view we may, on the one hand, suppose that rays of light, differing in their wave-length, may affect the chemical changes of the visual substance in different ways, some promoting constructive changes (changes of assimilation), others promoting destructive changes (changes of dissimilation); and on the other hand, that the different changes in the visual substance may give rise to different sensations.

We may, for instance, suppose that there exists in the retina a visual substance of such a kind that when rays of light of certain wave-lengths—the longer ones for instance of the red side of the spectrum—fall upon it, dissimilative changes are induced or encouraged, while assimilative changes are similarly promoted by the incidence of rays of other wave-lengths, the shorter ones of the blue side. But, it must be remembered, that in dealing with sensations it is difficult to determine what part of the apparatus causes them; we may accordingly extend the above view to the whole visual apparatus, central as well as peripheral, and suppose that when rays of a certain wave-length fall upon the retina, they in some way or other, in some part or other of the visual apparatus, induce or promote dissimilative changes and so give rise to a sensation of a certain kind, while rays of another wave-length similarly induce or promote assimilative changes and so give rise to a sensation of a different kind.

The hypothesis of Hering applies this view to the six fundamental sensations spoken of above, and supposes that each of the three pairs is the outcome of a particular set of dissimilative and assimilative changes. It supposes the existence of what we may call a red-green visual substance, of such a nature that so long as dissimilative and assimilative changes are in equilibrium, we experience no sensation, but that when dissimilative changes are increased, we experience a sensation of (fundamental) red, and when assimilative changes are increased we experience a sensation of (fundamental) green. A similar yellow-blue visual substance is supposed to furnish, through dissimilative changes, a yellow, through assimilative changes a blue sensation; and a white-black visual substance similarly provides for a dissimilative sensation of white and an assimilative sensation of black. The two members of each pair are therefore not only complementary but also antagonistic. Further, these substances are supposed to be of such a kind that while the white-black substance is influenced in the same way, though in different degrees, by rays along the whole range of the spectrum, the two other substances are differently influenced by rays of different wave-length. Thus, in the part of

the spectrum which we call red, the rays promote great dissimilative changes of the red-green substance with comparatively slight effect on the yellow-blue substance; hence our sensation of red.



The vertical shading represents the red and green, and the horizontal shading the yellow and blue, antagonistic pairs of sensations. The thick line indicates the curve of the white sensation.

In that part of the spectrum which we call yellow the rays effect great dissimilative changes of the yellow-blue substance, but their action on the red-green substance does not lead to an excess of either dissimilation or assimilation, this substance being neutral to them; hence our sensation of yellow. The green rays, again, promote assimilation of the red-green substance, leaving the assimilation of the yellow-blue substance equal to its dissimilation; and similarly blue rays cause assimilation of the yellow-blue substance, and leave the red-green substance neutral. Finally, at the extreme blue end of the spectrum, the rays once more provoke dissimilation of the red-green substance, and by adding red to blue give violet. When orange rays fall on the retina, there is an excess of dissimilation of both the red-green and the yellow-blue substance; when greenish-blue rays are perceived there is an excess of assimilation of both these substances; and other intermediate hues correspond to varying degrees of dissimilation or assimilation of the several visual substances.

When all the rays together fall on the retina, the red-green and yellow-blue substances remain in equilibrium, but the white-black substance undergoes great changes of dissimilation; and we say the light is white.

According to this theory what are called red and green blindness are identical. The yellow-blue and white-black sensations remain, but the red-green sensation is absent in both. The white or grey seen in the spectrum would then be due to the white-black sensation, as it alone is stimulated at that point.* (*See* Note *b.*)

Colour-blindness caused by disease.

The kinds of colour-blindness so far alluded to are the congenital types, but there is another form of colour-blindness which is induced by disease or injury. The former is apparently by far the most common, and so far as we have ascertained, is incurable, but the latter may be induced at any period of life, and in very many cases is capable of improvement or cure.

Colour-blindness induced by disease or injury exhibits distinctive features of its own, which are not present in cases of congenital colour-blindness. It is usually confined to the central region of the retina, and the extent of the diseased area varies largely. Defective form-vision is an invariable accompaniment, and it can be usually diagnosed by the recognized tests. (For these tests *see* Appendix VI.) In several cases induced by excessive use of tobacco, as also in that induced by progressive atrophy of the optic nerve, the Committee have found in examinations made with the spectrum that the sensations of white and blue alone were perceived in the central portions of the retina. The blue seen corresponded with the blue region of the spectrum, and all other colours were described as white. In other cases, a faint yellow in the yellow portion of the spectrum was perceived together with the blue and white, as in the first-named cases (*see* No. 5, Plate I). That these sensations were rightly described is to be assumed from the fact that these persons when in health have normal vision, and also, that on healthy portions of the retina all colours stimulate the normal sensations. (*See* Appendix C.)

Statistics of colour-blindness.

