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A STANDARDIZED LANTERN FOR TESTING
COLOUR VISION

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Abstract

A Lantern for testing Colour-Vision is arranged to show test colours in pairs as in the Board of Trade Lantern. It is adapted to use electric light, and is standardized by stringent testing. The paper discusses the experiments and considerations which led to the formulation of the allowable tolerances in the transmission and colour co-ordinate specifications of the filters, the colour temperature of the lamps and so on. The results of tests on normal and colour-defective subjects are described.

In the year 1912 a special Departmental Committee of the Board of Trade published a report on sight tests (including colour vision) with special reference to the requirements of the Mercantile Marine. The type of lantern for colour vision testing advocated by that report has been in constant use by the Board of Trade since that time, and a committee of the Medical Research Council, in considering colour vision tests for entry into the Royal Navy, has recently advocated the employment of a similar lantern for Naval purposes.*

* Medical Research Council, Special Report Series No. 185, p. 37 (1933)

Small coloured lights are shown by the original Board of Trade lantern, singly or in pairs. The angular diameters of the lights are fixed by circular diaphragms, and the observer views them from a fixed distance, effectively twenty feet, with the aid of a mirror. The larger apertures are intended to represent the subtense of an average ship's light at 200 yards' distance. The small apertures, when shown in pairs, represent two ships' lights separated by a beam of 25 ft. as seen at 2,000 yards. The light is furnished by an oil lamp and the colour filters consist of specimens of "flashed ruby" and "signal green" glasses combined with neutral photographic filters. In this way red, green, and neutral coloured lights can be shown, but the transmission of each set of filters is intended to give equal brightness to the normal eye. Some nine filters in all, red, green, and neutral, mounted near the circumference of a disc of approximately 11 ins. diameter are employed. The ruby and signal-green glasses vary somewhat amongst themselves, representing permissible variations in coloured glasses approved by the Board of Trade and Trinity House for ships' lights.

Conditions have greatly changed since 1912, and the general availability of electric power suggested the possibility of substituting an electric light for the oil lamp and thus improving the simplicity and convenience of the lantern. At the request of the Colour Vision Sub-Committee of the Medical Research Council, the present writer undertook to design such a lantern, aiming at the simplification of the whole test as far as possible consistent with efficiency.* Many refinements and details of the construction have been worked out by Messrs. Kelvin, Bottomley, and Baird, Ltd., who undertook the manufacture.

The general construction is shown in the figure (Fig. 1). The colour filters are mounted around the circumference of a cylindrical drum rotating about a vertical axis. The movement is effected by a small hand-capstan-wheel in the base of the lantern. A handle close to the capstan permits the diaphragm apertures to be changed; these apertures comprise two of diameter 0.2 ins. and two of diameter 0.02 ins. The colours shown are indicated by key letters appearing in a window at the side of the lamp, the letters being mounted in suitably disposed apertures of the same drum which holds the colour filters. Nine colour pairs can be shown, and a number, corresponding to the pair exhibited, also appears at the window. An extension of the cylinder containing the apertures indicates, at the same window, the dispositions of the apertures seen by the observer. An auxiliary 15-watt lamp, with a separate switch, provides light for recording results at the rear of the lantern.

* British Patent, 449,047 of 1936.

FIG. 1.*

A. Wheel carrying colour filters and indicators.	F. Front aperture or window.
B. Colour filters.	G. Aperture for indicators.
C. Indicators.	H. Hand-wheel for carrying filters.
E. Sector carrying diaphragms.	J. Head for control of stops.
	M. Main lamp.

It is not the intention to make the lantern test so subtle that it will reject cases in which the colour deficiency is not of a dangerous character; this is the chief justification for the attempt to simulate practical conditions as closely as possible for use in the testing of large numbers of candidates, rather than to perfect any test, however good, of a laboratory type. Other types of lantern test have suffered from over-complexity and, bearing this in mind, it seems that even the original B.T. lantern colour filters may be drastically reduced in number. Since the least saturated "red" and "blue-green" allowed by the regulations

* Block lent by Messrs Kelvin, Bottomley and Baird.

for ships' lights are likely to be the hardest colours to distinguish from white they must be retained. Further, the provision of a relatively saturated red will detect cases of shortening of the red end of the spectrum. These colours, together with neutral, are all that need be shown; the retention of others merely leads to more complexity and waste of time. This applies only, however, to tests for marine watch-keeping purposes. Other filters can be added if required for other tests.

