CHARACTERISTICS OF COLORS

To bring color firmly within the grasp of understanding, we need to know how it is caused, how it varies, and how it is affected by viewing conditions. Most important of all, we need to know what the variable *quantities* of color are, for only with these is it possible to evaluate color as a *quality*.

PRODUCTION OF COLOR

There are a number of different ways in which color can be produced. Those which are most important to the practical color photographer are described in the following paragraphs.

Absorption. The colors of most ordinary objects are due to the fact that they do not absorb the same amount of light at each wave length. We have already noted that a green filter absorbs from white light all waves except those giving rise to a sensation of greeness. The color of an object such as green construction paper is due to the same cause; in both cases the coloring material has such a physical structure that it absorbs red and blue light. The surface of the paper is an irregular arrangement of translucent fibers which have been treated with the coloring materials. Into these fibers the light penetrates fairly deeply. Before it is reflected to the eye of the observer, it has passed through several of the fibers, and the coloring material has absorbed the blue and red components of the original white light. Thus, whether the paper is viewed by reflected light or whether it is held over a strong light source and viewed by transmitted light, it always appears green, and the color is due to the removal of light that is not green.

Other surfaces, whether rough or smooth, act in the same way. Light falling on them penetrates far enough to undergo the absorption which is characteristic of the surface and then returns to the observer to cause the sensation of color. In the case of a surface covered with paint, the color is influenced by the absorption characteristics of the vehicle in which the pigment particles are suspended, the size of the particles if they are opaque (this is the usual case), and the color of the surface underneath if the particles are transparent as shown in the illustration at the upper left of page 16.

Surface Characteristics. A few materials, chiefly polished metals like copper or brass, have the property of selective reflection at their front surfaces. This phenomenon gives rise to “surface” or “metallic” colors, as distinguished from the more common “body” or “pigment” colors. An example is gold, which has a surface quite unlike that of most nonmetallic objects. Specular or mirror-like reflections from gold are always of a characteristic color which indicates the selective reflection of yellow and red light. They are not white, as they would be in the case of most other objects such as the paint layer illustrated on page 13.

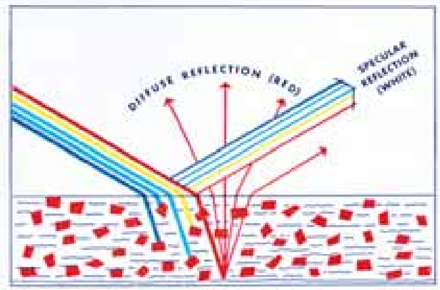
The distinction between surface and body color is emphasized by what happens with a piece of gold leaf thin enough to transmit light. Here, white light falling on the gold film can be reflected, absorbed, or transmitted. Since red and yellow light are strongly reflected, and blue is strongly absorbed, such a film appears predominantly green by transmitted light. Certain brightly colored insects and the crystals of some organic chemicals also exhibit this type of metallic coloration.

Scattering. The color of the blue sky is due to scattering of light by the atmosphere, shown diagrammatically on page 16. Variations in the density of the atmospheric gases act in such a way that they scatter light of the shorter wave lengths at the blue end of the spectrum much more than they scatter light of the longer wave lengths at the red end of the spectrum. When the air is dusty or contains water in the form of droplets or ice crystals, the particles scatter more light of the longer wave lengths. Thus the sky is bluest when it is clearest, and whiter when it is less clear. If there were nothing in the atmosphere to scatter light, the sky would always be dark and the stars would be visible at any hour of the day or night.

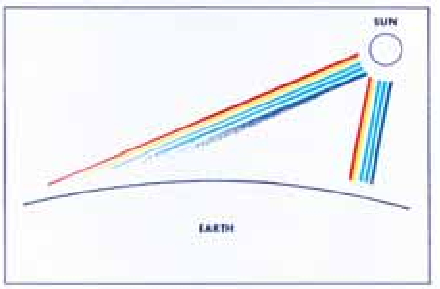
Scattering of light by the atmosphere is also responsible for the reddishness of the sun when it rises or sets. When the sun is high in the sky, the direct rays pass through the atmosphere without noticeable subtraction of blue light by scattering. Early or late in the day, however, the rays of the sun strike the earth approximately at a tangent, as shown in the illustration, and consequently they must pass through a much greater thickness of atmosphere. Depending on the angle of the rays and the sizes of the particles present in the atmosphere, light of different wave lengths is scattered and the sun appears yellow, orange, or even a fairly deep red.

On a sunny day, distant mountains appear a hazy blue, lacking in detail, because the blue light arising from scattering in the atmosphere is superimposed on the light reaching the observer from the mountains themselves. Any distant object on the horizon is thus seen through a veil of blue haze which strongly affects its appearance.

