Avoidance of Color Troubles Caused by Electric Light

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(*Continued from September issue, page* 908)

The Physiological Basis of Color

What happens in the visual apparatus when we see color? That is one of the most baffling questions with which the physiologist and the psychologist has had to deal, and to which a full and authentic answer is yet to be obtained. A great number of theories have been presented, one scientist having counted over eighty; but all of these have developed some weak spots. From what has been determined definitely, it seems most probable that all color sensations are produced in the brain by three kinds of physiological action—probably electro-chemical in its nature—which takes place in the retina as a result of the action of light, and which produce three different kinds of nerve currents. How these nerve currents differ is not known, because the nature of the nerve current itself is unknown. These three kinds of nerve currents, in different amounts, reaching the nerve terminals in the brain, produce all the various sensations which we know as color vision. These three actions in the retina can be produced by single wave-length light which gives the color sensations of red, greenish-yellow, and violet-blue respectively. The correctness of this theory is confirmed by the familiar three-color process of printing, in which the blending of the colors is accomplished by printing with inks of the three colors in varying amounts, on the same picture. These commonly are called Primary Colors.

Analysis and Classification of Colors

All of the color tones, that is, the colors of the spectrum aside from the elementary colors, can be produced by two different wave forms; one, a simple wave, the other a combination of two simple waves. Thus, the orange color-sensation will result from a simple wave of only one length, and also from a complex wave-form combining red and yellow wave-lengths. In a similar manner, white light may consist of a highly complicated wave-form, as in the case of sunlight, in which there are practically an infinite number of component waves of different lengths; or it may consist of a very simple wave-form containing only two wave-lengths. Thus, yellow and blue waves of certain lengths and amplitudes will combine to form visually white light; as will also red and green, orange and purple, yellow-green and violet. These are called Complementary Colors. It is obvious that if we divide the spectrum into two parts at any point, the colors formed by the combination of the colors on each side of this point will be complementary, since their combination will form physically white light. Complementary colors are always pure. When diluted with white or adulterated with black they form contrasting tints or shades. The polariscope affords a means of studying complementary colors in endless variety, and of perfect balance. It should give much valuable information to color designers.

Hues have been defined as mixtures of the three primaries which do not produce white. Theoretically, the colors of dyed or pigmented objects always are hues; that is, the colors contain some of all three primaries. Practically, there are a number of pigments, and many aniline dyes, that produce colors which visually are pure, and a considerable number of aniline dyes which produce almost perfectly pure spectral colors. By far the larger number of distinguishable colors, however, are hues. In attempting to reduce these to some sort of classification popular usage will be followed as far as possible.

The logical starting point of any classification is a division into two classes. Following this rule, we may divide all hues into "warm" and "cold" colors. In so doing, however, we will have to provide a special place for yellow, which forms a neutral zone between the two classes. The red at one end of the spectrum is decidedly "warm," and the blue and violet at the other end as decidedly "cold." These opposite effects decrease, proceeding from either end toward the yellow, which is neutral in this respect. Hues are, then, warm or cold according as the longer or shorter wave-lengths, i.e., the red or blue rays, give the dominating effect in the combination.

Classes of hues are formed about each of the four elementary colors, and gray. Red is dominant in the hues of orange, brown and maroon. Of these three classes, brown requires special consideration. There are brown hues that are so difficult for the mind to analyze into component colors that they might almost be classed as elementary. The division of the class into warm and cold browns is easily made, and depends upon the dominance of the red or blue components respectively. Brown is a compound of the three primaries, red, yellow, and blue. The source of the trouble in analyzing browns, which has puzzled even the psychologists, is the visual red component in spectral violet. Like orange, the violet color sensation can be produced either by a light-wave of simple form, (single frequency), or by a complex wave having red and blue components. The violet light or single frequency can supply the visual red for the production of brown, the hue thus produced being generally cold. This is shown very convincingly by the fact that browns can be seen by mercury light which contains no single-frequency, or spectral red, but is rich in spectral violet. The effect of this light on browns is to give them a colder tone.