The Board of Trade Lantern has been criticised by some for the reason that the apparent brightness of the apertures, even if equalised to the normal eye, may not appear equal to the colour-blind. Colour-blind persons, as is well known, often describe changes of brightness as changes of hue, and it therefore appears possible that clever brightness discrimination might enable the correct colour names to be given. The luminosity curves of normal subjects and deuteranopes show comparatively little variation, but there is a marked difference between these and protanopes.* The hue wave-length of the deep red filter is approximately 0.625μ , at which region the apparent luminosity of an "equal energy spectrum" is only about one-twentieth part of the maximum spectral brightness to some classes of protanope, whereas it is about one-third of the maximum spectral brightness to the normal eye. We may therefore expect that if a "red" and "white" have the same apparent luminosity to the normal eye, this protanope will see such a great brightness contrast that he will employ it to identify red under lantern conditions.

This is admittedly the case, and it is easily noticed in examining the records of tests of some colour-blind subjects with such a lantern. On the other hand the operation of this basis of discrimination is made extremely difficult with the small apertures of the Board of Trade Lantern, where considerable brightness differences are hard to detect. A person with a deficiency of such a marked amount invariably makes glaring mistakes, especially in his confusion of green and white.

In order to minimise the risk (small though it has proved in practice) of passing a candidate with such a deficiency, the new lantern is fitted with auxiliary dimming filters which can be employed (when required) to reduce the brightness of either right or left-hand light to about one-third of its original value without altering the quality of the colour. A protanope using apparent brightness inequality to identify red will probably guess at colour differences when shown two whites or two greens of unequal brightness.

* F. H. G. PITT, — Medical Research Council. Special Report Series No. 220, p. 25 (1935).

Only a limited number of the original Board of Trade Lanterns were manufactured and, from the experience of the present writer, the aim at equality of brightness of the coloured lights as seen by the normal eye does not seem to have been very accurately realised. When the first of the new lanterns had been made up with filters very carefully prepared and tested to secure accurate brightness equality throughout, it was tested and compared with one of the original Board of Trade Lanterns. In the opinion of the writer the older lantern showed relatively great brightness contrasts and inconsistencies; if this observation was correct (and it was confirmed by another observer) it seems that the practical success of the older lanterns has not been spoilt by the technical errors in their production. It is not easy to make photographic neutral filters to exactly prescribed densities.

This does not imply that a deliberate carelessness in the production of the new lantern will ensure success or inspire confidence. Every lantern ought to give the same results for the same observer, but in view of the complexities of colour-blindness we have no means of knowing the limits of tolerance in regard to the variations of the colour-filters and source of light which would be required to ensure such a consistency. It would appear probable, however, that if the allowable variations of the filters, etc., are small in comparison with those detectable by the normal eye under the conditions of the lantern, all reasonable requirements will be fulfilled.

Discrimination of brightness and colour is difficult when the sources are separate bright points in a dark field. Even with the large sources the effect of a modifying filter reducing transmission to one third does not appear very drastic; it will be recalled that stellar magnitudes have long been divided into six "just distinguishable" steps for the range of visible stars; each step has 2.5 times the brightness of the step below it. Conditions are a good deal more favourable in the lantern owing to the close angular position of the apertures, but a 30 per cent. difference of brightness is extremely difficult to detect with certainty, unless careful observation is made with the large apertures, the observer being close up to the lantern. With the small apertures the difference is not detectable. It therefore appears reasonable to suggest that tolerances of the order of ± 15 per cent. of the standard are allowable as far as brightness is concerned. Even this accuracy cannot be attained, however, unless considerable care is taken in production.

The flame of the oil lamp employed in the original lantern would probably have a colour temperature of about 2,000°K or slightly more,* and a brightness of the order of 0.012 candles per

* J. W. T. WALSH.—Photometry, p. 478.

sq. mm. It is proposed in the new lantern to use a specially selected single-coil 40 watt opal bulb lamp (Ediswan Fullolite). Such a lamp provides a fairly uniformly illuminated " disc of light " about $2\frac{1}{2}$ inches in diameter, and makes an efficient substitute for an oil lamp flame.

