COLOUR-VISION AND COLOUR-BLINDNESS.[1]

IT is a matter of familiar knowledge that the sense of vision is called into activity by the formation, on the retina or internal nervous expansion of the eye, of an inverted optical image of external objects—an image precisely analogous to that of the photographic camera. The retina lines the interior of the eyeball over somewhat more than its posterior hemisphere. It is a very delicate transparent membrane, about one-fifth of a millimetre in thickness at its thickest part, near the entrance of the optic nerve, and it gradually diminishes to less than half that thickness at its periphery. It is resolvable by the microscope into ten layers, which are united together by a web of connective tissue, which also carries blood-vessels to minister to the maintenance of the structure. I need only refer to two of these layers: the anterior or fibre-layer, mainly composed of the fibres of the optic nerve, which spread out radially from their point of entrance in every direction, except where they curve around the central portion of the membrane; and the perceptive layer, which, as viewed from the interior of the eyeball, may be likened to an extremely fine mosaic, each individual piece of which is in communication with a nerve fibre, by which the impressions made upon it are conducted to the brain. The terminals of the perceptive layer are of two kinds, called respectively rods and cones; the former, as the name implies, being cylindrical in shape, and the latter conical. The bases of the cones are directed towards the interior of the eye, so as to receive the light; and it is probable that each cone may be regarded as a collecting apparatus, calculated to gather together the light which it receives, and to concentrate this light upon its deeper and more slender portion, or posterior limb, which is believed to be the portion of the whole structure which is really sensitive to luminous impressions. The distribution of the two elements differs greatly in different animals; and the differences point to corresponding differences in function. The cones are more sensitive than the rods, and minister to a higher acuteness of vision. In the human eye, there is a small central region in which the perceptive layer consists of cones only, a region which the fibres avoid by curving round it, and in which the other layers of the retina are much thinner than elsewhere, so as to leave a depression, and are stained of a lemon-yellow colour. In a zone immediately around this yellow spot each cone is surrounded by a single circle of rods; and, as we proceed outwards towards the periphery of the retina, the circle of rods around each cone becomes successively double, triple, quadruple, or even more numerous. The yellow spot receives the image of the object to which the eye is actually directed, while the images of surrounding objects fall upon zones which surround the yellow spot; and the result of this arrangement is that, generally speaking, the distinctness of vision diminishes in proportion to the distance of the image of the object from the retinal centre. The consequent effect has been well described by saying that what we see resembles a picture, the central part of which is exquisitely finished, while the parts around the centre are only roughly sketched in. We are conscious that these outer parts are there; but, if we desire to see them accurately, they must be made the objects of direct vision in their turn.

The indistinctness with which we see lateral objects is so completely neutralized by the quick mobility of the eyes, and by the manner in which they range almost unconsciously over the whole field of vision, that it seldom or never forces itself upon the attention. It may be conveniently displayed by means of an instrument called a perimeter, which enables the observer to look steadily at a central spot, while a second spot, or other object, is moved along an arc, in any meridian, from the circumference of the field of view towards the centre, or *vice versâ*. Slight differences will be found between individuals; but, speaking generally, a capital letter one-third of an inch high, which is legible by direct vision at a distance of sixteen feet, and is recognizable as a dark object at 40° or 50° from the fixing point, will not become legible, at a distance of one foot, until it arrives within about 10°.

The image formed upon the retina is rendered visible by two different conditions—that is to say, by differences in the amount of light which enters into the formation of its different parts, and by differences in the quality of this light, that is, in its colour. The former conditions are fulfilled by an engraving, the latter by a painting. It is with the latter conditions only, and with the power of perceiving them, that we are concerned this evening.

Before such an audience as that which I have the honour to address, it is unnecessary to say more about colour than that it depends upon the power, possessed by the objects which we describe as coloured, to absorb and retain certain portions of white or other mixed light, and to reflect or transmit other portions. The resulting effect of colour is the impression produced upon the eye or upon the brain by the waves of light which are left, after the process of selective absorption has been accomplished. Some substances absorb two of the three fundamental colours of the solar spectrum, others absorb one only, others absorb portions of one or more. Whatever remains is transmitted through the media of the eye; and, in the great majority of the human race, suffices to excite the retina to a characteristic kind of activity. Few things are more curious than the multitude of different colour sensations which may be produced by the varying combinations of the three simple elements, red, green, and violet; but this is a part of the subject into which it would be impossible for me now to enter, and with which most of those who hear me must already be perfectly familiar.

Apart from the effect of colour as one of the chief sources of beauty in the world, it is manifest that the power of distinguishing it adds greatly to the acuteness of vision. Objects which differ from their surroundings by differences of colour are far more conspicuous than those which differ only by differences of light and shade. Flowers are much indebted to their brilliant colouring for the visits of the insects by which they are fertilized; and creatures which are the prey of others find their best protection in a resemblance to the colours of their environment. It is probably a universal truth that the organs of colour-perception are more highly specialized, and that the sense of colour is more developed, in all animals, in precise proportion to the general acuteness of vision of each.

