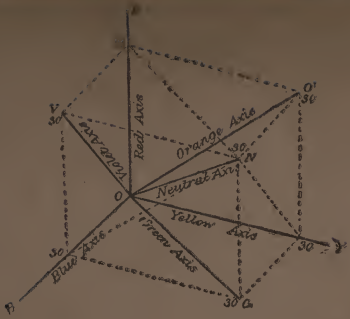


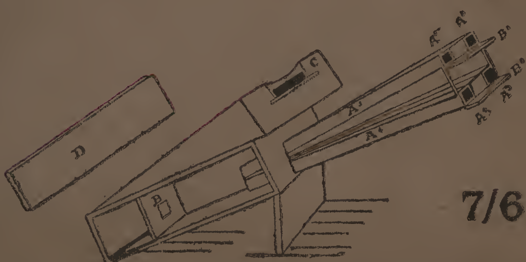
MEASUREMENT

OF

LIGHT AND COLOUR

SENSATIONS

J. W. Lovibond



7/6

MEASUREMENT

OF

LIGHT AND COLOUR SENSATIONS

A NEW METHOD OF INVESTIGATING THE PHENOMENA OF LIGHT AND COLOUR BY MEANS OF THE SELECTIVE ABSORPTION IN COLOURED GLASS, GRADED INTO SCALES OF EQUIVALENT COLOUR VALUE

BY

JOSEPH W. LOVIBOND, F.R.M.S.

THE COLOUR LABORATORIES, SALISBURY, WILTS.

ALL RIGHTS RESERVED

LONDON

GEORGE GILL AND SONS

MINERVA HOUSE, WARWICK LANE, E.C.

TINTOMETER APPARATUS
FOR MEASURING COLOUR OF LIQUIDS.

A^1 In a six-feet stratum.

A^2 In a four-feet stratum.

A^3 In a two feet stratum.

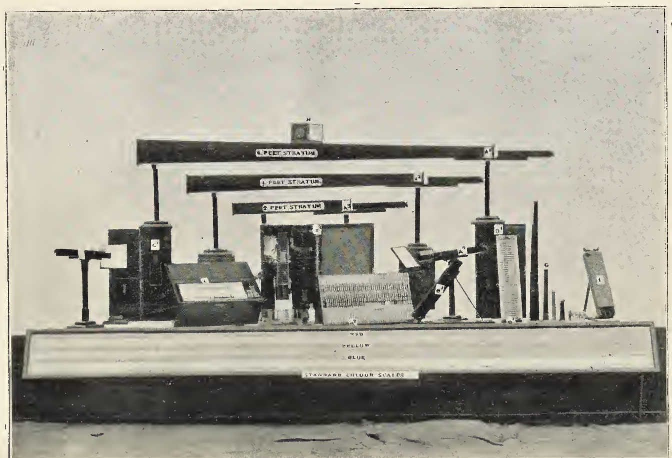
A^1 In strata ranging from two inches to $\frac{1}{1000}$th of an inch.

Dyer's Complete Set.

B^1 The optical instrument.

B^2 The set of glass standards.

B^3 The case to contain the whole; the smaller apparatus shown outside.



The Brewer's and Wine Merchant's Set.

C^1 The open case showing the apparatus as packed.

C^2 The optical instrument arranged for use.

C^3 White reflector.

The Miller's Set.

D^1 The open case showing the apparatus as packed.

D^2 The standard glasses.

E Set for carbon in steel and ammonia estimations.

F The colour vision binocular instrument.

G Cells for liquids, varnishes, resins, etc., ranging from two feet to capillary films.

H Prize medal of the Sanitary Institute of Great Britain for estimating in degrees of known value the colour and turbidity of potable and contaminated waters.

PREFACE

THIS work is a record of some investigations on light and colour carried out whilst the author was perfecting a colorimeter, which he terms **"The Tintometer."**

Experiments to this end were commenced about twenty-five years ago, and continued, by a process of eliminating errors and faulty methods, down to the present time.

The first crude efforts by means of test tubes and coloured fluids have been extended through a wide range of experimental work and apparatus, and have resulted in the production of reliable colour standards for manufacturing and scientific purposes.

The features of the perfected method consists in the adoption of graded coloured glass for standards, of apparatus for cutting off side lights, and of giving a direct view without the aid of lens, prisms, or reflectors.

The scope is limited to that form of radiant energy which is appreciable to the eye as light and colour; and although some of the phenomena dealt with may have a bearing on the physical laws of light, the main question is psychological, that is to say, dealing with the power of the vision to appreciate, rather than with the definition of the laws themselves.

It is not here purposed to inquire into the structure of the visual apparatus itself, but to accept the sensation of a normal vision as *pro tanto* evidence of fact. This course may be safely adopted, for it has been found that when the conditions of observation are identical, and the terms of description have a common meaning, any number of normal visions agree in their description of a given colour.

In view of the many conflicting theories on such fundamental questions as to the precise number of colours, and which amongst them are primary colours, the author, at an early stage, determined to accept no theory as proved until it was demonstrated by experiment.

At first sight this may appear unjust to the many original workers whose researches have evolved theoretical truths long before actual demonstration was possible. It has, however, been accomplished without this injustice by dividing all theoretical positions into two classes.

First, theories which are capable of confirmation by means of actual experiment.

Second, theories which are incapable of confirmation by actual experiment ; considering these latter as working hypotheses to be used as aids to investigation, but not to be defended as if already demonstrated. However arbitrary this distinction may be, it has enabled the author to devote much of his time and energy to actual work, which would otherwise have been employed in profitless controversy.

No popular colour terms will be used except the six—red, orange, yellow, green, blue, and violet. These will be defined, and their mixtures as colours and with white light will be quantitatively stated by means of a scheme of notation similar in exactness to that employed in quantitative chemistry.

The possibility of accomplishing this was first formulated in a paper read before the London section of the Society of Chemical Industry in January 1890, and demonstrated in a paper read before the Physical Society of London in May 1892. The principal investigations were, for reasons which will be stated, at first carried out without reference to the spectrum colours, and before any method of colour-matching by means of spectroscopic lights was published.

The whole may be considered as an attempt to define the laws which limit and govern the power of the normal vision to appreciate light and colour, and then by these means to investigate the phenomena which arise under those laws from complex conditions.

An important factor in the development of this work has been the suggestions and requests from others for new and wider applications of the method of colour measurement.

It could never have arrived at its present position but for much help from scientific friends, amongst whom are:—

Dr. Munro, of the Downton College of Agriculture, who has taken great interest in the progress, and has suggested the mathematical method of representing every possible colour by reference to space of three dimensions; he has also made investigations in connection with colorimetric methods of estimating ammonia and other bodies.

Mr. H. Le Neve Foster, who has worked out a method of estimating carbon in steel.

Mr. T. Jobson, junr., of the Stocksbridge Works, Sheffield, who overcame a difficulty in estimating carbon in some steel solutions of a reddish tinge, and has designed and perfected a very delicate colorimetric method for estimating minute quantities of lead in water, together with a table of colour-unit factors in relation to the lead in solution.

Professor Hummell, of the Yorkshire College, Leeds, who suggested a method of bringing surfaces, uneven in texture or colour, to a suitable condition for comparison by throwing them slightly out of focus with a lens at the eyepiece, and has in many ways shown much interest in the method.

Dr. Knecht, of the Technical College, Bradford, who has also made some comparisons in Turkey reds.

Mr. Boverton Redwood, who, in co-operation with myself, has worked out standards of colour for petroleum, scale, and cocoa-nut oils.

Mr. Priestly Smith, of Birmingham, for suggested improvements in apparatus for testing colour blindness.

Mr. Sanderson, Secretary of the Association of British and Irish Millers, who has co-operated in working out standard colours for measuring the colour of flours, and fixing colour factors of commercial value for the estimation of their baking value.

And last, but not least, I am indebted to the kindness of Mr. E. M. Nelson, who not only gave me his valuable assistance, but placed his admirable monochromatic-light apparatus at my service in endeavouring to measure the lights for microscopic work.

CONTENTS.

CHAPTER I.

CHAPTER II.

CHAPTER III.

CHAPTER IV.

CHAPTER V.

CHAPTER VI.

CHAPTER VII.

CHAPTER VIII.

APPENDIX A.

APPENDIX B.

APPENDIX C.

APPENDIX D.

TABLES.

FIGURES.

COLOUR CHARTS.

COLOURED PLATES.

CHAPTER I.

GENERAL REMARKS.

Some of the results obtained are so intimately connected with the varying conditions of light, under which they were established, that, in order to present a more comprehensive view of the whole question, some general remarks are necessary before detailing the experiments by means of which the results were arrived at.

Many of the results are not new, and it is essential for the unity of the work, that an attempt should be made to separate what appears to be new from the mass of conflicting theories and evidence, which has hitherto surrounded that part of the colour question which is interpreted by the vision.

So far as the author knows, the following points are amongst the new ones :—

The *optical instrument*.

The *glass colour scales* and the *colour equivalence of their several units*.

The *scheme of notation*, and *colour nomenclature*.

The system of *colour charts*.

The *definition of normal white light* as being made up of the six colour-producing rays in equal colour proportion.

The *limitation of the number of separate colour sensations* appreciable by the vision to twelve—six of these being simple, and six compound.

The *determination of the smallest increment of colour* appreciable by a trained normal vision ; the *decreasing action of luminosity* in lights as they become more complex.

The *method of quantitatively separating the six colour rays* from normal white light by selective absorption.

The *apparatus for their quantitative combinations.*

An unexpected *variation* in the power of the vision for the appreciation of the different colours *in camera.*

The *method of measuring* the luminous intensities of lights and mixtures of lights.

During the process of my experiments I have demonstrated the truth of a hypothetical position taken up by M. Chevreul. In the English translation of his work by Mr. Charles Martlett, at page 57, par. 156, the following propositions are laid down :—

"1. There are three primary colours, *Red, Yellow,* and *Blue.*"

"2. Equal parts of any two of these colours mixed together yield a pure *secondary colour.*"

"3. Equal parts of the three primary colours yield *black.*"

"It is easy to demonstrate that the last two propositions are purely hypothetical, since they cannot be demonstrated by experiment."

Had the power of analysing a beam of light by means of the standard glasses been then in existence, M. Chevreul could not only have demonstrated the truth of his Nos. 2 and 3 hypotheses, but, as the work proceeds, it will be seen that this is because No. 1 hypothesis is only partly true, inasmuch as *red, yellow,* and *blue,* whilst being visually monochromatic, are structurally trichromatic. The colour developed by a mixture of pigments in equal parts is not a secondary colour, but is monochromatic both structurally and visually, and is distinguishable because it is the only unabsorbed colour ray in the original mixture.

It is also found that mixtures of any two equal lights in the three colours *red, yellow,* and *blue* also develop a so-called secondary, which is distinguishable in these cases because it is the only ray common to both colours, and therefore, by addition, becomes the preponderating ray of the mixture.

In the first instance the colour is developed by an analytical method, namely, as an absorption of all the composing colour rays except the one distinguished.

In the second instance the same colour is developed by the synthesis of two complex lights, each of which contains the developed colour ray, dormant in the single lights, but preponderating when both lights are mixed.

One effect of my investigations has been to define the limits of a normal trained vision for appreciating minute differences of colour. This limit is six-thousandths (·006) of a standard colour unit, and the standard glasses are gradable, in consequence, down to this point.

The smallest fraction of difference in normal light, appreciable to the vision, has not yet been reached by the standard glasses, although two-thousandths of a normal white-light unit can be registered by means of a single thin slip of colourless glass.

THE APPARATUS.

It is almost impossible without special arrangements to arrive at a reliable judgment between two colours which are very nearly, but not quite, alike, when these are placed openly side by side. The difficulty arises from the unequal incidence of light —sometimes of the direct light, frequently of the side lights, or from both combined. The disturbing effect is so great that a slight change of position in either of the samples, or of the observer, generally reverses the first judgment.

The same causes account for the frequent differences of opinion between two persons judging the same colour ; in fact, the colour sensations of our surroundings are so governed by the ever-varying conditions of light, surface, substance, texture, and chemical composition, that the mere mention of an apparatus for their measurement requires an explanation ; and, perhaps, the best way to obtain a clear understanding of the present apparatus and system will be to describe, shortly, the earlier efforts, and arrive at the present method by a process of eliminating the errors.

Test Tubes. — The first attempts were made with coloured liquids in test tubes of equal diameters, and by these means some useful information was obtained. The liquids, however, soon changed colour, requiring frequent renewals ; and there was always a little uncertainty concerning their exact reproduction. Also a curious inequality of colour relation was found to exist between the regular increase of strata thickness, and their resulting colour. This prevented liquids from being suitable as standards, because some liquids increase in colour depth in direct proportion to increase of strata thickness. Some increase in colour in a less but regular proportion to increase of strata thickness, whilst others increase in a less and irregular proportion.

Another difficulty arose from the convex surfaces of the test tubes acting as a lens, and increasing the disturbance arising from unequal light incidence. The convexity was reduced by using larger tubes, and enclosing them in a blackened case with narrow longitudinal apertures for looking through the middle of the tubes. The results, although useful, were too unsatisfactory for systematic work.

Coloured Glass was next tried, and long rectangular wedges in glass of different colours, with gradually graded tapers, were ground and polished for standards, whilst correspondingly tapered vessels were made for the liquids to be measured. These were arranged to work, at the end of the instrument, up and down at right angles before two apertures, side by side, with a fixed centre line to read off the thickness of each before the aperture when a colour match was made ; but here also the difference of ratio between the thickness and colour depth of the different coloured glass and liquids proved fatal to the method.

An incidental observation was made during these experiments concerning the difficulty of arriving at a final judgment with tapering colours, owing to one shade gradually blending into the next without a break of any kind to arrest the vision. The mental effort to arrive at a decision, under these conditions of gradual colour-blending, was troublesome and vexatious in the extreme. Any person may realise this difficulty by attempting to fix a definite point by the vision in a graduated colour line. I was enabled entirely to remove the difficulty by using separate glass slips for standards ; the line of colour decision made by each additional standard-glass slip used being a precise definition between the most minute shades.

The effect of these partial failures enabled me to more clearly define the conditions from which successful work might be expected, which are as follows :—

Gauged Cells.—The cells for the liquids must have parallel transparent ends and be gauged to definite strata thickness. These are now made to measure the colour in thicknesses varying from one-thousandth of an inch up to six feet.

Optical Instrument.—The standard and the sample must be viewed under equal conditions of illumination. This is accomplished by means of an optical instrument, of which the following is a general description :—

A longitudinal section of the instrument is shown in **Fig. 1**, which consists of a rectangular tube about ten inches long, divided in the middle by a taper partition, B, terminating in a knife edge at the eyepiece C, the aperture of which it divides into two equal parts. This cell is represented crosswise in aperture.

At the other end are two openings, A, A, which admit two equal but separate beams of light to the eyepiece in such a manner, that, on looking through it, the eye commands a simultaneous distinct view of both openings. The knife edge of the partition, being inside the range of vision, does not disturb this distinctness of view.

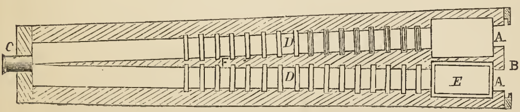


Fig. 1.

The grooves, D, D, are intended to receive the graded slips of coloured glass for intercepting the beams of light transmitted through the tubes before reaching the eye.

The opening at E is intended to receive the gauged vessel containing the coloured liquid to be measured.

In making measurements, light from the coloured object to be measured is transmitted through one tube and a beam of white light through the other. The beam of white light is then disintegrated by means of the standard glasses until it corresponds in colour and intensity, and therefore, as far as the vision is concerned, in composition with that from the coloured object. The degree of disintegration can then be obtained in the numerical terms of the graded standard glasses used.

Fig. 2 represents the instrument as arranged for measuring colour in liquids up to two inches in thickness. The optical instrument, D, slides into the upright stand at A, to receive the gauged cells at H on either side. Light is taken from the standard white reflector, D, on stand D B C, for transmission through the tubes to the eyepiece.

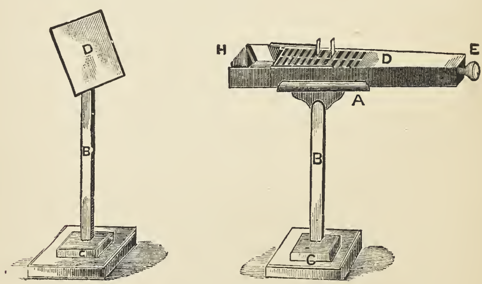


Fig. 2.

A separate stand is required for cells which are longer than two inches. The method of arrangement is shown in **Fig. 3**, where one end of the longer cell rests on the stand, A, which also carries the optical instrument, B, whilst the other is supported by a separate stand, F, which can be moved to accommodate a tube of any length. The reflector, D, is used as in **Fig. 2.**

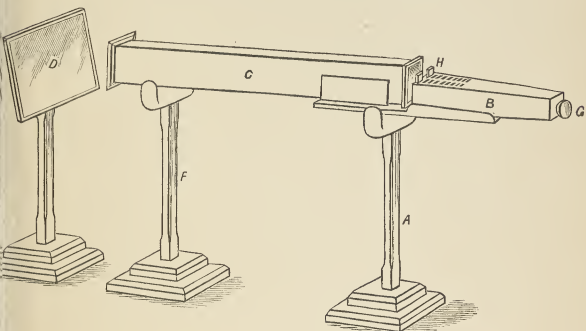


Fig. 3.

Fig. 4 shows the arrangement for measuring colour in opaque objects. The optical instrument, B, is here shown as a binocular, but the monocular described in Fig. 2 fits equally well into the shoe at A^1, the bottom of which is commanded by both tubes of the instrument. Under one side, at F, is placed the opaque substance to be measured, and under

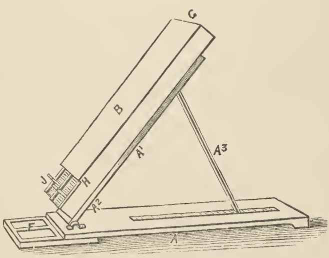


Fig. 4.

the other the standard white (pure precipitated lime sulphate pressed to an even surface), for reflecting the beam of white light, which is then intersected at J by the suitable standard glasses, as already described for transparent colours.

Equality of Light.—Before making a measurement, it is in all cases necessary to adjust the instrument for equality of light in both tubes. This equality of light is easily obtained by placing a piece of paper, or some other smooth evenly-coloured surface, under the tubes and turning the instrument at an angle towards the light until both fields of view are equally illuminated. When this is attained, the standard white and the coloured sample may be placed indifferently on either side without affecting the measurement.

In all cases diffused daylight must be used, preferably from the north, as the glasses are not graded for direct sunlight, and the optical instrument should be as near a right angle as possible to the surface to be measured consistent with obtaining sufficient light.

SUNLIGHT.

The term *direct sunlight* can only be a general one, even on the brightest day, from the varying and unknown absorptive power of the atmosphere through which the rays must pass before reaching the earth. Also direct sun rays are too intense for critical observation by the unaided vision, and any means yet taken to bring them within the scope of observation, by the use of lens, prisms, reflectors, etc., must have a modifying effect, both by the selective absorption of the substances, and by the selective reflection of the surfaces.

The modification from these causes may be small in relation to the whole when the light is intense, but it is an increasing factor, as the light intensity decreases ; and when this is within the visual limits for discriminating small variations in colour, the disturbing elements named may entirely change the colour of the light dealt with, since a small excess of a single ray governs the colour of the whole beam.

DAYLIGHT.

All ordinary conditions of daylight may be said to come under the head of "*diffused daylight*," but these conditions are so varied and subject to such constant changes that the term can have no precise scientific value unless accompanied by a statement of the modifying conditions, or, better still, by actual measurements. This becomes evident on comparing simultaneous measurements (made on a very clear day) of light approaching the vision from the sun, with light receding from the vision. The approaching light will be found to contain an excess of *red*, *orange*, and *yellow rays*, and the receding light an excess of the *violet*, *blue*, and *green rays*. But if a body, such as a cloud for instance, appears in the path of the receding rays, then light, reflected back from this to the vision, contains a preponderance of *red*, *orange*, and *yellow rays*, similar in character to light approaching from the sun.

From these and similar experimental facts it may be assumed as a working hypothesis that, in a clear atmosphere, the *red*, *orange*, and *yellow rays* have a tendency to pass through our atmosphere into space; whilst the *violet*, *blue*, and *green rays* have a tendency to be detained by our atmosphere and reflected back, producing the phenomenon of a blue sky; which becomes bluer as the atmosphere becomes free from aqueous and other particles.

Between these two extremes there exist innumerable combinations, brought about by the reflections from, and the selective absorption by, such substances in the atmosphere as clouds, rain, mist, or dust, and, presumably, by the refractive and diffractive action of each particular particle on the different colour rays. These combinations are further complicated by reflections to and from the earth, each reflection effecting some change in the composition of the reflected ray. In this way the diffused daylight is made up of innumerable broken rays, reflected at all angles in endless variety, from endless substances, filling the vision and forming, as it were, a sea of light in which objects are distinguishable by the alteration they effect in that portion of the impinging light, the residue of which reaches the vision.

It is obvious that the character of this sea of diffused light varies with every altitude of the sun, and with every atmospherical change. But whatever these changes may be, this surrounding diffused light is always a standard of comparison for lights reflected from objects immersed in it.

The vision takes little notice of these changes in the diffused daylight except in extreme cases, so long as the light is sufficient to satisfy or fill the vision, even although the light may be distinctly coloured, as in the case of a blue sky for instance.

The difference between light reflected from an object and the surrounding light may be one of quantity, or one of quality, or of both combined.

If the difference is one of quantity only, then the object will be apparent to the vision as a variation of brightness only. For instance, a polished surface may reflect many times its own area of light to the vision, in which case it will appear brighter than the surrounding light. On the other hand, the surface may be so roughened as to reflect less than its own area of light to the vision, in which case it will appear less bright than the surrounding light. If the difference is one of quality, it arises from the power of selective colour absorption or selective colour reflection, resident in that particular object, which will then be the colour of the preponderating unabsorbed rays of the impinging light which reaches the vision.

It is obvious that mixtures of these two conditions may exist in endless variety.

There is also a difference between the diffused rays of a light, and the direct rays of the original light, which has a direct bearing on the normal white condition of the light used for grading the glass standards into units of equivalent value.

When direct sunlight has passed by innumerable reflections through a fog which is uncontaminated by solid or gaseous impurities, other than aqueous particles, it creates a distinct sensation of whiteness, and reduces that penetrating character of the red ray, which prevents ordinary daylight from being used in grading the standards, into neutral tint units, in quantitative colour accord with the other colour rays of the light.

This condition of normal whiteness can be produced artificially in ordinary daylight, and approximately with the direct sun rays, by transmitting the light through a sufficient number of colourless glass slips, the surfaces of which have been slightly roughened. These, placed before the slit of the spectroscope, so modify the light that all the colours can be simultaneously absorbed by means of neutral-tint glasses, without any undue prominence of the red ray. The normal vision is unable to differentiate between two equal lights which have been equally reduced in intensity, one by dispersion, and the other by absorption.

MEASURING COLOUR IN SPECTRUM OF DAYLIGHT BY PROGRESSIVE ABSORPTION.

Apart from direct sunlight and its more directly reflected rays, the colour ray composition of diffused daylight can be approximately measured by intercepting the spectrum of the light with neutral-tint glasses until the weakest colour ray is absorbed, then adding the necessary glasses until the next weakest, and so on until all are absorbed, when the glasses used will approximately indicate the proportion of the several colour rays in unit terms of the glass standards.

In comparing the absorption of the colours of a continuous spectrum with colour absorption of diffused daylight, it must be borne in mind that colours which have been already separated by a prism must be almost totally absorbed before their separate colour sensations are lost, whereas with daylight colours it is only necessary to absorb the preponderating portion of the colour-producing ray in order to obliterate its colour sensation in favour of the next ray in preponderance.

Observations in Camera.—Investigations into the different kinds of daylight are incomplete without observations in camera; and, in order that these may be reliable for comparison and reference, some characteristics of the vision for this class of observation must be first dealt with. According to the rule laid down, these characteristics will not be treated from a physiological point of view, but only measured and noted, so that the required precautions may be taken to ensure reliable work.

The characteristics referred to are mainly—

First.—The adaptability of the vision by time for discerning low lights in camera.

Second.—The varying rate of vision adaptability for different colours in camera.

Two examples are given, one from a south cloudy sky, and the other from a dull north-east sky, with rain falling. The observations in Table I. were made at intervals of thirty seconds and twenty minutes, and in Table II. at intervals of ten seconds and ten minutes. An examination of the results will at once show the necessity of a uniform time for all observations in camera which are to be compared with each other.

The numbers in the first two horizontal lines of both Table I. and Table II. are the units of glass standards required to wholly absorb their corresponding colour ray in the time of observation named in the margin; or, in other words, the numbers are in units of resistance offered by the glass standards to the penetration of their corresponding rays in the time given.

The third line is the difference between the two observations, and the fourth line is the difference per cent., illustrating the unequal rates of vision adaptation for the different colours between the intervals of time named.

TABLE I.

LIGHT FROM A SOUTH CLOUDY SKY.