As a preliminary experiment, measurements were made in the laboratory of the relative brightness variation of one such lamp across a diameter of the bulb perpendicular to the axis, and from tests at equal linear intervals with an accurate surface-brightness photometer, the directions of the view being parallel, the following figures (arbitrary units) were obtained: 97.4, 102.6, 102.6, 100, 97.4, 97.4, 92.8. Provided the extreme edge of the bulb is not used, and if lamps free from noticeable irregularity in the bulb are selected, selected lamps may be expected to be adequately uniform. The same photometer was used to obtain measurements of the intrinsic brightness of the opal bulb relative to a paraffin oil-lamp flame with flat wick, and the ratio was found to be 78:100. Most of these lamps have, however, shadows and reflections from the filament supports on some parts of the globe; it is therefore important to select the most uniform aspect of the bulb and to place this part adjacent to the apertures in the lantern. The finally selected parts of the bulb will be suitably marked.

The lamps for the lantern will be specially selected and will be fitted with screw-cap holders to prevent the ready employment of unsuitable lamp bulbs.

Lamps of the above kind, running at 240-200 volts normally have a colour temperature, according to the makers, of between $2,500^{\circ}$ and $2,550^{\circ}$ K. The life is about 1,000 hours and the change of colour temperature during life is about 1.8 per cent. This change has only a small effect on the luminosity transmission of the colour filters. Mr. J. G. Holmes of Messrs. Chance Bros. & Co., Ltd., kindly sent me the following figures for typical deep-red and signal-green glasses:

PERCENTAGE TRANSMISSION OF VISIBLE LIGHT			
	2360°K	2500 K	2848°K
Red - -	9.6	9.0	7.9
Blue-Green -	8.8	9.3	10.3

From these figures it can be seen that the change in relative transmission of the red during the life of the lamp will be approximately from 8.75 per cent. to 9 per cent., while the transmission of the green will fall from about 9.5 per cent. to 9.3 per

cent. Changes of this order will be negligible under lantern conditions, but it will be advisable that a record shall be kept of the time of burning for every lantern so that the bulb may be changed after 1,000 hours' use.

The average surface brightness of 40 watt lamps varies slightly in lamps for different voltages. Assuming the rated surface brightness of a 230 volt lamp to be 100, a 250 volt lamp has a brightness of about 97 and a 200 volt gives about 105. Variations of this kind from lantern to lantern would not be of material importance, but will be avoided as explained below.

According to the makers, a change of ± 4 per cent. in voltage will give approximately a change of ± 15 per cent. in brightness and ± 2 per cent. in colour temperature; thus a 240 volt lamp running on 230 v. will be near a colour temperature $2,500^{\circ}\text{K}$ instead of $2,550^{\circ}\text{K}$.

The case of low-voltage supply, 100-130 volts, requires separate consideration, but there are now comparatively few places where this kind of voltage is in use. The makers state that the range of colour temperature for 100-130 volt lamps is $2,700^{\circ}\text{K}$ to $2,650^{\circ}\text{K}$, the lower voltage lamps running at the higher colour temperature. These lamps also have a higher surface brightness. Taking a 230 volt 40 watt lamp as 100, the surface brightness of 40 watt lamps ranges from 133 for a commercial 100 volt lamp to 126 for a 130 volt lamp. Lamps of this kind can be suitably under-run in the lantern, and special provision must clearly be made for this.

The rapid extension of the grid system has resulted in some relaxation of the Board of Trade regulations regarding the necessary precision of voltage on public supply circuits, and it is understood that variations of ± 6 per cent. may be encountered; as this would mean a possible brightness variation of more than ± 20 per cent., it appears that such fluctuations might cause appreciable variations in the performance of the lantern. The difficulties noted in this and the previous paragraph are clearly best met by the provision of a suitable rheostat and voltmeter with each lantern. The lamps will then be run at the pre-determined voltage to give a standard surface brightness, and such lamps will be selected in respect of a certain tolerance in colour temperature as described below.