The earlier statistics of defective colour-sense must be dismissed as untrustworthy, having been arrived at by various, and frequently by inaccurate methods of examination, and having, on the whole, a marked tendency to error in the direction of excess. The first on which reliance can be placed are probably those of Dr. Joy Jeffries, of Boston, U.S.A., who personally examined 19,183 male persons, mostly in educational institutions, and who found among them 802 colour-blind, or 4·12 per cent. Among 14,764 females, he found only 11 cases, or 0·0084 per cent. In 1880, the Ophthalmological Society of London appointed a Committee to inquire into the subject, and they found that amongst 14,846 males, 617 or 4·16 per cent. were colour-blind. Amongst 489 females, 0·4 per cent. were defective in colour-vision. The report of this Committee is contained in the first volume of the "Transactions" of the Society, and an extract from it will be found in Appendix I.

The Committee were furnished with some statistics regarding colour-blindness in two Japanese regiments. Out of 1,200 men examined, 19 were red-blind, 10 green-blind, 12 incompletely colour-blind, and 27 had weak colour-vision. This gives 3·4 per cent. of soldiers who were colour-defective, without including those who are classed as having weak colour-vision. The above statistics all point to the prevalence of colour-blindness amongst the male population, and to the fact that such defects are not confined to one nationality or race. The small percentage of colour-blindness found amongst women is remarkable, but as it does not enter into the questions on which the Committee have to report, it need not be further dwelt upon.

* Without deciding between these two theories, it has been found convenient to accept the terminology of the Young-Helmholtz theory.

Results and dangers of colour-blindness.

The Committee have already briefly alluded to the mistakes which congenitally colour-blind people are likely to make; but in order to emphasize it, they will enter rather more fully into the subject. In the first place, let it be remembered that to the red-blind and to the green-blind there is one green in the spectrum which they cannot distinguish from white, and which for convenience may be designated as their *neutral colour*. On the one side of this neutral band they see but green or red, more or less diluted with their neutral colour, and on the other side blue, also similarly diluted. The dilution increases as the neutral point is approached, and for some little distance on each side of it (unless a comparison with white be at hand) the dilution is so large that the colour may be mistaken for the neutral colour.

As all colours in nature, except purples, can be matched by the normal eye with some one spectrum colour (which we may call the *dominant colour*) more or less diluted with white light, we can, where the dominant spectrum colour of a signal is known, indicate in the terms used by a person possessing normal vision what each class of colour-blind would see.

Perhaps this is best shown as a tabulated statement:—

Colour of Signal.	To a Red-Blind Observer.	To a Green-Blind Observer.
Red.	Green.	Red.
Green, the dominant spectrum green being on the red side of the neutral band.	Green mixed with a large proportion of neutral colour.	Red mixed with a large proportion of neutral colour.
Green, the dominant spectrum green being at the neutral band of the red-blind.	Neutral colour.	Red mixed with a very large proportion of neutral colour.
Green, the dominant spectrum green being at the neutral band of the green-blind.	Blue mixed with a very large proportion of neutral colour.	Neutral colour.
Green, the dominant spectrum green being well on the blue side of the neutral band.	Blue mixed with a large proportion of neutral colour.	Blue mixed with a large proportion of neutral colour.
White.	Neutral colour.	Neutral colour.

The neutral colour on the Young-Helmholtz theory in the case of the red-blind, would be a peacock-green, and in that of the green-blind a purple.

The table shows that a signal exhibiting certain hues of green might be mistaken for a red one, since they both might appear to the one class green and to the other red; and that with one hue of green (differing slightly in the two cases, however) it would give the same sensation as white. In only one case, viz., that in which the dominant spectrum colour to the normal-eyed is well on the blue side of the neutral points, would the signals be distinctly different in colour.

Colours of railway signal glasses.

The following table gives the wave-length in the spectrum of the dominant colours of the signals which have been adopted by some of the principal railway companies when illuminated by (1st) a light of the whiteness of the arc electric light, which does not differ much from that of day-light, and (2nd) by gas-light. The percentage of white light mixed with the spectrum colour is also shown, together with the luminosity of the light transmitted. How closely the green signals approach to the neutral points of the completely colour-blind, when the mental standard of whiteness is that of daylight, can be well judged if it be remembered that these points lie between 5,200 and 4,900 for both types (*see* Note *c*, page 304).