Yellow forms but one class of hues, which are slightly warm in tone, blending without any sharp line of division into the hues of orange. Flesh color lies in this dividing zone, varying from a red hue to a yellow hue, including brown.

Green hues are divided quite sharply into warm and cold, the former being included under the general term of "olive green," while the latter contains a number of tones designated by special names, as "sea green," "poison green," etc.

Blue forms two classes of hues, both of which are cold. One class blends into the cold green, "robin's egg blue" and "peacock blue" lying near the dividing line. The other class runs into the short-wave red, or crimson, and contains the purple and violet hues.

Gray forms two sets of hues, warm, and cold. The hues in which red or yellow are perceptible fall into the warm class. Neutral gray is properly a tone of white and black.

All hues contain black, resulting from the two complementary colors present. It is possible to use black instead of the third primary color in the production of hues; and this does not prevent the use of white to produce light shades of the hue.

It is possible to analyze any color into components of the three primary colors, red, yellow and blue, expressed as numerical quantities. There are several instruments on the market for this purpose. It thus is possible to state the chroma of any given colored surface in numerical terms expressing the amounts of each of the three primaries present. By the further statement of the brightness of the color, which likewise can be expressed numerically as a photometric quantity, the color can be described fully and accurately.

The Color of Surfaces as Affected by the Color of Light

The general effect of any given light upon colors will be determined by its color composition as compared to daylight, which can be determined accurately only with the spectroscope; but the practical results can be arrived at by observing the relative brightness and color of the four elementary colors and their intermediate tones, under equal intensities of illumination, by the different kinds of light. The colors as they appear by incandescent electric light, and by mercury light, in comparison with daylight, are shown in Figs. 4a and b.

Incandescent light contains more yellow, and much less blue than daylight, and almost no violet. Its effect upon pure red surfaces is, therefore, to add a yellow component. Yellow being the brightest of the colors, the effect is to make the red surface appear brighter, and of a slight orange tone. In practice, pure red surfaces are found seldom; there is generally either a yellow or a blue component. The effect of incandescent light on yellow-reds is to make them brighter and nearer to orange. The effect upon blue-reds is to suppress the blue component and add yellow. This effect on dyed material may be so marked as to entirely change the chroma. Thus, red variously designated as cerise, cherry, American beauty, etc., appears nearly pure red.

Mercury light contains no spectral red; it, therefore, shows pure red surfaces as black. It contains, however, an excess of yellow, blue, and violet; as a result it shows the yellow-reds as cold, dark browns, and the blue-reds as violet-blues, thus radically changing the chroma.

Yellow is given a slight red component by incandescent light, and a perceptible green component by mercury light. Any noticeable green component in yellow is recognized as such; while a slight red component deepens the color of the yellow, without being itself recognized.

Green becomes deeper in shade by incandescent light, and is given an olive-yellow hue by mercury light.

Blue becomes black, with a perceptible blue component at high intensities, under incandescent light, and assumes a vivid violet-blue tone under mercury light.

The intermediate tones, as would be expected, show greater divergence of color under the different kinds of light. Orange becomes more red under incandescent light. Mercury light brings out the fact, in a very striking manner, that colors which are visually the same may be produced by quite different kinds of light-waves. Thus, an orange produced by a mixture of red and yellow pigments will appear olive green, while a fabric dyed orange may appear a warm brown, as shown in Fig. 4b.

Yellow-green tones become darker, and of olive-green hue under incandescent light, and lighter tints of yellow-green under mercury light.

Blue-greens become warm in tone by the addition of a slight red content, under incandescent light, and of a deeper shade under mercury light.

Violet becomes more red under incandescent light, and of a deep violet blue under mercury light.

Crimson shows nearly its natural color under incandescent light, and black under mercury light.