Selection of Colour-filters and Neutral Filters

Messrs. Chance Bros. & Co., Ltd., were good enough to provide the writer with specimens of ruby and signal-green glass representing the extreme variations allowable in glasses for ships' lights. The darkest and lightest red and the lightest blue-green

FIG. 2.

were selected for use in the first experimental lamp. The curves for spectral transmission are given in Fig. 2. The percentage luminosity transmission for a source of colour temperature $2,600^{\circ}\text{K}$ are:

Red 1 = 8.8 per cent.	} As calculated from the spectro- photometric transmission measurements.
Red 2 = 13.2 ,,	
Green = 16.2 ,,	

These are not the actual standards finally adopted in the commercial lantern, but are very close approximations to them.

Measurements of the density of the photographic neutral filters fitted to an original Board of Trade Lantern allowed of the specification of a series of neutral filters which, when employed with the opal-bulb lamp, should produce the same effect as the original lantern with its oil lamp. After some preliminary trials with photographic filters, a set of Ilford Neutral Filters was obtained which gave an effect approximating very closely to the Board of Trade Lantern now actually in use at the Board of Trade. These filters were produced to yield exactly prescribed densities.

A routine method of producing photographic filters to prescribed densities with a minimum of uncertainty has now been worked out in conjunction with the makers of the new lantern, Messrs. Kelvin, Bottomley, & Baird, Ltd., and a photometric comparator is used to ensure that the photographic filters will yield the required effect, under the lantern conditions. Considerable care

is essential in tests of this kind, as the scattering of the light by a photographic filter makes its apparent density dependent largely on the conditions of operation. The total apparent density of colour filter *plus* neutral is a little over 2.

Photographic filters are selected for use in the new lantern mainly because the experience of their use in the old Board of Trade lantern has demonstrated their stability under lantern conditions. Filters containing a dye might be expected to deteriorate if allowed to become warm. It is an advantage also that the grain of the filter helps to make the brightness of the aperture less dependent on any slight local irregularity in the luminosity of the opal bulb.

The "neutral" filters first selected consisted of a piece of neutral glass with a photographic filter. A combination of another neutral with an Ilford filter proved too yellow, whereas two photographic neutral filters gave an effect with the opal lamp rather more white than the oil lamp with photographic filter only, and made the test easier to colour defectives. A return was therefore made to the original neutral glass *plus* photographic filter which had proved satisfactory under trial. Most of the tests with the experimental lamp were made with photographic filters only for "white." This was the case in the very first set of trials* with an original B.T. lantern fitted with an opal-bulb lamp carried out by Surgeon Commander Macleod and the present writer in 1931. The use of the neutral glass will make the white a little harder to distinguish from the red.

Tolerances.—The actual standards for the filters to be employed will be a set of glass filters (together with the corresponding photographic neutrals) which measurements have shown to represent a close approximation to the mean for the available glasses having the required colour quality.

The question of the practical tolerances for variations amongst the colour filters, apart from the compensating filters, is not an easy one to settle. As stated above, we have no data for determining how far individual lanterns may vary before they give different results with colour-defective eyes, and the only common-sense method is therefore to prescribe the closest limits which can reasonably be expected in commercial production.

Through the kind co-operation of Messrs. Chance Bros. & Co., Ltd., a supply of glass has been obtained for all four sets of filters: R1, R2, G and W, and the greatest care has been taken to make sure that the glasses finally selected were as closely as possible identical in colour. The reds could be selected from flashed glasses, but the greens and neutrals have had to be ground and polished to the required thickness.

* Medical Research Council.—Special Report Series, *ibid.*, p. 1.

FIG. 3a.

Colour co-ordinates of glass colour-filter, in Wright's system. Abscissae are R values, ordinates are G values.

FIG. 3b.

FIG. 3c.

The tolerance for colour quality must be as strict as possible consistent with the avoidance of undue difficulty in obtaining the quantity of glass required for the commercial production of the lantern. The trichromatic coefficients of a representative set of nine R1, eight R2, thirteen G, and fifteen neutral glasses were measured, using a source of colour temperature $2,848^{\circ}\text{K}$. The points so determined are plotted in Figs. 3a, 3b, and 3c, in which the Wright system* of units is employed. Some points for rejected glasses are omitted. In order to obtain results which would approximate to those given by an "average observer," the quantity scales for R, G, and B, for the actual observer were adjusted so that they gave the "average observer's" result for a measurement on the standard source, as previously determined in the colour-vision laboratory in the Imperial College.