From a variety of considerations, into which time will not allow me to enter, it has been concluded that the sense of colour is an endowment of the retinal cones, and that the rods are sensitive only to differences in the quantity of the incident light, without regard to its quality. Nocturnal mammals, such as mice, bats, and hedgehogs, have no cones; and cones are less developed in nocturnal birds than in diurnal ones. Certain limitations of the human colour sense may almost be inferred from the anatomy of the retina. It is found, as that anatomy would lead us to suppose, that complete colour sense exists only in the retinal centre, or in and immediately around the yellow spot region, and that it diminishes as we pass away from this centre towards the periphery. The precise facts are more difficult to ascertain than might be supposed; for, although it is easy to bring coloured objects from the circumference to the centre of the field of vision on the perimeter, it is by no means easy to be quite sure of the point at which the true colour of the advancing

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object can first be said to be distinctly seen. Much depends, moreover, on the size of this advancing object; because, the larger it is, the sooner will its image fall upon some of the more sparsely distributed cones of the peripheral portion of the retina. Testing the matter upon myself with coloured cards of the size of a man's visiting card, I find that I am conscious of red or blue at about 40° from the fixing point, but not of green until it comes within about 30°; while, if I take three spots, respectively of bright red, bright green, and bright blue, each half a centimetre in diameter, and separated from its neighbour on either side by an interval of half a centimetre, spots which would be visible as distinct and separate objects at eight metres, I cannot fairly and distinctly see all three colours until they come within 10° of the centre. Beyond 40°, albeit with slight differences between individuals, and on different meridians for the same individual, colours are only seen by the degree of their luminosity—that is, they appear as light spots if upon a dark ground, and as dark spots if upon a light ground. Speaking generally, therefore, it may be said that human vision is only trichromatic, or complete for the three fundamental colours of the solar spectrum, over a small central area, which certainly does not cover more than 30° of the field; that it is bi-chromatic, or limited to red and violet, over an annulus outside this central area; and that it is limited to light and shade from thence to the outermost limits of the field.

The nature and limitations of the colour-sense in man long ago suggested to Thomas Young that the retina might contain three sets of fibres, each set capable of responding to only one of the fundamental colours; or, in other words, that there are special nerve fibres for red, special nerve fibres for green, and special nerve fibres for violet. It has also been assumed that the differences between these fibres might essentially consist in the ability of each set to respond only to light-vibrations of a certain wave-length, much as a tuned string will only respond to a note with which it is in unison. In the human subject, so far as has yet been ascertained, no optical differences between the cones are discoverable; but the analogy of the ear, and the facts which have been supplied by comparative anatomy, combine to render Young's hypothesis exceedingly probable, and it is generally accepted, at least provisionally, as the only one which furnishes an explanation of the facts. It implies that elements of all three varieties are present in the central portion of the retina; that elements sensitive to green are absent from an annulus around the centre; and that the peripheral portions are destitute of any elements by which colour-sense can be called into activity.

According to the observation already made, that the highest degree of acuteness of vision is necessarily attended by a corresponding acuteness of colour-sense, we should naturally expect to find such a highly-developed colour-sense in birds, many of which appear, as regards visual power, to surpass all other creatures. I need not dwell upon the often-described acuteness of vision of vultures, or upon the vision of fishing birds; but may pass on to remark that the acuteness of their vision appears not only to be unquestionable, but also to be much more widely diffused over the retina than is the case with man. If we watch domestic poultry, or pigeons, feeding, we shall frequently see a bird, when busily picking up food immediately in front of its beak, suddenly make a lateral dart to some grain lying sideways to its line of sight, which would have been practically invisible to a human eye looking in the same direction as that of the fowl. When we examine the retina the explanation both of the acuteness of vision and of its distribution becomes at once apparent. In birds, in some reptiles, and in fishes, not only are cones distributed over the retina much more abundantly and more evenly than in man, but the cones are provided with coloured globules, droplets of coloured oil, at their apices, through which the light entering them must pass before it can excite sensation, and which are practically impervious to any colour but their own. Each globule is so placed as to intervene between what is regarded as the collecting portion of the cone and what is regarded as its perceptive portion in such a way that the latter can only receive colour which is capable of passing through the globule. The retinæ of many birds, especially of the finch, the pigeon, and the domestic fowl, have been carefully examined by Dr. Waelchli, who finds that near the centre green is the predominant colour of the cones, while among the green cones red and orange ones are somewhat sparingly interspersed, and are nearly always arranged alternately, a red cone between two orange ones, and *vice versâ*. In a surrounding portion, called by Dr. Waelchli the red zone, the red and orange cones are arranged in chains, and are larger and more numerous than near the yellow spot; the green ones are of smaller size, and fill up the interspaces. Near the periphery the cones are scattered, the three colours about equally numerous and of equal size, while a few colourless cones are also seen. Dr. Waelchli examined the optical properties of the coloured cones by means of the micro-spectroscope, and found, as the colours would lead us to suppose, that they transmitted only the corresponding portions of the spectrum; and it would almost seem, excepting for the few colourless cones at the peripheral part of the retina, that the birds examined must have been unable to see blue, the whole of which would be absorbed by their colour globules. It would be necessary to be thoroughly acquainted with their food in order to understand any advantage which the birds in question may derive from the predominance of green, red, and orange globules over others; but it is impossible to consider the structure thus described without coming to the conclusion that the birds in which it exists must have a very acute sense of the colours corresponding to the globules with which they are so abundantly provided, and that this colour-sense, instead of being localized in the centre, as in the human eye, must be diffused over a very large portion of the retina. Dr. Waelchli points out that the coloration of the yellow spot in man must, to a certain extent, exclude blue from the central and most sensitive portion of his retina.