Some other colors in nature are due to the same cause. For example, blue feathers often contain not blue pigment but finely divided particles, which are suspended within a translucent framework and scatter blue light more effectively than light of other wave lengths.

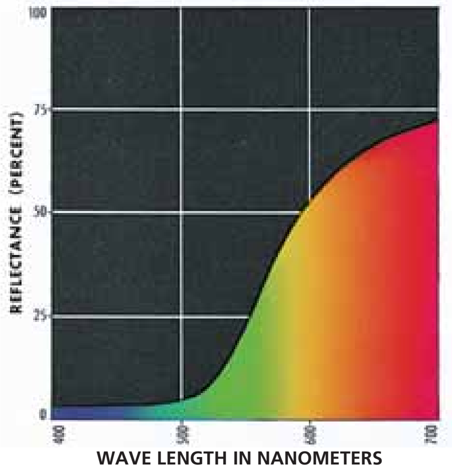


The specular reflection of white light from a smooth red surface is also white, but the diffuse reflection is red, because the light of other colors has been absorbed.

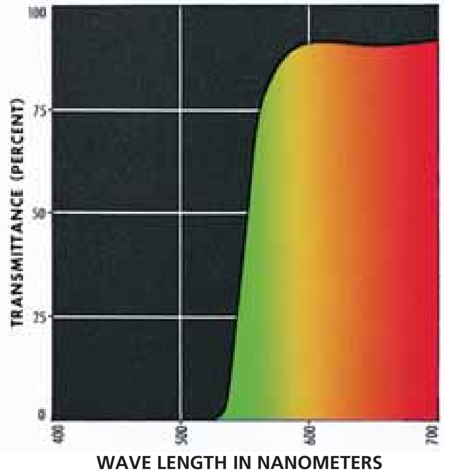


At sunset, the path of sunlight through the atmosphere is longer than at noon, and increased scattering of blue and green light makes the sun appear reddish.

Orange peel and standard white surface mounted in spectrophotometer. The spectral reflectance curve determined by the instrument is shown in color at the right.



The filter above approximately matches the orange, but its purer color is shown by the sharper break and greater exclusion of wave lengths from 400 to 530 nanometers.



Scattering also explains why veins close to the surface of the skin are bluish rather than reddish, as might be expected from the color of blood. Actually, the red hemoglobin in these veins is present in such a high concentration that it effectively absorbs all of the light striking it. Hence the usual reflection of light from the deeper tissues does not occur. The only light reflected to the eye is the blue light scattered by the vein wall and the skin layers just above it.

Interference. Color can also be produced by the interference of light waves in thin films. Examples are to be found in a soap bubble or a film of oil floating on water. The light reflected from the top surface of such a film undergoes a reversal of phase, but the light reflected from the bottom surface does not undergo this type of change. With films that are extremely thin in comparison to the wave length of the light, the two reflected rays interfere with each other and cause the film to appear very dark. If the films are somewhat thicker, waves of some lengths interfere, while waves of other lengths reinforce each other, giving rise to colors which vary with the thickness. The reflected light is variously colored, even though the film is illuminated by white light and contains no differentially absorbing materials.

Interference phenomena are also responsible for the colored patterns known as Newton's rings which sometimes cause trouble in color printing work. In this case, the difficulty is due to the proximity of two smooth optical surfaces, such as those of glass and the base side of photographic film. Since neither surface is a perfect plane, there are some areas of actual contact and others where the two surfaces are separated to varying degrees. The colored patterns are formed by interference among the light rays reflected from the two surfaces.

Fluorescence. The use of fluorescence in stage costumes has already been mentioned in another connection. Here the molecules of the fluorescent material absorb energy at one wave length and reradiate it at another. The same principle was used during WW II in the manufacture of colored signalling fabrics. These materials could be seen from remarkable distances because of the intense coloration produced by fluorescent dyes. As a matter of fact, a number of fluorescent dyes are regularly used in the textile industry, because they extend considerably the range of colors which can be made available in finished cloth.

Dispersion. Finally, color may arise from differences in the refractive or bending power of a transparent medium for light of different wave lengths. The rainbow and the spectrum formed by a prism are examples. The flashes of color seen in viewing a cut and polished diamond illuminated by a concentrated light source are also due to dispersion.