The results have now to be related to the limits of detectable colour change. In the red region it is well known† that the limit of colour discrimination (hue-wave-length change) under the conditions of the colorimeter corresponds near 0.61μ to 0.0011μ , and near 0.62μ to 0.0015μ . The colours of the glasses fall very close to the line of spectral colours, and the range for colour discrimination can easily be shown. The circles of Fig. 3 have

* *Trans. Opt. Soc.*, Vol. XXX, p. 141, 1928-29.

† *Proc. Phys. Soc.*, Vol. XLVI, p. 459, 1934.

radii of two colour steps in the spectral line, and it thus appears that this can be taken as a reasonably strict limit for the colour variation of the reds, *i.e.*, that the green or red coefficient for any R1 or R2 glass shall not differ more than about two such steps from the standard or approximate mean value. The blue coefficient should be inappreciable. The actual glasses selected easily conform to such conditions; the limits are indicated.

A representative set of the blue-green and neutral glasses has also been examined, and their colour points are plotted in Figs. 3b and 3c. When the measurements were completed, an attempt was made to determine the limits of detectable colour change in the colour triangle by varying the match first by increasing the amount of red until a colour difference appeared, then by decreasing it. A similar test was made with the blue varying.

Since an alteration of one component will, in general cause a luminosity difference, the size of such steps will be smaller than those which involve hue changes alone. However, they will give a guide in the present case. The results of the test give in each case four points, of which opposite pairs are about two colour steps apart. They proved to be as follows:

Co-ordinates of Colours Showing Limits of Detectable Colour Change.

BLUE-GREEN.						
Blue	-	-	·388	·315	·338	·350
Green	-	-	·533	·596	·560	·578
Red	-	-	·079	·089	·102	·072
NEUTRAL.						
Blue	-	-	·153	·091	·122	·130
Green	-	-	·480	·561	·482	·512
Red	-	-	·367	·393	·396	·538

They are plotted in the figures (crosses) and suffice to give an idea of the amplitude of the steps in these regions of the colour triangle. The circles drawn around the centres of gravity of the points representing the glasses will be seen to have radii of about two colour steps (*i.e.*, steps estimated under colorimeter conditions). The selected glasses fall easily within such limits, and it seems as in the case of the reds, that two colour steps can be taken as a guide to a reasonably strict limitation for the lantern glasses.

The diagrams in Fig. 3 show the points plotted in the W.D.W. system of units.* They can be transferred to the C.I.E. system† by the following transformation:

* W. D. WRIGHT.—*Ibid*, p. 11.

† SMITH and GUILD.—*Trans. Opt. Soc.*, Vol. XXXIII, p. 73, 1931-1932.

$$bR = 1.3140 X + 0.4961 Y$$

$$bG = 0.1547 X + 0.8059 Y + 0.0394 Z$$

$$bB = 0.1862 X + 0.0384 Y + 1.0686 Z$$

This will allow of the transformation to any other system of units in which the relations to one or other of the above systems are known. The mean co-ordinates in the C.I.E. system are as follows :

	X	Y	Z
R1	.6908	.3068	.0024
R2	.6653	.3305	.0042
G	.2348	.4345	.3307
W	.4511	.4432	.1057

The co-ordinates and the corresponding approximate limits are shown plotted in Fig. 4 for the neutral glasses.

FIG. 4.

The tolerances for the luminosity transmission of the coloured glasses need not be stated separately, as the final test will be made on the combination of glass plus neutral filter. It may be noted, however, that the mean of the transmission and the maximum deviations from the mean for the glasses selected, as calculated

from colorimeter measurements with a source at 2,848K were as follows:

	Mean percentage transmission.	Maximum deviation from mean.
R1	9.28	0.80
R2	14.81	1.09
G	19.0	1.0
W	8.2	0.6

The variation of the total transmission of the glasses can to some extent be adjusted by the selection of the accompanying neutral filters. Measurements on representative sets showed that the variation of transmission can without difficulty be kept within one-tenth of the total transmission factor. This is the normal accuracy to be aimed at, but ± 15 per cent. may be suggested as a limit for the tolerance of error in the combination.