It is hardly necessary to mention how completely the high differentiation of the cones in the creatures referred to tends to support the hypothesis of Young, that a similar differentiation, although not equally manifest, exists also in man. If this be so, we must conclude that the region of the yellow spot contains cones, some of which are capable of being called into activity by red, others by green, and others by violet; that a surrounding annulus contains no cones sensitive to green, but such as are sensitive to red or to violet only; and that, beyond and around this latter region, such cones as may exist are not sensitive to any colour, but, like the rods, only to differences in the amount of light. When cones of only one kind are called into activity, the sensation produced is named red, green, or violet; and, when all three varieties are stimulated in about an equal degree, the sensation produced is called white. In the same way, the innumerable intermediate colour-sensations of which the normal eye is susceptible, must be ascribed to stimulation of the three varieties of cones in unequal degrees.

The conditions of colour-sense which, in the human race, or at least in civilized man, exist normally in outer zones of the retina, are found, in a few individuals, to exist also in the centre. There are persons in whom the region of the yellow spot is absolutely insensitive to colour, and recognizes only differences in the amount or quantity of light. To such persons, the term "colour-blind" ought perhaps in strictness to be limited; but the individuals in question are so rare that they are hardly

entitled to a monopoly of an appellation which is conveniently applied also to others. The totally colour-blind would see a coloured picture as if it were an engraving, or a drawing in black and white, and would perceive differences between its parts only in the degree in which they differed in brightness.

A more common condition is the existence, in the centre of the retina, of a kind of vision like that which normally exists in the zone next surrounding it—that is, a blindness to green. Persons who are blind to green appear to see violet and yellow much as these are seen by the normal-sighted; and they can see red, but they cannot distinguish it from green. Others, and this form is more common than the preceding, are blind to red; and a very small number of persons are blind to violet. Such blindness to one of the fundamental colours may be either complete or incomplete—that is to say, the power of the colour in question to excite its proper sensation may be either absent or feeble. In some cases, the defect is so moderate in degree as to be adequately described by the phrase "defective colour-sense."

The experiments of Helmholtz upon colour led him to supplement the original hypothesis of Young by the supposition that the special nerve elements excited by any one colour are also excited in some degree by each of the other two, but that they respond by the sensation appropriate to themselves, and not by that appropriate to the colour by which they are thus feebly excited. This, which is often called the Young-Helmholtz hypothesis, assumes that the pure red of the spectrum, while it mainly stimulates the fibres sensitive to red, stimulates in a less degree those which are sensitive to green, and in a still less degree those which are sensitive to violet, the resulting sensation being red. Pure green stimulates strongly the green-perceptive fibres, and stimulates slightly both the red-perceptive and the violet-perceptive—resulting sensation, green. Pure violet stimulates strongly the violet-perceptive fibres, less strongly the green-perceptive, least strongly the red-perceptive—resulting sensation, violet. When all three sets of fibres are stimulated at once, the resulting sensation is white; and when a normal eye is directed to the spectrum, the region of greatest luminosity is in the middle of the yellow; because, while here both the green-perceptive and the red-perceptive fibres are stimulated in a high degree, the violet-perceptive are also stimulated in some degree.

According to this view of the case, the person who is red-blind, or in whom the red-perceptive fibres are wanting or paralyzed, has only two fundamental colours in the spectrum instead of three. Spectral red, nevertheless, is not invisible to him, because it feebly excites his green-perceptive fibres, and hence appears as a saturated green of feeble luminosity; saturated, because it scarcely at all excites the violet-perceptive fibres. The brightest part of the spectrum, instead of being in the yellow, is in the blue-green, because here both sets of sensitive fibres are stimulated. In the case of the green-blind, in whom the fibres perceptive of green are supposed to be wanting or paralyzed, the only stimulation produced by spectral green is that of the red-perceptive and of the violet-perceptive fibres; and where these are equally stimulated, we obtain the white of the green-blind, which, to ordinary eyes, is a sort of rose-colour, a mixture of red and violet. In like manner, the white of the red-blind is a mixture of green and violet; and, if we consider the facts, we shall see that spectral red, which somewhat feebly stimulates the green-perceptive fibres of the normal eye, and spectral green, which somewhat feebly stimulates the red-perceptive fibres of the normal, and also of the green-blind eye, must appear to the green-blind to be one and the same colour, differing only in luminosity, and that in an opposite sense to the perception of the red-blind. In other words, red and green are undistinguishable from each other, as colours, alike to the red-blind and to the green-blind; but to the former the red, and to the latter the green, appears, as compared with the other, to be of feeble luminosity. In either case, the two are only lighter and darker shades of the same colour. The conditions of violet-blindness are analogous, but the defect itself is very rare; and, as it is of small industrial importance, it has attracted but a small degree of attention.

