"Application of Tri chromatic colourimetry for accurate measurement of brightness and shade matching of bleached/coloured pulp and paper"

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SUMMARY

This paper outlines the fundamental principles involved in the application of Trichromatic method of measuring Brightness of Bleached Pulps and Paper and for accurate shade matching of coloured/coated papers etc.

This method is well known internationally, and is widely used in the Textile, Plastic and Paint Industries for accurate shade and brightness matching.

Measurements are done in any universal Elrepho type colorimeter of Brightness meter using Tristimulus Red (X), Green (Y) and Blue (Z) filters. The values so obtained are computed for obtaining tri chromatic coefficients (x) (y) and (z) which are then compared for different samples.

The authors have carried out extensive studies for application of this method to measure Brightness and yellowness of Bleached pulps, and also for obtaining accurate shade matching data on coloured papers.

The various data are interpreted for obtaining important parameters such as yellowness factor (P. C. No.) etc.

Results of this method are compared with conventional brightness readings obtained by using the R 457 blue filter.

The method is quite reliable and gives useful information on additional parameters in a sample which is otherwise not possible in the conventional measurement of brightness.

The Science of colour and colour measurement

Colour is the essence of joy and unbound pleasure in our life. The human eye is gifted to perceive colour in its varying shades, and different hues in natural objects due to the presence of sunlight which is composed of a mixture of visible rays and invisible rays e.g. X-rays, gamma rays, and the ultra violet and infra red rays.

All radiations of the sun's energy have definite wave lengths and these rays range from Medium and short range radio waves, Radar, infra red, visible rays to ultra violet, X rays and gamma rays. Out of this wide range of energy rays, the human eye is sensitive only to the visible spectrum consisting of the seven well known colours VIBGYOR. (violet, Indigo, Blue, Green, Yellow, Orange and Red.) These rays have been further characterised by their respective wave lengths ranging from 400 nm to 700 nm as follows :

Violet	:	380	—	420	nm
Indigo	:	420	—	440	nm
Blue	:	440	—	470	nm
Green	:	470	—	560	nm
Yellow	:	560	—	580	nm
Orange	:	580	—	600	nm
Red	:	600	—	700	nm

An interesting feature of the human eye is that it is sensitive only within the above range of light rays, whereas many animals and birds have eyes which are sensitive to near and far infra red radiations which enables them to see clearly at night or in the dark also.

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The perception of colour in any system reqnires the following three conditions to be fulfilled so that the coloured object is seen, perceived and registered by the observer in its full glory.

a) Presence of bright light or sunlight.

b) Presence of coloured pigments in the object perceived
and

c) Normal colour vision to intake light rays, differentiate the colours and register the total colour phenomenon.

It is quite obvious that any short fall in satisfying all the three conditions stated above, will result in a defective or incomplete colour perception.

Importance of Bright light or Sun light for colour measurement

If the total visible component of sunlight or bright light is split into its coloured components through a diffraction grating or prism it is observed that all seven components possess nearly equal energies. In other words the light intensity of each component is nearly same, and hence the sunlight spectrum is called the *Equal energy* spectrum. This source of incident light is ideal for colour measurement through instruments. However, since it is not possible to obtain a constant source of light through sunlight it is necessary to use other sources of light energy such as a tungstun filament lamp or other incandescent lamps, which more or less resemble sunlight.

Considerable fundamental work on the evaluation of colour, its scientific measurement and the development of various colour systems has been carried out by the Colour Society of America, the French Colour Association and the famous colour laboratories of Kodak and Agfa Gavert Germany etc.

The Principles of colour matching and Instrumental colour measurement

Sunlight or white light can be split into its seven components by passing it through a glass prism or diffraction grating. These seven components when added together produce white light again. However it is seen that a minimum of three primary components, namely Red, Green and Blue, designated as R, G and B when mixed together will also produce white light. These three primary colours are known as *additives Primaries* as against their complimentary colours viz. Yellow, Cyan and Magenta, which produce total darkness, when white light is passed successively through these filters. These are called *Subtractive Primaries* (Fig. 1).