The color effects illustrated in Figs. 4a and b must not be misunderstood. What they show is the daylight appearance of the various colors under the two different kinds of electric light; that is, the color in the outer bands, seen by daylight, match the corresponding colors of the central band seen under the two kinds of electric light respectively.

The Two Fields of Color Vision in Industry

The field of color vision in industry divides itself very sharply into two divisions. The first includes those operatives whose special duty is the control of color as an essential property of the goods manufactured. Such an operative may be called a Colorist. The second class is made up of workmen who handle colored materials, and who must avoid mistaking one color for another.

The largest number of Colorists is to be found in the textile industry, in the capacity of designer, master dyer, bleacher, printer or inspector.

Among Colorists the designer alone is concerned with the esthetic values of colors with relation to one another, and to the uses of the articles in which they appear. He, therefore, has to consider the effects of the different lighting conditions under which the articles are to be used by the ultimate consumer. If they are to be seen only in daylight, the daylight values only of the colors need be considered. If the goods are to be seen only by electric light, as evening gowns, then the color values must be judged by this kind of light. And if the goods are seen by both kinds of light, as carpets and draperies, the color values must be judged accordingly. The designer has no part in the production of the colored materials or finished products, but works with such colors as are available commercially. In all cases he must have an abundance of daylight from a north window, and a good supply of well diffused incandescent electric light. A source of the so-called "artificial daylight," should be at hand for emergency use.

It is the class comprised of workmen who must merely avoid mistaking one color for another that presents the majority of problems of color vision in industry. The lighting conditions required by the Colorist are well known comparatively, and can be provided accordingly. The conditions required by the

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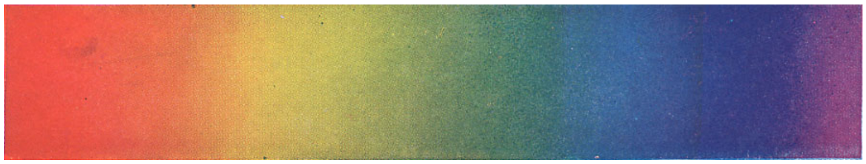


The Colors of the Solar Spectrum.

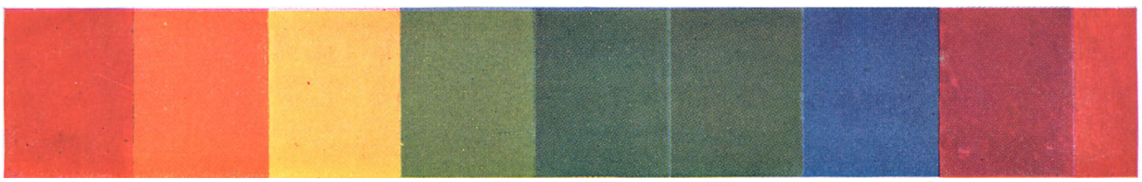
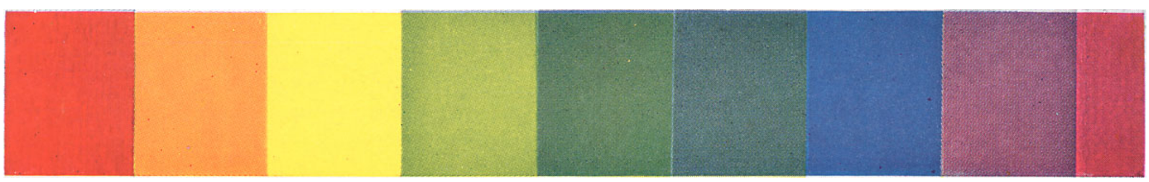


Figure 4a

The Colors of the Spectrum by Incandescent Electric Light.



Red | Orange | Yellow | Yellow-Green | Green | Blue-Green | Blue | Violet | Crimson

The Colors of the Spectrum as Seen by Daylight.