Very extensive investigations, conducted during the last few years both in Europe and in America, have shown that those which may be called the common forms of colour-blindness, the blindness to red and to green, exist in about four per cent. of the male population, and in perhaps one per thousand of females. Among the rest, there are slight differences of colour-sense, partly due to differences of habit and training, but of little or no practical importance. One such difference, to which Lord Rayleigh was the first to direct attention, has reference to yellow. The pure yellow of the spectrum may, as is generally known, be precisely matched by a mixture of spectral red with spectral green; but the proportions in which the mixture should be made differ within certain limits for different people. The difference must, I think, depend upon differences in the pigmentation of the yellow spot, rather than upon any defect in the nervous apparatus of the colour-sense. There is a very ingenious instrument, invented by Mr. Lovibond, and called by him the "tintometer," which allows the colour of any object to be accurately matched by combinations of coloured glass, and to be expressed in terms of the combination. In using this instrument, we not only find slight differences in the combinations required by different people, but also in the combinations required by the two eyes of the same person. Here, again, I think the differences must be due either to differences in the pigmentation of the yellow spot, or possibly also to differences in the colour of the internal lenses of the several eyes, the lens, as is well known, being usually somewhat yellow after middle age. The differences are plainly manifest in comparing persons all of whom possess tri-chromatic vision, and are not sufficient in degree to be of any practical importance.

Taking the ordinary case of a red-blind or of a green-blind person, it is interesting to speculate upon the appearance which the world must present to them. Being insensible to one of the fundamental colours of the spectrum, they must lose, roughly speaking, one-third of the luminosity of Nature; unless, as is possible, the deficiency is made good to them by increased acuteness of perception to the colours which they see. Whether they see white as we see it, or as we see the mixtures of red and violet, or of green and violet, which they make to match with it, we can only conjecture, on account of the inadequacy of language to convey any accurate idea of sensation. We have all heard of the blind man who concluded, from the attempts made to describe scarlet to him, that it was like the sound of a trumpet. If we take a heap of coloured wools, and look at them first through a glass of peacock-blue, by which the red rays are filtered out, and next through a purple glass, by which a large proportion of the green will be filtered out, we may presume that, under the first condition, the wools will appear much as they would do to the red-blind; and, under the second, much as they would do to the green-blind. It will be observed that the appearances differ in the two conditions, but that, in both, red and green are practically undistinguishable from each other, and appear as the same colour, but of different luminosity.

Prior to reflection, and still more, prior to experience, we should be apt to conjecture that the existence of colour-blindness in any individual could not remain concealed, either from himself or from those around him; but such a conjecture would be directly at variance with the truth. Just as it was reserved for Mariotte, in the reign of Charles II., to discover that there is, in the field of vision of every eye, a lacuna or blind spot, correspond-

ing with the entrance of the optic nerve, so it was reserved for a still later generation to discover the existence of so common a defect as colour-blindness. The first recorded case was described to Dr. Priestley by Mr. Huddart, in 1777, and was that of a man named Harris, a shoemaker at Maryport in Cumberland, who had also a colour-blind brother, a mariner. Soon afterwards, the case of Dalton, the chemist, was fully described, and led to the discovery of other examples of a similar kind. The condition was still, however, looked upon as a very exceptional one; insomuch that the name of "Daltonism" was proposed for it, and is still generally used in France as a synonym for colour-blindness. Such use is objectionable, not only because it is undesirable thus to perpetuate the memory of the physical infirmity of an eminent philosopher, but also because Dalton was a red-blind, so that the name could only be correctly applied to his particular form of defect.

Colour-blindness often escapes detection on account of the use of colour-names by the colour-blind in the same manner as that in which they hear them used by other people. Children learn from the talk of those around them, that it is proper to describe grass as green, and bricks or cherries as red; and they follow this usage, although the difference may appear to them so slight that their interpretation of either colour-name may be simply as a lighter or darker shade of the other. When they make mistakes, they are laughed at, and thought careless, or to be merely using colour-names incorrectly; and a common result is that they rather avoid such names, and shrink from committing themselves to statements about colour. Dr. Joy Jefferies gives an interesting description of the almost unconscious devices practised by the colour-blind in this way. He says:—

"The colour-blind, who are quick-witted enough to discover early that something is wrong with their vision by the smiles of their listeners when they mention this or that object by colour, are equally quick-witted in avoiding so doing. They have found that there are names of certain attributes they cannot comprehend, and hence must let alone. They learn, also, what we forget, that so many objects of every-day life always have the same colour, as red tiles or bricks, and the colour names of these they use with freedom; whilst they often, even unconsciously, are cautious not to name the colour of a new object till they have heard it applied, after which it is a mere matter of memory stimulated by a consciousness of defect. I have often recalled to the colour-blind their own acts and words, and surprised them by an exposure of the mental jugglery they employed to escape detection, and of which they were almost unaware, so much had it become matter of habit. Another important point is, that as violet-blindness is very rare, the vast majority of defective eyes are red or green blind. These persons see violet and yellow as the normal-eyed, and they naturally apply these colour-names correctly. When, therefore, they fail in red or green, a casual observer attributes it to simple carelessness—hence a very ready avoidance of detection. It does not seem possible that anyone who sees so much correctly, and whose ideas of colour so correspond with our own, cannot be equally correct throughout, if they will but take the pains to notice and learn."