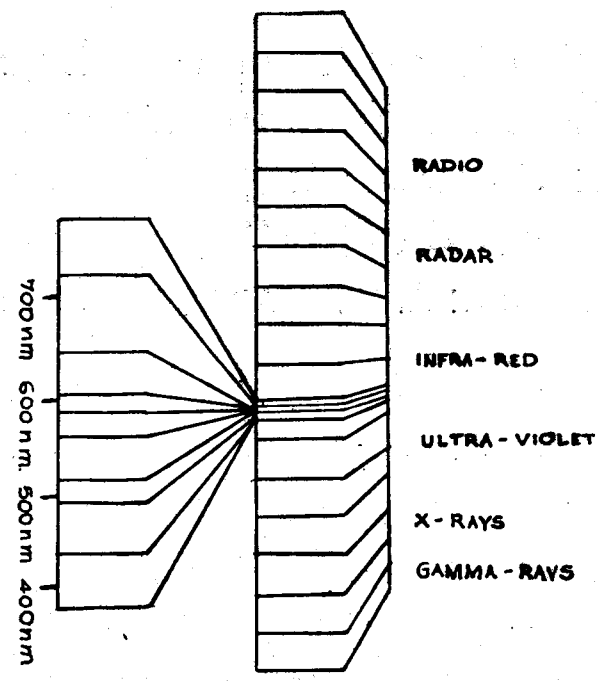


Fig. 1 Distribution of Sun's Rays Spectrum

Most of the optical instruments which measure colour are based on the use of Additive primary filters viz. Red, Green and Blue. These primary filters are called Tri stimulus filters and their specific wave length as well as intensity of colour are defined by the International Colour Societies of America and France.

Thus

Tri stimulus Red	(R)	=	595	nm
Tri stimulus Green	(G)	=	557	nm
Tri stimulus Blue	(B)	=	455	nm

The principle of measuring or matching various colours by means of the Tri stimulus filters (R, G and B) is known as *Tri chromatic Colourimetry*. The spectral distribution of these light filters is shown in fig. 1.

Fundamental principles of Trichromatic colourimetry

Any light/colour measuring instrument which incorporates the Tri stimulus R, G, B filters such as the ELREPHO or the new 'TECHNIBRITE', or a continuous wave length measurement spectrophotometer, will give the required data for colour matching or colour measurement by the above system.

The importance of this system lies in its superiority in distingushing the different components in a given colour or shade into three distrust values which are known as stimulus values X, Y and Z.

Thus R corresponds to X
G corresponds to Y
and B corresponds to Z

Thus a given colour, when examined by the three filters is split up into its three basic primary colours X, Y and Z which when added together produce the original colour.

These X, Y and Z values are then converted by using the given instrument constants to the three *Tri Chromatric Co efficients* x, y and z

such that

$$x = \frac{X}{X, + Y, + Z,}$$

$$y = \frac{Y}{X, + Y, + Z,}$$

and $$z = \frac{Z}{X, + Y, + Z,}$$

In this conversion it can be noted that
$x+y+z = 1$ or $x+y = 1 - z$

Thus for practical purposes or for a graphical representation it is only necessary to calculate x and y so that z is derived.

Diagrammatic Representation of Trichromatic Coefficients

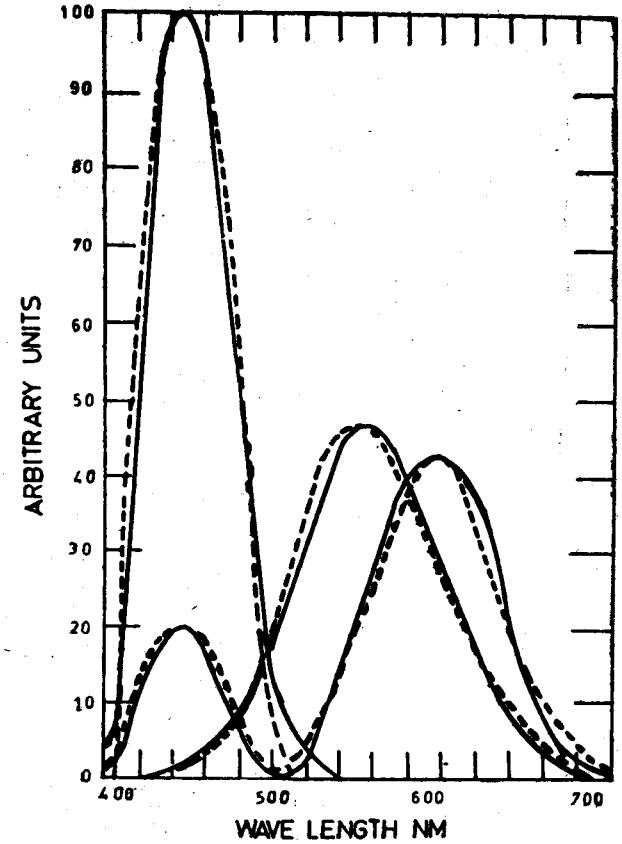
Various colours, their secondary and tertary mixtures are plotted graphically through their z and y co-ordinates on a chart and the accurate position of each colour can be noted down on the colour chart.