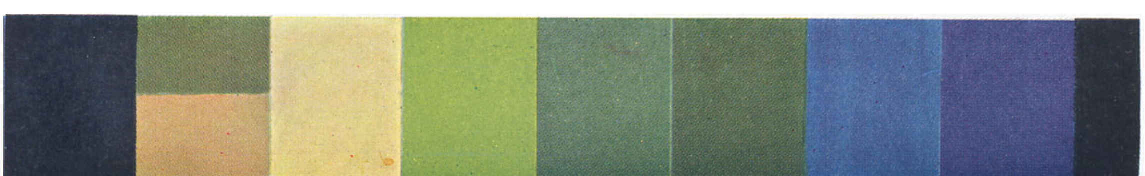


Figure 4b

The Colors of the Spectrum by Mercury Light.

workman handling colored materials generally are misunderstood, with resultant confusion and trouble. There are two errors that are so natural that their prevalence need cause no surprise. The first is, that the workman handling colored material must distinguish the colors. In the large majority of cases the colors do not affect the performance of the work in the slightest degree; the workman could do his work exactly as well if he were totally color blind. For example, the weaver on plain fabrics is not in the least concerned with their color. And yet, if a light is provided which distorts the colors, the first reaction of the weaver is to object that he can't see to do his work because he can't distinguish the color. It is surprisingly difficult to get this idea out of the workman's head. Unfortunately, commercial rivalry between the promoters of different systems of lighting has tended to confirm the workman in this error.

The second, and even more persistent error, is the notion that colored materials must be seen as they appear by daylight in cases in which they must be distinguished by the workman. The utmost that is required of the operative with respect to color vision is to avoid mistaking one color for another. How the colors look is of no consequence. Thus, if different tints of red must be distinguished, they may be quite as accurately distinguished as tints of brown or blue as tints of red.

Another phase of this same error is the belief that all color discrimination can be made most accurately by physically white light, or daylight. The difference between color matching and color discrimination may here be pointed out, a difference that is important, even though it may seem to be a "distinction without a difference." To perceive that two things are alike is not the same as perceiving that they are different. Thus, hues of blue are distinguished by the difference in the amount of the red or yellow content; and whether the difference is due to red or yellow, and to what extent, is the chief purpose of the discrimination on the part of the Colorist. Surprising as it may appear, it is nevertheless a fact, that the discrimination of colors can be made most accurately by light of different spectral composition than daylight, according to the color composition of the hue or tint. It is only when all the possible colors must be distinguished by the same light that physically white light must be provided. A striking example of this fact is furnished in the case of hues of black. It is common knowledge that hues of black are the most difficult of all to match. Under mercury light the differences in the amounts of the color components are so accentuated that the composition of the dye is revealed to such an extent as to afford a positive check on inferior processes.* On the other hand, the violet component in most Navy blues is so exaggerated by the excess of violet in mercury light as to render it useless for the commercial discrimination of this class of hues. The absence of violet, and deficiency of blue in ordinary incandescent light render it equally unsatisfactory for this purpose.

General Methods of Avoiding Color Troubles

The first step in avoiding color troubles is to educate the workman out of his mistaken notions in regard to what he needs to see. When he realizes that he does not need to see color in order to do his work, many alibis for poor work, and complaints of bad lighting, will disappear, along with an unreasoning prejudice against modern lighting methods. This, of course, applies to the cases in which discrimination of the colors of materials is not required. When such discrimination is necessary the education must go further, and show the workman that he does not need to see colors in their daylight value in order to discriminate them.