	Glass.	Electric light.			Gas light.		
		Dominant wave-length in ten millionths of million (?)	Percentage of white light in colour.	Luminosity, naked light = 100.	Dominant wave-length.	Percentage of white light in colour.	Luminosity, naked light = 100.
Reds	Great Western ruby glass	6250	7	10·4	6275	12	13·1
	L.B.S.C.	6200	0	10·4	6200	0	13·0
	Great Northern	6250	0	9·0	6275	0	10·0
Greens	Great Western	4925	46	21·8	5070	50	18·1
	L.B.S.C.	4925	38	16·2	5050	34	12·5
	Great Northern	5100	61	19·2	5170	62	19·4
	Great Eastern	5000	54	15·0	5120	40	15·0
	Saxby and Farmer's, as ordinarily supplied where no special glass is ordered	4925	24	7·6	5050	22	6·9
	Bottle green glass (District Railway)	5500	32	9·1	5320	50	10·6

In a testing-room, when signal lights are used as tests, colour-blind persons may possibly be able, with practice, to name the different coloured signals correctly, recognizing them by their

relative brightness, and by their dilution with neutral colour. Thus, a bluish-green signal might be distinctly known by its blue hue, whilst if yellowish-green, it might be recognized by the neutral colour being slightly tinged with the only other spectrum colour which they see. Again, a green whose hue, whether pure or diluted with white, accurately coincides with that part of the spectrum where the neutral band is situated, might probably be mistaken for white, though, even from that, it might be distinguished by its lower luminosity. The practical tests the Committee have carried out confirm this view; men who are absolutely colour-blind having passed such a test without being detected. It might be supposed that if the colours of signals could be rightly recognized in the testing-room they would be equally well recognized elsewhere. It must, however, be recollected that the atmospheric conditions of the testing-room are often very different from those which are found outside. As a rule any judgment of the colour of a signal which depended upon its brightness would be fallacious. A dirty glass, or a misty atmosphere, would introduce a liability to error. The red signal of danger might then be mistaken for the green or white signal of safety, and *vice versâ.* It must also be remembered that a signal light, as a rule, has no white light adjacent to it with which to compare it, and thus a decision as to whether a light is neutral, or slightly coloured, has to be arrived at under great disadvantages. We shall presently call attention to the conditions which regulate the choice of the colours to be used as signals; here it is sufficient to say that, even if a green were used, whose dominant spectrum colour lay on the blue side of the neutral bands, mistakes might still occur, more particularly in certain conditions of foggy weather, when white light in its passage is deprived of the blue rays in greater proportion than the green, and the green in greater proportion than the red (*see* Note *d*, page 305).

Description of incomplete colour-blindness.

We have so far confined our attention to colour-blind vision of the dichromatic type. Incomplete colour-blindness is less likely to lead to accident than that which is complete; but any colour-blindness, in which there is approximately a neutral or grey point in the spectrum, should be regarded with great suspicion. On the other hand, there are many people who have a slightly shortened spectrum, who are yet able to distinguish all colours, and see no neutral point. These cannot be considered to be practically colour-blind. There are again others to whom the spectrum is considerably shortened, but not to the extent that it is in complete red-blindness, and they have what is apparently a neutral point in the spectrum, lying very close to that which is found in the complete colour-blind cases. The presence of this neutral colour points to such a degree of imperfection in colour sense that it must be classed as dangerously defective. A certain and prompt recognition of a green signal colour by these last would undoubtedly be difficult under some conditions of atmosphere, or if the mind were disturbed by some imminent danger.

Colour-blindness induced by disease.

In colour-blindness, induced by disease or injury, although the loss of colour sense is usually confined to a small area of the retina, yet, as it is the central area, and therefore the part on which the image of small objects naturally falls, the danger of mistaking a colour is as great, and even more so than in congenital colour-blindness; for loss of colour-sense is in this case as already has been stated accompanied by loss of form-sense.

Colour-blind persons should be rejected for certain occupations.

On the general grounds that have been explained, the Committee are of opinion that it would, under any circumstances, be dangerous to trust the reading of signals to anyone who is totally or even partially colour-blind to the extent indicated above, and this opinion is fortified by practical tests which they have carried out. They consider that such a person under no circumstances should be allowed to take a post for which this defect renders him physically unfit, and with this object in view the tests employed in the examination should be of a nature to at once detect, not only pronounced colour-blindness but defective colour-vision of the above character.

Most suitable colours for signals, and causes which modify their selection.

On some railways white lights instead of green have been used as safety signals, but the former are liable to be confounded with other white lights which are not signals, more particularly in the neighbourhood of towns. At sea the evidence shows that the use of a second coloured light in addition to a red is a necessity, and that a white light could not be substituted for it.

It has been suggested, on theoretical grounds, that all danger of misreading signals would be avoided by using for one a red and for the other a pure blue, as each of these colours is recognized by the red-green blind. Certain difficulties, however, present themselves in practice which preclude the employment of the blue, more especially for night signals. The desiderata for signals are, that they should be as bright as possible, and that their colour should be distinct when viewed at a distance. A red glass transmits about 10 per cent. of the luminosity of the lamp-light behind it; it is also a saturated colour, and appears unaltered in hue from whatever distance it may be viewed. A blue glass, as ordinarily met with, will appear purple, or even whitish, by lamp-light, as it transmits, besides blue, a large proportion of red rays, and, if it be pale, it will also transmit a variable quantity of all the colours of the spectrum: moreover, the luminosity of the light transmitted is, at the best, only some 4 per cent. of the naked light. If two glasses, one of blue-green and another of cobalt blue, be placed together, in front of the light, the red rays will be cut off, and the light will be a fairly pure blue, but the luminosity will be reduced to about 2 per cent. When the effect of foggy weather on the carrying power of different lights is considered (*see* Note *a*, page 303), it will be understood how this small luminosity will be again diminished, and that it will become practically *nil*. In making