A less stringent tolerance, say, ± 25 per cent., may be suggested for the photographic neutral filters used for the auxiliary dimmers. Standards for these have also been selected.

The official tolerances for the combined filters both for colour quality and transmission, as agreed with the National Physical Laboratory after tests on ten completed lanterns agree closely with the general suggestions above, although the specification is expressed differently, and the limits adopted for variation of the colour co-ordinates are somewhat more stringent.

Tolerance for the Colour-temperature of the Lamps and Method of Initial Selection

The tolerance for colour temperature variation in the lamps used for the lantern should clearly not exceed the colour variation of the filters. First, the colour co-ordinates, in the C.I.E. system, corresponding to various colour temperatures are known.* They are plotted in the "neutral" section of the diagram Fig. 4, and it is noticed that the range of 2,360°K to 2,848°K is about two to three colour steps in that region, as determined by the approximate experiment described above. Accordingly we take one-third of the above colour temperature difference, *i.e.*, $488/3 = 163^\circ$ (approx.) as an approximate estimate of one such colour step under colorimeter conditions; this is, then, 6.5 per cent. at 2,500°K approximately.

Referring to the makers' figures cited above, we may take it that a change in voltage of ± 6 per cent. will not cause a change in colour temperature exceeding ± 4 per cent.; and hence at a

* D. B. JUDD.—*Jour. Opt. Soc. Amer.*, Vol. XXIII, p. 366, 1933.

colour temperature of 2,500°K this ± 6 per cent. voltage change will not produce a change in colour temperature corresponding to as much as one colour step under colorimeter conditions; far less than one colour step under the conditions of the lantern.

It should be noticed, however, in passing, that even the "colorimeter conditions" of a 2° angular field are not particularly sensitive for colour discrimination. When a larger field is employed with suitable precautions the discriminable steps may be much smaller.*

Under the present conditions therefore it seems that lamps should be selected initially to give a certain brightness when run at a prescribed voltage, about 10 per cent. less than that of the supply, and this voltage should be maintained during the use of the lamp by a suitable rheostat and voltmeter. The colour temperature of the lamp can then be subject to a final tolerance to be determined.

A batch of ten lamps, initially selected with the aid of a spherical integrator, has been submitted to the National Physical Laboratory. Tests of the surface brightness of each bulb were made for a series of points around the diameter; it was then found possible to find pairs of points about 1 inch apart, on any bulb, which gave equal surface brightness, and would thus furnish equal illumination to the apertures in the lantern when the bulb is suitably positioned. By varying the voltage on each bulb the local surface brightness could be adjusted to agree with the mean brightness of the whole set; the colour temperature was then determined. It was found that the colour temperatures agreed with one another within $\pm 50^\circ\text{K}$, and this figure was adopted as the appropriate tolerance; it clearly represents a very small colour difference.

The rheostat and voltmeter forms a separate unit to be plugged into the lantern, and the dial of the voltmeter is illuminated so that the voltage across the lamp can be adjusted when the apparatus is being used in a darkened room. On account of the fairly wide tolerances described above there will be no occasion to try and correct small voltage variations of one or two per cent., but larger deviations can be detected. As is well known, the variation is generally greatest at certain times of the day such as dusk, when the load on the supply stations is changing rapidly, and it will clearly be better to use the lantern at times when a steadier voltage can be expected.

Tolerances for size of apertures.—It is not a particularly easy matter to produce small holes of diameter 0.02 inch with a high degree of consistency, but the N.P.L. tests of the effective areas

* D. B. JUDD.—*Ibid.*, Vol. XXVI, p. 421, 1936.

of the apertures in the first ten lanterns showed that the errors did not exceed ± 5 per cent. of the mean. This figure is taken as a tolerance for the areas; an error of this magnitude is clearly harmless in view of the allowable variations of brightness.

Considerable care is necessary that the apertures do not become choked with dust during the use of the lantern over any long period.

Method of use.—The technique of the Board of Trade Lantern has been fully described in the Report referred to above, but the arrangements of the new lantern require some modification of the directions.