SPECTRAL REFLECTANCE AND TRANSMITTANCE

In the laboratory, the color of any surface (with the exception of one that fluoresces) can be specified in terms of its reflectance at each wave length in the visible spectrum. The instrument used in making such determinations is called a spectrophotometer. Essentially, it consists of an optical system in which the light from a lamp is dispersed into a spectrum by a prism. One narrow band of wave lengths at a time is reflected in such a way that half of the beam of colored light is allowed to fall on the sample being tested, the other half on a standard white surface. In the automatic recording type of spectrophotometer, a photocell measures the relative intensities of the two halves of the beam after they have been reflected from the two surfaces. As the comparative reflectance of the sample is measured, the instrument draws a continuous graph, wave length by wave length, such as those shown on page 16. In the illustrations, the areas under the curves are shown in color so that the behavior of the samples at the various wave lengths can be visualized more readily. The spectrophotometer can also be adapted easily for measuring the spectral transmittance of translucent samples such as filters.

In spectrophotometric determinations of reflectances, the light source must emit light of all the wave lengths at which measurements are to be made. The reason for this requirement is obvious when we consider that if no light of a given wave length were available, the photocell in the instrument would have no way of measuring the relative reflectance of sample and standard at that wave length. As long as reasonable amounts of light at each wave length are provided, however, the spectral reflectance curve determined by a spectrophotometer is the same regardless of the color quality of the light source. Furthermore, the same curve is obtained whether the eye, a photocell, or a photographic film is used to receive the light from sample and standard.

Since the characteristics of human vision do not enter into the determination of a spectrophotometric curve, the curve can be considered as a purely physical measurement. Two samples which have identical curves will match in appearance under all viewing conditions. In the case of reflecting samples, it is also necessary that the surface texture be the same. *If two samples match in appearance under one set of viewing conditions, however, we cannot assume that their spectrophotometric curves are identical.* This statement follows from the fact, already pointed out, that colors can be matched without matching the distribution of energy at each wave length.

From the point of view of color photography, the converse of the italicized statement above is even more important: *In order to match visually, two samples need not have identical spectrophotometric curves.*

Thus a color transparency which matches a certain area of the subject visually may not match it spectrophotometrically. The fact that a spectrophotometric match is not necessary enormously simplifies the problem of obtaining satisfactory color reproduction.

It is also of interest from the photographic point of view to note that two colors which appear alike may not photograph alike. Furthermore, while two colors which appear alike may photograph alike on one type of film, they will not necessarily do so on another type of film.

Since the spectrophotometric curve does not take human vision into account, it does not, by itself, describe the visual sensation aroused in viewing the sample. Although a smooth curve provides a rough indication of the appearance of a sample, an irregular curve usually does not, even to a trained worker.

EFFECT OF LIGHT SOURCE AND VIEWING CONDITIONS

Since light sources vary in their distribution of energy throughout the spectrum, the distribution of energy after reflection from a given colored sample will also vary from one light source to another. In other words, the physical stimulus reaching the eye will vary. As a result, the visual sensation aroused in viewing the sample will depend on the character of the illumination. This effect is not so pronounced as might be expected, owing to a visual phenomenon known as *approximate color constancy* (see page 59). However, the shift in appearance is quite noticeable with surfaces which are highly selective with respect to wave length in their absorptions, or in other words, surfaces which show sharp peaks and depressions in their spectral reflectance curves. It is also quite noticeable with light sources having energy distribution curves of a similar character.

Certain types of fluorescent lamps are relatively so rich in some wave lengths and so poor in others that they exert a marked influence on the apparent colors of objects. Most of us have noticed the color distortion produced by such lighting, especially the rather unnatural skin tones. Similarly, the appearance of fluorescent dyes is likely to change when the light source is changed. With the introduction of a number of fluorescent textile dyes, it is not uncommon to find fabrics which change color to a much greater extent than other objects.

Surroundings also affect visual judgment of a color. In the group of four illustrations on page 21, the central patch of color is physically similar in all cases, yet its appearance is strikingly different. Thus it is apparent that we cannot establish the relationship between the physical characteristics of a surface and the visual sensation it arouses unless the viewing conditions are specified. A standard set of conditions, recommended by the International Commission on Illumination (abbreviated CIE for Commission Internationale de l'Eclairage),* has gained general acceptance for this purpose. The CIE recommendations include specifications for standard light sources and for the visual response characteristics of a "standard observer".

The "standard observer" is an imaginary observer whose color vision is described by the average of the response curves of a number of actual observers. In selecting the actual observers, those having any detectable abnormalities in their color vision (see pages 9 and 50) were excluded. However, it has long been recognized that even so-called "normal" color vision varies slightly from one individual to another. To obtain a representative set of response curves, it was therefore necessary to average the results obtained with a number of observers.

COLOR AS A SENSATION

According to the modern scientific definition of color, it is not legitimate to ascribe color to an object, but only to the light reflected from it. However, it is a convenience, even a practical necessity, to assign colors to reflecting surfaces seen under customary types of illumination such as daylight or tungsten light. When we do so, we are referring to the capacity of a surface to modify the color of the light falling on it. We should remember that an object has no single characteristic color, because its appearance is affected by a number of factors, the most important of which are the quality and intensity of the illumination.