the selection of signal colours, these facts have to be taken into account. The choice of a red light as a signal light is one in which theory and practice really agree, and it is in the selection of a colour for a second signal that the difficulty arises. The only colour for the latter, which the red-green blind would be able with certainty to distinguish from the red, is the pure blue, and this has been shown to be an impracticable choice. This being the case, the second signal should be of the kind most suitable for normal colour-vision without regard to the requirements of those who are colour-defective. Evidently for carrying power it should be as near the brightest part of the spectrum as possible, but far enough away from the red to render the signals easily distinguishable. A yellow or greenish-yellow is inadmissible, as it might be mistaken for a white light under some circumstances, as is also the case with those greens which, when sufficiently light to be effective, allow some red rays to pass.

Colours for signals adopted by railways.

It is for reasons such as these that most railway companies have adopted as a danger signal a rich ruby-red, and for a safety signal (where a white light is not used) a blue-green, which varies slightly in hue on different lines, as was shown in the table given at page 292.

Standard signal glasses used in Royal Navy.

The sealed pattern standards of red and green glasses used in the Royal Navy are the best that have come before the Committee, and they suggest their adoption both for railways and the mercantile marine. The sealed pattern green inclines to blue and cuts off all red light. The blue-green of the spectrum, when mixed with about 25 per cent. of white light, matches the hue of this glass, and owing to this comparatively small dilution it will also appear as a fairly saturated colour. Its luminosity also approaches that of the standard red light, which is very desirable.

Accidents through colour-blindness.

The direct evidence before the Committee is not sufficient to enable them to say that accidents, either by land or by water, have conclusively been traced to defective colour-vision, yet this by no means disproves the high probability that accidents have really occurred from such defects.* There can be no doubt that every colour-blind person employed afloat, or upon railways, in certain capacities, must of necessity be a source of danger to the public. As is known, colour-blindness is hereditary to a large extent, and we have it in evidence before us that in the training vessels in which the orphan children of sailors are educated there are about 4 per cent. of colour-blind boys. We may therefore take it, apart from all other evidence, that a considerable number of the fathers of these orphans who were employed as sailors must have suffered from the same defect; and we have it in direct evidence that a considerable number of colour-blind people, officers and seamen, are actually at sea at

* In Dr. Joy Jeffries' book on "Colour-blindness; its Dangers and its Detection," the case of the loss of the "Isaac Bell" is fairly conclusively traced to colour-blindness. Other cases are mentioned in Mr. Bickerton's evidence.

the present time. Allowing for those whose colour-vision has been found defective by the inadequate tests used, and who may not be afloat, it is certain that out of the 120,000 seamen who are employed, there must be a large number who are colour-defective, and consequently a source of danger to life. The statistics of the examinations of eyesight on railways, so far as they have come before the Committee, are eminently unsatisfactory. Although candidates for employment are occasionally rejected for defective colour-vision, yet the percentages of the rejections on different railways differ widely from each other, and from the average percentage of colour-blindness of the male population. The evidence taken on this subject points to these differences being due to the variation in efficiency of the tests employed, and the Committee have been forced to the conclusion that some men, whose vision is defective for colour and for form, are in all likelihood employed in positions where normal vision is essential for public safety.

The evidence, moreover, points to the fact that steps have not hitherto been taken (at least, as a rule) in judicial inquiries relating to the causes of accidents, to ascertain whether they were due to defective vision. The Committee are strongly of opinion that in cases of collision or accident, where the evidence is conflicting as to the recognition of a coloured light, witnesses should be examined both for colour- and form-sense.

The Committee have had before them evidence regarding the colour-vision testing of the marine service as laid down by the Board of Trade.

Board of Trade tests for colour-vision.

Tests may be divided into two classes: one dependent upon the correct naming of a colour, and the other on its correct appreciation. The first class are intended to combine with the detection of colour-blindness that of colour-ignorance, or the defective knowledge of the names of colours. The last class are intended to detect colour-blindness alone, colour-ignorance being independently tested. The tests which the Board of Trade have officially adopted, are described in Appendix II. The examination consists in requiring the examinee to name correctly the colours of cards by day-light, and of coloured glasses by lamp-light. The correct naming of the colours is alone insisted upon.

Naming colours, a defective test.