The International Colour Society has compiled a comprehensive chart of all the available primary, secondary and tertary colours which can be measured through an instrument and have prepared a model chart known as **"The Colour Triangle"**. This is shown in fig. 2.

The colour triangle can be used for measurement and interpretation of a number of important parameters viz.

(a) The location of a white light source is roughly in the centre of the triangle at $x = 0.33$ and $y = 0.33$.

(b) As we proceed radially from the centre of the Triangle towards the outer perimeter in a straight line, the colour becomes saturated.



SPECTRAL CURVES OF TRISTIMULUS FILTERS.

Fig. 2

(c) The exact wave length of each colour is plotted on the periphery of the triangle and its accurate location is known through the x and y co-ordinates.

(d) The complimentary wave length for any colour can be easily located by drawing a straight line from the particular wave length passing it through the white centre and reaching the opposite side.

This method is very useful for balancing colour schemes through complimentary colours.

Colour Matching on the Colour Triangle

Any given colour can be accurately matched by plotting its x and y co-ordinates on the colour triangle. The specimen to be matched is also then measured and its x and y co-ordinates are placed simultaneously on the colour triangle. In this manner a large number of readings are obtained and the overall variation or spread is then plotted within a given tolerance limit.

By this method the colour match can be defined within a given % tolerance limit.

Measurement of Brightness or whiteness of Bleached Pulp and Paper Samples

In conventional brightness/whiteness measurements on the ELREPHO or photovolt meters, a blue filter at 457 nm is used to record the % light reflected on a bleached white surface.

The same filter can also be used to measure coloured material, but is not particularly recommended since it is specific only for blue region of the spectrum.

One of the important drawbacks of using the Single R 457 filter is that it does not give any indication of the extent of yellowness or degree of yellowness in a bleached sample of pulp or paper. Since no amount of bleaching or brightening can produce an ideal white surface without any appreciable yellow component, it is essential to have a method which will also simultaneously give the % yellowness of the sample. This is possible in the Trichromatic system, wherein the percent yellowness is expressed as

$$\% \text{ yellowness} = \frac{A-B}{G} \times 100$$

where A = Reading on Amber/Red filter
B = Reading on Blue filter
G = Reading on Green filter

Further, it is interesting to note that since the R 457 filter and the Tristimulus Blue filter having a wave length of 455 nm are very nearly matching in wave length characteristics, the brightness readings obtained with R 457 filter very nearly match those of the Tristimulus Blue filter. These data have been earlier published by one of the authors, elsewhere[1].

It has also been shown in the same study that the P. C. Number of bleached and aged samples obtained by the TAPPI standard method using the relationship.

$$\frac{(1-R_2)^2 - (1-R_1)^2}{2R} \times 100 = \text{P. C. No.}$$

shows an almost linear relationship with the % yellowness of the bleached and aged samples, when the increment $\triangle$ y i.e. difference in initial and final % yellowness is plotted against the P. C. No. (1).

These studies, reported earlier, have shown that the improved system of measuring brightness and % yellowness can be very well adapted and gives values almost equivalent to the TAPPI standard method using the R 457 filter.

Colour/Brightness matching of various samples by the Trichromatic method

In the case of ELREPHO, or photovolt instruments, it is necessary to have the Tristimulus Red, green and Blue filters mounted in the instrument circuit, for which there exists a provision.

The sample is then exposed and successive readings of X, Y and Z filters are obtained. These are converted into the Trichromatic Co-efficients X, and Y, and plotted on the triangle. For each X and Y coordinate, a point reading is obtained on the chart, and several samples can be examined, and the spread or distribution of the various points is observed. Tolerance limits of $\pm 5\%$ or $\pm 10\%$ can then be set below and above a standard reference sample.