Wholly absorbed by the corresponding glass standards:	Neutral Tint. (Daylight)	Red Ray.	Orange Ray.	Yellow Ray.	Green Ray.	Blue Ray.	Violet Ray.
In a *30 seconds' observation*	20	192	117	750	43	272	37
20 minutes' observation	40	236	135	1371	97	968	80
Difference being increase	20	44	18	621	54	696	43
Difference per cent. . .	100	22·91	15·38	82·8	125·58	255·88	114·22

TABLE II.

LIGHT FROM A DULL NORTH-EAST SKY, WITH FINE RAIN.

Wholly absorbed by the corresponding glass standards:	Neutral Tint. (Daylight)	Red Ray.	Orange Ray.	Yellow Ray.	Green Ray.	Blue Ray.	Violet Ray.
In a *10 seconds' observation*	14	87	61	492	28	175	21
10 minutes' observation	24	93	65	952	46	560	45
Difference being increase	10	6	4	460	18	385	24
Difference per cent. . .	71·43	6·89	6·55	93·52	64·28	220	114·48

The increase in the first table varies from 15·38 per cent. for the orange to 255·88 per cent. in the blue, whilst for the daylight it is 100 per cent. in 20 minutes.

In the second table the minimum increase is 6·55 per cent. in the orange to 220 per cent. in the blue, and for the daylight is 71·43 in 10 minutes.

This variation may also have some relation to the luminous intensity of the separate colour rays. It is also evident that the variations in luminous intensity are not regularly progressive from red, through the intermediate colours to violet, as in the case of wave-length variations in the solar spectrum. This irregularity may, however, be due to certain imperfections in the absorption glasses.

No doubt, more practical work by a number of observers is required on this interesting question of preferential colour discrimination in the vision. I simply give the examples as experimental facts to illustrate the necessity of a uniform time for such observations.

COLOURLESS LIGHT.

As all colour is a condition of light, it is necessary to define a standard; or, in other words, a normal white light by which coloured lights can be compared. The definition of a normal white light adopted for the system of colour work here described, is one which contains the six colour rays *red*, *orange*, *yellow*, *green*, *blue*, and *violet*, in equal colour proportions. Any departure from this equivalence constitutes an abnormal light, and therefore a coloured light. It does not follow that the colours of all abnormal lights are distinguishable by the unaided vision, as there are at least three conditions when the colour of a light fails to induce its corresponding colour sensation.

First.—In abnormal lights of medium luminosity; when the colour of the abnormal or preponderating rays are masked by excess of accompanying white light, as in the case of the rainbow which is distinguishable in proportion to a decrease in the quantity of surrounding light, or in the interior of large buildings with little other light than through coloured-glass windows. The coloured light reflected from objects in the building will be distinguishable as the direct rays transmitted through the coloured glass increase in proportion over the diffused light of the interior.

Second.—In abnormal lights of high luminosity; when the abnormal or preponderating colour rays are masked by the luminous intensity of the light itself, as in the unclouded sun which appears coloured only as the luminosity is decreased. Again, in the case of ordinary illuminating coal gas, a single jet produces a distinct yellow-orange colour sensation, which becomes white to the vision when a number of jets are placed near each other, although not sufficiently near to influence the chemical changes arising from the combustion of each.

Third.—In abnormal lights which are too low in luminosity to excite a full sensation of light in the vision within certain definite degrees of complexity, in these, the abnormal colour rays under certain conditions appear to be lost in the sensation of grey.

This inability of the unaided normal vision to distinguish colour in abnormal lights, outside these limits of luminous intensity and complexity, has an important bearing on experimental conclusions arrived at by means of mixtures of such lights. It will be demonstrated in the course of the experiments on mixed lights, that it is the preponderating one, or in some cases two, colour rays in an abnormal light which governs the colour sensation of the light under ordinary daylight conditions, any remaining abnormal colour rays being lost in the general luminosity of the light.

SUITABLE LIGHT FOR COLOUR WORK.

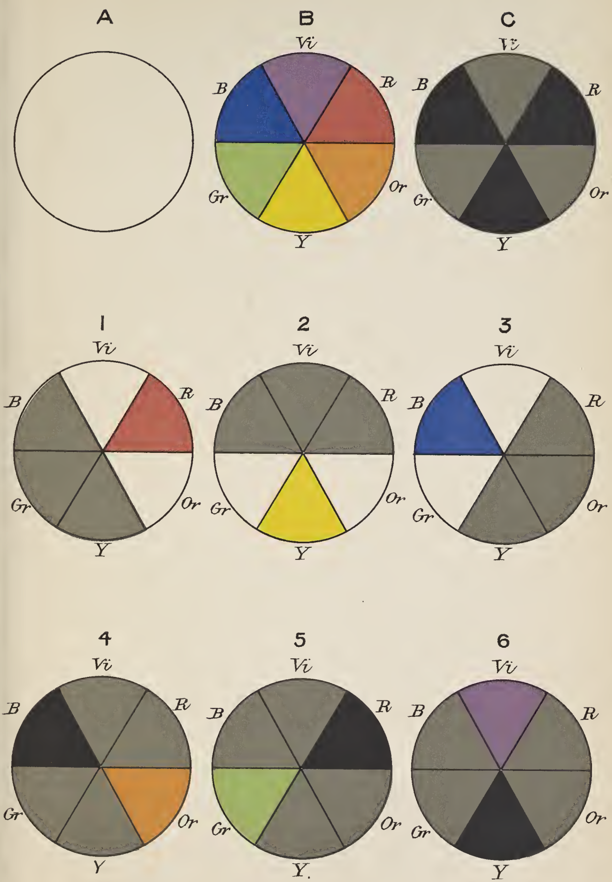
Considerable differences of view exist concerning the most suitable light for colour work. Some authorities consider that daylight is too unreliable in composition, and that an artificial light, such as the electric arc, is best, as being always uniform.

Captain Abney's work and apparatus, at first sight, go a long way towards establishing this view. Some valid reasons, however, in my opinion, exist in favour of daylight ; as it is the light to which normal vision is most accustomed, and it is available, without cost at a moment's notice, during daylight hours, whereas artificial lights require to be worked in camera with somewhat expensive apparatus. Again, by far the largest proportion of artistic and commercial colour work is carried on by daylight, so that measurements made by means of any other light must be transposed into terms of daylight values before reliable comparisons can be made. Without doubt the vision can work longer and with less fatigue by daylight than by intense artificial light.

Here, also, more experimental work is wanted. The author has, however, found that a colour measurement, made under suitable precautions with sufficient daylight, is uniform under all conditions of ordinary diffused daylight, and that the distinct colour of the daylight may be altered, within limits not yet clearly defined, without altering the colour measurement in question.

This is easily demonstrated by means of a stratum of water measured in daylight, the measure remaining constant although the visual colour sensation may be altered at will by intercepting the light with glass of different colours.

PLATE I.



(To face Page 27)

CHAPTER II.

PRIMARY COLOURS.

A PRIMARY colour, in the usual acceptance, is one which cannot be further disintegrated; and much confusion has arisen through attempting to build up a primary colour by mixing lights which were already complex.

Considering that the composition of these complex lights has been hitherto indefinable, the evidence on the subject is somewhat conflicting, and has given rise to a number of theories as to how many primary colours there really are in a continuous spectrum. The following list of theories is probably incomplete, but it will suffice to illustrate the confusion which exists on the subject:—

A **Three-Ray**	**Theory,**	consisting	of	*Red, yellow, and blue.*
,, **Three**	,,	,,	,,	*Red, green, and violet.*
,, **Four**	,,	,,	,,	*Red, yellow, green, and blue.*
,, **Five**	,,	,,	,,	*Red, yellow, green, blue, and violet.*
,, **Six**	,,	,,	,,	*Red, orange, yellow, green, blue, and violet.*
,, **Seven**	,,	,,	,,	*Red, orange, yellow, green, blue, indigo, and violet.*

The experimental work which follows, carried out by means of carefully selected *red, yellow, and blue* glass, and illustrated by a series of colour circles, defines the number of separate colours in the spectrum as being six, namely:—

Structurally tri-chromatic, visually monochromatic — called the three **Dominants.**	Colour	Structurally and visually mono-chromatic—called the three **Subordinates.**
→	RED	
	ORANGE	←
→	YELLOW	
	GREEN	←
→	BLUE	
	VIOLET	←

The above six are divisible into two classes, one class containing the colours *red*, *yellow*, and *blue*. These colours, as transmitted through the separate coloured glasses, are alike in being visually *monochromatic* and structurally *trichromatic*. These I propose to call the **Dominant** colours, because each colour masks its two accompanying rays.

The other class contains *orange*, *green*, and *violet*, which are the colours transmitted by pairs of the above glasses, and are alike in being *monochromatic*, both structurally and visually. These I propose to call the **Subordinate** colours, because they only become evident as pairs of the dominants absorb each other. Since, by this method, they cannot be further disintegrated, *orange*, *green*, and *violet* may be here considered as the three primaries in the original sense of the word, not being divisible into other colours.

All light and colour is destroyed by mutual absorption of the six colour rays, in suitable combinations of red, yellow, and blue glass.

The specific action of each of the coloured glasses on a beam of normal white light may be illustrated as follows :—

Let circle A, in **Plate 1**, represent a beam of normal white light, and circle B a similar beam, coloured in six equal divisions to represent the six composing colour rays, and circle C a similar beam wholly absorbed by red, yellow, and blue glass of suitable and equal colour values.

(The deeper shading in the red, yellow, and blue divisions is only intended to illustrate the double absorptions in these divisions, and not to signify incomplete absorption in the orange, green, and violet divisions.)

PLATE II.

Fig. 1.

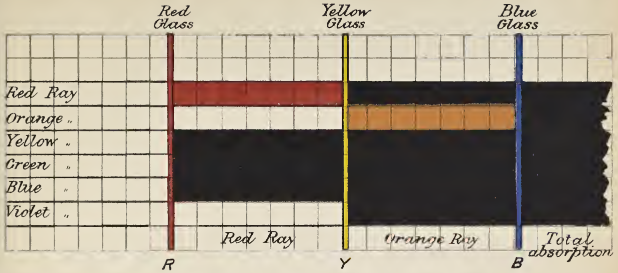


Fig. 2.

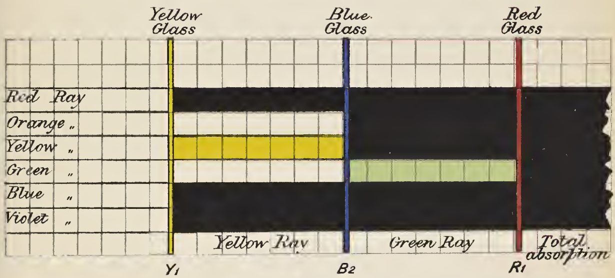
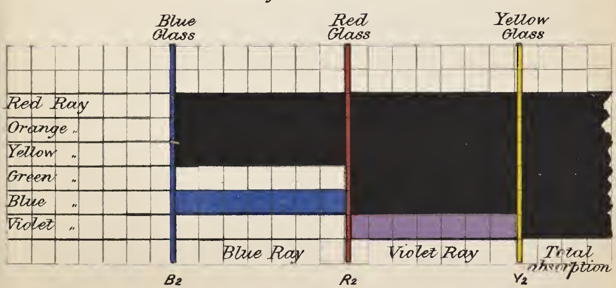


Fig. 3.



(To face Page 26)

Circle 1 illustrates the effect of intercepting normal white light with red glass, which absorbs the yellow, green, and violet rays, transmitting the violet, red, and orange rays, the red alone being visually colour evident.

Circle 2 illustrates a similar beam as intercepted by yellow glass, which absorbs the blue, violet, and red rays, transmitting the orange, yellow, and green rays, the yellow alone being visually colour evident.

Circle 3 illustrates a similar beam as intercepted by blue glass, which absorbs the red, orange, and yellow rays, transmitting the green, blue, and violet rays, the blue alone being visually colour evident.

Circle 4 illustrates a similar beam as intercepted by red and yellow glass, showing violet as the colour developed, all the other colour rays being extinguished by mutual absorption.

Circle 5 illustrates a similar beam as intercepted by yellow and blue glass, showing green as the colour developed, all the other colour rays being extinguished by mutual absorption.

Circle 6 illustrates a similar beam as intercepted by blue and red glass, showing violet as the colour developed, all the other colour rays being extinguished by mutual absorption.

Another way of stating the phenomena illustrated in *Circles* 4, 5, and 6, **Plate 1**, is by saying that, in each case, the colour developed is the only one transmitted in common by the pairs of intercepting glasses.

The circle illustrations in **Plate 1** are intended to represent a normal white light of given intensity, and the intercepting glasses to show a colour depth just sufficient to absorb all the colour rays of the light, having, in fact, an equivalence of colour-absorptive value in reference to the normal white light.

It may be here stated that red, yellow, and blue glass are the only colours which lend themselves to systematic work, the use of any other coloured glass leading to confusion.

It is not intended to affirm that the red, yellow, and blue rays may not prove to be structurally monochromatic, but only that, when met with in nature, they are structurally trichromatic.

The method of absorption is further illustrated in **Plate 2**, where the only three combinations possible with the other three glass standards are shown as gradually absorbing three beams of normal white light.

In *Fig.* 1 the beam, A_1, first impinges on the red glass, R_1, which absorbs the yellow, green, and blue rays, transmitting violet, red, and orange ; the red alone exciting a colour sensation. These three transmitted rays next impinge on the yellow standard marked Y_1, which absorbs the red and violet rays, transmitting only the orange, which is finally absorbed by the blue glass, marked B_1.

In *Fig.* 2 the beam first impinges on the yellow glass, Y_2, which absorbs the blue, violet, and red, transmitting the orange, yellow, and green ; the yellow alone exciting a colour sensation. These three transmitted rays next impinge on the blue glass, B_2, which absorbs the orange and yellow rays, transmitting only the green, which is finally absorbed by the red ray, R_2.

In *Fig.* 3 the beam first impinges on the blue glass, B_3, which absorbs the red, orange, and yellow rays, transmitting the green, blue, and violet ; the blue alone exciting a colour sensation. These three transmitted rays next impinge on the red glass, R_3, which absorbs blue and green rays, transmitting only the violet, which is finally absorbed by the yellow glass, Y_3.

In these cases also the colour intensity of the glass used is of the full equivalent colour depth for absorbing all the colour rays in the normal beam ; and as this is true for the whole light, the absorption of the smallest fraction by glass of suitable colour depth is also true.

THE COLOUR SCALES.

During the earliest adoption of various coloured glasses for standards, some colours only were found suitable for grading into equal divisions, forming scales. These divisions, or units, were arbitrary ; and the unit dimensions of one scale had no relation to the unit dimensions of another scale.

The experimental work done, however, with the red, yellow, and blue glass then available, gave such regular results in developing the orange, green, and violet colours, and also in the obliteration of colour, as to suggest the possibility of definite laws, which apparently only required purer colours in glass to elucidate. Great difficulty was experienced in securing these purer colours until, at last, the glass used in the present scales was obtained, when it was found that not only could the red, yellow, and blue glass be graded into equal units throughout each scale, but that combinations of three scales could be made which destroyed all colour, although with what then appeared to be an unaccountable uncertainty, as the same combination of glasses which destroyed all colour at one time developed colour at another time. These discrepancies were soon traced to variations of colour in the light employed, resulting in the discovery that the light from a white mist gave fairly uniform results, and on those occasions, when observations taken from north, south, east, and west agreed with each other, the measurements were always uniform. By means of light from such a white mist the standard glasses now in use were graded, and the units of the three scales which hitherto had no relation towards each other were brought into accord by transposing the dimensions of the yellow and blue unit into relative agreement with the value of the red unit, which proved to be the least in colour value in the original scales.

Since no other light has yet been found, which even nearly approaches this in equality of colour-ray composition, *the light from a white mist (sea fog), when there is no variation in the colour readings, whether taken from the north, south, east, or west, must for the present be considered as the standard normal white light.* When such a light has been gradually absorbed to extinction by successive interceptions with neutral-tint units without developing any colour, it has passed the most severe test at present available for normal whiteness. Any development of colour must be due either to the abnormal character of the light used, or to irregularities in the standard scales.

This character of colour equivalence in the six rays of normal white light may be roughly tested by means of the spectroscope, because the spectrum of such a light can be wholly absorbed by means of glass standard neutral-tint units, without any undue prominence of one colour over another as the point of total absorption is approached. But I do not consider this test a delicate one, mainly because the vision has a varying power in appreciating the different colour rays by time in camera, and also because the spectroscopic prism presents the several colour rays under different conditions; those rays at the violet end of the spectrum being more expanded than the rays at the red end.

In absorbing the spectrum colours they are necessarily low in luminosity, and therefore not susceptible of minute colour differences, but are still sufficiently susceptible to make it evident that no one ray greatly preponderates over the others, as in the case of a spectrum of sunlight, or of artificial lights. The unit of the scales is uniform, and complies with all the requisites of a standard, inasmuch as it is recoverable and arbitrary. But it is neither more nor less arbitrary than the inch of a foot rule, or the mass of distilled water which has been chosen as equal to a gramme, or any other standard measure. The actual dimensions of the unit is not a matter of supreme importance.

The true essentials of a standard scale are complied with, in that they are, like other standards, uniform and recoverable; they are also equal throughout, and are subdivided into the smallest fractional parts between which the vision can differentiate.

This mode of fixing the equality of the unit in each of the three scales, is based on the purely experimental observation that **the three colour units which go to make up a neutral-tint unit are equal**, which is only another way of saying that they absorb the coloured components of normal white light in equal proportions.

Neutral tint may also be described as a decrement of normal white light, and, when represented in standard units, is a measured decrement of normal white light.

CHECKING THE STANDARD SCALES.

Since the grading of these scales on the basis of equivalent colour values, they have been in constant use for analytical colour work in many laboratories, and for practical colour work in many manufactories, without any expression of doubt as to the exactness of measurements made by their means.

Also, there is no doubt whatever in the minds of the trained matchers, who grade the standards, as to the uniformity, both of **dimensions** and of **colour** in the unit values of the various sets which they examine. This confidence is the result of a system of cross-checking the different parts of each scale, and the different scales of each set, with the original standards. It is also confirmed by the utter inability to make the neutral-tint unit colourless, unless this correspondence of colour value in each glass of similar grade is maintained.

But something more than the confidence of workers in the harmony of their own work is necessary before a new method of measurement, such as this, for light and colour can be accepted as a standard of common reference.

The scientific nature of the system must be clearly established, and the means of checking the colour and dimensions of the unit honestly placed within the power of every scientific worker. The object of this chapter is to establish both these propositions.

THE SPECTROSCOPE AS A VERIFICATION OF THE STANDARD SCALES.

The spectroscope naturally first suggests itself as a means of checking the colour unit in the standard glasses. Investigation up to the present time gives but little encouragement in this direction; for although the spectrum of light from a white mist, similar to that used in grading the glass, is found to be practically in accord with the absorption equivalents of the standard glasses themselves, yet the colours are too low in luminosity for critical comparison; and when lights of greater luminosities are used, all the old difficulties arising from uncertain intensity and unequal colour-ray composition, which occurred in the search for a normal white light, recur ; but for this purpose under more aggravated conditions.

1st. In those lights where the red ray already preponderates, the preponderance is accentuated by its more concentrated condition, caused by less refraction than the violet rays at the other end of the spectrum. This disturbance is necessarily common to all prism-refracted colour.

2nd. Also, in the red division, another disturbing element is the greater diffraction of the red ray compared with the violet, which is caused by the edges of the slit in the spectroscope. How much this difference of diffraction complicates the visual appearance of the several colours is at present unknown, but it may possibly have some relation to the manifestly more confused (not to say impure) colour at the red end of the spectrum.

3rd. The rays in the middle of the spectrum are doubly overlapped, that is, by the rays on each side of the middle, whereas the rays at each end of the spectrum are singly overlapped, that is, by the rays on one side only. How these resulting inequalities of ray composition affect the several colour sensations is as-yet an unsolved problem.

4th. Beyond the limits of ordinary daylight the vision becomes less sensitive to colour as the light intensity increases. In these cases the sensation produced is no index to the ray composition of the colour, visual whiteness being compatible with a light of unequal colour-ray proportions when the lights are of high luminosity.

These difficulties appear to exclude the spectroscope, in its present form, as a means of checking the minute gradations in the Tintometer colour scales ; but the internal evidence of the correctness of the theory on which it is based is too exhaustive to be ignored, in the face of the numerous series of experiments which have been made with it.

CHECKING THE UNIT.

Uniformity of units and fractions of units, both for colour and dimensions in a single scale, can be verified by a system of cross-checking the different parts.

The glasses of one set can be verified with glasses of another set by interchanging, and then cross-checking. Considering that the smallest variation in colour between which the vision can discriminate is discoverable in the scales by this system, any other method, to be of value, must be at least as efficient as this.

A knowledge of this power does not, however, dispose of the necessity for investigators having the means of verifying themselves the standards with which they may be working.

A perfect means already exists in every authentic recorded measurement of a coloured substance of known percentage, value, and of absolute purity, as, when such a pure substance has been once correctly measured and recorded by means of one set of standards, it is evident that all measurements of a similar substance made by means of other sets should agree with the first if the different sets are in accord with each other. Any variation is evidence of want of accord, and the amount of variation is a measure of the difference.

The whole construction of the scales is so perfectly in accord with this scientific basis, that if every set in existence was simultaneously destroyed the whole could be exactly reconstructed upon the basis of one such authentic recorded measurement of a known coloured substance.

COLOUR PURITY AND COLOUR BRIGHTNESS.

The above terms are not synonymous, but the unaided vision is frequently unable to differentiate between them. A colour is really pure in proportion as it is free from mixture with rays of other colours, and in another sense from mixture with a greater proportion of normal white light. A pure colour may be of any degree of brightness, which has relation to the quantity of rays compared with the surrounding light. The power of the vision to appreciate brightness is greatest when the lights are viewed in camera.

A colour is impure either in proportion to its mixture with other colour rays, or with normal white light. In the first case, the visual degree of colour purity has relation to the kind of rays with which the colour is mixed. Those not adjacent in the spectrum order have a more degrading effect than those adjacent in the spectrum order. The phenomena due to both these causes can be examined more in detail when dealing with the quantitative experiments with mixed colours and lights.

The brightness of an impure colour may be of any degree; it also has relation to the surrounding light, and is greatest in camera.

A colour, whether pure or impure, rapidly loses its power of exciting a corresponding colour sensation as it becomes mixed with normal white light.

A theoretically pure colour is practically impossible, whether as separated by the spectroscope, or by any known method of selective absorption. The spectrum colours owe their beauty to the intensity of the lights from which they are usually developed, and to their being viewed in camera; but they have no right to be called pure colours according to the strict definition. All who have experimented with these colours know how small a mixture of daylight decreases, and, as the proportion increases, destroys their power of creating their corresponding colour sensations.

The glass standard scales, although not pure in colour, do furnish a definite line of colour purity and of brightness from which departures can be measured on either side.

COLOUR NOMENCLATURE.

The popular method of naming a colour according as it resembles some well-known substance, such as indigo, etc., however convenient for general purposes, is unsuitable for a scientific nomenclature, which requires that a colour name should indicate the composition of the colour itself.

The nomenclature here adopted applies to colours under daylight conditions, and is founded on the following simple laws :—

1st.—The vision is sensitive to light under two aspects, describable as *colour* and *luminosity*.

2nd.—In *abnormal lights*, it is the preponderating colour ray or colour rays which govern the colour sensation of the light.

3rd.—A *normal vision* is not simultaneously sensitive to more than two colour sensations. Therefore, not more than two colour terms are required in describing a complex colour.

4th.—When two colours are simultaneously distinguishable, they are always those which are adjacent in the solar spectrum ; red and violet being considered adjacent for this purpose.

5th.—In abnormal lights all the rays which are not colour evident are merged in the general luminosity, the degree of which is describable by a single term.

It follows that any light, however complex, is describable by two colour terms and one light term, and when these are quantitatively stated they not only give the analytical composition, but also a verbal description of the visual characteristics.

The **colour** terms available are, in the first instance, the six **visually monochromatic** colours :—

Red.	*Green.*
Orange.	*Blue.*
Yellow.	*Violet.*

Under Law 4, the following are the only six possible colour combinations, the constituents of which may, however, be in any proportion to each other, these being adjacent in spectrum order :—

Red-Orange.	*Blue-Green.*
Yellow-Orange.	*Blue-Violet.*
Yellow-Green.	*Red-Violet.*

The light term which rules the brightness of a colour may vary from the point where colour sensation is lost in deficiency of light, to the point where colour sensation is lost from excess of light—that is, through all degrees of brightness from black itself to the most brilliant light.