The Committee consider that the tests themselves and the method of applying them are necessarily open to very grave objection. The Board of Trade test cards and coloured glasses can be procured from dealers, and the Committee have no hesitation in saying that the colours may be correctly named in the testing room by colour-blind persons after a certain amount of instruction, which would consist in teaching them to distinguish the different cards or test glasses by their different luminosities. The glasses are red, pink, three kinds of green, yellow, neutral, standard blue, and pale blue, all of which are viewed by artificial light, usually that of an oil lamp. In trials made before the Committee, several people, whom Holmgren's test had proved to be colour-blind, passed this lantern test, a fact sufficient to show that it is unsafe to trust to it. But besides this uncertainty as to the rejection of the colour-blind, it appears to the Committee that an injustice may also be done to the candidates by its use. They believe that a perfectly normal-eyed person, who has been educated to observe colours, would not be able to speak positively as to the precise names of the colours of some of these glasses when illuminated by lamp-light. Less educated candidates would be much more liable to make mistakes in these puzzling tints (which the Committee consider have neither use nor significance), and, from sheer confusion, to misname those colours which are the only real tests, and thus to fail to pass the examination. The only safeguard to a candidate thus rejected lies in the fact that he can be re-examined, and that more than once. Cases have been brought before the Committee's notice where a candidate who has failed at first has passed in a subsequent examination. If the test for colour-blindness used by the Board of Trade were fair to the candidate, and perfectly efficient, such a re-examination would be unnecessary, and passing upon re-examination would be impossible.

Railway companies' tests.

The evidence given by representatives of various railway companies shows that very few have any adequate system of testing. Nearly all the methods employed are defective, and even where the wool-test is applied it usually breaks down from a choice of improper colours, both for standards and comparisons. In some instances, a person, whom the Committee know to have very defective colour-vision, has been passed in their presence by railway examiners as possessing normal eyesight, and the impression made on the Committee is that many have probably been passed into the service who should most certainly have been excluded.

Tests in the Royal Navy.

The Committee have had the opportunity of examining the different tests carried out by the Royal Navy, and are glad to find that they are most efficient, and of such a nature that it may be presumed that no one can pass them who is sufficiently defective in colour-vision to be any source of danger. The long periods over which the examination lasts, however, precludes the adoption in their entirety of these tests used for railways or the mercantile marine. The sealed pattern glasses for signals are excellent, and, as already stated, the Committee would suggest their adoption as the universal signal colours.

Tests for colour-blindness.

The Committee are of opinion that the tests for colour-blindness should be of such a character that they will readily determine whether a man is or is not colour-blind, but that, except for scientific purposes, it is not necessary that they should indicate what kind of mistakes he is likely to make. The fact that a person is found to be colour-blind by an efficient test, properly applied, is amply sufficient to show that his employment in certain occupations is a danger to the public. We lay some stress on this point, as, if it were required from the examiner that he should specify what would be the nature of a mistake that an examinee would be likely to make, it would open the door to controversy, and thus defeat the ends for which an examination is instituted. What should be required of the examiner is merely a statement that the candidate has either passed or failed in the examination. In cases of failure, where the candidate is under the impression that a mistake has been made, an appeal to some properly appointed expert should be allowed, and his decision should be final.

Tests recommended by the Committee.

The Committee have carefully considered the question as to what tests should be recommended for general adoption on railways and for the marine service.

They are of opinion that tests which involve the naming of colours should be avoided in deciding the question of colour-blindness. Failure to satisfy these tests may be due to colour-ignorance, and lead to the rejection of persons who are not really colour-blind. A candidate who fails should be informed to what cause his failure is due, whether to colour-blindness or to colour-ignorance, with a view to subsequent re-examination in the latter case. On the other hand, if the objects which the examinee is required to name are few in number and accessible to the public, since the chances are that no two of them are exactly alike even to a colour-blind person, he might be instructed as to the names which he is expected to give them, and thereby persons who are really and seriously colour-blind might be passed by the examiner as being free from any defect. Besides trustworthiness, the tests should be adapted for the examination of large bodies of men, and, provided efficiency be not sacrificed, they should be of an inexpensive nature. After practical trials, and also from theoretical considerations, the Committee are of opinion that the simplest efficient test is the wool-test of Holmgren, applied either in the form which Holmgren himself recommends, or in that of Jeaffreson, which is based on precisely the same principles.

Holmgren's test.

A full description of Holmgren's test, and of the proper methods of applying it, extracted from Holmgren's work on the subject, is given in Appendix III, page 375.

It is most important that the standard test-colours should be of a proper character both as to hue and also as to dilution with white, the efficiency of the test depending almost entirely on a proper selection. The Committee recommend that sealed patterns of all three test-colours should be kept by some central authority—such as the Board of Trade; and that every set of test-wools should be officially passed as fulfilling the necessary conditions as to these standard colours, and also as to the sufficiency and variety of confusion colours.

The standard test-colours which have been approved by Professor Holmgren have been referred to the spectrum. The first standard is a light green colour, which can be matched with a green in the spectrum (λ 5660), when 40 per cent. of white is added

The second standard skein is light purple or pink, and its complementary colour is a green in the spectrum λ 5100. The colour is diluted with about 40 per cent. of white. The third test-skein has a colour corresponding with a red of the spectrum (λ 6330) diluted with 18 per cent. of white.