If we are asked the color of an object such as a sweater, our first reaction may be to say, for example, that it is red. By this means, we identify the *hue* of the object, that is, whether it is red or yellow or purple.

However, we are all conscious, at least in a vague way, that this description is inadequate. In an effort to be more specific, we may say that the sweater is light red or dark red. When we do this, we are describing the *brightness* of the color. If we stop to think about it, we realize that this characteristic of a color is independent of the hue, that is, we can have two colors which are of the same hue but of different brightness.

We might also say of the sweater that it is a dull red or a bright, vivid, or brilliant red. Here we are attempting to describe still another characteristic of a color, that is, its *saturation*. The saturation of a given color may be regarded as a measure of the extent to which it departs from a neutral gray of the same brightness. For further reading and additional examples, see Josef Alber's INTERACTION OF COLOR (Yale University Press, 1963) also available in interactive CD-ROM.

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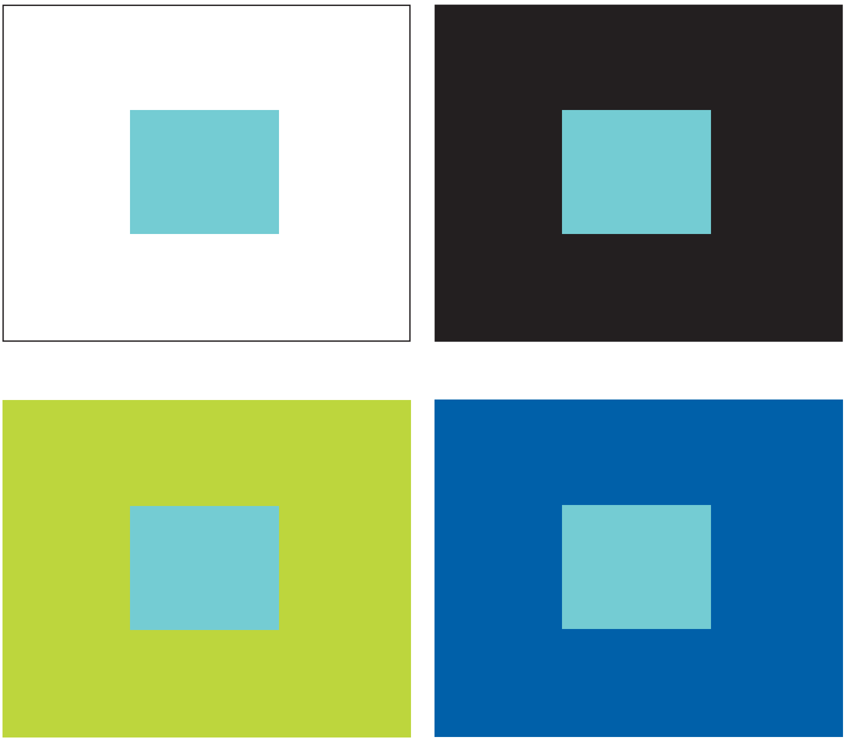
* International Commission of Illumination, *Proceedings of the Eighth Session*, Cambridge, England, 1931.



A color is affected by the color of its surrounds. All four blue-green patches are exactly the same color. When surrounded by white, the patch looks darker. When surrounded by black, the patch looks lighter. When surrounded by yellow-green, the patch looks bluer and of medium brightness. When surrounded by dark blue, the patch looks greener and lighter.

Thus any color perception has three characteristics, any one of which can be varied independently of the other two. In psychological usage, the correct term is *attributes*, because we are really describing sensations, not the object or the physical stimuli reaching the eye.

While we experience little difficulty in detecting hue differences, we frequently become confused in judging brightness and saturation differences because we cannot decide whether two colors differ only in brightness or whether their saturation is also different. This fact is of some importance in color photography, because it affects our judgment of color rendering. For example, an excessively deep blue sky in a color picture may give the impression of high saturation when it is actually low in brightness. If the reproduction of the sky is compared with a Kodak Wratten No. 47 (blue) Filter, the relatively low saturation in the photograph is immediately apparent. The confusion between saturation and brightness is typified by the frequency with which the word “bright” is used in everyday speech to describe a highly saturated color.

SYSTEMS OF COLOR SPECIFICATION

Frequently we attempt to describe a color more or less completely by a single term, sometimes the name of some object which is more or less familiar to everyone. For example, pink, cherry, cerise, dusty pink, rose scarlet, vermilion, crimson, and rust are all used to describe various reds. The difficulty is that each term means different things to different people. We would all agree that pink describes a red which is high in brightness, fairly low in saturation, and slightly bluish in hue. Even within these limitations, however, there are many possibilities; we would certainly not think of buying yarn to complete a half-finished sweater, specifying only that it was to be pink. Instead, we would match the two yarns directly, and with some experience in the ways of color, we would also make sure that the two samples matched both in daylight and in artificial light.