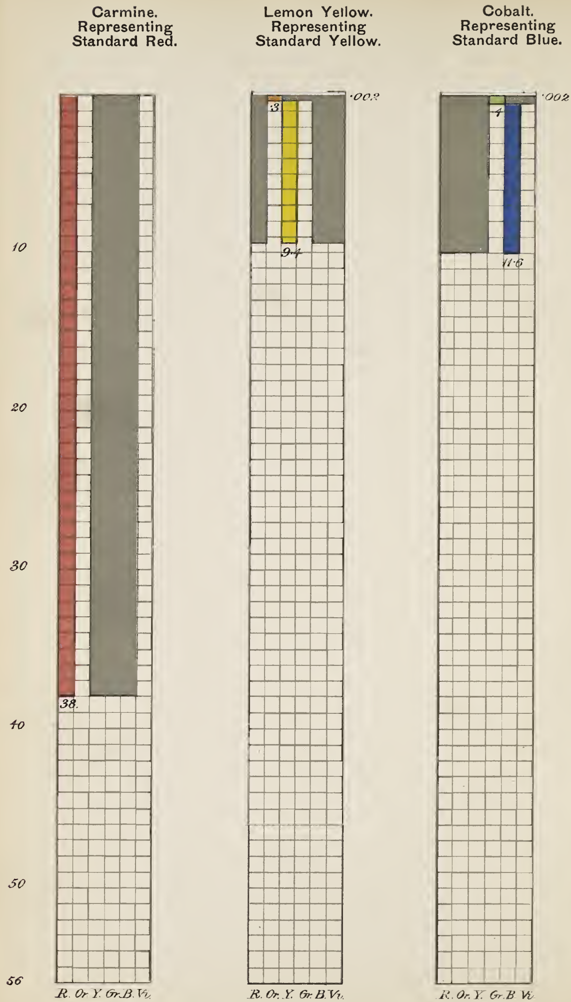
The composition of a measured colour, as a verbal definition of the colour sensation it produces, is obtained by means of an equation, the first half of which contains a statement of the separate glasses used to disintegrate the light, and the second half a statement of the colour-ray composition of the light transmitted. These, together with the unaltered white light, produce that particular colour sensation.

PIGMENTS REPRESENTING THE SIX STANDARD COLOURS.

In order to illustrate the system of nomenclature, the following examples of opaque-colour measurements are those of the six water-colour pigments, originally used in the coloured diagrams, as most nearly resembling the three glass standards, and the three normal colours of the scales. All were measured as impalpable powders pressed as directed, except the mauve, which was not obtainable as powder, and was therefore measured dried on paper.

The measurements and equations, with remarks, are given in Table III., and the quantitatively coloured sections of measured light in Plate III.

PLATE III.



(To face Page 39)

TABLE III.

Table of Pigments nearly corresponding to Glass Standards.

Standard Colours.	Representative Pigments.	Light brighter than Standard.	Standard Glasses used.			Light transmitted by the Standard Glasses.*		
			Red	Yellow	Blue			
Standard Red:	*Carmine* . .		=38·0	+ 0·0	+ 0·0	= 0·0	Red +38·0	—
Standard Yellow:	*Lemon Yellow*.	N.T. +·002	= 0·3	+ 9·4	+ 0·0	= Or. ·3	Yellow + 9·1	light +·002
Standard Blue:	*Cobalt* . . .	+·002	= 0·0	+ 0·4	+12·0	= Green ·4	Blue +11·6	+·002
Normal Orange:	*Orpiment*. .	—	7·4	+ 6·8	+ 0·0	= Or. 6·8	Red + ·6	—
Normal Green:	*Emerald Green*.	+ 2·5	= 0·0	+14·0	+14·0	= Green 14·0	light + 2·5	—
Normal Violet:	*"French Mauve"*	—	8·4	+ ·6	+ 6·8	= Violet 6·2	Red + 1·6	Black +·6

Carmine is in exact accord with the glass-standard red.

Lemon yellow is ·3 orange off glass-standard yellow, and ·002 of light brighter.

Cobalt is ·4 green off glass-standard blue and ·002 of light brighter.

Orpiment is ·6 red off normal orange.

Emerald green is in exact colour accord with normal green, but 2·5 units brighter.

French mauve is 1·6 red and ·6 black out of accord with the normal violet.

The *luminous intensity* of the particular beam of light used in these measurements, as reflected from the standard lime-sulphate surface through the optical instrument, and intercepted to total absorption by neutral tint standards at the eyepiece, was equal to 56 *neutral tint units* on a ten-seconds observation.

* The second half of the equation represents the visual colour, including their proportions, and is a re-arrangement of the first half, according to their visual equivalents, as described in the last paragraph on page 46.

As there are six colour rays, each of 56 colour units, in this normal beam, it follows that a section of this light can be represented by means of a rectangular figure, 56 units long and 6 units wide, containing 336 equal colour areas ; and as the colour areas are in accord with the standard colour units, any colour developed can be quantitatively represented in the diagram by colouring a corresponding number of squares; and the light absorbed may be illustrated by blackening six horizontal areas representing the six colour sections of a normal unit of light.

The alterations effected by a pigment on the incident beam of 336 colour areas can be also stated in a tabular form, containing the numerical values of the altered and unaltered colour areas.

Before doing this it must be pointed out that there are two kinds of absorption, which are so different in their influence on the colour sensation of a pigment as to require a separation of their values and a difference in their terms of description.

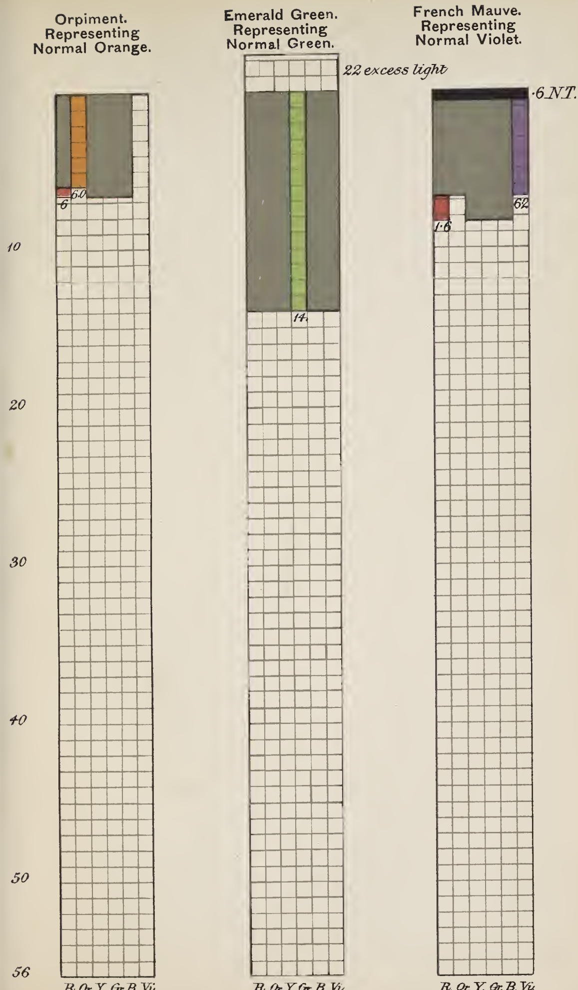
The first kind is that effected by a combination of three standard glasses. Light so absorbed has a degrading influence on the colour beam from which it has been abstracted, corresponding in effect to a mixture of black pigment with a pure coloured pigment. For the purposes of the present investigation this class of absorbed light will be called "**Black-Ray Areas**" in the tables, and will be coloured black in the diagrams.

The second kind of absorption is that effected by one or by a combination of two standard glasses. Light so absorbed has no degrading effect on the purity of colour in the beam from which it has been abstracted. This, pending fuller investigation, will be called in the tables "**Absorbed Light,**" and will be indicated in the diagrams by a lighter shading than black.

The light appearing in the measurements as "purer than standards" will be called "**Excess-Light Areas**" in the tables, and will be figured in the diagrams by placing the corresponding areas as additions to the measured beam.

This excess light has a greater effect on the brilliancy of a

PLATE IV.



(To face Page 40)

colour than its small quantity seems to warrant. It may be shown how the light transmitted through the matching glasses produces the colour sensations belonging to the different pigments. In the case of *carmine* light, containing 336 *colour units* before impinging on the glasses, the composition of beam after impinging represents the colour of carmine as 38 *red* units, and 184 unaltered light, leaving 114 units absorbed by the glasses. The colour diagrams represent this in printed colours. The analyses of the diagram representing each colour will be as follows :—

TABLE IV.

ANALYSIS OF COLOURED PIGMENTS.

		Units of Colour-Ray Areas.
Carmine	*Red*	38
	Absorbed	114
	Unaltered	184
	Total Ray Areas	336

TABLE V.

Lemon Yellow	*Orange*	·3
	Yellow	9·4
	Absorbed	29·7
	Unaltered	296·6
		336·0
	Excess Light	·012
	Total Ray Areas	336·012

TABLE VI.

Cobalt	*Green*	·4
	Blue	11·6
	Absorbed	36·8
	Unaltered	287·2
		336·0
	Excess Light	·012
	Total Ray Areas	336·012

TABLE VII.

		Units of Colour-Ray Areas.
Orpiment	*Red*	·6
	Orange	6·0
	Absorbed	31·8
	Unaltered	297·6
	Total Ray Areas	336·0

TABLE VIII.

Emerald Green	*Green*	14·0
	Absorbed	70·0
	Unaltered	252·0
		336·0
	Excess Light	13·2
	Total Ray Areas	349·2

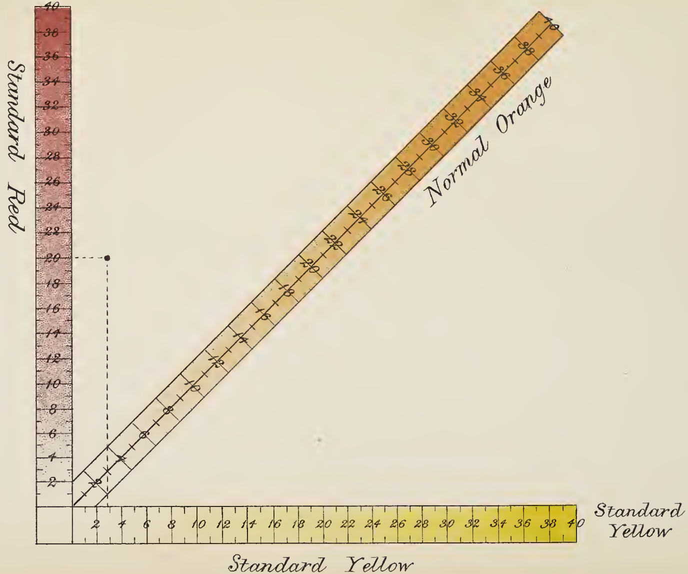
TABLE IX.

Mauve	*Red*	1·6
	Violet	6·2
	Black	3·6
	Absorbed	35·8
	Unaltered	288·8
	Total Ray Areas	336·0

As already pointed out, these diagrams and tables deal with the whole beam of light as transmitted through the instrument; but for general purposes it will be only necessary to illustrate by colour quantities those rays which the vision recognises as being affected by the standard glasses used, all the other rays being merged into the general luminosity of the coloured beam. And as the "absorbed light" in the above tables is not definable, as such, by the vision, it need not be indicated in future diagrams of measured colours—at least, until this phase of the question is better understood.

CHART I.

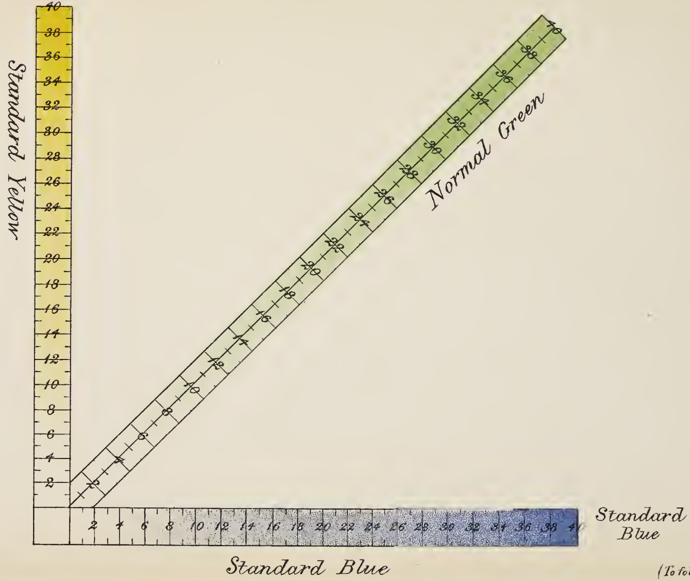
NORMAL ORANGE.



(To face page 42)

CHART II.

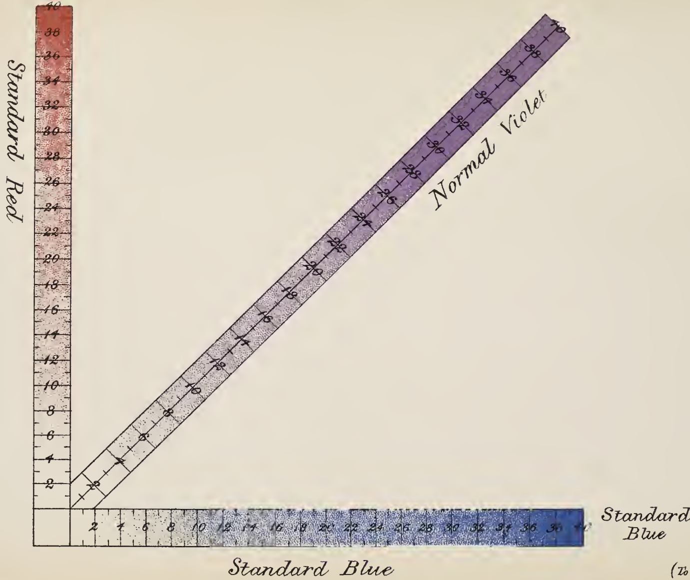
NORMAL GREEN.



(To follow Chart 1 page 42)

CHART III.

NORMAL VIOLET.



(To follow Chart 2 page 42)

CHAPTER III.

THE COLOUR CHARTS.

There are *nine colour charts* in number, forming *two sets*. The first is a set of three, *the normal colour charts*, made by combination in pairs from three lines which correspond in colour and in grading with the sets of glass standards—*red*, *yellow*, and *blue*.

These lines are called the standard colour lines, and are synonymous with the visually monochromatic, but structurally trichromatic, rays already described on page 28.

Each chart is a right angle formed by any two of the *standard colour lines*, with the zero ends at the angle. The combinations will then be :—

No. I.	Chart made by the	*red*	and *yellow*	lines.
,, II.	,, ,,	*yellow*	,, *blue*	,,
,, III.	,, ,,	*blue*	,, *red*	,,

Any measured colour is chartable in the terms of the glasses used, upon one or another of this first set of three charts : for example,—

A colour which is matched by a single glass standard will find a position directly on that corresponding colour line where the number coincides with the unit number on the glass used.

A colour which is matched by two glass standards will find a position at the point where two lines meet, which are drawn at right angles to the lines and through the numbers corresponding to the two glass standards used : for instance, the measurement of vermilion powder, which was matched by 20 red and 2·4 yellow standards, finds a position on No. I. Chart, where perpendiculars drawn through 20 on the red line and 2·4 on the yellow line meet, as shown in the illustration.

A colour which is matchable by three glass standards is chartable where the two preponderating colour lines meet, as in the case of the vermilion, whilst the third and least is written near this point.

In this way a *Prussian Blue* powder, matched by

	Standard Glasses.
	R. *Y.* *B.*
Prussian Blue . .	9 + 1·0 + 6·8,

will find a position on No. III. Chart, where a perpendicular drawn through 9 on the red line meets a perpendicular drawn through 6·8 on the blue line; the 1·0 of yellow is written in numerals near this point.

It must not be forgotten that colours charted on the first set of three (the normal colour charts) are in the terms of standard glasses used, in contradistinction to the ray composition of the light they transmit.

The principal value of the above set of three charts is to demonstrate the *normal orange*, *green*, and *violet colour lines*, which are synonymous with the corresponding monochromatic colour rays, and are necessary in forming the second set of six charts used for charting the colour sensations of measured colours in the terms of the second half of their equations, *i.e.*, of the terms of light transmitted by the standard glasses.

The normal *orange line* is in that diagonal of No. I. Chart where perpendiculars from equal numbers on the red and yellow lines meet.

The normal *green line* is in that diagonal of No. II. Chart where perpendiculars from equal numbers on the yellow and blue lines meet.

The normal *violet line* is in that diagonal of No. III. Chart where perpendiculars from equal numbers on the blue and red lines meet.

CHART IV.

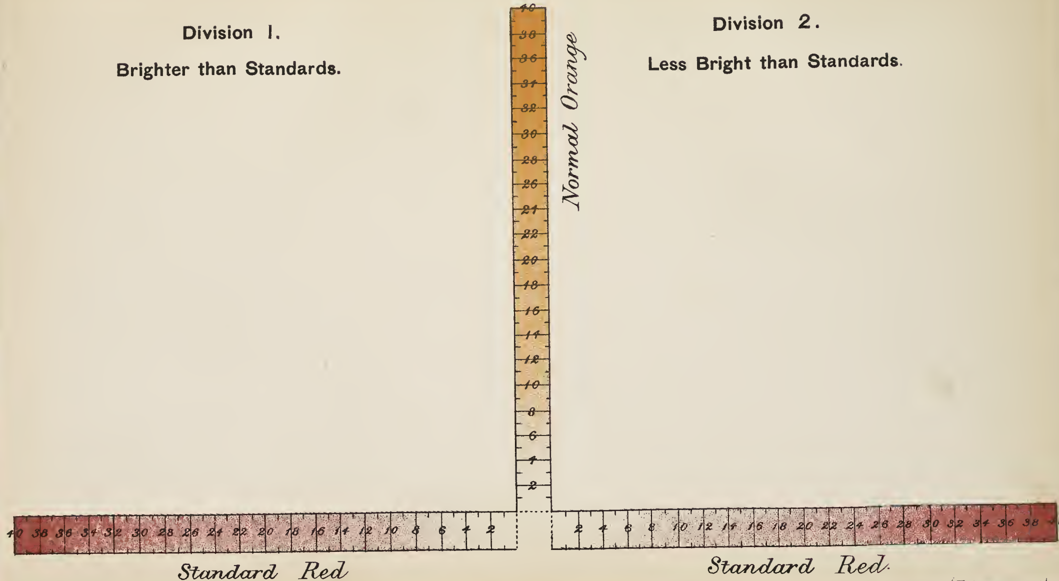
RED ORANGES.

Division I.

Brighter than Standards.

Division 2.

Less Bright than Standards.



(To face page 44)

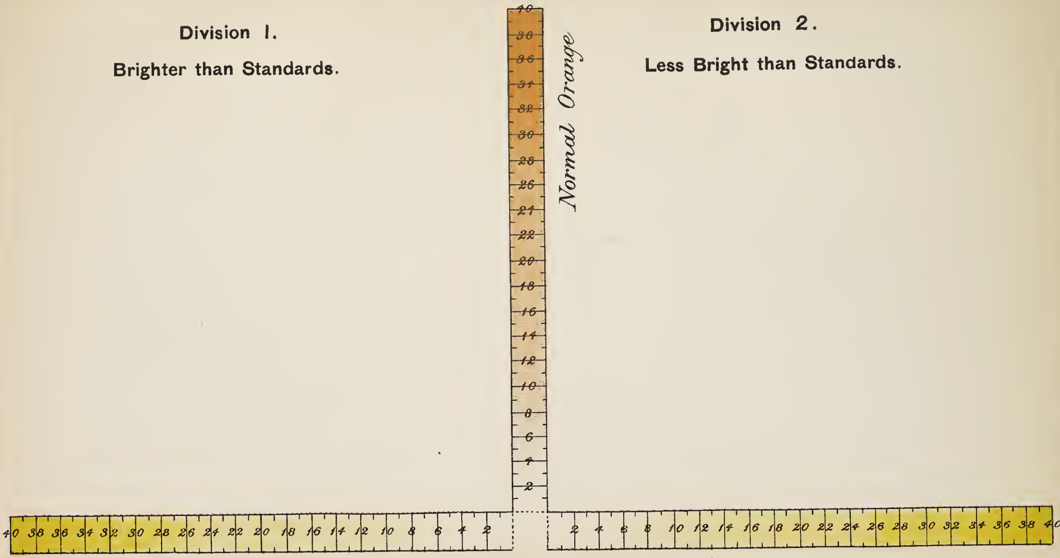
YELLOW ORANGES.

Division I.

Brighter than Standards.

Division 2.

Less Bright than Standards.



(To follow Chart 4 page 44)

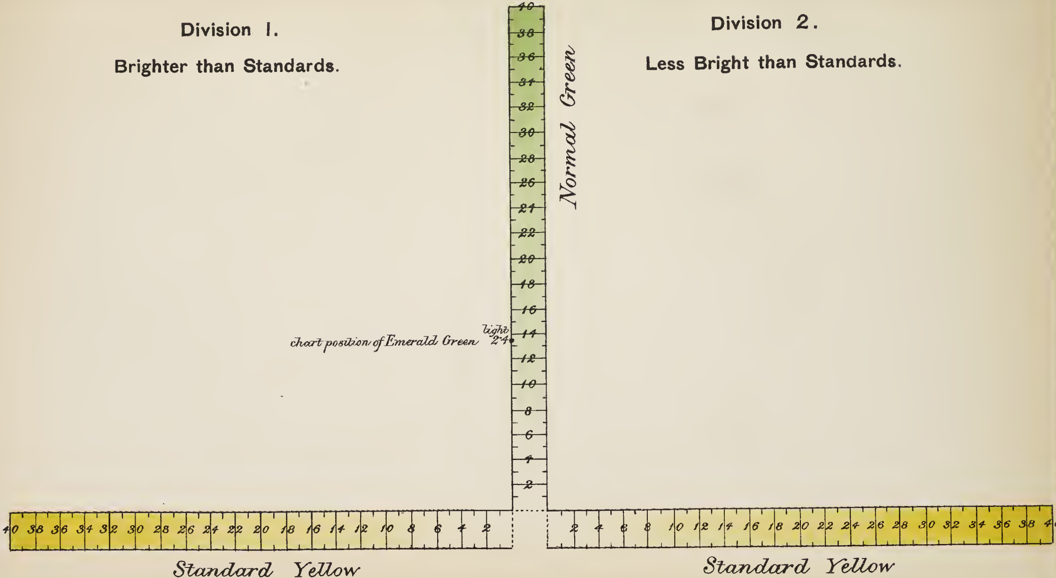
YELLOW GREENS.

Division 1.

Brighter than Standards.

Division 2.

Less Bright than Standards.



(To follow Chart 5 page 44)

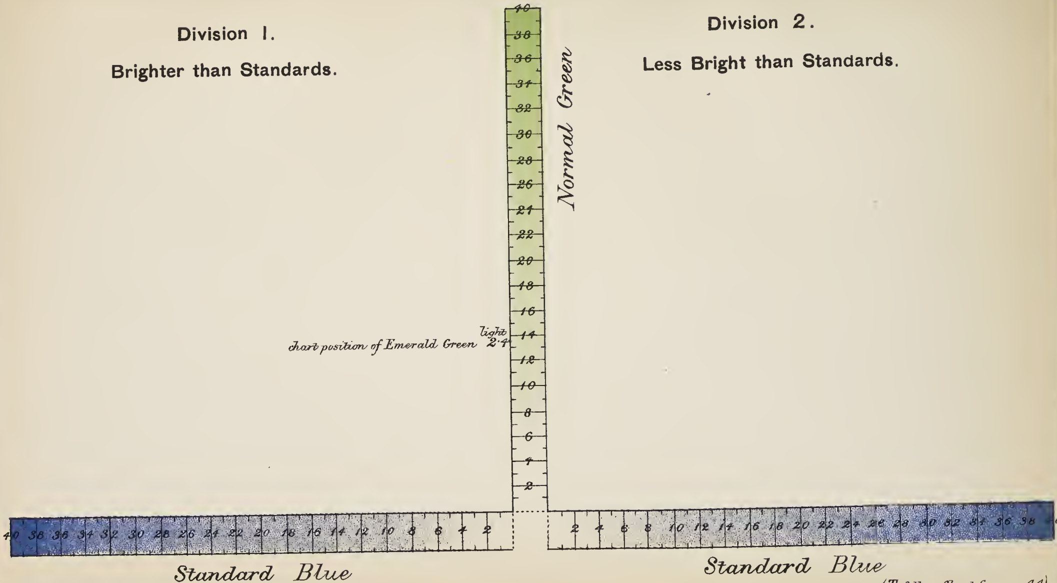
BLUE GREENS.

Division 1.

Brighter than Standards.