Should an accident happen at any time to the standard sealed pattern skeins, the exact hues can be reproduced from the spectrum by a reference to these numbers. The Committee cannot conceal from themselves the fact that the wools are apt to deteriorate with use, both by the constant handling and also, to some extent, by light. In the test as carried out by Holmgren there is but little doubt that almost as much information is conveyed to the examiner by the way in which the different skeins are picked up to match the test-skein as by the absolute matching itself, and this procedure involves handling them and also exposure to light. The assortment of wools which is used in practical testing should therefore be renewed from time to time.

Jeaffreson's test.

In Jeaffreson's form of this test, which is given in Appendix IV, page 392, the handling of the colours is avoided, the match being made as there described. The hesitation evinced by the colour-blind in matching the test-colour is, in this instrument, also, of great utility to the examiner; moreover, it has been found practically that as many, or even more persons can be examined in a given time by it than by the original plan. The Committee are therefore of opinion that this modification may be admitted if desired by the examiner.

These wool-tests will detect red-, green-, and violet-blindness, and all other forms of congenital defective colour-vision. The matches of colours will indicate to the examiner the character and extent of the defect.

Examination on appeal.

In cases of appeal the examinations should take a wider range. The test with the spectroscope is decisive, and in Appendix V. is described a method of applying it which the Committee think may be convenient and satisfactory.

Tests to be avoided.

All tests in which the wools are suspended from a bar, even though the test-skeins may be of proper colour and tone, should be avoided, since the order of arrangement might be ascertained by some means or another by those who are tested. It is quite true that the order might be changed; but in an examination of this character, where large numbers may be under trial, any frequent changing of the order would be impracticable, and hence there would be no security that the test was efficient. The same objection applies to all diagrams of colours which the examinees are required to match with standard colours. Coaching here is even more easily carried out than with the suspended wools, since the diagrams are in the market, and the tints cannot be changed in position.

Other tests.

There are some other efficient tests that are less adapted for examining large bodies of men than the wool-tests, but which may be well applied to demonstrate the presence of colour-blindness in individual cases. Those of Dr. Grossmann are a good example of this class of test. An opinion has been expressed, and with some plausibility, that the only fair tests by which to prove that a man's colour-vision renders him unfit to distinguish coloured lights or signals are the coloured lights themselves when seen under the same circumstances as those under which they would have to be observed. It has already been shown that, with practice, it may be possible for a colour-blind person to distinguish between colours by their different luminosities and dilution with white, but it has also been pointed out that such recognition would be rendered uncertain by differing states of the atmosphere and by other conditions. If it were possible to eliminate the chances of correct guessing, which would be very large when using such tests, it would be necessary that the examination should be a prolonged one, being repeated many times with differing conditions of weather. If it were not carried to this extent, it might equally well be conducted in a testing room, where the apparent size of the signals to the eye could be imitated with great exactness. But the uncertainty of this method, even when the variable factor of weather is absent, is exemplified by the results of the examination of railway employés at Swindon, conducted by the Committee. They found, as already stated (*see* Appendix VII), that several passed the lamp-test who had failed to pass the wool-test, and that some passed one lamp-test, but failed to pass another similar one on the same occasion. Had the examination of these men been to ascertain their fitness for certain employments requiring normal colour-vision, and been conducted by the lamp-test only, some would have been admitted into the service, and have been a source of danger to the public.

Colour-ignorance.

The Committee have had to consider whether what has been called colour-ignorance, that is, ignorance as to the names of colours, is as objectionable as colour-blindness for certain employments. The possibility of the existence of real colour-ignorance, such as would lead to a non-recognition of the true colour of a signal, appeared to them very doubtful until they had taken the evidence of Staff-Surgeon Preston, R.N.; for it was hard to conceive of ignorance which would lead to confusion in naming a red, a green, and a white signal. His evidence, however, was conclusive of its existence at certain recruiting centres, and more especially in a certain class of recruit. It may be mentioned that in the actual testing of large bodies of men by the Committee, in no case was there a trace of colour-ignorance exhibited by those possessing normal vision, unless in regard to nondescript colours. Red, green, blue, and white were always correctly named, except where the person examined was proved to be colour-deficient.

There is one type of colour-ignorance which of course may often be encountered; a foreigner on board an English-commanded vessel, would be, practically speaking, colour-ignorant if he were unable to name the colours in English. It is in evidence before us that in navigation it is often requisite that the look-out man should, without a moment's delay, pass to the officer in charge the name of the colour of a light, and that hesitation, whether caused by true colour-ignorance or from want of knowledge of English terms, might involve disaster. This being the case, the Committee are strongly of opinion that for the marine services the examination for colour-vision should exclude not only men who are colour-blind within the limits already indicated, but also those who are colour-ignorant, whether from defective education or from want of knowledge of the English names. No man should be accepted as a look-out unless he were found capable of naming the signal colours correctly and intelligibly, and without hesitation.