The need for an accurate language of color becomes acute when, as often happens, circumstances do not permit direct comparisons. Actually, we do not have a universal language, but we do have systems of color specification and notation which answer most of our needs. The Pantone Color System and various computer graphic software, in addition to the Munsell System, provide the color user with many options.

Munsell System. In the United States, one of the best known systems of color notation is that developed by Albert H. Munsell. Essentially, this system is an orderly arrangement into a three-dimensional solid of all the colors which can be represented by actual surface samples prepared from stable pigments. The general shape of the solid is shown on page 24.

The various hues are spaced horizontally around a circle in such a manner that they appear approximately equidistant to a normal observer, provided they are examined under illumination of the correct quality. The circle, also shown on page 24, is divided into ten Major Hues, consisting of five Principal Hues (Red, Yellow, Green, Blue, and Purple) and five Intermediate Hues (Yellow-Red, Green-Yellow, Blue-Green, Purple-Blue and Red-Purple). Each of these ten Major Hues is number 5 of a hue series of 10 numbers. Thus the complete hue circle consists of 100 hues, 40 of which are represented by actual samples in the *Munsell Book of Color**. This book is supplied as a Matte Finish Collection and a Glossy Finish Collection. An abridged collection† designed for student purposes is also available.

Extending vertically through the center of the hue circle is the scale of reflectances, know as *values* in the Munsell System. Numbered 10, at the top of the value scale, is a theoretically perfect white (100 percent reflectance); numbered 0, at the bottom, is a theoretically perfect black (0 percent reflectance). In between, there are value steps represented by actual samples.

From a photographic point of view, the value scale deserves more than passing notice. Superficial reasoning would indicate that the midpoint of the scale should have a reflectance of 50 percent, that is, it should reflect 50 percent of the light falling on it. However, the eye tends to see as equal tone steps not equal differences in reflectance (e.g., 10, 20, 30 and 40 percent, where there is a constant difference of 10 percent), but rather equal ratios of reflectance (e.g., 10, 20, 40, and 80 percent, where the ratio of each reflectance to the preceding one is 2). As a result, the gray which impresses the eye as falling midway between white and black actually has a reflectance of about 20 percent. It is interesting to note that this value is close to the 18 percent reflectance of the gray side of the KODAK Gray Card, which is used as an exposure-meter target to represent the over-all reflectance of an average scene.

Radiating out from the scale of values, which is the central core of the color solid, are the steps of saturation, known as *chroma* in the Munsell System. Here again the steps appear approximately equidistant to a normal observer. The numbers extend from 0, which is the neutral gray, to numbers as high as 16, depending on the degree of saturation attainable with a given hue at a given value level. Because of variations in attainable saturation with hue and value, the color solid is not symmetrical.

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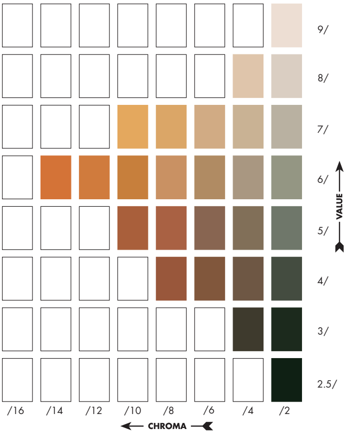
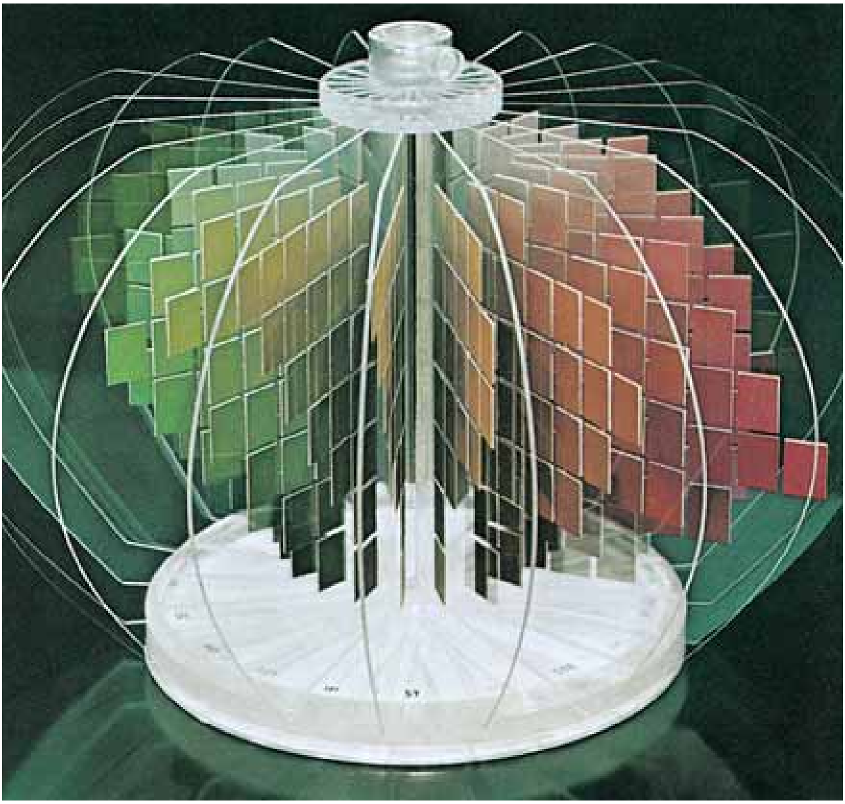
*Published by Macbeth; New Windsor, N.Y.