In the first place, the lamp has to be mounted in the lantern so that the calibrated and marked region of the surface is turned towards the apertures. This is accomplished by a small sighting device furnished as an auxiliary to each lantern. If for any reason the lamp is subsequently removed from the lantern, it is obvious that it must be replaced exactly in the same position, and the top of the lamp holder is specially designed to facilitate this.

With regard to the actual system of tests, there are now only nine colour permutations which can be presented with the filters as fixed in the drum, and these might possibly be learned in order. Two packs of nine cards, each bearing the numbers 1-9 are therefore provided with the lantern, and these are shuffled in order to give an arbitrary order in which to exhibit the colour pairs to the candidate. It will be remembered that the colour pair exhibited is indicated by a key number appearing at the side window.

For most candidates twelve permutations will be sufficient. Take all the cards of the first pack (red) and three at random from the second pack (green). Shuffle these together and expose the combinations in the order so obtained. This will ensure that no candidate shall receive any assistance by knowing that repetition of a permutation is not to be expected.

After a few trials with one or two of the large apertures to give the candidate confidence, tests are made with both small apertures equally bright, using the order given by the cards. If the candidate's answers are perfect throughout, there is little likelihood of any defect in his colour vision. If, however, there is any ground for suspecting some defect given by uncertainty of answers (some tendency to confuse green and white, for example), the test with the auxiliary dimming filters will make his defect (if serious) much more apparent. Further, it should clearly eliminate any candidate who might pass by means of a clever brightness discrimination.

The procedure suggested is as follows : Take the nine red cards

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as before and three others at random from the green pack and shuffle. Use the modifying filter holder in the topmost position, say, for odd numbers, in the next lower position for even numbers. (The bottom gives both apertures clear.) While moving the capstan handle from one filter combination position to another in this test, the modifying filter handle can be held in the half-way position, entirely screening the lights. It is clearly important that they should not appear at all before the candidate is asked to name them.

This test with the modified brightness of the lights is a very difficult one, and even a normal-sighted person may occasionally make slight mistakes owing to colour contrast effects. The following are the results of trials by four persons with normal colour vision established by a number of tests in the laboratory; dimming of one aperture was employed.

Combination shown	F. L. B.	B. K. J.	S. A. B.	L. C. M.
G W:	G W	G W	G W	G W
G G:	G G	? G	G G	G G
R G:	R G	R G	R G	R G
W R:	W R	W R	Orange R	G R
W W:	W W	? W	W W	W R
R W:	R W	R W	R W	R W
R R:	R R	R R	R R	R R
G R:	G R	G R	G R	G R
W G:	W G	W G	W G	W G

The present writer's results with modifying glasses are given in the last column and show two mistakes. In the first a dimmed white (shown against a bright red) is taken for green. In the second a dimmed white shown against a brighter white is taken for a red. Two young students, F.L.B. and S.A.B., make no mistakes, but a lecturer, B.K.J., is uncertain of the dimmed colour in two cases. No person should be failed through such mistakes on the dimmed lights alone unless there is definite confusion of red and green. *The use of the dimmed lights is only to be taken as helpful in deciding doubtful cases.*

Results with Partially Colour-blind and other Subjects

The procedure recommended above with cards, etc., was adopted in testing all the following cases, with the exception that only nine combinations were shown to each subject, first normally and

then modified. For convenience in presenting the results, however, the same order of the combinations and answers is used in all the tables following. The dimmed lights are shown by the small letters. All the results shown relate to the small apertures only, but in the comments following some notes will be found on the candidates' performances with the large apertures in cases where anything worthy of notice was found. The colour vision of all these persons had been previously examined by other methods.