When the colour-blind are placed in positions which compel them to select colours for themselves and others, or when, as sometimes happens, they are not sensitive with regard to their defect, but rather find amusement in the astonishment which it produces among the colour-seeing, the results which occasionally follow are apt to be curious. They have often been rendered still more curious, by having been the unconscious work of members of the Society of Friends. Colour-blindness is a structural peculiarity, constituting what may be called a variety of the human race; and, like other varieties, it is liable to be handed down to posterity. Hence, if the variety occurs in a person belonging to a community which is small by comparison with the nation, and among whose members there is frequent inter-marriage, it has an increased probability of being reproduced; and thus, while many of the best known of the early examples of colour-blindness, including that of Dalton himself, were furnished by the Society of Friends, the examinations of large numbers of scholars and others, conducted during the last few years, have shown that, in this country, colour-blindness is more common among Jews than among the general population. The Jews have no peculiarities of costume; but the spectacle, which has more than once been witnessed, of a venerable Quaker who had clothed himself in bright green or in vivid scarlet, could scarcely fail to excite the derision of the unreflecting. Time does not allow me to relate the many errors of the colour-blind which have been recorded; but there is an instance of a clerk in a Government office, whose duty it was to tick certain entries, in relation to their subject-matter, with ink of one or of another colour, and whose accuracy was dependent upon the order in which his ink-bottles were ranged in front of him. This order having been accidentally disturbed, great confusion was produced by his mistakes, and it was a long time before these were satisfactorily accounted for. An official of the Prussian Post-Office, again, who was accustomed to sell stamps of different values and colours, was frequently wrong in his cash, his errors being as often against himself as in his favour, so as to exclude any suspicion of dishonesty. His seeming carelessness was at last explained by the discovery of his colour-blindness, and he was relieved of a duty which it was impossible for him to discharge without falling into error.

The colour-mistakes of former years were, however, of little moment when compared with those now liable to be committed by engine-drivers and mariners. The avoidance of collisions at sea and on railways depends largely on the power promptly to recognize the colours of signals; and the colours most available for signalling purposes are red and green, or precisely those between which the sufferers from the two most common forms of colour-blindness are unable with any certainty to discriminate. About thirteen years ago there was a serious railway accident in Sweden, and, in the investigation subsequent to this accident, there were some remarkable discrepancies in the evidence given with regard to the colour of the signals which had been displayed. Prof. Holmgren, of the University of Upsala, had his attention called to this discrepancy, and he found, on further examination, that the witness whose assertions about the signals differed from those of other people was actually colour-blind. From this incident arose Prof. Holmgren's great interest in the subject, and he did not rest until he had obtained the enactment of a law under which no one can be taken into the employment of a Swedish railway until his colour-vision has been tested, and has been found to be sufficient for the duties he will be called upon to perform. The example thus set by Sweden has been followed, more or less, by other countries, and especially, thanks to the untiring labours of Dr. Joy Jeffries, of Boston, by several of the United States; while at the same time much evidence has been collected to show the connection between railway and marine accidents and the defect.

It has been found, by very extensive and carefully conducted examinations of large bodies of men, soldiers, policemen, the workers in great industrial establishments, and so forth, as well as of children in many schools, that colour-blindness exists in a noticeable degree, as I have already said, in about four per cent. of the male industrial population in civilized countries, and in about one per thousand of females. Among the males of the more highly educated classes, taking Eton boys as an example, the colour-blind are only between two and three per cent., and perhaps nearer to two than to three.

Whether a similar difference exists between females of different classes, we have no statistics to establish. The condition of colour-blindness is absolutely incurable, absolutely incapable of modification by training or exercise, in the case of the individual; although the comparative immunity of the female sex justifies the suggestion that it may possibly be due to training throughout successive generations, on account of the more habitual occupation of the female eyes about colour in relation to costume. However this may be, in the individual, as I have said, the defect is unalterable; and if the difference between red and green is uncertain at eight years of age, it will be equally uncertain at eighty. Hence the existence of colour-blindness, among those who have to control the movements of ships or of railway trains, constitutes a real danger to the public; and it is highly important that the colour-blind, in their own interests as well as in those of others, should be excluded from employments the duties of which they are unfit to discharge.

The attempts hitherto made in this country to exclude the colour-blind from railway and marine employment have not been by any means successful. As far as the merchant navy is concerned, so-called examinations have been conducted by the Board of Trade, with results which can only be described as ludicrous. Candidates have been "plucked" in colour at one examination, and permitted to pass at a subsequent one; as if correct colour-vision were something which could be acquired. Such candidates were either improperly rejected on the first occasion, or improperly accepted on the second. On English railways there has been no uniformity in the methods of testing; except, in so far as I am acquainted with them, that they have been almost uniformly misleading, calculated to lead to the imputation of colour-blindness where it did not exist, and to leave it undiscovered where it did. In these circumstances it is not surprising that great discontent should have arisen among railway men in relation to the subject; and this discontent has led, indirectly, to the appointment of a Committee by the Royal Society, with the sanction of the Board of Trade, for the purpose of investigating the whole question as completely as may be possible.