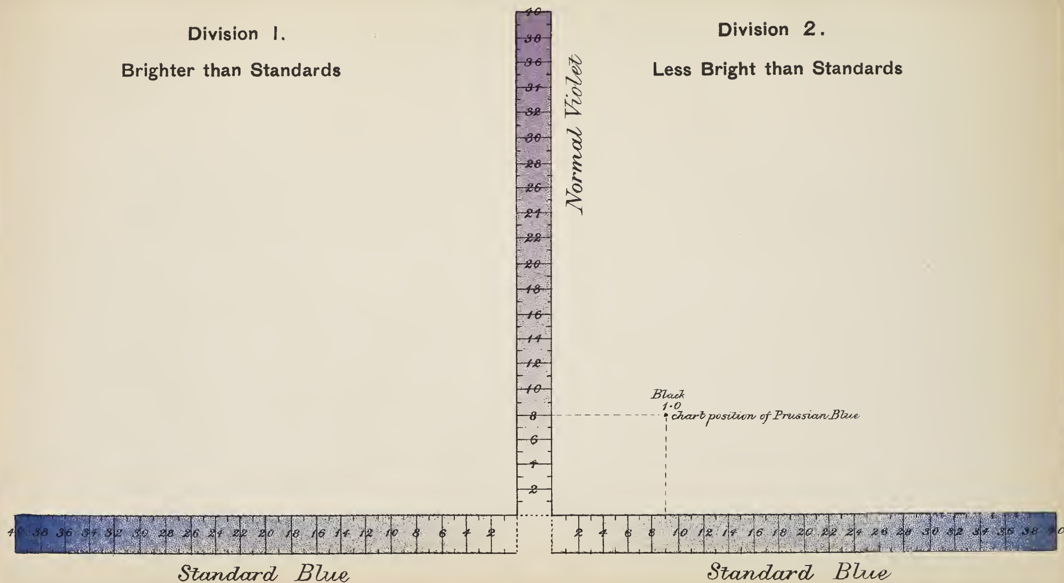
Division 2.

Less Bright than Standards.



(To follow Chart 6 page 44)

BLUE VIOLETS.



(To follow Chart 7. page 44)

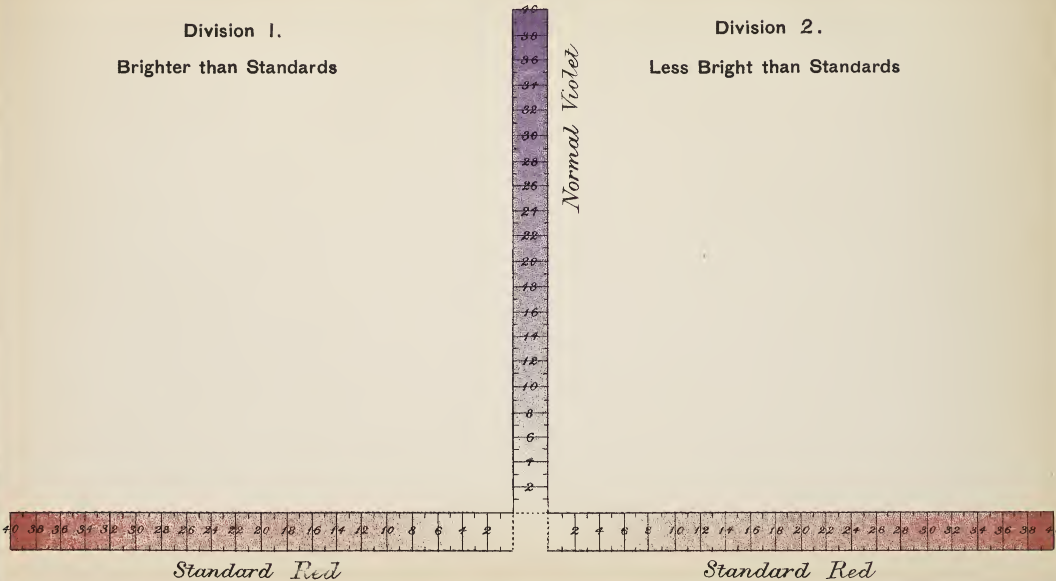
RED VIOLETS.

Division 1.

Brighter than Standards

Division 2.

Less Bright than Standards



(To follow Chart 8. page 44)

FOR CHARTING DAYLIGHT COLOURS.

The second set of colour charts are also right angles formed by two colour lines with their zero ends at the angle. In all cases the two lines in each chart must correspond to two colours which are adjacent to each other in the spectrum order; **red** and **violet** being considered adjacent for this purpose.

Under this rule the six colour lines naturally form but six charts. Each chart contains, therefore, one standard and one normal colour line, as follows :—

No. IV. the *Red-Orange* Chart.
" V. " *Yellow-Orange* "
" VI. " *Yellow-Green* "
" VII. " *Blue-Green* "
" VIII. " *Blue-Violet* "
" IX. " *Red-Violet* "

In order to separate colours which are brighter than the *standards* from colours of standard and less than standard brightness, each chart is doubled; the normal perpendicular dividing the two right angles.

Colours which are brighter than the standards find places on the *left-hand charts,* whilst colours which are less bright than the standards find places on the right-hand charts.

Colours which are of standard brightness are placed for convenience on the right-hand chart, but might have been placed on the left hand without disturbing the system.

The perpendicular is a standard line of brightness, as well as a standard line of colour; therefore departures from standard brightness can be indicated as well as departures in colour.

The method of charting the colour sensations in the second half of the equations of measured colours is as follows :—

When there is only a single colour it is chartable directly on the corresponding line and number. If there is also a light factor it is marked in numerals on the side to which it belongs; an instance of such a colour is the emerald-green powder as measured on

Plate 4, showing a colour sensation of 13·5 units of *normal green* with 2·4 units of normal light brighter than standards.

This would be chartable at 13·5 on the green line of either Chart VI. or Chart VII., and the 2·4 excess light units written near on the left-hand chart.

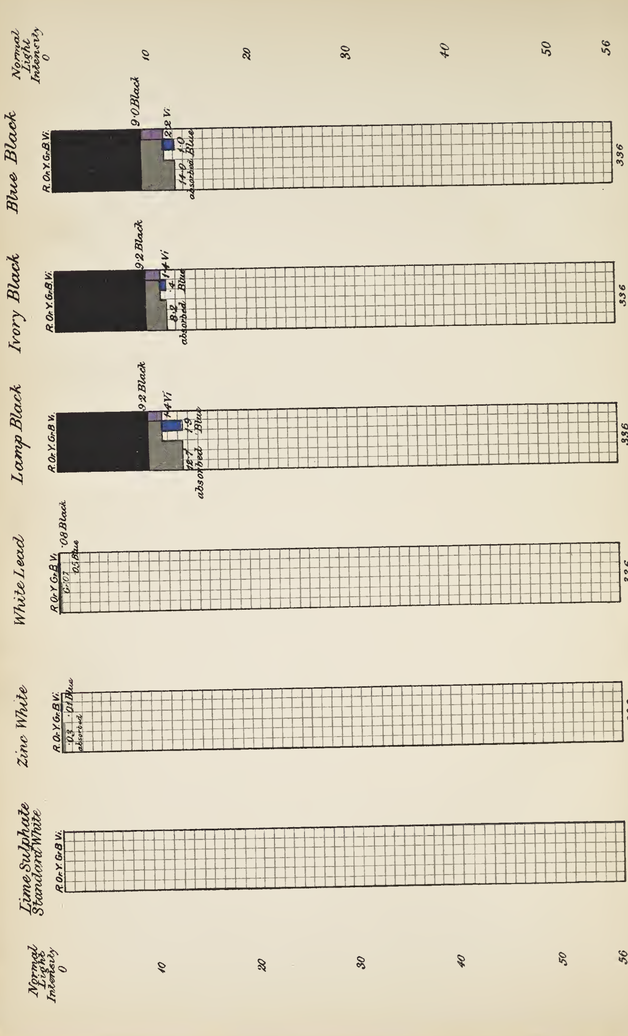
When there are two colours in the second half of an equation it is a colour of two simultaneous colour sensations, and is chartable at that point where perpendiculars from the corresponding numbers on the lines meet. If there is also a light term, it is written near this point.

An example of a colour less bright than the standards is a *Prussian blue* measuring $\overset{R.}{9} \times \overset{Y.}{1} \times \overset{B.}{18} = \overset{Vi.}{8} \times \overset{Blue.}{9} \times \overset{Black.}{1}$, the factors in the second half of the equation being 9 *blue*, 8 *violet*, 1 *black*. This would find a place on the right-hand side of blue-violet Chart No. VIII., at the point where perpendiculars drawn through 9 on the blue line and 8 on the violet line meet; the 1 normal white light unit, less bright than standards, is written near this point as 1 *black*.

A position can be found for any measured daylight colour upon these principles in one or other of this set of six charts.

The principles may be shortly summed up as follows. A normal vision under ordinary daylight conditions is simultaneously sensitive to not more than two colour sensations, and one light sensation. These sensations and their proportions are found by means of the equation already mentioned, the first half of which contains the terms of the standard glasses used, and the second half a quantitative statement of the rays they transmit, which latter is obtained from their known powers of selective absorption: for instance, the lamp-black in Table III., page 39, was matched by 10·6 red, 9·2 yellow, and 12·5 blue; beginning with the least of these, 9·2 yellow, which, with 9·2 red and 9·2 blue, absorb 9·2 normal light, treating this as a pigment, may be called 9·2 black; the remaining 1·4 red with 1·2 of the blue absorb each other and transmit 1·2 of violet, leaving 1·9 blue. The colour is therefore a blue-violet darkened by black in the following proportions $\overset{V.}{1{\cdot}4} + \overset{B.}{1{\cdot}9} + \overset{Black.}{9{\cdot}2}$. This method applies to all cases.

PLATE V.



(To face page 47)

Scale : 1/… of … inch per colour area.

REPRESENTATION OF COLOURS IN SPACE OF THREE DIMENSIONS.

As Suggested by Dr. Munro.

The relations of the different colours to one another and to neutral tint are, perhaps, best represented to the mind by a solid model, or by reference to three co-ordinate axes, as employed in solid geometry.

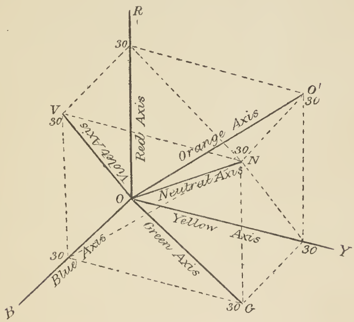


Fig. 5.

Let the three adjacent edges, O R, O B, O Y, of the above cube be three axes, along which are measured degrees of *red*, *yellow*, and *blue*, respectively, starting from the origin O. Every point in space on the positive side of this origin will then represent a conceivable colour, the constituents of which, in degrees of red, yellow, or blue, are measured by the three co-ordinates of the points. *Pure reds* all lie on the axis O R, *pure yellows* on the axis O Y, *pure blues* on the axis O B. All normal oranges, normal greens, and normal violets lie on the diagonals of the faces of the cubes O O′, O G, O V respectively. Pure neutral tints lie on the diagonal O N of the cube, equally inclined to the three principal axes ; *red violets* will be found on the plane R O B, between O V and O R ;

blue violets on the same plane, between O V and O B; "saddened" *red violets* are all within the wedge or open space enclosed by the three planes whose boundaries are O B, O V, O N. The other colours, *red* and *yellow oranges*, *blue* and *yellow greens*, *pure* and saddened, are found in corresponding positions in relation to the other axes.

If the axes are cut off at the limits of visibility of *red*, *yellow* and *blue*, *orange*, *green* and *violet*, rays, as determined by the degrees of glass of the same colours required to totally absorb the respective rays, and the end of the axes be joined by a curved surface, we find a solid model, shown in Figs. 6 and 7, representing two aspects of the same figure, within which is located every colour and shade appreciable by the eye under the conditions of the experiments. This model shows in a very striking way the difference in the penetrating power of the various rays for glass of the same colour. (See Figs. 6 and 7, page 49.)

This model is constructed from observations made with light from a north, dull sky, at 4.20 p.m. on April 13th, 1891, on a thirty-seconds observation in camera, to a scale of five colour units per inch, and is lettered similarly to the colour cube; each plane between two dominant rays forming a normal chart, the lines of which are prolonged to the point of extinction.

Total absorption	of Light	by	20	N.T. glass standards.	
"	" *Red ray*	"	154	Red	units.
"	" *Orange*	"	100	Orange	"
"	" *Yellow*	"	680	Yellow	"
"	" *Green*	"	42	Green	"
"	" *Blue*	"	257	Blue	"
"	" *Violet*	"	37	Violet	"

THE STANDARD WHITE.

In considering the most suitable substance to be used as a standard white, from which departures of light and colour may be measured, the choice ultimately lay between pure precipitated **Lime Sulphate** and **Zinc White.** The lime sulphate reflects

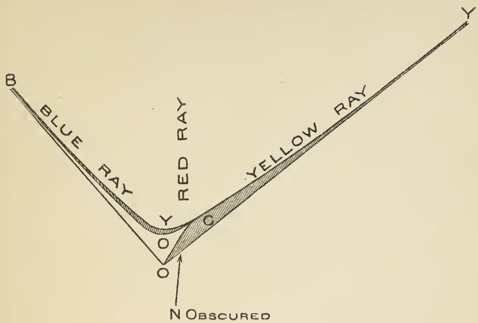

Y
B
BLUE RAY
RED RAY
YELLOW RAY
Y
G
O
O
N OBSCURED

Fig. 6.

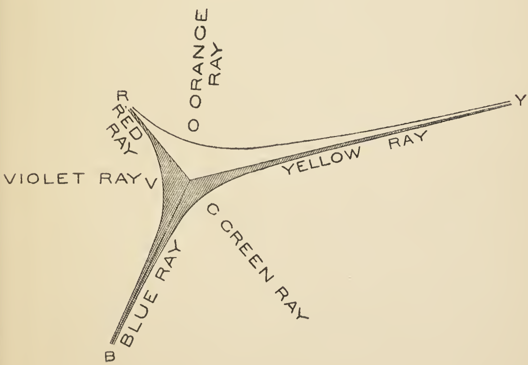

ORANGE RAY
O
R
RED RAY
Y
YELLOW RAY
VIOLET RAY
V
G GREEN RAY
BLUE RAY
B

Fig. 7.

about ·001 unit of light more than the zinc white. This is about half the quantity absorbed by a thin slip of colourless glass. It also has about ·005 of a unit of standard red compared with the zinc white, which has about ·005 standard yellow compared with the lime sulphate.

The lime sulphate was chosen for the standard white as reflecting a little more light, and therefore available for the direct measurement of more delicate colours, although the difference between them is scarcely measurable. Therefore, in Table X., lime sulphate is considered as zero, and the other measurements departures therefrom, zinc white showing a departure of only ·01 unit of blue, and the white lead, ·08 black, ·07 green, and ·05 blue. These blacks are all blue violets mixed with black in different proportions; if red or yellow preponderated instead of blue, then the purity of the black is destroyed, and a dinginess produced in proportion to the preponderance.

TABLE X.

	Standard Glasses.			Light transmitted.		
	Red.	Yellow.	Blue.			
Lime Sulphate	0·0	+ 0·0	+ 0·0	=	—	—
Zinc White	—	—	·01	=	Blue. ·01	—
White Lead	·08	+ ·15	+ ·2	= Black. ·08	+ Green. ·07	+ Blue. ·05
Lamp Black	10·6	+ 9·2	+12·5	= 9·2	+ Violet. 1·4	+ 1·9
Ivory „	10·6	+ 9·2	+11·0	= 9·2	+ 1·4	+ ·4
Blue „	11·2	+ 9·0	+12·0	= 9·0	+ 2·2	+ 1·0

The above five measurements were made with a north light requiring 56 neutral-tint units for total absorption on a 10-seconds observation.

The colour sensations represented in the second half of the equation are also quantitatively illustrated by coloured sections of the light reflected from them in Plate 5, and also by numerical statements of the ray composition of lights under the several headings.

ANALYSIS OF REFLECTED LIGHT.

		Colour-Ray Areas.
Lime Sulphate—unaltered		336
Zinc White	*Blue*	·01
	Absorbed	·03
	Unaltered	335·96
		336·00
White Lead	*Blue*	·05
	Green	·07
	Black	·48
	Absorbed	·50
	Unaltered	334·90
		336·00
Lamp Black	*Blue*	1·9
	Violet	1·4
	Black	55·2
	Absorbed	12·7
	Unaltered	264·8
		336·0
Ivory Black	*Blue*	·4
	Violet	1·4
	Black	55·2
	Absorbed	8·2
	Unaltered	270·8
		336·0
Blue Black	*Blue*	1·0
	Violet	2·2
	Black	54·0
	Absorbed	14·0
	Unaltered	264·8
		336·0

CHAPTER IV.

LIGHT AND COLOUR BY SYNTHESIS.

The following experiments were undertaken to elucidate the laws which govern the colour sensations produced by definite mixtures of coloured lights, beginning with the simple rays and progressing in complexity up to white light by a method of **synthesis** in contrast to that of **selective absorption**, already dealt with. The Tintometer standard glasses are especially adapted for this kind of research, from their ability to define a normal white light and to bring it within the colour-perceptive limits of a normal vision; and from their power of isolating the composing colour rays without admixture of white light, and free from the complications arising from the use of lenses, reflectors, or prisms.

The ray composition of the colour and light available is necessarily limited by the power of ray separation in the standard glasses, already defined in the article on primary colour, as consisting of :—

Three Monochromatic Colours	Orange.		
	Green.		
	Violet.		
Three Trichromatic Colours	Red	accompanied by	Violet and Orange.
	Yellow	,, ,,	Orange and Green.
	Blue	,, ,,	Green and Violet.

Normal Daylight is an equal mixture of . . . . . . { Red. Orange. Yellow. Green. Blue. Violet.

Therefore the colours and light available are :—

Orange, Green, and Violet, lights of one colour ray.
Red, Yellow, and Blue, lights of three colour rays.
Normal daylight, a light of six colour rays.

THE APPARATUS FOR MIXING LIGHTS.

Fig. 8 is an illustration of the apparatus used for mixing the lights : the side D is removed in order to show the interior.

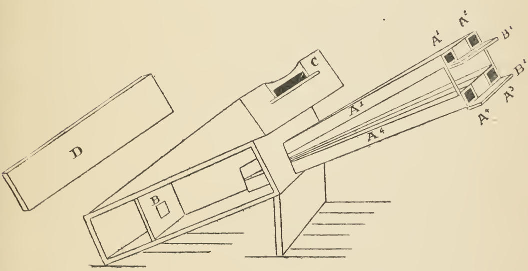


Fig. 8.

It consists of four eighteen-inch tubes, $\overset{1}{A}$, $\overset{2}{A}$, $\overset{3}{A}$, $\overset{4}{A}$, blackened on the inside and provided with stops and diaphragms for transmitting beams of light of ½-inch-square section. The tubes are arranged at such an angle that the light from all is converged to one spot in camera on the lime-sulphate screen B at 4½ inches from the ends of the tubes. The aperture C for viewing the superposed lights is ten inches from the image, and at an angle of 45 degrees. The outer end of each tube is furnished with stages B^1, B^2, for holding the standard glasses used to intercept the daylight and separate the colours for mixing.

By this means any combination of the coloured lights already named, up to four, can be superposed on the screen for observation.

The apparatus is so sensitive that changes from normal in the daylight used are frequently first noticed by the observer working in camera through alterations in the colours under observation at the time of change.

All the observations, except a few accidental omissions, which have been since made to complete the series, were made before any classification was attempted. The whole number formed a confused mass of evidence until a method suggested itself of arranging the beams in groups according to the number of colour areas in each beam, when the whole fell into regular order of the following groups and divisions.

By this method the **group number** of a mixed light is fixed by the aggregate number of separate colour rays in all the lights of the mixed beam. A separate colour ray for this purpose is one of composition, whether visually distinguishable as such, or not ; thus :—

One area of a **subordinate light** has one colour area only.
One area of a **dominant light** has three separate colour areas.
One area of a **normal daylight** has six separate colour areas.

Therefore a mixture of one subordinate and one dominant light belongs to Group 4, that being the total number of colour areas in the mixture. Again, one dominant coloured light and one normal white light belongs to Group 9, that being the total number of colour areas in this mixture, and so on.

The **groups** are subdivided into divisions according to the manner in which the group number is made up.

The number of divisions into which a group is divisible is governed by the number of different combinations producible by the lights used, and an instrument capable of combining more than four areas would require a greater number of subdivisions in each group, after Group 4.

The **colour depth** of a separate ray is that of its equivalence in the normal light of which it forms part, or from which it was separated. And as all these observations were made with normal white light of 15 neutral-tint units luminous intensity in camera on a 5-seconds observation, each separate colour ray is of 15 units colour intensity. This being so, the unit colour depth of each separate ray will not be stated in the examples, as would be necessary if the lights employed varied in luminous intensity.

Several reasons combined to fix 15 N.T. units as the most convenient intensity for this class of observation.

1st. *When the subordinate rays are separated from lower normal white light than* 15 N.T., *their luminosity is insufficient to create a pure colour sensation.*

2nd. *When a light of higher luminosity than* 15 N.T. *is used, it builds quicker into greys and white light by synthesis.*

3rd. *It is the intensity at which daylight is most frequently normal, and therefore affords more opportunities of work.* This is of great importance, since it required two winters to collect the observations contained in these tables.

These observations appear to indicate that 15 is the lowest degree of illumination for the appreciation of a single pure colour ray by a normal vision.

MIXED COLOURED LIGHTS.

The first column in the group tables contains the numbers of the experiments and the names of the lights used, each light occupying a separate line. The second column contains the number of colour areas in each light with the composing colour rays arranged under their suitable heading; each total appears separately in the last line. The third column contains the total number of colour areas in the mixture, which necessarily corresponds to the group number. The fourth column contains the colour sensations of the mixtures as described by a trained normal vision.

GROUP 1.

Containing three beams, each of one subordinate.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Orange .		1						
		1					1	Pure Orange, low in luminosity.
2 One Green .				1				
				1			1	Pure Green ,, ,,
3 One Violet .						1		
						1	1	Pure Violet ,, ,,

GROUP 2.

DIVISION 1.

Containing three beams, each of dissimilar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Orange .		1						
One Green .				1				
		1		1			2	Orange, less pure than No. 1, [Group 1.
2 One Green .				1				
One Violet .						1		
				1		1	2	Violet and Green, separately dis- [tinguishable.
3 One Violet .						1		
One Orange .		1						
		1				1	2	Orange and Violet ,, ,,

DIVISION 2.

Containing three beams, each of two similar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Orange .		1						
One Orange .		1						
		2					2	Pure Orange, brighter but no [deeper than No. 1, Group 1.
2 One Green .				1				
One Green .				1				
				2			2	Pure Green, brighter but no [deeper than No. 2, Group 1.
3 One Violet .						1		
One Violet .						1		
						2	2	Pure Violet, brighter but no [deeper than No. 3, Group 1.

GROUP 3.

Division 1.

Containing one beam of three dissimilar subordinate rays.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Orange .		1						
One Green .				1				
One Violet .						1		
		1		1		1	3	Orange Violet, less pure than [No. 3, Group 2, Division 1.

Division 2.

Containing three beams, each of three similar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Orange .		1						
One Orange .		1						
One Orange .		1						
		3					3	Orange, pure, brighter than No. 1, [Group 2, Division 2.
2 One Green .				1				
One Green .				1				
One Green .				1				
				3			3	Green, pure, brighter than No. 2, [Group 2, Division 2.
3 One Violet .						1		
One Violet .						1		
One Violet .						1		
						3	3	Violet, pure, brighter than No. 3, [Group 2, Division 2.

Division 3.

Containing three beams of one dominant ray each.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1	3	Red, pure, luminosity rather low.
2 One Yellow .		1	1	1			3	Yellow, pure, more luminous [than No. 1.
3 One Blue .				1	1	1	3	Blue, pure, luminosity rather low.

GROUP 4.

Division 1.

Containing three beams, each of four similar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 Four Orange.		4					4	Orange, pure, brighter than No. 1, [Division 2, Group 3.
2 Four Green .				4			4	Green, pure, brighter than No. 2, [Division 2, Group 3.
3 Four Violet .						4	4	Violet, pure, brighter than No. 3, [Division 2, Group 3.

Division 2.

Containing three beams, each of two similar rays in dissimilar pairs of subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 Two Orange .		2						
Two Green .				2				
		2		2			4	Dingy Orange.
2 Two Green .				2				
Two Violet .						2		
				2		2	4	Dingy Blue Green.
3 Two Violet .						2		
Two Orange.		2						
		2				2	4	Orange Violet.

Division 3.

Containing six beams, each in unequal dissimilar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 Three Orange		3						
One Green .				1				
		3		1			4	Brightish Orange.
2 Three Orange		3						
One Violet .						1		
		3				1	4	Brightish Orange, slightly tinged [Blue.
3 Three Green .				3				
One Violet .						1		
				3		1	4	Brightish Green, tinged Blue.
4 Three Green .				3				
One Orange .		1						
		1		3			4	Pale dingy Greenish Orange.
5 Three Violet .						3		
One Orange .		1						
		1				3	4	Brightish Violet, tinged Orange.
6 Three Violet .						3		
One Green .				1				
				1		3	4	Dingy Blue Violet.

Division 4.

Containing nine beams, each of one dominant and one subordinate.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Orange .		1						
	1	2				1	4	Orange Red.
2 One Red .	1	1				1		
One Green .				1				
	1	1		1		1	4	Low Violet.
3 One Red .	1	1				1		
One Violet .						1		
	1	1				2	4	Blue Violet.
4 One Yellow .		1	1	1				
One Orange .		1						
		2	1	1			4	Orange Yellow.
5 One Yellow .		1	1	1				
One Green .				1				
		1	1	2			4	Yellow Green.
6 One Yellow .		1	1	1				
One Violet .						1		
		1	1	1		1	4	Dingy Yellow.
7 One Blue .				1	1	1		
One Orange .		1						
		1		1	1	1	4	Blue Violet.
8 One Blue .				1	1	1		
One Green .				1				
				2	1	1	4	Blue, Green, and Violet.
9 One Blue .				1	1	1		
One Violet .						1		
				1	1	2	4	Blue.