Combination	C.H.F.B.	J.T.K.	G.V.C.D.	Y	H.L.P.	B	J.C.J.
1. G W:	G W	G G	G W	G W	G W	G —	G G
2. G G:	W W	G W	— —	G G	G W	G R	W G
3. R ₁ G:	R W	R G	R G	R G	W R	R R	R G
4. W R ₁ :	R W	G R	W W	W R	G R	R R	W R
5. W W:	W W	G W	R W	W W	G R	G W	W W
6. R ₂ W:	R G	R G	R W	R W	W G	R R	R G
7. R ₁ R ₂ :	R W	R R	R R	R R	W R	R R	R R
8. G R ₁ :	G W	G R	G R	G R	G R	G W	G R
9. W G:	W W	G G	W G	W G	W R	R G	R G
1. G W:	G R	— W	— W	G W	W R	— G	G W
2. G G:	W G	G —	— G	W G	G R	— —	G W
3. R G:	G W	— G	R G	R —	R W	— —	R G
4. W R:	W G	G G	W R	W G	W R	G R	W R
5. w W:	G R	G G	— R	W W	R W	— G	R W
6. R w:	R G	W W	R W	R W	W G	R G	R W
7. R R:	G R	R R	R G	R R	G W	G R	W R
8. G R:	W G	— R	G R	G R	G R	R R	G R
9. w G:	G G	— G	G W	W G	G W	— G	W G
Mistakes with undimmed lights:	9	5	4	0	10	8	4
Mistakes with dimmed lights:	12	10	7	3	11	13	3

Notes on the above cases.—H.L.P. is the worst case and makes serious mistakes even with the large lantern aperture, such as calling two greens a white and red. He is not, however, a perfect dichromat, and needs three primaries for colour matches near the end of the spectrum.

B. is deuteranomalous and confuses white and green even with the large lantern apertures.

C.H.F.B. is very deuteranomalous. He does not make mistakes with the large apertures, but confuses red with white, and green with white with the small apertures. The use of the modifying glasses makes him confuse red and green.

G.V.C.D. is also very deuteranomalous, and confused white and green even with the large apertures of the lantern. His record with these apertures shows one answer of red where it should have been green, but this may have been due to nervousness. With the modifying glasses he is clearly guessing in many cases.

J.T.K. is somewhat deuteranomalous. He makes no mistakes with the large apertures but cannot distinguish white and green with the small ones. He confuses red and green with the modifying filters.

J.C.J. is slightly anomalous but has a good colour discrimination. He is an interesting case because he made some mistakes even with the large lantern apertures, as follows :

G W called G R, W G called W W, G G called W W. Yet even with the modifying glasses and small apertures he makes no more mistakes than people with perfect colour vision. He was very conversational and may have been nervous in the first place. Sheer nervousness may cause serious errors even in these simple tests. He has a heightened sense of colour contrast, and is extremely unlikely ever to confuse red and green.

Y. is a lady who was found to give a somewhat abnormal reading with the Nagel anomaloscope, but whose colour-vision characteristics, when tested, seemed practically normal. She gives no indication of any marked defect.

The tests so far carried out indicate that the lantern in its present form should provide a means by which little doubt should remain as regards the watch-keeping abilities of any person. No case has been found in which any person with serious colour deficiency as regards hue discrimination has been able to pass. On the other hand, the test will not fail those like Y. above who may have some colour abnormality of a harmless type.

The present writer will be glad to hear the results which others may obtain and of any difficulties experienced, since an efficient test of this kind is highly desirable from the point of view of the public interest.

It is the intention to develop modifications of the lantern for use by railways and other bodies who may require special features in the lantern, such, for example, as the addition of an orange filter, but this will be made the subject of a supplementary paper.

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VITAL STAINING OF THE RETINA: Preliminary Clinical Note

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THE use of colouration in the study of tissues goes back to at least the sixteenth century but it is owing to the development of synthetic dyes in the second half of the last century and largely to the work of Ehrlich that vital staining has become a significant procedure. It has found applications in the study of the metabolic behaviour of tissues in tracing paths of transmission of fluids and sites of deposit of cells, and it is mainly by this approach that the conception of the reticulo-endothelial system has been elaborated by Goldmann, Kiyono and Aschoff. One obvious application, the *intra vitam* staining of cells for histological purposes has on the whole proved disappointing, partly because of the difficulty in fixing sections without washing the dye out. Negative results in attempts at staining the central nervous system led Goldmann to postulate the existence of a blood-brain barrier preventing dyes from reaching nervous tissue.

The conception of the blood-brain barrier gives a theoretical basis for the clinical experience that toxins circulating in the blood stream do not kill by a paralytic action on vital centres, and that toxic substances injected intrathecally are less well tolerated than when injected intravenously. The existence of a blood-brain barrier also explains the failure of therapeutic agents, such as the arsphenamides, to influence syphilitic lesions in the central