When the limit is marked on the colour triangle, a small circle or ellipse is obtained. All points which lie within this ellipa are nearly matched with the reference standard sample.

This method is applicable to white as well as coloured samples.

While using a variable wave length spectrophotometer, readings are obtained by adjusting the wave length corresponding to that of the Tristimulus filters.

Advantages of using the Trichromatic method

The x and y coordinates obtained by the above method, not only indicate the exactness to which a sample is matched with a reference standard, but also give deviations in terms of Red, Blue and Green content of the sample under test.

Thus when the x, y and z, values are tabulated, the variation in each component is calculated and corrective measures are taken.

For instance, when a coloured product is being manufactured on a high speed machine automatic sensors are continuously monitoring the tristimulus values and relaying the information to operators who adjust the rate of flow of various dye solutions accordingly.

The method has been now widely used in Textile, Paint, and other industries where even computorized colour measurements and shade matchings are now in practice.

Advantages of a spectrophotometer over ELREPHO or other Brightness meters

The ELREPHO, 'TECHNIBRITE' or other photovolt instruments use a limited number of coloured filters having a peak reflectance value in different regions of the light spectrum. Table 1,

TABLE - I THE ELREPHO FILTER CHART

POSITION OF FILTER	FILTER DISIGNATION	NM
1	R 68	681
2	R_1 62	620
3	R 57	577
4	R 53	540
5	R 49	495
6	R 46	464
7	R 42	426
8	R 457	457
9	FMX	RED
10	FMX	GREEN
11	FMZ	BLUE
12	NO FILTER	———

shows the various filters used in the ELREPHO with their specific wave length called dominent wavelength.

Hence while using these instruments, only a limited number of spectral reflectance readings are obtained. Further, any intermediate reading between the peak wave length of two successive filters can not be recorded on these instruments.

Another serious limitation of these instruments is that they measure only reflectance values from a solid matt and smooth surface, whereas coloured liquids can not be measured.

In this respect, a precision wide application spectrophotometer combines all the following features.

1) Wide range of colour measurement which extends from ultra violet region—through visible region to the near infra red range of the light spectrum.

2) Continuous wave length change is possible with a minimum of 1 nm or even 0.5 nm selector knob.

3) Tri chromatic measurements are also obtained.

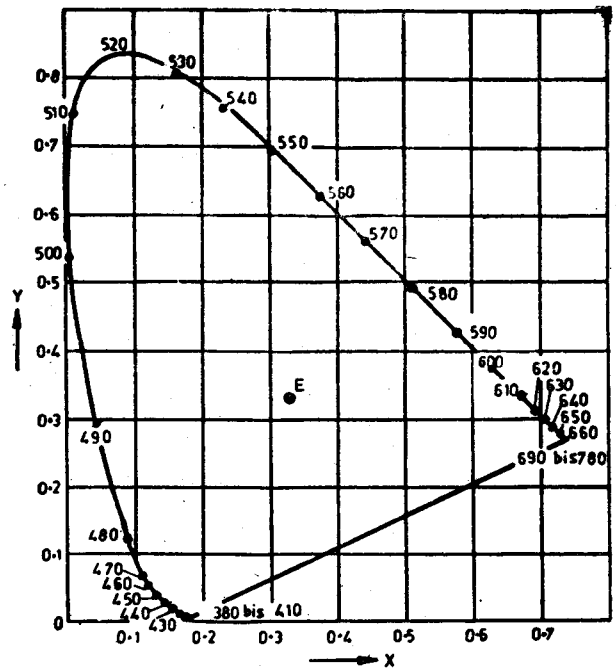
4) By fixing a specially designed integrating sphere, it is possible to measure coloured solid objects such as paper, textiles and coated surfaces.

5) Measurement of coloured liquids is primarily carried out on spectrophotometers.

6) Precise shade matching is possible by obtaining a continuous spectrum of reflectance/transmission values, on the spectrophotometer, without resorting to the Trichromatic method.

However one limitation of spectrophoto meters is that transmission measurements are reliable only on dilute coloured solutions.

The schematic arrangements of the ELREPHO, and a typical spectrophotometer are shown in figures 3 and 4.



THE C.I.E. COLOUR TRANGLE.