Ignorance of the names of signal colours should be a bar to employment.

Tests for colour-ignorance.

The tests which the Committee recommend for the detection of colour-ignorance are very simple. After the tests for colour-blindness have been satisfactorily passed it would suffice to ask the examinees to name the reds and greens of the wool-tests, and if any hesitation was evinced to test them with a lantern-test, such as that proposed by Mr. Galton. Men rejected for colour-ignorance of either type should not be considered permanently ineligible, but only until such time as their education in the subject was perfected, for it must be recollected that, unlike colour-blindness, colour-ignorance is curable.

Re-testing in the marine and railway services.

In the marine service, it appears that on each stage of promotion an officer is tested as to his colour-vision. On some railways also, on promotion, an employé's eyesight is re-tested. It does not appear that such tests are undertaken with the idea that colour-blindness of the congenital type may have become more pronounced, or may have induced it by disease, but rather with the view that those who have been previously tested may have been passed improperly. No doubt these re-examinations are a safeguard; but if the tests already passed had been such as to render detection a certainty, there would be no necessity for repetition except for the detection of such colour-blindness as may be due to disease, injury, or over-use of tobacco. Colour-blindness due to these last causes is at first very seldom appreciated by the sufferer, and is usually only discovered upon his consulting a medical man for impaired form-sense. This raises the question as to whether defective colour-sense other than congenital might not, in some cases, be found in those on whom the lives of passengers and others depend.

Tests for colour-blindness induced by disease.

Special tests for colour-blindness induced by disease will very rarely be necessary if, as should always be the case, every examination for colour-vision is preceded by one for form. These latter tests are so well known, that the Committee do not think it necessary to enumerate them. If a candidate is found to have defective form-vision of a pronounced type he certainly should be ineligible for the positions of responsibility from which colour-blind persons should be excluded, and the test for form-vision would as a rule therefore exclude the colour-blind of this type (*see* Appendix VI). It should be remarked that it is quite possible that the Holmgren wool-test might be passed satisfactorily by colour-blind people of this type, more particularly when the diseased area is confined to a small central spot in the retina; in fact, this has happened twice in the presence of the Committee.* The Committee would therefore rely rather on the form-test being stringently carried out, than on instituting another colour-test for this particular class of colour-blindness.

Persons to be entrusted with examination.

The qualification to be required from the examiners has received the careful consideration of the Committee. An examiner both in the railway and in the marine services would be called upon to carry out not only the tests for colour-vision but also those for form, and the Committee are of opinion that he should be required to obtain a certificate of competency from some duly constituted authority. Testing, such as we have recommended, requires careful training, and is not to be learnt except by practice, for it requires not only a registration of absolute mistakes, but also a ready observation of the manner in which the candidate acts whilst under examination. The Committee would not insist upon the examiner being a medical practitioner, but it is probable that a medical training would be of advantage. They are further of opinion that there should be a periodic inspection of the different testing stations by duly qualified ophthalmic surgeons, who should report upon the condition of the testing appliances and upon the mode in which the tests are carried out; and who might be the authorities to whom an appeal from a rejected candidate should be referred.

In no case should any test be allowed in substitution of those recommended, though supplementary tests might be tried if desired. The passing or rejection of the candidates should always be based on the tests which have been laid down.

Periodic examination.

As colour-blindness of the congenital character is never acquired, it is unnecessary that any one who has already been examined for colour-vision by efficient tests should be re-examined. But as tobacco-blindness is not uncommon, the form-sense of those men whose failure in vision would be dangerous to the safety of the public should be tested periodically, say, once every three years.

Persons to be examined.

The Committee are not prepared to give a list of those posts from which the colour-blind should be excluded. Pilots, look-out men and officers on board ship; engine-drivers, firemen and signal-men on railways, evidently require sight unaffected by defects in colour or form, and there may be other positions, both in the marine service and in that of railways, which should also be included. Some central authority should make a schedule of such positions, and should take measures to enforce the exclusion of colour-blind persons from them.

* Captain Abney prepared for the Committee pellets of baked clay of about $\frac{1}{5}$ inch diameter, coated with pigments in distemper of the same hues as those of the wools in the Holmgren test. The images of these small pellets fill such a minute area of the retina that those colour-blind persons were unable to pick out from a small trayful of them correct matches to any of the standard test colours, though they were perfectly able to pick out all those coloured with any shade of blue with ease. As stated above, they passed the ordinary wool-test, the colours being readily distinguished outside the diseased central retinal area.

Note (*a*).

Cases of abnormal colour-blindness.

The cause of the different sensations which are conveyed to the brain is a matter which is still in doubt. It is difficult to conceive that matter which is so comparatively gross as the rods and cones which are situated on the retina can be affected by the merely mechanical action of the vibrations of light.