It is perhaps worth while, before proceeding to describe the manner in which the colour-sense of large bodies of men should be tested for industrial purposes, to say something as to the amount of danger which colour-blindness produces. A locomotive, as we all know, is under the charge of two men—the driver and the fireman. In a staff of one thousand of each, allotted to one thousand locomotives, we should expect, in the absence of any efficient method of examination, to find forty colour-blind drivers, and forty colour-blind firemen. The chances would be one in twenty-five that either the driver or the fireman on any particular engine would be colour-blind; they would be one in 625 that both would be colour-blind. These figures appear to show a greater risk of accident than we find realized in actual working, and it is manifest that there are compensations to be taken into account. In the first place, the term "colour-blind" is itself in some degree misleading; for it must be remembered that the signals to which the colour-blind person is said to be "blind" are not invisible to him. To the red-blind, the red light is a less luminous green; to the green-blind, the green light is a less luminous red. The danger arises because the apparent differences are not sufficiently characteristic to lead to certain and prompt identification in all states of illumination and of atmosphere. It must be admitted, therefore, that a colour-blind driver may be at work for a long time without mistakes; and it is probable, knowing as he must that the differences between different signal lights appear to him to be only trivial, that he will exercise extreme caution. Then it must be remembered that lights never appear to an engine-driver in unexpected places. Before being intrusted with a train, he is taken over the line, and is shown the precise position of every light. If a light did not appear where it was due, he would naturally ask his fireman to aid in the look-out. It must be also remembered that to overrun a danger signal does not of necessity imply a collision. A driver may overrun the signal, and after doing so may see a train or other obstruction on the line, and may stop in time to avoid an accident. In such a case, he would probably be reported and fined for overrunning the signal; and, if the same thing occurred again, he would be dismissed for his assumed carelessness, probably with no suspicion of his defect. Colour-blind firemen are unquestionably thus driven out of the service by the complaints of their drivers; and none but railway officials know how many cases of overrunning signals, followed by disputes as to what the signals actually were, occur in the course of a year's work. I have never heard of an instance in this country, in which, after a railway accident, the colour-vision of the driver concerned, or of his fireman, has been tested by an expert, on the part either of the Board of Trade or of the Company; but a fireman in the United States has recently recovered heavy damages from the Company for the loss of one of his legs in a collision which was proved to have been occasioned by the colour-blindness of the driver. Looking at the whole question, I feel that the danger on railways is a real one, but that it is minimized by the several considerations to which I have referred, and that it is much smaller than the frequency of the defect might lead us to think likely.

At sea, the danger is much more formidable. The lights appear at all sorts of times and places, and there may be only one responsible person on the look-out. Mr. Bickerton, of Liverpool, has lately published accounts of three cases in which the colour-blindness of officers of the mercantile marine, all of whom had passed the Board of Trade examination, was accidentally discovered by the captains being on deck when the officers in question gave wrong orders consequent upon mistaking the light shown by an approaching vessel. The loss of the *Ville du Havre* was almost certainly due to colour-blindness; and a very fatal collision in American waters, some years ago, between the *Isaac Bell* and the *Lumberman*, was traced, long after the event, to the colour-blindness of a pilot, who had been unjustly accused of being drunk at the time of the occurrence. In how many instances colour-blindness has been the unsuspected cause of wrecks and other calamities at sea, it is impossible to do more than conjecture.

It is necessary, then, alike in the public interest and in the interest of the colour-blind, who have doubtless often suffered in the misfortunes which their defects have produced, to detect them in time to prevent them from entering into the marine and railway services; and the next question is, how this detection should be accomplished. We have to distinguish the colour-blind from the colour-sighted; but we must be careful not to confound colour-blindness with the much more common condition of colour-ignorance.

It would surprise many people, more especially many ladies, to discover the extent to which sheer ignorance of colour prevails among boys and men of the labouring classes. Many, who can see colours perfectly, and who would never be in the least danger of mistaking a railway signal, are quite unable to name colours or to describe them; and they are sometimes unable to perceive, for want of education of a faculty which they notwithstanding possess, anything like fine shades of difference. Mr. Gladstone once published a paper on the scanty and uncertain colour-nomenclature of the Homeric poems; and he might have found very similar examples among his own contemporaries and in his own country. I have lately seen a pattern card of coloured silks, issued by a Lyons manufacturer, which contains samples of two

thousand different colours, each with its more or less appropriate name. There is here a larger colour-vocabulary than the entire vocabulary, for the expression of all his knowledge and of all his ideas, which is possessed by an average engine-driver or fireman; and, just as most of us would be ignorant of the names of the immense majority of the colours displayed on that card, so hundreds of men and boys among the labouring classes, especially in large towns, where the opportunities of education by the colours of flowers and insects are very limited, are ignorant of the names of colours which persons of ordinary cultivation mention constantly in their daily talk, and expect their children to pick up and to understand unconsciously. It is among people thus ignorant that the officials of the Board of Trade, and of railways, have been most successful in finding their supposed colour-blind persons; and these persons, who would never have been pronounced colour-blind by an expert, have been able, as soon as they have paid a little attention to the observation and naming of colour, to pass an official examination triumphantly. The sense of colour presents many analogies to that of hearing. Some people can hear a higher or a lower note than others, the difference depending upon structure, and being incapable of alteration. No one who cannot hear a note of a certain pitch can ever be trained to do so; but, within the original auditory limits of each individual, the sense of hearing may be greatly improved by cultivation. In like manner, a person who is blind to red or green must remain so; but one whose colour-sense is merely undeveloped by want of cultivation may have its acuteness for fine differences very considerably increased.