GROUP 5.

Division 1.

Containing nine beams, each of one dominant and two similar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
Two Orange.		2						
	1	3				1	5	Bright Red Orange.
2 One Red .	1	1				1		
Two Green .				2				
	1	1		2		1	5	Dingy Violet Orange.
3 One Red .	1	1				1		
Two Violet .						2		
	1	1				3	5	Bright Violet Red.
4 One Yellow .	1	1	1					
Two Orange.	2							
	3	1	1				5	Bright Yellow Orange.
5 One Yellow .		1	1	1				
Two Green .				2				
		1	1	3			5	Bright Yellow Green.
6 One Yellow .		1	1	1				
Two Violet .						2		
		1	1	1		2	5	Very light, dingy, Yellow Green
7 One Blue .				1	1	1		
Two Orange.		2						
		2		1	1	1	5	Light Dingy Violet.
8 One Blue .				1	1	1		
Two Green .				2				
				3	1	1	5	Bright Blue Green.
9 One Blue .				1	1	1		
Two Violet .						2		
				1	1	3	5	Bright Blue Violet.

DIVISION 2.

Containing nine beams, each of one dominant and two dissimilar subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Orange .		1						
One Green .					1			
	1	2			1	1	5	Red Orange.
2 One Red .	1	1				1		
One Green .						1		
One Violet .				1				
	1	1		1		2	5	Red Violet.
3 One Red .	1	1				1		
One Violet .		1						
One Orange .						1		
	1	2				2	5	Orange Violet.
4 One Yellow .		1	1	1				
One Orange .		1						
One Green .				1				
		2	1	2			5	Yellow, Orange tinge.
5 One Yellow .		1	1	1				
One Green .				1				
One Violet .						1		
		1	1	2		1	5	Green Yellow.
6 One Yellow .		1	1	1				
One Violet .						1		
One Orange .		1						
		2	1	1		1	5	Yellow Orange.
7 One Blue .				1	1	1		
One Orange .		1						
One Green .				1				
		1		2	1	1	5	Bluish, Violet Orange.
8 One Blue .				1	1	1		
One Green .				1				
One Violet .						1		
				2	1	2	5	Blue, tinged Green.
9 One Blue .				1	1	1		
One Violet .						1		
One Orange .		1						
		1		1	1	2	5	Blue Violet.

GROUP 6.

Division 1.

Containing one beam of normal white light.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One normal white light.	1	1	1	1	1	1	6	Grey, low and colourless.

Division 2.

Containing three beams, each of two similar dominants.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Red .	1	1				1		
	2	2				2	6	Red, pure, brighter but not deeper [than No. 1, Division 3, Group 3.
2 One Yellow .		1	1	1				
One Yellow .		1	1	1				
		2	2	2			6	Yellow, pure, brighter, not deeper [than No. 2, Division 3, Group 3.
3 One Blue .				1	1	1		
One Blue .				1	1	1		
				2	2	2	6	Blue, pure, brighter, not deeper [than No. 3, Division 3, Group 3.

Division 3.

Containing three beams, each of two dissimilar dominants.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Yellow .		1	1	1				
	1	2	1	1		1	6	Yellow Orange, low.
2 One Yellow .		1	1	1				
One Blue .				1	1	1		
		1	1	2	1	1	6	Greenish Grey.
3 One Blue .				1	1	1		
One Red .	1	1				1		
	1	1		1	1	2	6	Violet.

Division 4.

Containing nine beams, each of one dominant and three similar subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Orange .		1						
One Orange .		1						
One Orange .		1						
	1	4				1	6	Bright Orange Red.
2 One Red .	1	1				1		
One Green .				1				
One Green .				1				
One Green .				1				
	1	1		3		1	6	Dingy Grey, tinged Orange.
3 One Red .	1	1				1		
One Violet .						1		
One Violet .						1		
One Violet .						1		
	1	1				4	6	Light Violet with Reddish tinge.
4 One Yellow .		1	1	1				
One Orange .		1						
One Orange .		1						
One Orange .		1						
		4	1	1			6	Medium Yellowish Orange.
5 One Yellow .		1	1	1				
One Green .				1				
One Green .				1				
One Green .				1				
		1	1	4			6	Medium Greenish Yellow.
6 One Yellow .		1	1	1				
One Violet .						1		
One Violet .						1		
One Violet .						1		
		1	1	1		3	6	Low Grey, tinged Yellowish Violet.
7 One Blue .				1	1	1		
One Orange .		1						
One Orange .		1						
One Orange .		1						
		3		1	1	1	6	Violet Orange.

Division 4—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
8 One Blue .				1	1	1		
One Green .				1				
One Green .				1				
One Green .				1				
				4	1	1	6	Brightish Blue Green.
9 One Blue .				1	1	1		
One Violet .						1		
One Violet .						1		
One Violet .						1		
				1	1	4	6	Bright Blue Violet.

Division 5.

Containing three beams, each of one dominant and three dissimilar subordinates

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Orange .		1						
One Green .				1				
One Violet .						1		
	1	2		1		2	6	Dingy Orange Violet.
2 One Yellow .		1	1	1				
One Orange .		1						
One Green .				1				
One Violet .						1		
		2	1	2		1	6	Dingy pale Yellow Orange.
3 One Blue .				1	1	1		
One Orange .		1						
One Green .				1				
One Violet .						1		
		1		2	1	2	6	Pale, dull Violet.

Division 6.

Containing nine beams, each of one dominant and two unequal subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Orange .		1						
One Orange .		1						
One Green .				1				
	1	3		1		1	6	Dull Red Orange.
2 One Red .	1	1				1		
One Green .				1				
One Green .				1				
One Violet .						1		
	1	1		2		2	6	Low Violet.

DIVISION 6—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
3 One Red .	1	1				1		
One Violet .						1		
One Violet .						1		
One Orange .		1						
	1	2				3	6	Red Violet Orange.
4 One Yellow .		1	1	1				
One Orange .		1						
One Orange .		1						
One Green .				1				
		3	1	2			6	Medium Orange.
5 One Yellow .		1	1	1				
One Green .				1				
One Green .				1				
One Violet .						1		
		1	1	3		1	6	Pale Yellow Green.
6 One Yellow .		1	1	1				
One Violet .						1		
One Violet .						1		
One Orange .		1						
		2	1	1		2	6	Dull Yellow Orange.
7 One Blue .				1	1	1		
One Orange .		1						
One Orange .		1						
One Green .				1				
		2		2	1	1	6	Confused Orange Violet.
8 One Blue .				1	1	1		
One Green .				1				
One Green .				1				
One Violet .						1		
				3	1	2	6	Bright Blue, tinged Green.
9 One Blue .				1	1	1		
One Violet .						1		
One Violet .						1		
One Orange .		1						
		1		1	1	3	6	Brightish Blue Violet.

GROUP 7.

Division 1.

Containing nine beams, each of two similar dominants and one subordinate.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Red .	1	1				1		
One Orange .		1						
	2	3				2	7	Brightish Red Orange.
2 One Red .	1	1				1		
One Red .	1	1				1		
One Green .				1				
	2	2		1		2	7	Dull Red Orange.
3 One Red .	1	1				1		
One Red .	1	1				1		
One Violet .						1		
	2	2				3	7	Red Violet.
4 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Orange .		1						
		3	2	2			7	Bright Yellow Orange.
5 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Green .			1					
		2	3	2			7	Light Yellow Green.
6 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Violet .						1		
		2	2	2		1	7	Dingy Yellow Green.
7 One Blue .				1	1	1		
One Blue .				1	1	1		
One Orange .		1						
		1		2	2	2	7	Light Blue Violet.
8 One Blue .				1	1	1		
One Blue .				1	1	1		
One Green .				1				
				3	2	2	7	Blue faintly tinged Green.
9 One Blue .				1	1	1		
One Blue .				1	1	1		
One Violet .						1		
				2	2	3	7	Full Blue.

DIVISION 2.

Containing nine beams, each of two dissimilar dominants and one subordinate.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Yellow .		1	1	1				
One Orange .		1						
	1	3	1	1		1	7	Orange, lessened colour, more [light.
2 One Red .	1	1				1		
One Yellow .		1	1	1				
One Green .				1				
	1	2	1	2		1	7	Orange, pale.
3 One Red .	1	1				1		
One Yellow .		1	1	1				
One Violet .						1		
	1	2	1	1		2	7	Orange, pale.
4 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Orange .		1						
		2	1	2	1	1	7	Yellow Orange, low.
5 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Green .				1				
		1	1	3	1	1	7	Green, distinct but low.
6 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Violet .						1		
		1	1	2	1	2	7	Grey, tinged Green.
7 One Blue .				1	1	1		
One Red .	1	1				1		
One Orange .		1						
	1	2		1	1	2	7	Orange and Violet, both distin- [guishable, but pale.
8 One Blue .				1	1	1		
One Red .	1	1				1		
One Green .				1				
	1	1		2	1	2	7	Violet, pale light.
9 One Blue .				1	1	1		
One Red .	1	1				1		
One Violet .						1		
	1	1		1	1	3	7	Violet, pale light.

Division 3.

Containing three beams, each of one daylight and one subordinate.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight .	1	1	1	1	1	1		
One Orange .		1						
	1	2	1	1	1	1	7	Grey, faintly tinged Orange.
2 One daylight .	1	1	1	1	1	1		
One Green .				1				
	1	1	1	2	1	1	7	Grey, faintly tinged Violet Green.
3 One daylight .	1	1	1	1	1	1		
One Violet .						1		
	1	1	1	1	1	2	7	Grey, faintly tinged Violet.

GROUP 8.

Division 1.

Containing nine beams, each of two similar dominants and two similar subordinates.

1 One Red .	1	1				1		
One Red .	1	1				1		
One Orange .		1						
One Orange .		1						
	2	4				2	8	Bright Red Orange.
2 One Red .	1	1				1		
One Red .	1	1				1		
One Green .				1				
One Green .				1				
	2	2		2		2	8	Dingy low Orange Violet.
3 One Red .	1	1				1		
One Red .	1	1				1		
One Violet .						1		
One Violet .						1		
	2	2				4	8	Brightish Red Violet.
4 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Orange .		1						
One Orange .		1						
		4	2	2			8	Bright Yellow Orange.

DIVISION 1—*continued.*

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
5 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Green .				1				
One Green .				1				
		2	2	4			8	Bright Yellow Green.
6 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Violet .						1		
One Violet .						1		
		2	2	2		2	8	Confused Green Yellow.
7 One Blue .				1	1	1		
One Blue .				1	1	1		
One Orange .		1						
One Orange .		1						
		2		2	2	2	8	Bright Blue, Violet, Orange.
8 One Blue .				1	1	1		
One Blue .				1	1	1		
One Green .				1				
One Green .				1				
				4	2	2	8	Brightish Blue Green.
9 One Blue .				1	1	1		
One Blue .				1	1	1		
One Violet .						1		
One Violet .						1		
				2	2	4	8	Brightish Blue.

DIVISION 2.

Containing nine beams, each of two similar dominants and two dissimilar subordinates.

1 One Red .	1	1				1		
One Red .	1	1				1		
One Orange .		1						
One Green .				1				
	2	3		1		2	8	Confused Yellow Orange, tinged [Violet.
2 One Red .	1	1				1		
One Red .	1	1				1		
One Green .				1				
One Violet .						1		
	2	2		1		3	8	Confused Violet Orange.

Division 2—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
3 One Red .	1	1				1		
One Red .	1	1				1		
One Violet .						1		
One Orange .		1						
	2	3				3	8	Brightish Red, tinged Violet.
4 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Orange .		1						
One Green .					1			
		3	2	2	1		8	Brightish confused Yellowish [Green.
5 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Green .				1				
One Violet .						1		
		2	2	3		1	8	Confused light Greenish Yellow.
6 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Violet .					1			
One Orange .		1						
		3	2	2	1		8	Bright Yellow Orange.
7 One Blue .				1	1	1		
One Blue .				1	1	1		
One Orange .		1						
One Green .				1				
		1		3	2	2	8	Brightish Blue Violet.
8 One Blue .				1	1	1		
One Blue .				1	1	1		
One Green .				1				
One Violet .						1		
				3	2	3	8	Light Blue.
9 One Blue .				1	1	1		
One Blue .				1	1	1		
One Violet .						1		
One Orange .		1						
		1		2	2	3	8	Light Blue Violet.

Division 3.

Containing nine beams, each of two dissimilar dominants and two similar subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Yellow .		1	1	1				
One Orange .		1						
One Orange .		1						
	1	4	1	1		1	8	Confused light Yellow Orange.
2 One Red .	1	1				1		
One Yellow .		1	1	1				
One Green .				1				
One Green .				1				
	1	2	1	3		1	8	Light Orange Green.
3 One Red .	1	1				1		
One Yellow .		1	1	1				
One Violet .						1		
One Violet .						1		
	1	2	1	1		3	8	Very light confused Orange, [tinged Violet.
4 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Orange .		1						
One Orange .		1						
		3	1	2	1	1	8	Confused light Orange, tinged [Violet.
5 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Green .				1				
One Green .				1				
		1	1	4	1	1	8	Confused pale Blue Green, tinged [Orange.
6 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Violet .						1		
One Violet .						1		
		1	1	2	1	3	8	Grey, tinged Greenish Blue.
7 One Blue .				1	1	1		
One Red .	1	1				1		
One Orange .		1						
One Orange .		1						
	1	3		1	1	2	8	Light confused Orange Violet.

DIVISION 3.—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
8 One Blue .				1	1	1		
One Red .	1	1				1		
One Green .				1				
One Green .				1				
	1	1		3	1	2	8	Confused Greenish light.
9 One Blue .				1	1	1		
One Red .	1	1				1		
One Violet .						1		
One Violet .						1		
	1	1		1	1	4	8	Grey, tinged Violet.

DIVISION 4.

Containing nine beams, each of two dissimilar dominants and two dissimilar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Yellow .		1	1	1				
One Orange .		1						
One Green .				1				
	1	3	1	2		1	8	Confused pale Orange.
2 One Red .	1	1				1		
One Yellow .		1	1	1				
One Green .				1				
One Violet .						1		
	1	2	1	2		2	8	Dull confused Yellowish Orange.
3 One Red .	1	1				1		
One Yellow .		1	1	1				
One Violet .						1		
One Orange .		1						
	1	3	1	1		2	8	Light Yellowish Orange.
4 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Orange .		1						
One Green .		1						
		3	1	2	1	1	8	Grey, tinged confused Orange.
5 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Green .				1				
One Violet .						1		
		1	1	3	1	2	8	Greenish Blue light.

DIVISION 4—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
6 One Yellow .		1	1	1				
One Blue .				1	1	1		
One Violet .						1		
One Orange .		1						
		2	1	2	1	2	8	Grey, tinged Violet Orange.
7 One Blue .				1	1	1		
One Red .	1	1				1		
One Orange .		1						
One Green .				1				
	1	2		2	1	2	8	Brightish Red Violet.
8 One Blue .				1	1	1		
One Red .	1	1				1		
One Green .				1				
One Violet .						1		
	1	1		2	1	3	8	Light confused Violet.
9 One Blue .				1	1	1		
One Red .	1	1				1		
One Violet .						1		
One Orange .		1						
	1	2		1	1	3	8	Lightish confused Violet, tinged [Red.

DIVISION 5.

Containing three beams, each of one daylight and two similar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight .	1	1	1	1	1	1		
One Orange .		1						
One Orange .		1						
	1	3	1	1	1	1	8	Confused Orange Grey.
2 One daylight .	1	1	1	1	1	1		
One Green .				1				
One Green .				1				
	1	1	1	3	1	1	8	Pale confused Green.
3 One daylight .	1	1	1	1	1	1		
One Violet .						1		
One Violet .						1		
	1	1	1	1	1	3	8	Grey, tinged Violet.

Division 6.

Containing three beams, each of one daylight and two dissimilar subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight .	1	1	1	1	1	1		
One Orange .		1						
One Green .				1				
	1	2	1	2	1	1	8	Grey, faintly tinged Orange and [Green.
2 One daylight .	1	1	1	1	1	1		
One Green .				1				
One Violet .						1		
	1	1	1	2	1	2	8	Grey, faintly tinged Violet and [Green.
3 One daylight .	1	1	1	1	1	1		
One Violet .						1		
One Orange .		1						
	1	2	1	1	1	2	8	Grey, faintly tinged Violet and [Orange.

GROUP 9.

Division 1.

Containing three beams, each of three equal dominants.

1 One Red .	1	1				1		
One Red .	1	1				1		
One Red .	1	1				1		
	3	3				3	9	Red, pure, brighter, no deeper [than No. 1, Division 2, Group 6.
2 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Yellow .		1	1	1				
		3	3	3			9	Yellow, pure, brighter, no deeper [than No. 2, Division 2, Group 6.
3 One Blue .				1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
				3	3	3	9	Blue, pure, brighter, no deeper [than No. 3, Division 2, Group 6.

Division 2.

Containing one beam of three dissimilar dominants.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Yellow .		1	1	1				
One Blue .				1	1	1		
	1	2	1	2	1	2	9	Grey, tinged Orange.
2 One Red .	1	1				1		
One Red .	1	1				1		
One Yellow .		1	1	1				
	2	3	1	1		2	9	Confused Orange.
3 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Blue .				1	1	1		
		2	2	3	1	1	9	Light Greenish Yellow.
4 One Blue .				1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
	1	1		2	2	3	9	Blue Violet, tinged Red.

Division 3.

Containing three beams, each of one daylight and one dominant.

1 One daylight .	1	1	1	1	1	1		
One Red .	1	1				1		
	2	2	1	1	1	2	9	Low Red Violet.
2 One daylight .	1	1	1	1	1	1		
One Yellow .		1	1	1				
	1	2	2	2	1	1	9	Pale confused Yellow.
3 One daylight .	1	1	1	1	1	1		
One Blue .				1	1	1		
	1	1	1	2	2	2	9	Pale Blue Grey.

Division 4.

Containing three beams, each of one daylight and three similar subordinates.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight .	1	1	1	1	1	1		
One Orange .		1						
One Orange .		1						
One Orange .		1						
	1	4	1	1	1	1	9	Very light confused Orange.
2 One daylight .	1	1	1	1	1	1		
One Green .				1				
One Green .				1				
One Green .				1				
	1	1	1	4	1	1	9	Confused Greenish Grey.
3 One daylight .	1	1	1	1	1	1		
One Violet .						1		
One Violet .						1		
One Violet .						1		
	1	1	1	1	1	4	9	Greyish Violet.

Division 5.

Containing one beam of one daylight and three dissimilar subordinates.

1 One daylight .	1	1	1	1	1	1		
One Orange .		1						
One Green .				1				
One Violet .						1		
	1	2	1	2	1	2	9	Grey confused Orange tinge.

GROUP 10.

Division 1.

Containing nine beams, each of one daylight, one dominant, and one subordinate.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Orange .		1						
	2	3	1	1	1	2	10	Pale Orange Grey.
2 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Green .				1				
	2	2	1	2	1	2	10	Grey faintly tinged Violet.
3 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Violet .						1		
	2	2	1	1	1	3	10	Pale Blue Grey.
4 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Orange .		1						
	1	3	2	2	1	1	10	Pale Yellow, tinged Orange.
5 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Green .				1				
	1	2	2	3	1	1	10	Pale Yellow Green.
6 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Violet .						1		
	1	2	2	2	1	2	10	Grey tinged confused Yellow.
7 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Orange .		1						
	1	2	1	2	2	2	10	Pale Blue Violet.
8 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Green .				1				
	1	1	1	3	2	2	10	Pale Blue Green.
9 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Violet .						1		
	1	1	1	2	2	3	10	Pale Blue Violet.

GROUP 11.

Division 1.

Containing nine beams, each of one daylight, one dominant, and two similar subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Orange .		1						
One Orange .		1						
	2	4	1	1	1	2	11	Light confused Orange, tinged [Violet.
2 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Green .				1				
One Green .				1				
	2	2	1	3	1	2	11	Low Grey, very faintly tinged [Orange Violet.
3 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Violet .						1		
One Violet .						1		
	2	2	1	1	1	4	11	Light Grey, tinged Violet.
4 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Orange .				1				
One Orange .				1				
	1	2	2	4	1	1	11	Very pale confused Orange.
5 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Green .				1				
One Green .				1				
	1	2	2	4	1	1	11	Very light Green, tinged Yellow.
6 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Violet .						1		
One Violet .						1		
	1	2	2	2	1	3	11	Grey confused, indefinable.

DIVISION 1—*continued.*

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
7 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Orange .		1						
One Orange .		1						
	1	3	1	2	2	2	11	Light confused Violet Orange.
8 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Green .				1				
One Green .				1				
	1	1	1	4	2	2	11	Bluish, Greenish Grey.
9 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Violet .						1		
One Violet .						1		
	1	1	1	2	2	4	11	Very light confused Blue Violet.

DIVISION 2.

Containing nine beams, each of one daylight, one dominant, and two dissimilar subordinates.

1 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Orange .		1						
One Green .				1				
	2	3	1	2	1	2	11	Pale Orange.
2 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Green .				1				
One Violet .						1		
	2	2	1	2	1	3	11	Grey, tinged Red Violet.

DIVISION 2—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
3 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Violet .						1		
One Orange .		1						
	2	3	1	1	1	3	11	Pale Red Violet.
4 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Orange .		1						
One Green .				1				
	1	3	2	3	1	1	11	A Yellowish Light.
5 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Green .				1				
One Violet .						1		
	1	2	2	3	1	2	11	Pale Green.
6 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Violet .						1		
One Orange .		1						
	1	3	2	2	1	2	11	Pale Yellow Orange.
7 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Orange .		1						
One Green .				1				
	1	2	1	3	2	2	11	Pale Blue Violet.
8 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Green .				1				
One Violet .						1		
	1	1	1	3	2	3	11	Pale Greenish Violet.
9 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Violet .						1		
One Orange .		1						
	1	2	1	2	2	3	11	Pale Blue Violet.

GROUP 12.

Division 1.

Containing three beams, each of four equal dominants.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Red .	1	1				1		
One Red .	1	1				1		
One Red .	1	1				1		
	4	4				4	12	Pure Red, brighter but no deeper [than No. 1, Division 1, Group 9.
2 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Yellow .		1	1	1				
		4	4	4			12	Pure Yellow, brighter but no deeper [than No. 2, Division 1, Group 9.
3 One Blue .				1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
				4	4	4	12	Pure Blue, brighter but no deeper [than No. 3, Division 1, Group 9.

Division 2.

Containing three beams of two dissimilar dominants in pairs.

1 One Red .	1	1				1		
One Red .	1	1				1		
One Yellow .		1	1	1				
One Yellow .		1	1	1				
	2	4	2	2		2	12	Yellow Orange.
2 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Blue .				1	1	1		
One Blue .				1	1	1		
		2	2	4	2	2	12	Greenish Grey.
3 One Blue .				1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
One Red .	1	1				1		
	2	2		2	2	4	12	Red Violet, impure.

Division 3.

Containing six beams, each of three similar and one dissimilar dominants.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One Red .	1	1				1		
One Red .	1	1				1		
One Red .	1	1				1		
One Yellow .		1	1	1				
	3	4	1	1		3	12	Confused dark Orange
2 One Red .	1	1				1		
One Red .	1	1				1		
One Red .	1	1				1		
One Blue .				1	1	1		
	3	3		1	1	4	12	Deep Red Violet
3 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Blue .				1	1	1		
		3	3	4	1	1	12	Pale Yellow Green.
4 One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Red .	1	1				1		
	1	4	3	3		1	12	Deep Yellow Orange.
5 One Blue .				1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
	1	1		3	3	4	12	Pure, deep Violet Blue.
6 One Blue .				1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Yellow .		1	1	1				
		1	1	4	3	3	12	Pale Blue Green.

Division 4.

Containing three beams, each of one daylight and two similar dominants.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight .	1	1	1	1	1	1		
One Red .	1	1				1		
One Red .	1	1				1		
	3	3	1	1	1	3	12	Light Red Violet.
2 One daylight .	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Yellow .		1	1	1				
	1	3	3	3	1	1	12	Very Pale Yellow.
3 One daylight .	1	1	1	1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
	1	1	1	3	3	3	12	Light Blue.

Division 5.

Containing three beams, each of one daylight and two dissimilar dominants.

1 One daylight .	1	1	1	1	1	1		
One Red .	1	1				1		
One Yellow .		1	1	1				
	2	3	2	2	1	2	12	Grey, tinged Orange.
2 One daylight .	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Blue .				1	1	1		
	1	2	2	3	2	2	12	Greenish Grey.
3 One daylight .	1	1	1	1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
	2	2	1	2	2	3	12	Pale Violet.

Division 6.

Containing one beam of two normal white lights.

1 One daylight .	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
	2	2	2	2	2	2	12	Bright Grey.

GROUP 13.

Division 1.