The little we know about the actual nature of sensations leads us rather to believe that the nervous processes which are the foundation of sensations are, like other nervous processes, the outcome of chemical changes in nervous substances. And it has been suggested that vision originates in the chemical changes of a certain substance (or substances) in the retina, that the chemical condition of this substance, which has been called visual substance, is especially affected by the incidence of light, and that the changes so induced determine the beginnings of visual impulses and thus of visual sensations. We know that light can decompose a substance by acting on its molecules, and thus induce a chemical change in it.

In photographic processes, for instance, we know that the molecules of the sensitive substance are split up by white light, and further, that when these comparatively simple substances are exposed to the spectrum, although it is found that a considerable extent of it produces chemical changes, there is one particular part which acts more strongly than the rest of it. The curve of sensitiveness exhibits the same characteristics as those of the colour sensations in the Young-Helmholtz theory. If it be conceded that the retinal substance acted upon by light is a mixture of three analogous compounds, each having a maximum sensitiveness at a different point of the spectrum, we can account for the three fundamental sensation curves shown in the diagram at page 286.

Note (*b*).

Any complete theory of colour-vision must account not only for normal vision and congenital colour-blindness, but also for those cases of defective colour-sense which are due to disease or injury, and which differ so widely in character from each other.

Difficulties of accounting

It is somewhat difficult to see how the Young-Helmholtz theory accounts for the last species of colour-blindness. According-

for colour-blindness induced by disease by the Young-Helmholtz theory.

ing to this theory, the mixed sensations of red, green, and violet produce the sensation of white light; but evidently in the cases where colour is absent in every part of the spectrum except in the blue—the rest being seen as white—some different explanation is required. Or again, if we take into account the fact that at a certain distance from the centre of the retina all sensation of colour, varying according to its luminosity and its hue, is lost, though light is still seen, the ordinary application of the theory cannot be insisted upon.

Hering's theory and colour-blindness induced by disease.

It may seem that Hering's theory is fully capable of explaining most of these phenomena, but there are facts against its acceptance which are very weighty. For instance, according to this theory, the sensations of red and green, and of yellow and blue, ought always to be present together, but in some cases of colour-blindness caused by over-use of tobacco, and atrophy of the optic nerve, the blue is the only colour sensation felt, the yellow being absent from that part of the spectrum in which it should be present. Again, when the intensity of the light producing the spectrum is reduced the sensation of red disappears long before that of green, which shows that the two sensations are not always co-existent. The shortened spectrum of what are called the red-blind is also opposed to the theory, for the luminosity of the green is proportionally much greater to them than the red than it is to the green-blind.

Note (*c*).

The neutral point of the spectrum will vary in all cases of colour-blindness according to the whiteness of the light with which the spectrum is compared. Even to the normal eye there is a ray near the yellow which can match very closely indeed the light of a gas lamp or candle, though there is none which matches the whiteness of ordinary day- or sun-light. Now a match made by the normal eye of a coloured light with some ray of the spectrum will be equally a match to the colour-blind of either type, since in both the colour and its match in the spectrum the same one sensation will be absent. It therefore follows that their neutral point, with a candle or oil lamp as a standard of whiteness, must be the same yellow ray, but to the red-blind this ray would appear greenish if compared with the white of day-light, and to the green-blind reddish. If the mental picture of white light were that of day-light, then evidently the green signal light would have to be much bluer to the colour-blind than to the normal eye, to prevent a confusion between it and their neutral colour than would have to be the case when lamp-light is the mental image of white light. In testing a large number of men by lamp-light it was invariably found that its light was always called yellow or orange by the normal-eyed, and we may therefore suppose that the general idea of whiteness is derived from

Shift of the neutral point in the spectrum caused by different qualities of white light.

day-light. As this is the case with the normal-eyed, it may be assumed that the same mental standard of whiteness would be adopted by the colour-blind.

Note (*d*).

Effect of fog on the colour of signals.

In discussing the most suitable colour of signals, the question of the possible alteration of hue by the interposition of fog between them and the observer must be taken into account. There are white fogs and yellow fogs, the difference between the two being chiefly in the size of the particles of water, dust, or soot which are to be found in them. In a white fog away from large towns the particles are chiefly water, but whilst the great majority must be large compared with the length of a wave of light, yet some will be present which are very much smaller. In a yellow fog the fine particles are much more largely present, and the yellowness is largely due to this fact, for when particles, whose sizes are comparable to a wave-length of light, are present between the source of light and the observer, the law of scattering requires that the blue part of the spectrum of the light reaching the latter should be much more enfeebled than the green, the green than the yellow, and the yellow than the red. A blue-green signal glass will therefore appear rather less blue in a white fog, and even yellowish-green in a yellow fog, and it may happen that the loss of what are blue and green to the normal eye will shift the colour of the signal to the red side of the neutral point in the spectrum of each type of a colour-blind person, and then both red and green signals will appear of the same tint to him, though the latter will appear more diluted with the neutral colour. It follows therefore that in a fog the liability of the colour-blind to mis-read signals is very much greater than in ordinary clear weather.