In order to test colour-vision for railway and marine purposes, the first suggestion which would occur to many people would be to employ as objects the flags and signal lanterns which are used in actual working. I have heard apparently sensible people use, with reference to such a procedure, the phrase upon which Faraday was wont to pour ridicule, and to say that the fitness of the suggested method "stands to reason." To be effectual, such a test must be applied in different states of atmosphere, with coloured glasses of various tints, with various degrees of illumination, and with the objects at various distances; so that much time would be required in order to exhaust all the conditions under which railway signals may present themselves. This being done, the examinee must be either right or wrong each time. He has always an even chance of being right; and it would be an insoluble problem to discover how many correct answers were due to accident, or how many incorrect ones might be attributed to nervousness or to confusion of names.

We must remember that what is required is to detect a colour-blind person against his will; and to ascertain, not whether he describes a given signal rightly or wrongly on a particular occasion, but whether he can safely be trusted to distinguish correctly between signals on all occasions. We want, in short, to ascertain the state of his colour-vision generally; and hence to infer his fitness or unfitness to discharge the duties of a particular occupation.

For the accomplishment of this object, we do not in the least want to know what the examinee calls colours, but only how he sees them, what colours appear to him to be alike and what appear to be unlike; and the only way of attaining this knowledge with certainty is to cause him to make matches between coloured objects, to put those together which appear to him to be essentially the same, and to separate those which appear to him to be essentially different. This principle of testing was first laid down by Seebeck, who required from examinees a complete arrangement of a large number of coloured objects; but it has been greatly simplified and improved by Prof. Holmgren, who pointed out that such a complete arrangement was superfluous, and that the only thing required was to cause the examinee to make matches to certain test colours, and, for this purpose, to select from a heap which contained not only such matches but also the colours which the colour-blind were liable to confuse with them.

After many trials, Holmgren finally selected skeins of Berlin wool as the material best suited for this purpose; and his set of wools comprises about 150 skeins. The advantages of his method over every other are that the wool is very cheap, very portable, and always to be obtained in every conceivable colour and shade. The skeins are not lustrous, so that light reflected from the surfaces does not interfere with the accuracy of the observation; and they are very easily picked up and manipulated, much more easily than coloured paper or coloured glass. The person to be tested is placed before a table in good daylight, the table is covered by a white cloth, and the skeins are thrown upon it in a loosely arranged heap. The examiner then selects a skein of pale green, much diluted with white, and throws it down by itself to the left of the heap. The examinee is directed to look at this pattern skein and at the heap, and to pick out from the latter, and to place beside the pattern, as many skeins as he can find which are of the same colour. He is not to be particular about lighter or darker shades, and is not to compare narrowly, or to rummage much amongst the heap, but to select by his eyes, and to use his hands chiefly to change the position of the selected material.

In such circumstances, a person with normal colour-sight will select the greens rapidly and without hesitation, will select nothing else, and will select with a certain readiness and confidence easily recognized by an experienced examiner, and which may even be carried to the extent of neglecting the minute accuracy which a person who distrusts his own colour-sight will frequently endeavour to display. Some normal-sighted people will complete their selection by taking greens which incline to yellow, and greens which incline to blue, while others will reject both; but this is a difference depending sometimes upon imperfect colour education, sometimes upon the interpretation placed upon the directions of the examiner, but the person who so selects sees the green element in the yellow-greens and in the blue-greens, and is not colour-blind. The completely colour-blind, whether to red or to green, will proceed with almost as much speed and confidence as the colour-sighted; and will rapidly pick out a number of drabs, fawns, stone-colours, pinks, or yellows. Between the foregoing classes, we meet with a few people who declare the imperfection of their colour-sense by the extreme care with which they select, by their slowness, by their hesitation, and by their desire to compare this or that skein with the pattern more narrowly than the conditions of the trial permit. They may or may not ultimately add one or more of the confusion colours to the green, but they have a manifest tendency to do so, and a general uncertainty in their choice. One of the great advantages of Holmgren's method over every other is the way in which the examiner is able to judge, not only by the final choice of matches, but also by the manner in which the choice is made, by the action of the hands, and by the gestures and general deportment of the examinee.

When confusion colours have been selected, or when an unnatural slowness and hesitation have been shown in selecting, the examinee must be regarded as either completely or incompletely colour-blind. In order to determine which, and also to which colour he is defective, he is subjected to the second test. For this, the wool is mixed again, and the pattern this time is a skein of light purple—that is, of a mixture of red and violet, much diluted with white. To match this, the colour-blind always selects deeper colours. If he puts only deeper purples, he is incompletely colour-blind. If he takes blue or violet, either with or without purple, he is completely red-blind. If he

takes green or gray, or one alone, with or without purple, he is completely green-blind. If he takes red or orange, with or without purple, he is violet-blind. If there be any doubt, the examinee may be subjected to a third test, which is not necessary for the satisfaction of an expert, but which sometimes strengthens the proof in the eyes of a bystander. The pattern for this third test is a skein of bright red, to be used in the same way as the green and the purple. The red-blind selects for this dark greens and browns, which are much darker than the pattern; while the green-blind selects greens and browns which are lighter than the pattern.