†Published by Fairchild Publications; New York, N.Y.



THE MUNSELL SYSTEM
(Left) Hue circle showing the Major Hues. Each is number 5 of a family of 10 adjoining hues. (Right) Chart showing variations in value and chroma for 2.5YR. (Below) Color tree showing the 3-dimensional relationship of hue, value, and chroma. (Illustrations by Munsell Color Company).



For glossy samples, the highest chroma of 5 Red is 14, whereas the highest chroma of 5 Blue-Green, opposite Red, is only 8. Yellow reaches its maximum chroma at a high value; Purple-Blue, opposite Yellow, reaches its maximum chroma at a low value. The Munsell System has the advantage over some other systems that if a new pigment is produced which permits samples of higher saturations to be prepared, there is no difficulty in adding the new samples to the appropriate hue chart.

The *Munsell Book of Color* can be used to describe colors by comparing them with the actual samples in the book. The arrangement in notation of hue, value and chroma is H V/C. A certain blue, for example, might be identified as 5B 4/6. If no sample that matches the color exactly is found in the book, an intermediate notation can be estimated.

Strictly speaking, any system of color specification which relates our perceptions to their physical causes, as the Munsell System does, must be considered to be a psychophysical system. The Munsell System is unique, however, in that primary emphasis has been placed on the judgment of observers in spacing the color samples when they are illuminated by a standard source. Consequently, the steps in the Munsell scales of hue, value, and chroma correspond rather closely to our mental or psychological concepts of equal steps in hue, brightness, and saturation.

Much research has been done by the National Bureau of Standards and the Optical Society of America to improve and standardize this system. As a result, the *Munsell Book of Color* provides the method recommended by the American National Standards Institute for the popular identification of color. Tables have been published which give the equivalent specifications in terms of the technical standard system described in the following paragraphs.

CIE System. In connection with the effects of light sources on color, we mentioned the recommendations of the International Commission on Illumination. Acknowledgment of the need for a basic standard has led important scientific groups the world over to adopt the CIE recommendations and the psychophysical system of color specification which is based on them.

We have already seen that by mixing three colored lights, a red, a green, and a blue in the proper proportions, we can match almost any color. All spectrum colors cannot be matched with real primaries, but the data obtained with real primaries can be transformed mathematically to arrive at a set of imaginary primaries with which all the spectrum colors could be matched. The fact that these primaries cannot be obtained experimentally does not detract from their value.

The CIE System, in effect, specifies colors in terms of the amounts of each of three selected primaries necessary to form a match with the sample in question. The color mixture curves for the "standard observer" show the amounts of each of the three primaries required to match each wave length of the spectrum.

The other essential of the CIE System is standardization on a few light sources, such as daylight and tungsten light. The spectral energy distributions of the standard sources are accurately known and can be reproduced by well defined means.

Given the "standard observer" and a standard light source, we need only the spectrophotometric curve of a sample to compute its color specification.* Since the system is based on data accepted internationally, the specification means the same thing everywhere and is not dependent on the visual characteristics of a single individual.

On page 29 is shown the *chromaticity diagram* of the CIE System. This diagram is of particular interest because it forms what might be described as a map of all possible colors. The relationship of a given sample to all the colors can thus be visualized readily.

The horseshoe shaped boundary represents the positions of the colors which have the highest possible saturations; these are the spectrum colors. The colored area represents the limits of saturation possible with a set of modern process printing inks. Near the center of the colored area is the "illuminant point" for daylight, likewise the position of any neutral gray illuminated by daylight.