Having brought the workman to a rational view of the demands upon his color vision, or perhaps rather as a preliminary to this understanding, it rests with the manufacturer to use every practical means of relieving the workman of the necessity of making judgments of color. This is in accord with the first rule of practice in all efficiency methods; namely, to reduce the amount of thinking required of the workman to a minimum. Thinking, which is the process of forming judgments, takes time, and always results in a certain amount of er-

* I am indebted to Dr. Schwarz, Editor of THE MELLIAND, for this interesting and important piece of information.

rors. The more nearly automatic the human machine can be made the more efficient it becomes, just the same as with any other machine. This is not discouraging the use of reason by workmen, but simply placing it in its proper place, or rather keeping it from interfering where it does not belong. The proper use of thinking on the part of the workman is to find out ways of avoiding the necessity for its use. Wherever it is possible for the workman to identify a colored material by a number or symbol, such means should be provided. The various cases will be taken up in detail later.

Colors That May Be Confused Under the Different Kinds of Light

After all has been done to reduce the necessity for color discrimination to a minimum, there remain some cases in which the workman must judge colors in order to perform his task; and in these cases the colors must be discriminated by electric light as well as by daylight. Since mercury light is now used largely in the industries, its effect upon the apparent colors of surfaces must be considered along with those of incandescent light.

The study of a practical case may afford the best approach to this problem. The fugitive dyeing of silk for identification in the production of woven fabrics from the skeins of raw materials furnishes such a case. No manufacturer will deny that there is still much to be desired in the practice of this method. To begin with, it is obvious that the colors used must be distinguishable clearly under all three kinds of light, at fairly low intensities, by operatives whose color vision is more or less defective. It is not sufficient that they show a barely perceptible difference to a trained Colorist under good daylight. Furthermore, allowance must be made for variation in the tint or shade of a given color on account of the somewhat rough processes of such dyeing.

A sample card containing twenty-seven colors that have been worked out especially for this purpose showed the following pairs of colors that might be confused under the different kinds of light:

Daylight: peach and orange; lilac and orchid; green and olive; russet and brown.

Incandescent Light: peach and orange; orchid and lilac; green and olive.

Mercury Light: orchid and lilac; yellow and canary; blue and turquoise; green and olive; peach and orange.

It probably will surprise some readers to note that there is less chance of confusion by incandescent light in this case than by daylight; also, that there is but one more chance of confusion by mercury light than by daylight.

There are three pairs of these colors that are liable to confusion under all three kinds of light; two other pairs that are liable to confusion under mercury light, and one other pair liable to confusion by daylight. In order to render the series clearly distinguishable under all kinds of light, therefore, six of the colors must be eliminated, one member of each of the pairs given.

It is important to note that the six pairs of colors that are liable to confusion are all hues, and each pair of practically equal brightness. It can be shown easily that small differences in brightness are detected more readily than small differences in color. Furthermore, differences in brightness are affected comparatively little by the kind of light and by defects in the color vision of the observer. The surest method of securing a series of colors for this purpose is, therefore, to use different tints of the four elementary colors and the intermediate tones. The following series includes probably the maximum number of colors that can be quickly and positively identified under all of the lighting conditions as they exist in actual practice:

Pure red; three tints of orange; yellow, yellow-green; three tints of green; two tints of blue green; two tints of blue; two tints of violet; three tints of cerise red; three tints of gray; white. Natural yellow silk presents difficulties in dyeing that will reduce materially the number of colors that can be used.

It is a well known fact that colors change with the intensity of illumination, the extent of the change depending upon the color. If a uniformly high intensity of illumination, such as is required for maximum visual perception, is provided, the number of colors can be increased somewhat. The colors used will depend also to some extent upon the kind of light used. Contrary to what would be supposed in view of the color distortions produced by mercury light, quite as many colors clearly distinguishable under this light are available as in the case of any other light. Tones of orange and hues of brown may be confused, and also hues of brown and olive green. Browns and olive greens, however, are tricky colors in any case, and to be avoided if possible. Again, contrary to general opinion, more tints and tones of red can be distinguished by mercury light than by incandescent light; they will be seen as different tints of brown when pure red dyes are used, and as tints of reddish blue if cerise-red dyes are used. It is a simple matter of experiment to find out what colors can be distinguished, and what colors may be confused, under the kind of light to be used, and discard the latter.