The method of examination thus described is, I believe, absolutely trustworthy. It requires no apparatus beyond the bundle of skeins of wool, no arrangements beyond a room with a good window, and a table with a white cloth. In examining large numbers of men, they may be admitted into the room fifty or so at a time, may all receive their instructions together, and may then make their selections one by one, all not yet examined watching the actions of those who come up in their turn, and thus learning how to proceed. The time required for large numbers averages about a minute a person. I have heard and read of instances of colour-blind people who had passed the wool test satisfactorily, and had afterwards been detected by other methods, but I confess that I do not believe in them. I do not believe that in such cases the wool test was applied properly, or in accordance with Holmgren's very precise instructions; and I know that it is often applied in a way which can lead to nothing but erroneous results. Railway foremen, for example, receive out of store a small collection of coloured wools selected on no principle, and they use it by pulling out a single thread, and by asking the examinee, "What colour do you call that?" Men of greater scientific pretensions than railway foremen have not always selected their pattern colours accurately, and have allowed those whom they examined, and passed, to make narrow comparisons between the skeins in all sorts of lights, in a way which should of itself have afforded sufficient evidence of defect.

Although, however, the expert may be fully satisfied by the wool test that the examinee is not capable of distinguishing with certainty between red and green flags or lights in all the circumstances in which they can be displayed, it may still remain for him to satisfy the employer who is not an expert, the railway manager, or the ship-owner, and to convince him that the colour-blind person is unfit for certain kinds of employment. It may be equally necessary to convince other workmen that the examinee has been fairly and rightly dealt with. Both these objects may be easily attained, by the use of slight modifications of the lights which are employed. Lanterns for this special purpose were contrived, some years ago, by Holmgren himself, and by the late Prof. Donders of Utrecht, and what are substantially their contrivances have been brought forward within the last few months as novelties, by gentleman in this country who have re-invented them. The principle of all is the same—namely, that light of varying intensity may be displayed through apertures of varying magnitude, and through coloured glass of varying tints, so as to imitate the appearances of signal lamps at different distances, and under different conditions of illumination, of weather, and of atmosphere. To the colour-blind, the difference between a red light and a green one is not a difference of colour, but of luminosity; the colour to which he is blind appearing the less luminous of the two. He may therefore be correct in his guess as to which of the two is exhibited on any given occasion, and he is by no means certain to mistake one for the other when they are exhibited in immediate succession. His liability to error is chiefly conspicuous when he sees one light only, and when the conditions which govern its luminosity depart in any degree from those to which he is most accustomed. With the lanterns of which I have spoken, it is always possible to deceive a colour-blind person by altering the luminosity of a light without altering its colour. This may be done by diminishing the light behind the glass, by increasing the thickness of the red or green glass, or by placing a piece of neutral tint, more or less dark, in front of either. The most incredulous employer may be convinced, by expedients of this kind, that the colour-blind are not to be relied upon for the safe control of ships or of locomotives. With regard to the whole question, there are many points of great interest, both physical and physiological, which are still more or less uncertain; but the practical elements have, I think, been well-nigh exhausted, and the means of securing safety are fully in the hands of those who choose to master and to employ them. The lanterns, in their various forms, are useful for the purpose of thoroughly exposing the colour-blind, and for bringing home the character of their incapacity to unskilled spectators; but they are both cumbrous and superfluous for the detection of the defect, which may be accomplished with far greater ease, and with equal certainty, by the wool test alone.

I have already mentioned that the examinations which have been conducted in the United States, thanks to the indefatigable labours of Dr. Joy Jeffries, have led to the discovery of an enormous and previously quite unsuspected amount of colour-ignorance, the condition which is frequently mistaken for colour-blindness by the methods of examination which are in favour with railway companies and with the Board of Trade; and this colour-ignorance has been justly regarded as a blot on the American system of national education. It has therefore, in some of the States, led to the adoption of systematic colour-teaching in the schools; and, for this purpose, Dr. Joy Jeffries has introduced a wall-chart and coloured cards. The children are taught, in the first instance, to match the colours in the chart with those of the cards distributed to them; and, when they are tolerably expert at matching, they are further taught the names of the colours. It must, nevertheless, always be remembered that a knowledge of names does not necessarily imply a knowledge of the things designated; and that colour-vision stands in no definite relation to colour-nomenclature. Even this system of teaching may leave a colour-blind pupil undetected.

COMPOUND LOCOMOTIVES.

THE present position of locomotive engineering in this country is of a very interesting nature; owing to the gradual increase of weight of trains hauled and the higher speeds now in use, it has been necessary to increase the power of the locomotive by leaps and bounds to cope with these demands. This naturally has not been done without great scheming on the part of the designers, for, with the standard gauge of railway of 4 feet 8½ inches, the engines are tied down to certain dimensions between the frame plates; in total length, to a certain extent, by the turn-tables in use; and in height of boiler for reasons of stability. These questions of design are interesting because they are intimately connected with the economical working of the engines, especially in the consumption of fuel, a question which of late years has taken a prominent position in the economical management of locomotives. For several years the highly economical results obtained at sea with the use of high pressures coupled with the compound or triple expansion engine have caused engineers to look in that direction for further improvements, with the result that two different types of compound locomotives were designed, and are considerably past the experimental stage. These engines are now working successfully on two of the English railways, and are being adopted on many foreign ones.