Since, as we have already noted, color as perceived has three dimensions, hue, brightness, and saturation, it is obvious that the two-dimensional chromaticity diagram cannot describe a given color completely. Actually, it provides indications of hue and saturation relative to other samples. The hue is indicated by the direction of a straight line drawn from the illuminant or neutral point toward the position of the sample. If this line is extended to intersect the curved line representing the spectrum colors, the hue can be specified in terms of the wave length at the intersection of the two lines. Such a specification is called the *dominant wave length*.

The straight line at the bottom of the horseshoe represents the magentas and purples of maximum saturation. Since these colors do not occur in the spectrum, their hues are expressed in terms of the wave lengths of green light to which they are complementary.

As we move away from the neutral point toward the spectrum colors, saturation increases, or in other words, the colors become more pure.

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*See *The Science of Color*, by the Committee on Colorimetry of the Optical Society of America, Thomas Y. Crosell Company, New York, NY, 1953.

If the distance from the neutral point to the sample point is divided by the total distance from the neutral point to the spectrum line, a measure of purity is obtained. This is called *excitation purity* and is expressed in percent. A spectrum color is 100 percent pure, whereas white, gray, and black have zero purity.

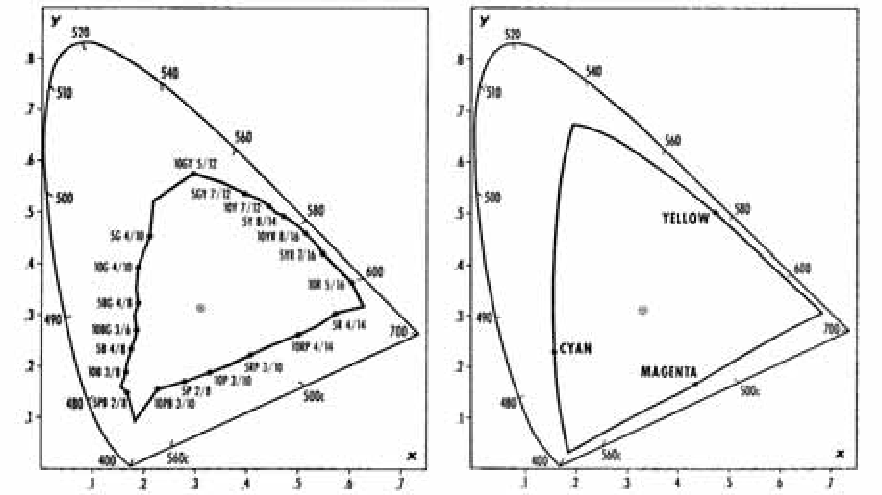
To make the specification of color complete, we must also include the brightness aspect of the sample, which is expressed in terms of *luminous reflectance* or *transmittance*. In this usage, the word "luminous" indicates that the value takes into account the color quality of the light source and the visual response characteristics of the standard observer.

Luminous reflectance (or transmittance) is a weighted average of the spectral reflectances (or transmittances) of the sample. The weighting function is the product of the spectral distribution of the illuminating light source and the spectral sensitivity of the standard observer, multiplied wave length by wave length. The spectral sensitivity of the standard observer, which is called the *luminosity function*, has been standardized internationally and is part of the CIE System.

Values for luminous reflectance (or transmittance) range from 0 to 100 percent. With any given sample, the value can be noted beside the point at which the sample plots on the chromaticity diagram. Two samples which differ only in reflectance (or transmittance) thus plot at the same point and are distinguished by the figures beside it.

In preceding sections, we have touched on the fact that, strictly speaking, color is defined in terms of light rather than the characteristics of an object or the attributes of the sensation aroused in viewing the object. Since light is a psychophysical concept (see page 4), the CIE System is a purely psychophysical method of color specification. As such, it does not always agree exactly with our mental (psychological) concepts of color. For example, the colors lying on a straight line between the illuminant point and the line representing the spectrum colors do not necessarily appear to have exactly the same hue. However, the CIE System is valuable in that it provides a scientific standard for the measurement of color. Its descriptive terms, dominant wave length, excitation purity, and luminous reflectance or transmittance (or other appropriate photometric quantity), are the psychophysical counterparts of hue, saturation, and brightness.