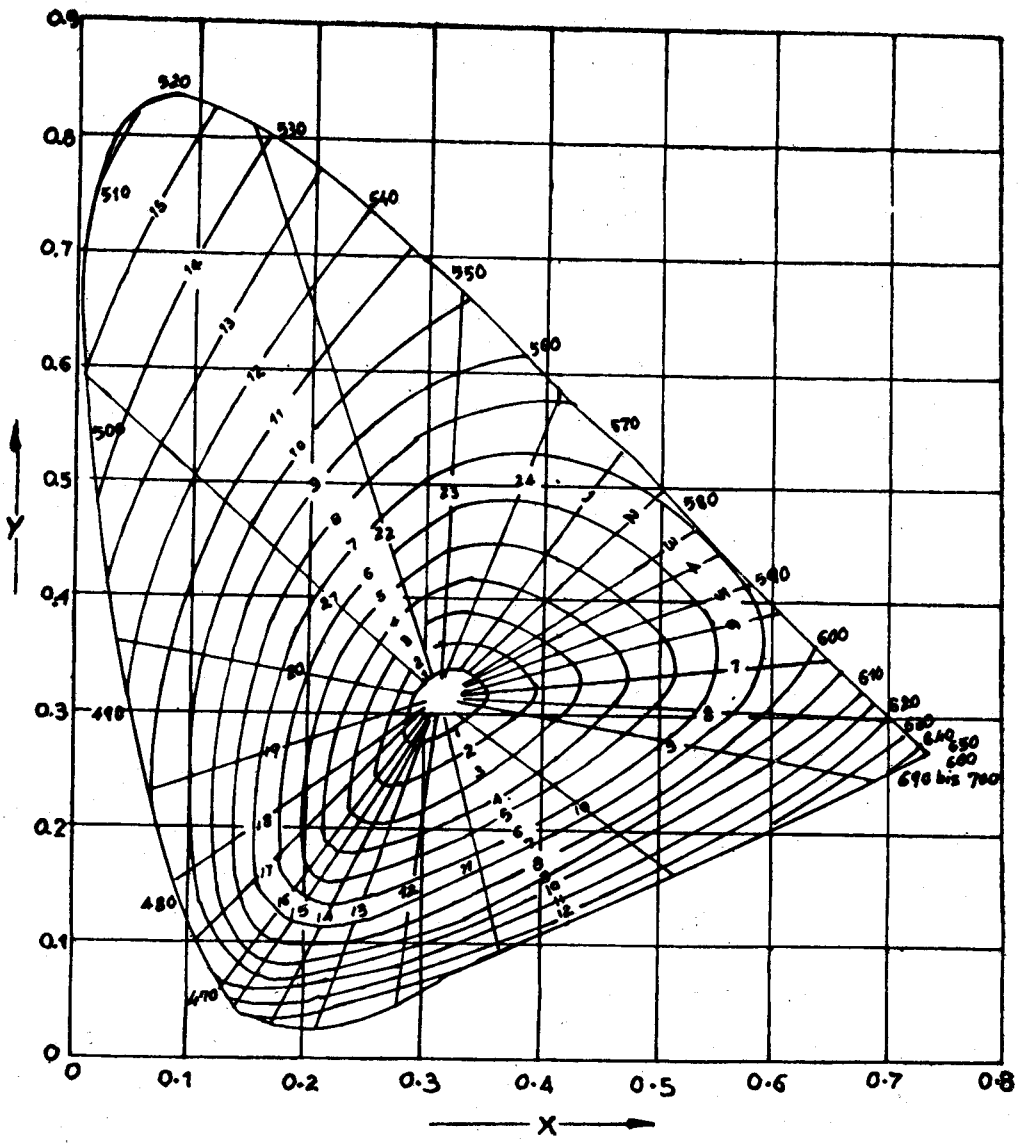
Fig. 3

General consideration for colour measurements
Colour Blindness

It is very important that for visual assessment of various colours and shades, the observer has perfect and normal vision, which responds well to different colours.

The human eye takes in the image of a coloured object on to the ratina where the impressions are gathered through the optic nerve and transmitted to the brain. Within the brain cells, there exist three separate piomented colour cells, which analyse and separate the different coloured components of the object perceived. Thus a final coloured image is registered by the brain.

The colour stimulus and retention ability of professional persons engaged in colour schemes e.g. Painters, Artists and Photographers is highly developed, and coloured impressions once memorized are quickly reproduced by them in their studios afterwards.



THE EQUAL INTENSITY CURVES.