Containing nine beams, each of one normal light, two similar dominants, and one subordinate.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Red .	1	1				1		
One Orange .		1						
	3	4	1	1	1	3	13	Pale Red Orange.
2 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Red .	1	1				1		
One Green .				1				
	3	3	1	2	1	3	13	Pale Red Orange.
3 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Red .	1	1				1		
One Violet .						1		
	3	3	1	1	1	4	13	Pale Red Violet.
4 One daylight.	1	1	1	1	1	1		
One Yellow .			1	1	1			
One Yellow .			1	1	1			
One Orange .			1					
	1	1	4	3	3	1	13	Pale Yellow Orange.
5 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Green .				1				
	1	3	3	4	1	1	13	Pale Greenish Yellow.
6 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Violet .						1		
	1	3	3	3	1	2	13	Grey Orange Yellow.

DIVISION 1—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
7 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Orange .		1						
	1	2	1	3	3	3	13	Pale Blue Violet.
8 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Green .				1				
	1	1	1	4	3	3	13	Pale Blue, tinged Green.
9 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Violet .						1		
	1	1	1	3	3	4	13	Blue Violet.

DIVISION 2.

Containing nine beams, each of one daylight, two dissimilar dominants, and one subordinate.

1 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Yellow .		1	1	1				
One Orange .		1						
	2	4	2	2	1	2	13	Low Orange light.
2 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Yellow .		1	1	1				
One Green .				1				
	2	3	2	3	1	2	13	Pale Yellow Orange.
3 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Yellow .		1	1	1				
One Violet .						1		
	2	3	2	2	1	3	13	Grey, tinged Orange.

DIVISION 2—*continued.*

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
4 One daylight .	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Blue .				1	1	1		
One Orange .		1						
	1	3	2	3	2	2	13	Grey, tinged Orange.
5 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Blue .				1	1	1		
One Green .				1				
	1	2	2	4	2	2	13	Light Greenish Blue.
6 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Blue .				1	1	1		
One Violet .						1		
	1	2	2	3	2	3	13	Low Grey.
7 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
One Orange .		1						
	2	3	1	2	2	3	13	Pale Red Violet.
8 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
One Green .				1				
	2	2	1	3	2	3	13	Grey, Violet tinge.
9 One daylight .	1	1	1	1	1	1		
One Blue .				1	1	1		
One Red .	1	1				1		
One Orange .		1						
	2	3	1	2	2	3	13	A Violet light, or light tinged [Violet.

DIVISION 3.

Containing three beams, each of two normal white lights and one subordinate.

Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight .	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
One Orange .		1						
	2	3	2	2	2	2	13	Light Grey, tinged Orange.
2 One daylight.	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
One Green .				1				
	2	2	2	3	2	2	13	Light Grey, tinged Green.
3 One daylight .	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
One Violet .						1		
	2	2	2	2	2	3	13	Light Grey, tinged Violet.

GROUP 14.

DIVISION 1.

Containing three beams of two daylights and two similar subordinates.

1 One daylight .	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
One Orange .		1						
One Orange .		1						
	2	4	2	2	2	2	14	Grey, faintly tinged Orange.
2 One daylight .	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
One Green .				1				
One Green .				1				
	2	2	2	4	2	2	14	Grey, faintly tinged Greenish.
3 One daylight .	1	1	1	1	1	1		
One daylight .	1	1	1	1	1	1		
One Violet .						1		
One Violet .						1		
	2	2	2	2	2	4	14	Grey, faintly tinged Violet.

Division 2.

Containing three beams, each of two daylights and two dissimilar subordinates.

Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1 One daylight.	1	1	1	1	1	1		
One daylight.	1	1	1	1	1	1		
One Orange .		1						
One Green .				1				
	2	3	2	3	2	2	14	Grey, confused Orange tinge.
2 One daylight.	1	1	1	1	1	1		
One daylight.	1	1	1	1	1	1		
One Green .				1				
One Violet .						1		
	2	2	2	3	2	3	14	Grey, Greenish tinge.
3 One daylight.	1	1	1	1	1	1		
One daylight.	1	1	1	1	1	1		
One Violet .						1		
One Orange .		1						
	2	3	2	2	2	3	14	Grey, Orange Violet tinge.

GROUP 15.

Division 1.

Containing three beams, each of one daylight and three similar dominants.

1 One daylight.	1	1	1	1	1	1		
One Red .	1	1				1		
One Red .	1	1				1		
One Red .	1	1				1		
	4	4	1	1	1	4	15	Very light Red Violet.
2 One daylight.	1	1	1	1	1	1		
One Yellow .		1	1	1				
One Yellow .		1	1	1				
One Yellow .		1	1	1				
	1	4	4	4	1	1	15	Very light Yellow.
3 One daylight.	1	1	1	1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
One Blue .				1	1	1		
	1	1	1	4	4	4	15	Light distinct Blue.

Division 2.

Containing six beams, each of one daylight, two similar and one dissimilar dominants.

	Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Red .	1	1				1		
	One Yellow .		1	1	1				
		3	4	2	2	1	3	15	Indistinct Red Orange.
2	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Red .	1	1				1		
	One Blue .				1	1	1		
		3	3	1	2	2	4	15	Distinct Red Violet.
3	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Yellow .		1	1	1				
	One Blue .				1	1	1		
		1	3	3	4	2	2	15	Distinct Pale Yellow Green.
4	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Yellow .		1	1	1				
	One Red .	1	1				1		
		2	4	3	3	1	2	15	Distinct Yellow Orange.
5	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Blue .				1	1	1		
	One Red .	1	1				1		
		2	2	1	3	3	4	15	Distinct Blue Violet.
6	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Blue .				1	1	1		
	One Yellow .		1	1	1				
		1	2	2	4	3	3	15	Blue Grey.

DIVISION 3.

Containing three beams, each of two daylights and one dominant.

	Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
		3	3	2	2	2	3	15	Light Grey, very faintly tinged [Red.
2	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
		2	3	3	3	2	2	15	Light Grey, tinged Yellow and [Green.
3	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
		2	2	2	3	3	3	15	Light Grey, tinged Blue.

GROUP 16.

Containing nine beams, each of two daylights, one dominant, and one subordinate.

	Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Orange .		1						
		3	4	2	2	2	3	16	Red Orange, fairly distinct.
2	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Green .				1				
		3	3	2	3	2	3	16	Orange and Violet, indistinct.
3	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Violet .						1		
		3	3	2	2	2	4	16	Red Violet, indistinct.

GROUP 16—*continued.*

	Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
4	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Orange .		1						
		2	4	3	3	2	2	16	Yellow Orange, distinct.
5	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Green .				1				
		2	3	3	4	2	2	16	Yellow Green, distinct.
6	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Violet .						1		
		2	3	3	3	2	3	16	Grey indistinct Yellowish Green.
7	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Orange .		1						
		2	3	2	3	3	3	16	Pale Blue Violet.
8	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Green .				1				
		2	2	2	4	3	3	16	Pale Blue Green.
9	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Violet .						1		
		2	2	2	3	3	4	16	Grey indistinct Bluish Violet [tinge.

GROUP 18.

DIVISION 1

Containing three beams, each of two daylights and two similar dominants.

	Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Red .	1	1				1		
		4	4	2	2	2	4	18	Pale Red with Orange tinge.
2	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Yellow .		1	1	1				
		2	4	4	4	2	2	18	Very pale Yellow.
3	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Blue .				1	1	1		
		2	2	2	4	4	4	18	Very light Bluish Violet.

DIVISION 2.

Containing three beams, each of two daylights and two dissimilar dominants.

	Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
	One Yellow .		1	1	1				
		3	4	3	3	2	3	18	Grey tinged Violet.
2	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
	One Blue .				1	1	1		
		2	3	3	4	3	3	18	Faint Greenish Grey.
3	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
	One Red .	1	1				1		
		3	3	2	3	3	4	18	Grey tinged Reddish Violet.

Division 3.

Containing one beam of three normal daylights.

	Superposed Lights.	Separate Colour Areas. R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
		3	3	3	3	3	3	18	Very light Grey.

GROUP 19.

Containing three beams, each of three normal daylights and one subordinate.

1	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One Orange.		1						
		3	4	3	3	3	3	19	Very pale Grey tinged Orange.
2	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One Green.				1				
		3	3	3	4	3	3	19	Pale Grey.
3	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One daylight.	1	1	1	1	1	1		
	One Violet.						1		
		3	3	3	3	3	4	19	Pale Grey.

GROUP 21.

Containing three beams, each of three daylights and one dominant.

	Superposed Lights.	R.	O.	Y.	G.	B.	V.	Total Colour Areas.	Description of Colour Sensation Produced.
1	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Red .	1	1				1		
		4	4	3	3	3	4	21	Grey with a Reddish tinge.
2	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Yellow .		1	1	1				
		3	4	4	4	3	3	21	Grey with a Yellowish tinge.
3	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One Blue .				1	1	1		
		3	3	3	4	4	4	21	Grey with a Bluish tinge.

GROUP 24.

One beam containing four normal daylights.

1	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
	One daylight .	1	1	1	1	1	1		
		4	4	4	4	4	4	24	Low colourless light.

OBSERVATIONS ON THE COLOUR SENSATIONS OF THE LIGHTS IN THE GROUPS.

The evidence of one set of experiments is insufficient for the purpose of formulating definite laws ; therefore the following observations are submitted as preliminary work, merely calling attention to some of the most prominent phenomena.

Monochromatic Rays.—The monochromatic colour rays—*orange*, *green*, and *violet*—are pure in colour, whether single or superposed in number, as they are free from mixture with other colour rays. *Compare group* 1 *with group* 2.

Trichromatic Rays.—The trichromatic colour rays—*red*, *yellow*, and *blue*—although not single-ray colours, yet produce a single pure colour sensation, which are also pure according to their freedom from mixture with other colour rays besides the original three.

Compare group 3, *div.* 3, *with group* 4, *div.* 4, *and with group* 5, *div*. 1.

Mixtures of Monochromatic Rays.—In mixtures of monochromatic colour rays, the vision is simultaneously sensitive to two colours which are not adjacent in their spectrum order, *as in group* 2, *div.* 1, No. 2 violet and green, No. 3 orange and green; in *group* 3, *div.* 1, orange and violet ; similarly in the greys of *group* 8, *div.* 6. The law which governs the colour of abnormal daylight begins to reassert itself, as the colours become more complex : that is, the two colours to which the vision is simultaneously sensitive are adjacent in their spectrum order.

Group 4, *div.* 4, No. 8 is an instance of three—blue, green, and violet being distinguishable simultaneously.

Mixtures of Trichromatic Rays.—In mixtures of two trichromatic colour rays, that ray governs the colour sensation which is common to both groups, and although indistinguishable in either separate ray it is colour evident in the mixture in consequence of being the predominant ray (*group* 6, *div.* 3).

Luminosity of Pure Colour.—The **colour depth** of a single pure colour ray is not increased by the addition of more and similar colour rays of the same colour depth, the effect of each addition being to increase the brilliancy, and not the depth of colour.

For instances of monochromatic rays compare *group* 1 with *group* 2, *div.* 2, with *group* 3, *div.* 2, and with *group* 4, *div.* 1.

For instances of trichromatic rays compare *group* 3, *div.* 3, with *group* 6, *div.* 2, with *group* 9, *div.* 1, and with *group* 12, *div.* 1.

Colour into Grey, Grey into Light.—As mixtures increase in complexity colour disappears, first into **grey**, then through all depths of grey into light.

The rapidity of colour disappearance seems to have relation to two causes.

First, the degree of preponderance of the colour-producing ray.

For instances compare No. 2 with No. 3, *group* 5, *div.* 1 ; also in the same group and div., Nos. 6 and 7 with Nos. 8 and 9 ; again, in *group* 6, *div.* 4, No. 1 with No. 2.

Second, the proximity of the other rays of the mixture to the colour-producing ray, the colours appearing purer as the other rays approximate to it.

Compare No. 2 with No. 4 and No. 8, *group* 6, *div.* 6 ; also No. 1 with No. 4, No. 8 and No. 9.

This may be stated in another way: namely, the mixture of adjacent rays deteriorates colour purity less than the mixture of non-adjacent rays.

No mixtures of two pure colours, complementary or otherwise, can produce white light.

For **Monochromatic rays** refer to *group* 2, *div.* 1. For **Trichromatic rays** refer to *group* 4, *div.* 4, Nos. 2, 6, and 7 ; *group* 12, *div.* 2, etc.

Pure colour mixed with white light rapidly loses its power of creating a colour sensation.

Some proportions may be observed in *group* 7, *div.* 3; *group* 9, *div.* 3, 4, and 5; *group* 12, *div.* 4 and 5; *group* 13, *div.* 1, 2, and 3; *groups* 14, 15, 16, 18, 19, and 21.

One area of normal light of 15 N.T., on a 10-seconds observation in camera, is seen as a low grey, *group* 6, *div.* 1;

Two areas as a bright grey, *group* 12, *div.* 6;

Three areas as a very light grey, *group* 18, *div.* 3; and

Four areas as a low colourless light, *group* 24.

During these observations a distinct impression was created that the blue and violet rays have a property of diffusion not noticed in the red and orange. No attempt is here made to define this diffusion, as it requires more time and apparatus than the author can at present command. I called attention to the fact when reading a paper before the British Association at their annual meeting held at Edinburgh in August 1892.

DECREASING RATIO OF LUMINOSITY IN MIXTURES OF EQUAL LIGHT OR COLOUR.

In mixing two equal areas of equal light or colour the luminous intensity of the mixture is less than the sum of the luminous intensities of the separate lights, the difference except in orange being greater for each additional area. The experiments in Table XI. give the luminous intensities of one, two, three, and four areas of normal daylight, and of each of the six composing colour rays in neutral-tint glass standard units required for total absorption at the eyepiece of the apparatus represented by Fig. 6 at page 49. The lights were superposed on the lime-sulphate screen, as already described in the article on mixed colours, and judged on a 5-seconds observation.

TABLE XI.

Normal White Light.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T. Units.			Increase per added Area of 15 Units.
1	containing	15	required	15	for total	absorption	
2	,,	30	,,	17·75	,,	,,	2·75
3	,,	45	,,	19·0	,,	,,	1·25
4	,,	60	,,	20·0	,,	,,	1·0

Red.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T. Units.			Increase per added Area of 15 Units.
1	containing	15	required	6·5	for total	absorption	
2	,,	30	,,	10·0	,,	,,	3·5
3	,,	45	,,	11·0	,,	,,	1·0
4	,,	60	,,	12·5	,,	,,	1·5

Orange.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T Units.			Increase per added Area of 15 Units.
1	containing	15	required	6·0	for total	absorption	
2	,,	30	,,	7·5	,,	,,	1·75
3	,,	45	,,	9·25	,,	,,	1·5
4	,,	60	,,	11·75	,,	,,	2·5

Yellow.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T. Units.			Increase per added Area of 15 Units.
1	containing	15	required	9·0	for total	absorption	
2	,,	30	,,	11·5	,,	,,	2·5
3	,,	45	,,	13·5	,,	,,	2·0
4	,,	60	,,	15·0	,,	,,	1·5

Green.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T. Units.			Increase per added Area of 15 Units.
1	containing	15	required	5·0	for total	absorption	
2	,,	30	,,	8·75	,,	,,	3·75
3	,,	45	,,	10·0	,,	,,	1·25
4	,,	60	,,	11·25	,,	,,	1·25

Blue.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T. Units for			Increase per added Area of 15 Units.
1	containing	15	required	5·5	for total absorption		
2	"	30	"	9·0	"	"	3·50
3	"	45	"	10·5	"	"	1·50
4	"	60	"	12·0	"	"	1·50

Violet.

Areas.		Total N.T. Units of Luminous Intensity.		Standard N.T. Units for			Increase per added Area of 15 Units.
1	containing	15	required	3·2	for total absorption		
2	"	30	"	5·5	"	"	2·25
3	"	45	"	6·75	"	"	1·25
4	"	60	"	8·25	"	"	1·5

Table XII. contains a summary of the above results.

TABLE XII.

N.T. Luminous Intensities at Eyepiece.

	One Area.	Two Areas.	Increase.	Three Areas.	Increase.	Four Areas.	Increase.
Normal Light	15·0	17·75	2·75	19·	1·25	20·0	1·0
Red	6·5	10·0	3·5	11·	1·0	12·5	1·5
Orange . . .	6·0	7·5	1·5	9·25	1·75	11·75	2·5
Yellow . . .	9·0	11·5	2·5	13·5	2·0	15·	1·5
Green . . .	5·0	8·75	3·75	10·0	1·25	11·25	1·25
Blue	5·5	9·0	3·5	10·5	1·5	12·	1·5
Violet . . .	3·25	5·5	2·25	6·75	1·25	8·25	1·5

A somewhat larger margin than usual must be allowed for errors of observation in work of this nature, where the point of final judgment is so near the limit of visual perception, and may possibly account for the irregularities in the rate of decrease per area in the red, the orange, and to a lesser degree in the violet rays.

CHAPTER V.

PENETRATION OF THE RED RAY IN DIRECT LIGHTS.

It has been already pointed out that direct light, either from the sun or from an artificial source, is not available for measuring colour by the system of colour-equivalent values in the standard glasses, although colours may be arbitrarily matched for record by their means.

The difficulty arises from a greater power of penetration which the red ray of direct light possesses compared to the penetration of the other rays. This is evidenced by an increase in colour depth and in colour purity, as the general luminosity of the light becomes lessened when intercepted by successive additions of a neutral-tint absorptive medium. The red ray in such a case is distinguishable long after the total absorption of all the other rays of the light.

A first impression is to attribute this excessive power of the red ray to a preponderance of quantity; but recent work makes it appear possible that it is due to a difference of condition, which enables this ray to penetrate the atmosphere more freely than the other rays; such a possibility has been already expressed in the chapter dealing with daylight at page 19.

The following experimental fact has some bearing on this view:—

When a direct light is intercepted by a diffusive medium, as distinct from an absorptive medium (a diffusive medium being one which interferes with the transmission of rays in a direct line from the light by breaking the rays up by reflection and re-reflection from a number of minute colourless surfaces), then the excessive penetration of the red ray is found to decrease in proportion as the density of the diffusive medium is increased until it assumes a colour equality with the other rays. The light may then be absorbed to extinction by a neutral-tint medium without any undue development of the red ray.

As all the rays of the direct light impinge equally upon the diffusive medium, and the red ray alone appears to be abnormally affected, it may be assumed, as a working hypothesis, that the original variation from the other rays was one of condition, and that it is the breaking up of the whole light by innumerable reflections which brings the red ray into the normal condition of colour equivalence with the other rays.

A perfect natural diffusive medium for this purpose is the white sea fog, upon which the colour equivalence of the standard scales is founded. The visual character of this fog may be more or less successfully imitated in a number of ways, the most successful of which is to lightly abrade the surfaces of a number of thin slips of colourless glass, then to arrange these into combinations of gradually increasing densities forming a scale of just perceptible differences.

If the scale is sufficiently comprehensive, one or other combination of this diffusive scale will reduce the red ray of the most intense light into colour equivalence with the other rays, the test of equivalence being arrived at when the light transmitted by the combination can be equivalently absorbed by the neutral-tint standards.

A direct light so absorbed is represented by the two kinds of combinations used; that is, first, by the value of the diffusive combination, which represents the abnormal penetration of the red ray, together with a certain amount of general loss of light; second, by the luminous intensity and colour character of the light transmitted by the diffusive combination.

The value of the standard glasses' neutral-tint unit has been already explained under section headed "The Colour Scales," page 30.

The fixing of a unit value for the diffusive scale is not so simple, and when a unit is fixed it can only be true under conditions of light and surroundings similar to those which obtained whilst the diffusive unit scale was made.

It is found that with diffused daylight any combination of diffusive glasses can be so perfectly matched in the instrument by means of the standard glasses that the vision is unable to differentiate between them.

When this has been accomplished, it is evident that, so far as the vision can distinguish, the unit values of the standard glasses apply equally to the diffusive combination under the conditions which held when the match was made; but the slightest alteration in the character of the light used, or in the distance of the diffusive glasses from the eye, disturbs their relation of visual equality.

Although the usefulness of the scale is thus limited, it may still be of some value for the purpose of investigation.

When the sun is viewed through a thin white fog it first creates a sensation of silvery whiteness, and as the fog increases in density it becomes yellow, which gradually disappears in the general obscurity of the increasing fog.

The yellow sensation, which can be artificially produced, and is also observable in experiments with sunlight in camera, was first attributed to a preponderance of the yellow ray; but it may be due to difference of condition similar in kind to that observable in the red ray.

The following simple experiments on the penetrating power of the red ray of a gaslight and sunlight under the interception of a diffusion scale must be considered as preliminary work only.

A gaslight which was wholly absorbed by 144 neutral-tint units with the usual strong development of the red ray was intercepted by "artificial fog" combinations of varying and known neutral-tint values. Then in each case the resultant diffused light was absorbed to extinction with N.T. units, and the colour sensation produced during the absorption noted. The total intensity of the light is then definable by means of two factors, one of a diffusion value sufficient to reduce the penetration of the red ray to colour-equivalent conditions, and the other in neutral-tint units of normal light required to absorb the remainder; the total absorption units for this particular light being 1·9 N.T. diffusion, and 27 N.T. standard units.

Original light absorbed by 144 N.T., with strong development of [red ray.
" " intercepted by ·55 diffusion units absorbed by 37 N.T., produced a fainter development of red ray.
" " " " 1·4 N.T. absorbed by 28 N.T., gave a red tinge.
" " " " 1·9 " " " 27 N.T., without any development of red.

A direct sunlight required 390 standard neutral-tint units for total absorption of the red rays; but on intercepting this sunlight with 11·2 diffusion units the red disappeared, the light transmitted creating a yellow sensation; this light was finally absorbed by 23 neutral-tint standard units.

Under the above working hypothesis, and with this particular diffusion scale, this sunlight would be described as containing the yellow ray in preponderance with a total luminosity of 390 N.T units, divisible into 11·2 penetration and 23 absorption.

FIRST APPEARANCE OF RED IN THE GRADUAL ABSORPTION OF DIFFERENT LIGHTS.

The following observations on Table XIII. made by me in 1890 have some bearing on the penetrating properties of the red ray through the neutral-tint standard glasses. They were made during investigations into the validity of the standard neutral-tint unit for direct lights of different character, before a distinction of quality as against quantity in the red ray was suspected. They are here noteworthy as establishing the point at which the penetrating property of the red ray begins to assert itself on the gradual absorption of each kind of light.

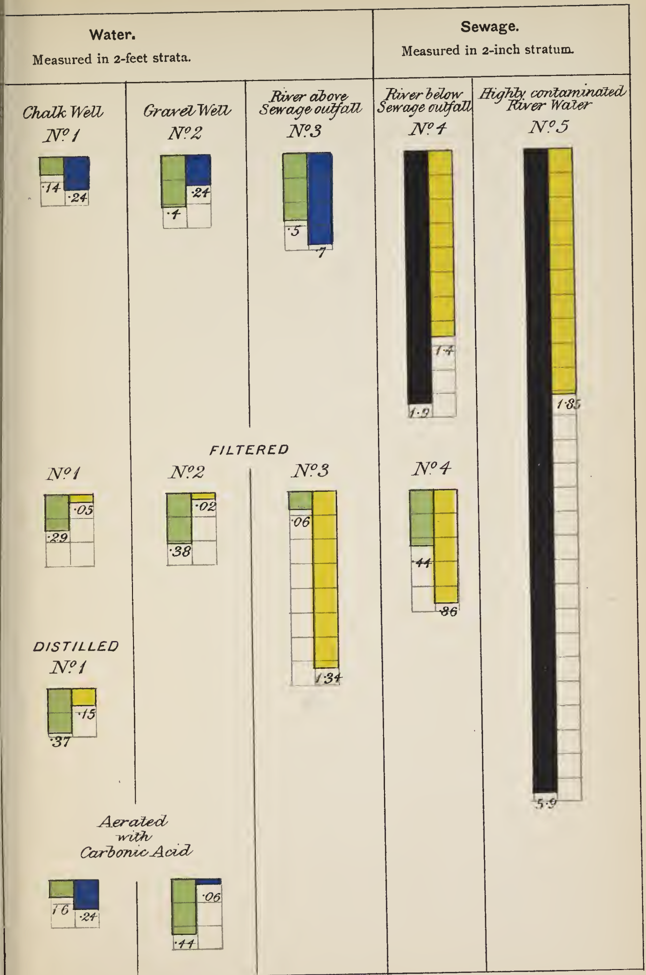
Previous experiments had already shown that, when similar lights were reflected from the standard white, the red ray had no excessive prominence. The opportunity of testing reflected light from snow here occurred for the first time.

It will be noted in Nos. 6 and 7 that in lights from a blue sky the red rays appeared at an earlier stage of absorption than in any other instance.

TABLE XIII.