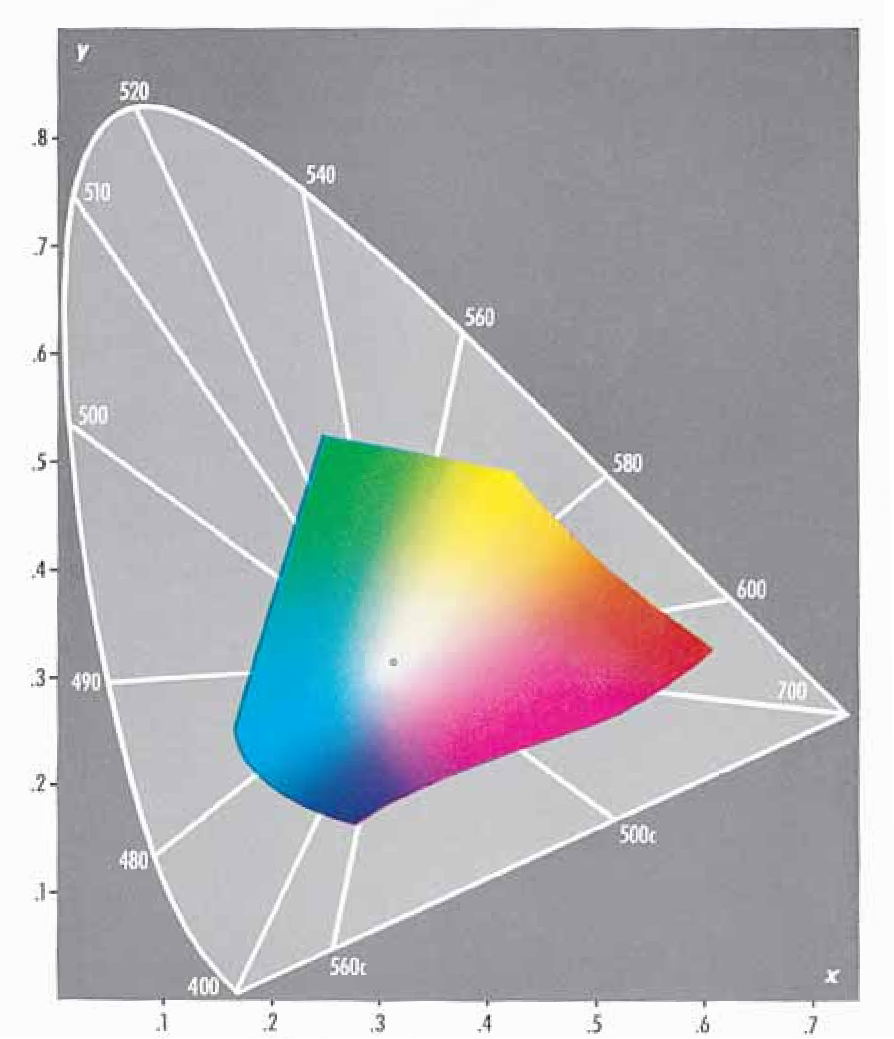
The diagram at the upper left of page 28 shows the limits of saturation obtained with the pigments used in preparing the samples in the *Munsell Book of Color*. At the upper right are shown the limits of color reproduction obtainable with a set of three subtractive dyes of the same type as those used in Kodak color films. This illustration indicates that the subtractive dyes are very satisfactory in regard to the range of chromaticities which they are potentially capable of reproducing.



The diagram at the left shows the range of colors bounded by glossy Munsell samples, each of which has the highest excitation purity for the given hue. At the right is shown the range of colors which can be produced by mixing three subtractive dyes of the type used in Kodak color films. (The method of plotting the colors is explained on the opposite page.)

Since the luminances corresponding to this gamut of chromaticities are not the same in different parts of the diagram, we should not expect a color film to provide good reproductions of colors at all levels of luminance even within this range of chromaticities. We obviously should not expect a film to provide good reproduction of colors having chromaticities that fall outside this gamut, as is the case with the saturated spectral colors. The appearance of a rainbow can be approximated in a color photograph only because most of the colors are less saturated than those of a pure spectrum. Some are due to mixtures of broad bands of wave lengths rather than narrow bands presented alone, and all colors are desaturated by the surrounding skylight.

In connection with the color gamut of a set of subtractive dyes, a comment on the shape of the gamut as plotted on the chromaticity diagram may be of interest. If we were dealing with additive mixtures of three colored lights, the boundary of the colors which could be matched would be a perfect triangle, with the primaries at the corners. Subtractive mixtures follow a different law, and thus plots of mixtures of any two of the dyes lie outside a straight line connecting the two points which represent the two dyes alone and at maximum concentration.



CIE CHROMATICITY DIAGRAM – On this "color map," the horseshoe-shaped boundary line around the light gray area shows the position of the pure spectrum colors. Some of these are identified by their wave lengths in nanometers. The straight line closing the horseshoe shows the positions of the magentas and purples, which are complementary to the greens of the spectrum. The edge of the colored area shows the purest colors which can be printed with a typical set of modern process inks. Near the center of this area is the "illuminant point" for the standard light source equivalent to daylight; this is also the position of any neutral gray illuminated by daylight. By simple mathematics, the spectrophotometric curve of any color sample can be translated into values of x and y. The position of the color can then be plotted on the diagram to show its relationship to all other colors.