Fig. 4

On the other hand a partially or totally colour blind person sees only a limited range of colours and grey non coloured objects.

Sample preparation for measurement

It is necessary that all coloured samples before measurement, are available in a smooth, continuous and evenly spread tablet or plate. Rough, matted or unbroken samples can not be measured accurately.

The prepared sample should be well protected from exposure to sunlight or daylight, to prevent colour fading or change in tone.

Standard white/reference samples

Most instruments are calibrated by using a pure grade Magnesium Oxide, or Magnesium Carbonate powder which is used for obtaining nearly 100% reflectance setting.

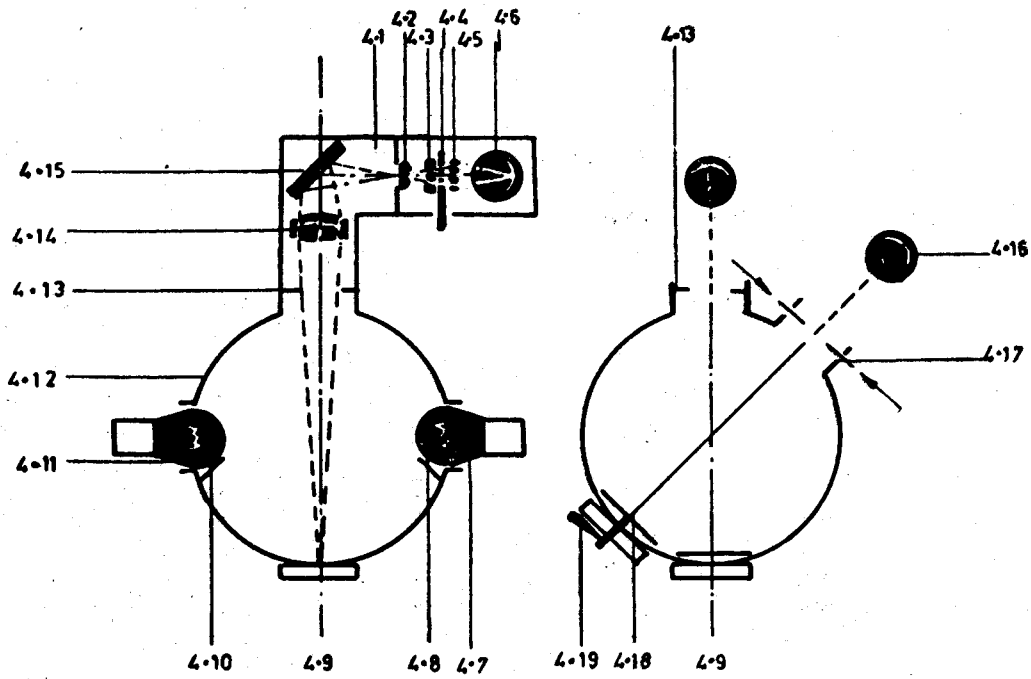


DIAGRAM OF ELREFO FOTO METER.

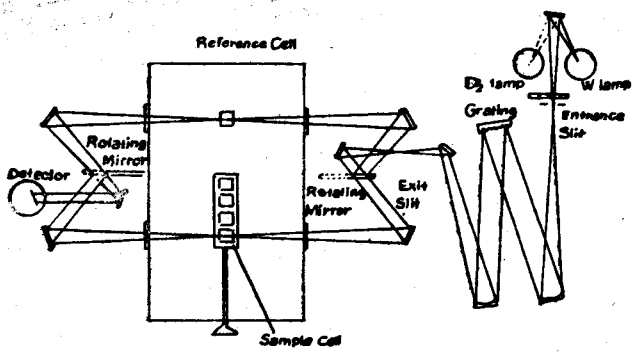
Fig. 5

These standards should be frequently rechecked and the instrument should be re-calibrated from time to time.

The samples should be well protected from light and stored in dark cupboards.

Conclusions

The science of colour measurement and colour matching has advanced considerably, and instrumental colour matching techniques have reached a high degree of sophistication.



OPTICAL DIAGRAM

Fig 6

In this paper, the authors have explained the important fundamental concept of colour measurement, and the techniques used in many industries such as Textiles, paints and Plastics, Paper etc.

It is important that the rare and most valuable faculty of colour perception which is endowed to mankind, should be fully understood and properly applied for colour perception.

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