No.	1890.			N.T. Units.		N.T. Units.
1.	Nov. 27th, 10 a.m.	North Blue Sky	red appears at	18	total absorption occurred at	99
2.	,, ,, 11 ,,	White Cloud	,,	20	,,	94
3.	,, ,, 12 ,,	Dark Cloud	,,	18	,,	60
4.	,, ,, 2 p.m.	,,	,,	18	,,	58
5.	,, ,, 3.3 ,,	,,	,,	16	,,	51
6.	,, 28th, 10.30 a.m.	Blue Sky	,,	14	,,	114
7.	,, ,, 12.0 ,,	,,	,,	14	,,	114
8.	,, ,, 2.30 p.m.	Whitish Sky and Snowy	,,	15	,,	77
9.	,, ,, 4.0 ,,	Whitish Sky	,,	15	,,	61
10.	,, ,, 4.0 ,,	,,	,,	15	,,	56
11.	,, 29th, 11.0 a.m.	Foggy	,,	18	,,	90
12.	,, ,, 12.0 ,,	,,	,,	15	,,	95
13.	Dec. 19th, 3.0 p.m.	Direct from Snow 60 ft. off	,,	16	,,	58
14.	,, ,, 3.0 ,,	Reflected from Snow 60 feet off.	no red appeared		,,	31

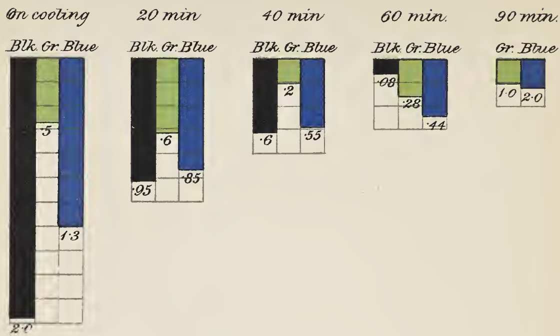
PLATE VI.



Scale—One colour unit per inch.

(To face Page 104)

PLATE VII.



Colour of No. 1 Chalk Well-water, boiled and measured for colour at intervals whilst the solid carbonates were being deposited.

(To face Page 105)

CHAPTER VI.

MEASURING TRANSPARENT COLOURS.

The apparatus for measuring transparent colours is illustrated at page 16, Fig. 2, when the monocular is required, and at page 17, Fig. 4, when the binocular is required. If the transparent substance is a solid, then it is simply inserted into one of the chambers at the end of the optical instrument; but if it is a liquid, it is measured in one of the graded glasses provided for the purpose. These range in thickness from an eighth of an inch to six feet; but only cells up to two inches thick can be carried on a single stand. In choosing the stratum thickness at which a given liquid should be measured, it must be borne in mind that the vision appreciates smaller differences in light colours than in dark colours. If the liquid be dark in colour, one way to decrease the colour for observation is to decrease the stratum thickness by choosing a thin glass, or, when the nature of the liquid permits, it may be proportionally diluted. The binocular can only be used for liquids from a one-inch stratum and under. It fits into the monocular stand as in Fig. 2.

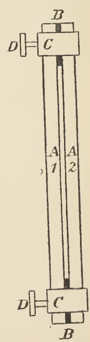


Fig. 9.

Some liquids will not permit of dilution, and are still too dark to be measured in the $\frac{1}{8}$th-inch vessel. The measured film apparatus, shown in section by Fig. 9, has been designed to meet these cases. This consists of two pieces of plate-glass, A_1 and A_2. At each end of these is cemented a small band of platinum foil, B B, of a measured thickness; the clamps, C, C, fitted with screws, D, D, slip over each end. On tightening the screws they press the two glass slips together as closely as the gauged platinum foil will allow. The space between the glasses is of the same thickness as the platinum foil, and can be filled by capillary attraction with the liquid to be measured.

Films of extreme thinness can be made, and accurately, in this way, and very dense colours be brought to transparent measurement.

When it is required to measure the colour of transparent solids, which can be melted at comparatively low temperatures, as wax, resin, lard, paraffin, these can be easily run into the capillary film arrangement, or even into the gauged glasses, and if it is required to keep the fused substance some time under observation in a fluid state, then a metal bottom is provided for the vessel to rest on, and the whole kept at a uniform temperature by means of a spirit lamp or small gas jet.

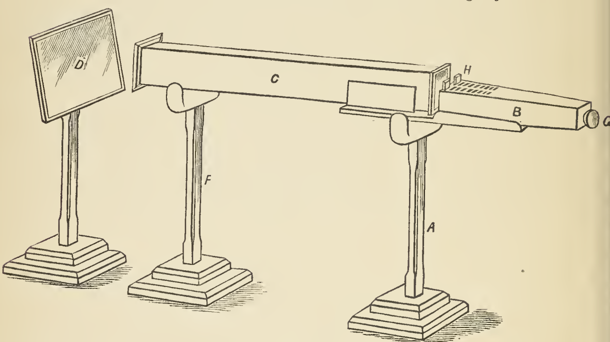


Fig. 9*a*.

When the liquid is so light in colour as to require more than a stratum of six inches to obtain appreciable colour, as in the case of water, water-white oils, glycerine, spirit, etc., then a separate support is required to carry one end of the long tank, as shown in Fig. 3, p. 17, and here repeated for convenience, where one end of the tank C rests on the support A, in line with the optical instrument B; the other end of the tank rests on the support F, which can be moved to accommodate a tank of any length; light is taken from the reflector D. These tanks are made up to six feet in length, and can be made longer if desired, but two feet gives sufficient depth for all liquids not lighter in colour than distilled water.

The tank should be covered to keep out dust, and to prevent top light from being reflected to the vision by any solid particles which may be in suspension.

In measuring liquids of very light colour no notice need be taken of variations of colour in the light used, so long as it is not direct sun rays. The register measure of a given water, for instance, is the same, no matter whether the light is taken from a blue sky, a light haze, a dense bank of clouds with heavy rain falling, or reflected from snow; but the visual colour sensation changes with every variation of light, so that the same water would be called a bright blue, a dull lead colour, or any shade of dingy yellow, according as the light changed. This may be easily tested by measuring a water and then intercepting the light with different coloured glass: if deep tinted glass is avoided no change in the measured colour will be observed, but the water will always appear to be the same colour as the intercepting glass.

The attention of water analysts is specially directed to this constant character of colour measurements made under varying conditions of light, as compared to the varying results of colour measurements made in the ordinary way by the colour impressions created, which are analogous in character to the changes of colour observable in the sea, when viewed from a height under the varying conditions of sky, cloud, etc., the colour of the water itself being manifestly constant.

The following experiments are given with a view to illustrate the capacity and range commanded by the apparatus and system:—

Waters Measured in Two-Feet Strata.

TABLE XIV.

	Standard Glasses used.			Colour of the Water.			
	Red.	Yellow.	Blue.	Black.	Green.	Blue.	Yellow.
1. Water from a chalk well .	0·0	+ ·14	+ ·38	= 0·0	+ ·14	+ ·24	+ 0·0
2. Water from a drift gravel	0·0	+ ·4	+ ·64	= 0·0	+ ·4	+ ·24	+ 0·0
3. Water from a river above sewage outfall . . .	0·0	+ 1·2	+ ·5	= 0·0	+ ·5	+ ·7	+ 0·0
4. Water from a river below sewage outfall . . .	1·9	+ 3·3	+ 1·9	= 1·9	+ 0·0	+ 0·0	+ 1·4
Measured in a Two-Inch Stratum.							
5. Water from a river highly contaminated	5·0	+ 6·83	+ 5·0	= 5·0	+ 0·0	+ 0·0	+ 1·83

The rules for obtaining the colour numerals in the second half of the equation have been fully described at page 46.

The colours in the second half of the equations are also represented by means of quantitatively coloured diagrams in Plates 3 and 4. The colour rays are shown separately side by side to a scale of one colour unit per inch, and the resultant colour is that of the mixture of these proportions of colour with the accompanying light by which they are viewed.

Effect of Solid Particles in Suspension.

Having in view that considerable difference of opinion exists concerning the effect of solid particles in suspension on the colour of water, the following experiments were made with a view to note the changes made by the carbonates of the chalk well water, No. 1, which were precipitated by boiling, then noting the alteration in colour caused by their gradual deposition until the water became quite clear:—

TABLE XV.

	Standard Glasses.			Colour Transmitted.		
	Red.	Yellow.	Blue.	Green.	Blue.	Black.
Original colour before boiling in two-feet stratum	—	·14	+ ·38	= ·14	+ ·24	—
After boiling, cooling, and agitating .	2·0	+ 2·5	+ 3·8	= 0·5	+ 1·3	+ 2·0
After standing 20 minutes	·95	+ 0·55	+ 2·4	= ·6	+ ·85	+ ·95
,, ,, 40 ,, ...	·6	+ ·8	+ 1·35	= ·2	+ ·55	+ ·6
,, ,, 60 ,, ...	·08	+ ·36	+ ·8	= ·28	+ ·44	+ ·08
,, ,, 90 ,, ...	0·0	+ ·19	+ ·39	= ·19	+ ·2	—

It will be seen that the changes effected by the gradual deposition of the solidified carbonates were changes of degree, and not of colour, which was a blue-green during the whole of the experiments. The intensity of the blue-green varied with the obstruction of light by the solid particles in suspension until in 90 minutes all had subsided, when the water was clear and closely approximated its original colour, the difference being—

	Green.	Blue.	Total.
Original colour	·14	+ ·24	·38
After boiling and settling . .	·19	+ ·2	·39

The variations in degree of colour are better realised in quantitatively coloured diagrams, Plate 6.

From these measurements, and from those of the sewage-contaminated waters in Table XIV., and of the solid particles in Table XV., it may be suggested that the working out of a factor for estimating the quantity of suspended substances in water by means of the quantity of light obstructed is only a question of time and labour.

Change of Colour in Water Effected by Distilling or Filtering.

Whilst carrying out these and similar experiments, it was observed that the operations of distilling or filtering waters, which were already clear, effected a complete change in their colour, provided that the measurements followed quickly on the operations.

The nature of the change was to alter the original blue-green of the water to a yellow-green; which, however, was not stable, the original colour being gradually restored on standing, and quickly restored on adding free carbonic acid.

Although a greater or less change was always noticeable, repeated trials under apparently similar conditions rarely gave exactly similar results. The following examples are illustrations of this new set of phenomena discovered by means of the Tintometer method of colour measurement, shown in Table XVI.

The waters employed are Nos. 1, 2, and 3, of Table XIV., page 107:—

Changes of Colour Effected by Filtering.

TABLE XVI.

	Before Filtering.		After Filtering.	
No.	Green.	Blue.	Green.	Yellow.
1. Chalk well water	·14	+ ·24	·29	+ ·25
2. Drift gravel water	·4	+ ·24	·38	+ ·02
3. River water	·5	+ ·7	·06	+ 1·34

Changes of Colour Effected by Distilling.

1. Chalk well water . . . . ·14 + ·24 | ·37 + ·15.

Restoration of Colour by Aerating Filtered Samples with CO_2.

TABLE XVII.

	Before Aerating with CO_2.		After Aerating with CO_2.		Original Colour.	
No.	Green.	Yellow.	Green.	Blue.		
1. Chalk well water . . .	·29	+ ·25	·16	+ ·24	·14	+ ·24
2. Drift gravel water . . .	·38	+ ·02	·45	+ ·23	·4	+ ·24

These changes are also more clearly observable in the quantitatively coloured diagrams in Plate 7.

CHAPTER VII.

MEASURING OPAQUE COLOURS.

THE method of measuring opaque colours is illustrated in Fig. 4, page 17. The sample to be measured is placed on the base, F, under one tube of the optical instrument, B, and the sample of standard white under the other tube. The light from this latter is intercepted by the suitable standard glasses, until both sides are equal in colour, when the light transmitted by the glasses will be in visual accord with the light reflected from the coloured substance, the composition of which is obtainable by means of an equation already fully described.

Arrangement of Light.

In all cases the light should be reflected through the optical instrument as nearly at right angles to the coloured surface as possible, in order to prevent an undue mixture of unaltered light—that is, of light which impinges on the substance outside the angle of absorption; also care must be taken that the two apertures are equally illuminated before making a measurement. This is effected by placing an even coloured surface under each aperture, and turning the instrument towards the light until both sides are equal in brightness.

Preparation of Samples.

The surface of the sample, if not already nearly corresponding in smoothness with the lime-sulphate surface, must be made to do so by any suitable cutting, grinding, polishing, etc.; or if the substance is a powder, then by pressing, and in order to ensure uniformity of pressure the following apparatus has been devised. Fig. 10 represents a small tray, 2″ by 1″ and $\frac{1}{10}$″ deep, to hold the pressed powder for measurement. B is a frame fitting over A, and also $\frac{1}{10}$″ deep, the combined depth being $\frac{2}{10}$″; the whole is then filled with the powder and evenly struck off. C is two pieces of glass cemented together, the smallest face of which just fits into the tray, and is used to slightly compress the powder, so that the frame, B, may be removed without disturbing it, after which the original two-tenths in thickness are pressed into one-tenth with the broad side of the glass presser. The whole is shown in section, Fig. D, with the upper part ready for removal.

The examples already given at p. 39 are sufficient to illustrate the method of measuring pigmentary powders.

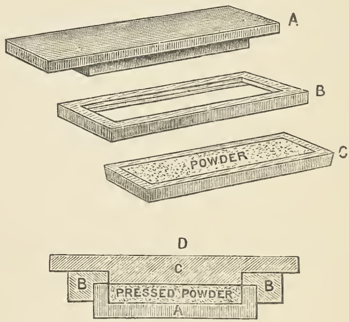


Fig. 10.

Fabrics and paper, if not already smooth, are made so by pinning on a block.

Yarns are wound closely on a block, and as illustrations I have permission to use a set of measurements of the "Holmgren" colour vision wools, which were made and classified for the use of the Colour Vision Committee of the Royal Society. A second set of measurements of these wools is to be made with a view to note any alteration of colour by time or use, it being possible that time and exposure may effect a complete change of colour in some of those wools whose preponderating colour rays were near the line which divides one colour from another.

The details of the colour measurements of these wools appear in the following table, where the original numbers are in the first column. These are not in regular order; the wools are classified according to the colour chart upon which each is chartable.

This order of classification is also observed in the quantitative colour diagrams illustrating the series, and which are to a scale of one-tenth of an inch per colour unit. It has not been considered necessary to figure the whole section of light in these diagrams, but only the altered colour rays. If pigments could be obtained exactly corresponding in colour to the standard glasses, then the colour sensation of each wool would correspond to equal quantities of mixtures in the corresponding pigments.

Colour Measurements of Holmgren's Set of Colour-Vision Wools.

Table XVIII.

Oranges, Red Oranges, and Saddened Red Oranges.

Skein No.	Measuring Glasses. Red.	Yell.	Blue.		Colour Transmitted. Red.	Orange.	N. T.	Chart No. 1.
*95	4·1 +	·9 +	...	=	3·2 +	·9 +	...	Red Orange.
96	7·0 +	1·0 +	...	=	6·0 +	1·0 +	...	„
97	10·2 +	1·3 +	...	=	8·9 +	1·3 +	...	„
98	14·5 +	2·0 +	...	=	12·5 +	2·0 +	...	„
23	7·0 +	7·0 +	4·0	=	... +	3·0 +	4·0	Saddened Normal Orange.
16	2·0 +	1·7 +	·54	=	·9 +	1·16 +	·54	Saddened Red Orange.
24	11·4 +	10·0 +	5·4	=	1·4 +	4·6 +	5·4	„
25	14·0 +	13·5 +	7·0	=	·5 +	6·5 +	7·0	„
26	17·0 +	12·5 +	8·5	=	4·5 +	4·0 +	8·5	„
36	12·0 +	11·5 +	6·6	=	·5 +	4·9 +	6·6	„
37	16·0 +	13·0 +	10·0	=	3·0 +	3·0 +	10·0	„
90	4·0 +	·5 +	·1	=	3·5 +	·4 +	·1	„
99	22·0 +	2·0 +	·2	=	20·0 +	1·8 +	·2	„
101	30·6 +	2·5 +	1·3	=	28·1 +	1·2 +	1·3	„
17	4·4 +	3·2 +	1·9	=	1·2 +	1·3 +	1·9	„
18	7·4 +	5·0 +	3·2	=	2·4 +	1·8 +	3·2	„
19	13·0 +	10·4 +	6·6	=	2·6 +	3·8 +	6·6	„
20	16·0 +	13·0 +	9·5	=	3·0 +	3·5 +	9·5	„
*102	27·0 +	3·0 +	3·0	=	24·0 +	... +	3·0	Saddened Red.

Table XIX.

Yellow Oranges and Saddened Yellow Oranges.

Skein No.	Measuring Glasses. Red.	Yell.	Blue.	Colour Transmitted. Yell.	Orange.	N. T.	Chart No. 2.
71	2·4 +	5·0 +	... =	2·6 +	2·4	+ ...	Yellow Orange.
72	3·1 +	5·0 +	... =	1·9 +	3·1	+ ...	"
21	4·0 +	4·1 +	2·1 =	·1 +	1·9	+ 2·1	Saddened Yellow Orange.
22	5·1 +	5·4 +	2·3 =	·3 +	2·8	+ 2·3	"
27	2·4 +	2·9 +	1·8 =	·5 +	·6	+ 1·8	"
28	4·4 +	5·4 +	2·5 =	1·0 +	1·9	+ 2·5	"
29	7·0 +	8·0 +	4·6 =	1·0 +	2·4	+ 4·6	"
30	8·6 +	10·0 +	6·2 =	1·4 +	2·4	+ 6·2	"
31	11·0 +	11·5 +	7·5 =	·5 +	3·5	+ 7·5	"
32	3·4 +	4·5 +	1·2 =	1·1 +	2·2	+ 1·2	"
33	4·5 +	6·4 +	1·9 =	1·9 +	2·6	+ 1·9	Saddened Yellow Orange.
34	6·2 +	9·2 +	3·2 =	3·0 +	3·0	+ 3·2	"
35	7·8 +	9·8 +	4·0 =	1·8 +	3·8	+ 4·0	"
63	1·1 +	4·4 +	·4 =	3·3 +	·7	+ ·4	"
64	2·1 +	15·0 +	1·4 =	12·9 +	·7	+ 1·4	"
65	3·6 +	17·0 +	1·8 =	13·4 +	1·8	+ 1·8	"
66	7·0 +	19·0 +	4·6 =	12·0 +	2·4	+ 4·6	"
67	10·0 +	21·0 +	7·0 =	11·0 +	3·0	+ 7·0	"
68	11·2 +	19·0 +	9·0 =	7·8 +	2·2	+ 9·0	"
69	·8 +	1·8 +	2·6 =	1·0 +	·54	+ 2·6	"
70	1·7 +	3·6 +	5·2 =	1·9 +	1·18	+ ·52	"

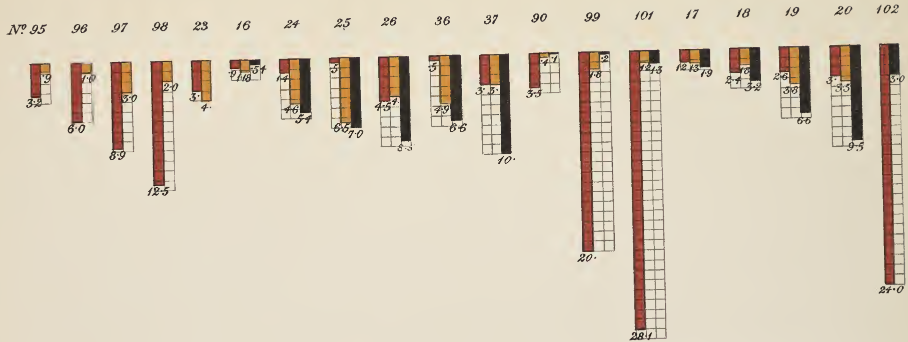
Table XX.

Yellow Green and Saddened Yellow Green.

Skein No.	Red.	Yell.	Blue.	Yell.	Green.	N.T.	Chart No. 3.
51	... +	3·3 +	3·0 =	·3 +	3·0	+ ...	Yellow Green.
126	... +	13·0 +	1·0 =	12·0 +	1·0	+ ...	"
7	1·5 +	3·0 +	2·6 =	·4 +	1·1	+ 1·5	Saddened Yellow Green.
8	3·2 +	6·0 +	5·2 =	·8 +	2·0	+ 3·2	"
9	3·6 +	8·0 +	6·2 =	1·8 +	2·6	+ 3·6	"
10	6·0 +	15·0 +	12·0 =	3·0 +	6·6	+ 6·0	"
11	1·1 +	2·4 +	1·9 =	·5 +	·8	+ 1·1	"
12	1·2 +	2·8 +	2·05 =	7·5 +	·85	+ 1·2	"
13	2·4 +	4·4 +	3·5 =	·9 +	1·1	+ 2·4	"
14	4·0 +	7·0 +	6·2 =	1·4 +	2·2	+ 4·0	"
133	1·0 +	17·0 +	2·8 =	14·2 +	1·8	+ 1·0	"
134	1·0 +	19·0 +	5·0 =	14·0 +	4·0	+ 1·0	"
135	2·5 +	26·0 +	8·5 =	17·5 +	6·0	+ 2·5	"
136	3·0 +	2·2 +	12·5 =	9·5 +	9·5	+ 3·0	

PLATE VIII.

RED ORANGE COLOURS.



Quantitative Colour Diagrams of "Holmgren's" Colour Vision Wools.

Scale : $\frac{1}{13}$ of an inch per colour unit.

(To follow the Table on page 113)

PLATE IX.

YELLOW ORANGE COLOURS.

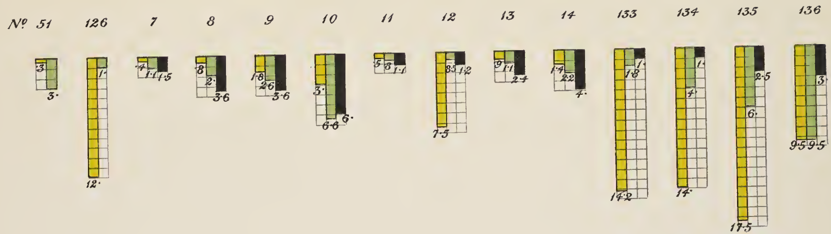
Quantitative Colour Diagrams of "Holmgren's" Colour Vision Wools.

Scale : $\frac{1}{15}$ of an inch per colour unit.

(To follow Plate 8 page 113)

PLATE X.

YELLOW GREEN COLOURS.



Quantitative Colour Diagrams of "Holmgren's" Colour Vision Wools.

Scale : $\frac{1}{13}$ of an inch per colour unit.

(To follow Plate 9 page 113)

PLATE XI.

BLUE GREEN COLOURS.

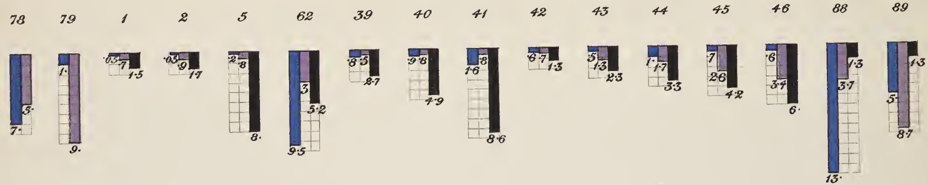
Quantitative Colour Diagrams of "Holmgren's" Colour Vision Wools.

Scale : $\frac{1}{13}$ of an inch per colour unit.

(To follow Plate 10 page 113)

PLATE XII.

BLUE VIOLET COLOURS.



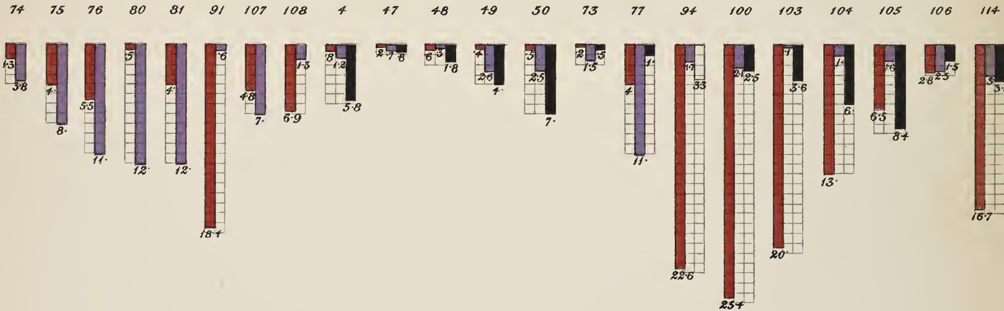
Quantitative Colour Diagrams of "Holmgren's" Colour Vision Wools.

Scale : $\frac{1}{13}$ of an inch per colour unit.

(To follow Plate 11 page 113)

PLATE XIII.

RED VIOLET COLOURS.



Quantitative Colour Diagrams of "Holmgren's" Colour Vision Wools.

Scale : $\frac{1}{13}$ of an inch per colour unit.

(To follow Plate 12 page 113)

Table XXI.

Blue Greens.

Skein No.	Measuring Glasses. Red.	Yell.	Blue.		Colour Transmitted. Blue.	Green.	N.T.	Chart No. 4.
52	... +	5·2 +	6·6	=	·8 +	5·2 +	...	Blue Green.
83	... +	1·0 +	6·8	=	5·8 +	1·0 +	...	"
84	... +	1·3 +	7·5	=	6·2 +	1·3 +	...	"
85	... +	1·3 +	10·0	=	8·7 +	1·3 +	...	"
86	... +	1·3 +	14·0	=	12·7 +	1·3 +	...	"
115	... +	2·2 +	3·9	=	1·7 +	2·2 +	...	"
82	... +	·8 +	4·0	=	3·2 +	1·7 +	...	"
6	·5 +	1·1 +	1·25	=	1·5 +	·6 +	·5	Saddened Blue Green.
53	·6 +	9·2 +	10·0	=	·8 +	8·6 +	·6	"
54	·4 +	10·8 +	13·0	=	2·2 +	10·4 +	·4	"
55	3·0 +	12·0 +	15·0	=	3·0 +	9·0 +	3·0	"
57	·15 +	1·2 +	3·0	=	1·8 +	1·05 +	·15	"
58	·16 +	1·9 +	6·8	=	4·9 +	1·74 +	·16	"
59	·38 +	2·6 +	10·0	=	7·4 +	2·22 +	·38	"
60	1·2 +	3·0 +	12·0	=	9·0 +	1·8 +	1·2	"
61	2·3 +	4·4 +	15·0	=	10·6 +	2·1 +	2·3	"
87	·8 +	1·3 +	17·0	=	15·7 +	·5 +	·8	"
137	2·0 +	19·0 +	20·0	=	1·0 +	17·0 +	2·0	"

Table XXII.

Blue Violets and Saddened Blue Violets.

Skein No.	Standard Glasses. Red.	Yell.	Blue.		Colour Transmitted. Blue.	Violet.	N.T.	Chart No. 5.
78	5·0 +	... +	7·0	=	7·0 +	5·0 +	...	Blue Violet.
79	9·0 +	... +	10·0	=	1·0 +	9·0 +	...	"
1	2·2 +	1·5 +	2·25	=	·05 +	·7 +	1·5	Saddened Blue Violet.
2	2·6 +	1·7 +	2·65	=	·05 +	·9 +	1·7	"
5	8·8 +	8·0 +	9·0	=	·2 +	·8 +	8·0	"
62	5·5 +	5·2 +	15·0	=	9·5 +	·3 +	5·2	"
39	3·2 +	2·7 +	4·0	=	·8 +	·5 +	2·7	"
40	5·7 +	4·9 +	6·6	=	·9 +	·8 +	4·9	"
41	9·4 +	8·6 +	11·0	=	1·6 +	·8 +	8·6	"
42	2·0 +	1·3 +	2·6	=	·6 +	·7 +	1·0	"
43	3·6 +	2·6 +	4·1	=	·5 +	1·3 +	2·3	"
44	5·0 +	3·3 +	6·0	=	1·0 +	1·7 +	3·2	"
45	6·8 +	4·2 +	7·5	=	·7 +	2·6 +	4·2	"
46	9·4 +	6·0 +	10·0	=	·6 +	3·4 +	6·0	"
88	5·0 +	1·3 +	18·0	=	13·0 +	3·7 +	1·3	"
89	10·0 +	1·3 +	15·0	=	5·0 +	8·7 +	1·3	"

Table XXIII.

Red Violets and Saddened Red Violets.

Skein No.	Standard Glasses. Red.	Yell.	Blue.		Colour Transmitted. Red.	Violet.	N.T.	Chart No. 6.
74	5·1	+ ... +	3·8	=	1·3 +	3·8	+ ...	Red Violet.
75	12·0	+ ... +	8·0	=	4·0 +	8·0	+ ...	„
76	16·5	+ ... +	11·0	=	5·5 +	11·0	+ ...	„
80	12·5	+ ... +	12·0	=	·5 +	12·0	+ ...	„
81	19·0	+ ... +	12·0	=	4·0 +	12·0	+ ...	„
91	19·0	+ ... +	·6	=	18·4 +	·6	+ ...	„
107	5·50	+ ... +	·7	=	4·8 +	·7	+ ...	„
108	8·2	+ ... +	1·3	=	6·9 +	1·3	+ ...	„
4	7·8	+ 5·8 +	7·0	=	·8 +	1·2	+ 5·8	Saddened Red Violet.
47	1·7	+ ·8 +	1·5	=	·2 +	·7	+ ·8	„
48	3·5	+ 1·8 +	3·1	=	·4 +	·3	+ 1·8	„
49	7·9	+ 4·0 +	6·6	=	·4 +	2·6	+ 4·0	„
50	10·0	+ 7·0 +	9·5	=	·5 +	2·5	+ 7·0	„
73	2·2	+ ·5 +	2·0	=	·2 +	1·5	+ ·5	„
77	16·0	+ 1·0 +	12·0	=	4·0 +	11·0	+ 1·0	„
94	27·6	+ 3·3 +	5·0	=	22·6 +	1·7	+ 3·3	„
100	30·0	+ 2·5 +	4·6	=	25·4 +	2·1	+ 2·5	„
103	24·	+ 3·6 +	3·7	=	20·3 +	·1	+ 3·6	„
104	20·	+ 6·0 +	7·2	=	13·0 +	1·0	+ 6·0	„
105	16·5	+ 8·4 +	10·0	=	6·5 +	1·6	+ 8·4	„
106	3·2	+ 1·5 +	·4	=	2·8 +	·25	+ 1·5	„
114	23·5	+ 3·8 +	6·8	=	16·7 +	3·0	+ 3·8	„

The re-measurement of these wools—mentioned on page 112 as having been made and classified for the Colour-Vision Committee of the Royal Society—is in progress, and the results will be published when finished. Whilst the majority of the colours already examined are unusually fast, in some the fading has been considerable, and would suggest the necessity of a registered colour standard for each wool, and a periodical re-measurement of those which are used for testing the eyesight of candidates for positions of responsibility where the question of colour vision is of importance. The following two examples are amongst the extreme cases of change :—

	Violet.	Blue.	Black.
No. 88. Blue Violet original . . .	3·7 +	13·0 +	1·3
„ „ „ re-measured . . .	1·95 +	12·8 +	0·75
Loss . . .	1·75	0·2	0·55

	Green.	Blue.
No. 121. Blue Green original . . .	6·0 +	6·0
„ „ „ re-measured . . .	5·4 +	4·8
Loss . . .	0·6	1·2

CHAPTER VIII.

ON THE MEASUREMENT OF COLOUR BLINDNESS.

THE standard glasses afford a means of quantitatively measuring all those defects of vision which are comprehended in the fullest sense under the term "colour blindness," embracing all degrees of departure from normal appreciation both of light and colour.

In dealing with this part of the question, I am much indebted to Mr. Priestly Smith, of Birmingham, who suggested improvements in the form of apparatus for this particular purpose. The optical instrument B is of the binocular form, but with three apertures, H_1, H_2, H_3, as shown in Fig. 11; the prolongations are grooved between each aperture for the insertion of the coloured standard glasses, so that light of any depth or colour can be made to appear in either aperture. Light is taken from the reflector F. By blocking the middle aperture, H_2, the instrument can be converted into the ordinary binocular, except that the two apertures are slightly farther apart than usual.

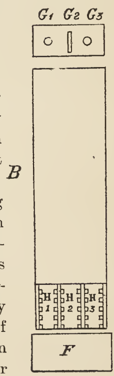


Fig. 11.

This form of instrument is also available for testing the vision by Holmgren's system of coloured wools, with the advantage of a wider means of checking the observations, by winding each wool closely on a block, as was done for measurements made for the Royal Society Colour-Vision Committee already described and figured. They are quite as available in this form for the method of testing by selection already in force as if they were in skeins; and, in addition, they can not only be put under the instrument for direct comparison with each other, but a wool may be altered at will either in colour or in depth by adding the necessary glasses; and if a screen, M, of cloth or paper be placed so as to screen the manipulation, as in Fig. 12, then these changes can be effected with the certainty that the person whose vision is being tested can have no knowledge of them other than that conveyed by his own sensations of colour.

The following method of procedure suggested itself, and was carried into effect on the vision of a friend whose sight was abnormal. The manipulation of the glasses was screened from observation. The colour depths were each of 30 units' intensity, and were not submitted in regular order.

The result of this examination demonstrated:—

1st. That this vision was not sensitive to red and green.

2nd. That it was sensitive to orange and yellow, but could not distinguish between them, calling both yellow.

3rd. That it was sensitive to blue and violet, but could not distinguish between them, calling both blue.

It is evident that the method can be extended in an organised fashion to any desirable combination.

Variation in Colour Perception between the Two Eyes of the Same Person.

Frequent discrepancies in the verbal description of measured colours amongst members of my own staff led to investigations which proved that variations in the colour-perceptive power between the two eyes of one person were far more frequent than "colour blindness" in the usual sense of the term.

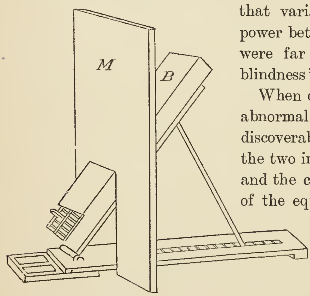


Fig. 12.

When one eye is normal and the other abnormal the discrepancy is not easily discoverable under ordinary conditions, as the two images are blended by the vision, and the colour sensation conveyed is that of the equal mixture, unless the eyes are unequal, when the colour viewed by the strongest will preponderate. But if care is taken to prevent the diagonal rays from the coloured object seen by one eye from reaching the other eye, so that each views only the colour opposite to itself, then the sensation of each eye is separately appreciated, and any difference in their perceptive power is evident as difference in colour.

For the purpose of measuring these differences the adaptation shown in Fig. 13 was devised; the three-aperture instrument is converted into one of two apertures by stopping the middle aperture, H_2, with an opaque slip. A longitudinal groove is made in the upper side of the optical instrument at K. Into this groove fits a slide shown separately at K_1. The effect of inserting this is to cut off the diagonal rays shown by dotted lines from the aperture at H_1 to the eyepiece G_3, and the rays from the aperture H_3 to the eyepiece G_1. Each eye then only sees the coloured aperture to which it is opposite; and if a similar colour fills each aperture, then any difference of colour-perceptive power between the eyes is at once evident. The following is an example of one such measurement made with the colours red, yellow, blue, and daylight. The intensity of the colours is represented by the unit numbers on the glasses, and the difference in colour between the right and the left lines represents the difference of perceptive power between the two eyes of the person examined, who pronounced both sides to be equal in colour; although the colours varied according to the glasses shown in the table.

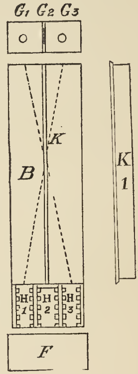


Fig. 13.

	Right Eye.		Left Eye.
The vision pronounced	5·7 Red,	equal to	6·0 Red
" "	4·4 Yellow, 1·6 Green	"	6·0 Yellow
" "	6·2 Blue	"	5·2 Blue, ·8 Violet

For balancing two equal daylights

The vision pronounced ·5 Green, equal to {·16 Orange, ·16 Yellow}

APPENDIX.

APPENDIX A.

On a New Instrument for the Measurement of Colour, more especially as applied to the Estimation of Carbon in Steel. Read before the Iron and Steel Institute.

By H. Le Neve Foster.

The object of this paper is to bring before the members of this Institute a new instrument called a tintometer, for the accurate measurement or matching of colours, and also by means of the same apparatus to introduce what may be termed a permanent standard for the matching of carbons in steel by the well-known Eggertz colour method, or by Stead's alkali method, as described before this Institute in 1883.

I will first proceed to describe the apparatus as patented by Mr. J. W. Lovibond, of Salisbury, which may be divided into two essential parts. The first is an instrument giving two fields of view under similar monocular conditions, freed from any errors which may arise from the introduction of unequal side-lights, and also the different power of distinguishing colour that often exists in the eye of the observer. The second part consists of a standard set of coloured glasses, each set being the same colour, but regularly graded for depth of tint.

By using several superimposed glasses from a set, a depth of colour is represented by the aggregate of tint number on glass used, whilst glasses from different sets produce a composite colour, and the exact proportion of each component colour can be read off.

The instrument consists of a tube, divided by a central partition terminating at the eye-piece in a knife-edge, which, being inside the range of vision, is not seen when the instrument is in use. At the other end of the instrument are two apertures of equal size, and alterable in size or shape by means of diaphragms. The two apertures are divided by the thick end of the central partition, which, together with the sides, is recessed by grooves, so as to hide the edges of the standard glasses as well as the sides of the gauged glass vessels that are used to contain the liquid which requires to be matched or compared. The whole is so arranged that the only light which can possibly meet the eye of the observer must first pass in equal quantities through the liquid in the gauged glass vessel in the one tube, and the standard glasses in the other tube. By this means it is possible to match or compare colours under much more favourable circumstances than by the method usually employed, whereby the results are often to a great extent falsified by means of the unequal side-lights, as is often seen when the position of the tubes is changed and an apparent difference of reading is indicated, showing that the varying character of the light exercises a disturbing influence.

Another advantage claimed for the tintometer is that the liquids to be examined are always placed in gauged glass vessels with parallel sides, so that the thickness of stratum is always the same.

Wishing to see how far the different standards of several steel-works varied, I obtained two samples of standard steel from Mr. Stead, in which he had estimated the carbon by combustion, and I sent them to different chemists, all of whom were connected with large steel-works, and asked them to compare them with their standards. The following results were obtained:—

	No. 1 Sample. Carbon per cent.	No. 2 Sample. Carbon per cent.	
	·21	·55 Stead	Combustion.
	...	·53 Riley	Combustion.
	...	·54 Average.	
Chemist No. 1.	·21	·68	
,, ,, 2.	·20	...	
,, ,, 3.	·21	·53	
,, ,, 4.	·213	·54	
,, ,, 5.	·22	·61	
,, ,, 6.	·20	·58	
,, ,, 7.	·22	·53	
,, ,, 8.	·205	·585	
,, ,, 9.	·23	·55	
,, ,, 10.	·195	·54	
,, ,, 11.	·20	·54	
,, ,, 12.	·19	·52	
,, ,, 13.	·23	·63	
,, ,, 14.	·25	·57	
,, ,, 15.	·17	·53	
,, ,, 16.	·17	·50	
,, ,, 17.	·19	·44	
,, ,, 18.	·17	·38	

You will see from the foregoing results that the carbons vary from 17 per cent. to 25 per cent. in the one case, and from 38 per cent. to 65 per cent. in the other.

I do not believe that this wide difference is altogether the fault of the manipulator, but I think it is due in a great measure to the varying of the standards. It is now generally acknowledged by metallurgists that the composition of steel in the same bar may vary very considerably; and only a short time since I had a piece of a round bar tested, when the outside gave 20 per cent. carbon, whilst the inside gave 26 per cent. This bar was intended for a standard, but fortunately was tested both inside and outside, and so was rejected for this purpose.

A permanent standard would not only reduce the risk of error in manipulation, but also the error which arises from the varying composition of the steel employed as standards.

I may mention that the tintometer is being largely employed by dyers to find the exact value of their colours; by brewers for ascertaining and recording the colour of malt and of beer, etc.; and by sugar manufacturers for valuing their raw materials.

It has also been used by printers, paper-makers, caramel manufacturers, and vine-growers, as well as by flour analysts.

The tintometer affords a ready means of measuring the depth of colour in potable and other waters, and is also applicable for Nessler's ammonia test as used in water analysis.

As applied in the estimation of carbon, I find that the best results are obtained by dissolving ·5 gramme of steel in 10 c.c. nitric acid, sp. 1·20, and boiling for twenty minutes, and then diluting to 50 c.c. and placing the liquid in a 1-inch cell. For mild steel this gives a colour that is easy to match.

The following results were obtained:—

	Found by Eggertz Method. Carbon per cent.	Found by Tintometer. Carbon per cent.
No. 1.	·17	·182
„ 2.	·18	·180
„ 3.	·15	·163
„ 4.	·17	·175
„ 5.	·19	·195
„ 6.	·21	·216
„ 7.	·25	·272
„ 8.	·24	·23
„ 9.	·21	·20
„ 10.	·23	·22
„ 11.	·20	·187
„ 12.	·21	·205

I do not think it necessary to give a greater number of analyses which have been matched by the tintometer, but will leave the instrument in your hands, so that you may judge for yourselves.

Before concluding, I should like to suggest the advisability of chemists uniting together to form a reliable standard, instead of such variable standards, and I do not think anything is more suitable for a permanent standard than coloured glass.

APPENDIX B.

Method of Estimating Lead in Water.

Worked out by Mr. T. Jobson, Jun., Brightside Works, Sheffield.

Take any suitable quantity of water—about half a pint will do, but no measured quantity is essential—add one or two drops of acetic acid, and two or three c.c. of sulphuretted hydrogen solution; fill a four-inch tintometer cell, and match the colour with series 52. The number of degrees divided by 40 or multiplied by 0·025 gives the grains per gallon of lead in the water. It will be seen that the colour once standardised, no weights or measures are required.

Experiments.

Known quantities of lead were added to successive quantities of water, and a few drops of acetic acid and sulphuretted hydrogen added thereto.* The solution was then placed in a six-inch cell, and the colour matched by means of a mixture of glass series 50 and 52. The results were as under:—

Lead Grains per Gall.	Tintometer Degrees.
0·01	0·50
0·02	1·00
0·05	2·50
0·08	4·00
0·10	5·00
0·20	9·8
0·20	10·0

With these data as a basis, I now added quantities of lead acetate from a graduated burette to a measured quantity of water, deferring the reading of the burette until after the determination of the quantities by the tintometer:—

Added Grains Lead per Gall.	Estimated by Tintometer Grains Lead per Gall.	Error Grains Lead per Gall.
†0·462	0·480	0·018
0·176	0·185	0·009
†0·574	0·555	0·019
0·056	0·065	0·009

The light was unfavourable for observations, continually changing.

* I found that if I added successive quantities of lead solution to the same water already containing H_2S_1, the readings were not concordant, owing to the different conditions of the lead sulphide.

† Estimated in 2″ cell and multiplied by three.

APPENDIX C.

Tintometer Measurements of Ammonia by Nessler's Test under Different Conditions.

By Professor Munro, of the Downton College of Agriculture.

Time.

	Degrees of series 52.
$\frac{1}{1000}$ milligrm. NH_3 per c.c. in 1″ cell gave four minutes after mixing.	3·75
The same solution kept in stoppered cylinder for five hours.	3·75

Age of Nessler's Solution.

$\frac{1}{250}$ milligrm. NH_3 per c.c. water with Nessler's solution in $\frac{1}{2}$″ cell:—

No. 1	7·75	8·0
„ 2	7·5	7·75
„ 3	7·5	7·75
„ 4	7·5	7·75

These solutions were of different ages, from a few days to four years.

Factor.—One degree of series 52 in 1″ cell = ·000516 Milligrms. NH_3 per c.c.
·000532 „

Since these observations were made it has been pointed out by Messrs. Hazen and Clark in the *Chemical News*, 1890, vol. ii., page 125, that the colour developed by Nessler's test in solutions of ammonia, varies much with the temperature of the solution, and attains a maximum at 25° C. Factors for use should therefore be determined for a definite temperature, which may be the one most convenient to work at, and all solutions should be brought to this temperature before Nesslerising.

APPENDIX D.

Colour as a Means of Valuing Flour.

Colour has always been one of the indices for judging the value of flour; and investigation has shown that a close relationship exists between the quantity and quality of colour and the baking or intrinsic value.

The details of this relationship were established by measuring a number of samples of known value and widely-ranging qualities, then tabulating them according to their quoted market values, at the same time associating with each the measured colour.

In the first set of experiments it was found that certain distinctive colour properties varied in close accord with variations in price. There was, however, one notable exception. A high-priced flour was, according to the colour test, relegated to a class three shillings per sack below its quoted price; and this judgment of value by colour was confirmed, after inquiry, by discovering that this particular sample was a "spurious brand," with no right to the original high price quoted.

With a view to discover the kind of flour best suitable as a standard from which to compute colour values, a large number of samples were forwarded to me by the editor of *The Miller*, from the Mark Lane market of June 15th, 1891, to measure and classify. From these American Spring Patent was the type selected, as least subject to accidental market fluctuations; and also as the one in which the market price was best in accord with the intrinsic, or, in other words, with the baking value.

But as there are variations in quality of the Spring Patent flour, it became necessary to select a representative of the best quality; and amongst the samples sent "Utopia Patent" appeared a suitable representative of the type. This was quoted at 34*s.* per sack on the day named, therefore Utopia Patent at 34*s.* per sack is the standard of value upon which the colour factors to be next described are based; but each expert should fix his own standard, as changes of value, even in so standard a flour as Spring Patents, may arise from a variety of causes.

The colour terms for wheaten flour are only four, and the factors of value apportioned to the four terms as under, are founded on a number of averages, besides those already spoken of :—

Bloom is estimated at 60/- per sack.	Orange is estimated at 30/- per sack.
Yellow „ „ 40/- „	Black „ „ 10/- „

The colour quantities of each flour found in the second half of the equation of the following table containing the six samples are selected as illustrations :—

	Standard Glasses.				Colour Transmitted.		
	N.T.	Red.	Yellow.	Blue.	Orange.	Yellow.	Bloom.
Fine Hungarian (Kaiser Konig)	+ ·15	= ·45	+ 1·2	—	= ·45	+ ·75	+ ·15
Fine Hungarian	·1	= ·4	+ ·9	—	= ·4	+ ·5	+ ·1
High-Grade Spring American, "Utopia Patent"	—	= ·6	+ 1·3	—	= ·6	+ ·7	—
							Black.
High-Grade Spring American	—	= ·59	+ ·99	+ ·08	= ·51	+ ·4	+ ·08
Chicago Average	—	= ·75	+ 1·25	+ ·22	= ·53	+ ·5	+ ·22
Outside Lot	—	= 1·0	+ 1·35	+ ·34	= ·66	+ ·35	+ ·34

To find the baking value, multiply each colour quantity in the second half of an equation by its allotted factor of value, add the results together, and divide the total by the total of factors of value. The quotient will be the intrinsic value of the flour as indicated by colour. The six samples work out as follows :—

The colour diagrams are drawn to a scale of three inches per colour degree.

It must be pointed out that flours from specially cleaned wheats are not always in accord with the average factors of colour values, as such flour from specially cleaned wheats gives a higher colour value than the intrinsic value of the wheats warrants.

But if such samples are measured when quite dry, the colour will have become darker than when damp, whilst flour from intrinsically good wheat remains nearly the same whether measured damp or dry.

Kaiser Konig.

	Colour Units.		Factor of value.		
Bloom	·15	×	60	=	9·0
Yellow	·75	×	40	=	30·0
Orange	·45	×	30	=	13·5
	1·35				52·5

Divide 52·5 by 1·35 gives 38/10½ colour value against 39/- Mark Lane value.

Fine Hungarian.

	Colour Units.		Factor of value.		
Bloom	·1	×	60	=	6·0
Yellow	·5	×	40	=	20·0
Orange	·4	×	30	=	12·0
	1·0				38·0

Divide 38 by 1 gives 38/- colour value against 39/- Mark Lane value.

High-Grade Spring American "Utopia Patent."

	Colour Units.		Factor of value.		
Yellow	·7	×	40	=	28
Orange	·6	×	30	=	18
	1·3				46

Divide 46 by 1·3 gives 35/4½ colour value against 34/- Mark Lane value.

High-Grade Spring American.

	Colour Units.		Factor of value.		
Yellow	·4	×	40	=	16·0
Orange	·51	×	30	=	15·3
Black	·08	×	10	=	·8
	·99				32·1

Divide 32·1 by ·99 gives 32/5 colour value against 34/- Mark Lane value.

Chicago Average.

	Colour Units.		Factor of value.		
Yellow	·5	×	40	=	2·0
Orange	·53	×	30	=	15·9
Black	·22	×	10	=	22·0
	1·25				39·9

Divide 39·9 by 1·25 gives 30/11 colour value against 32/- Mark Lane value.

Outside Lot.

	Colour Units.		Factor of value.		
Yellow	·35	×	40	=	14·0
Orange	·66	×	30	=	19·8
Black	·34	×	10	=	3·4
	1·35				37·2

Divide 37·2 by 1·35 gives 27/6½ colour value against 27/- Mark Lane value.

The above factors are not adapted to "spotty" flours, or to flours which are unusually deficient in gluten; for these, special factors have yet to be worked out. The Author had not access, during this course of experiments, to a sufficient number of samples for the purpose.

Mr. Sanderson, the Secretary of the Association of British and Irish Millers, has pointed out the following purposes in which the power of measuring and reproducing the colour of a given flour at any time will prove of service to the flour industry :—

1. For establishing a common standard of grade value for shipment, and for verifying deliveries at home ports.

2. As a means of arriving at the actual alteration of colour undergone during the voyage, and the difference of colour following storage in the country.

3. For registering the colour of a sample of flour from a certain wheat mixture, in order to ensure reproduction of the same standard from year to year as the new wheats come in.

4. Gives a new index of market value, which may be sometimes of service in checking other methods of judgment.

5. In new wheats millers can detect over-pressure in grinding by the increase of black over yellow and orange.

6. By detecting and measuring the effects of bad milling on fine wheats.

7. As a direct measure of bloom in high-grade flours.

8. Gives a fair index of the quality of glutens and starches in flour.

9. For tabulating the colour characteristics of flour made from wheats of different countries, and under the various conditions of ripening and harvesting.

INDEX.

APPENDICES.

84-B25346

13058?

79

LXX

GETTY RESEARCH INSTITUTE

3 3125 01312 0114

MEASUREMENT OF LIGHT AND COLOUR

7b
84-B
25346