Lighting for the Colorist

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In the previous series of articles* we discussed the problems of color vision pertaining to the handling of colored materials by the workman. We propose now to consider the subject of color from the standpoint of the colorist.

The field of the colorist is quite sharply divided into two sections, occupied respectively by the technical colorist and the artist. The technical colorist is responsible for the colors of the various materials found in the articles of commerce in which color is an essential quality. His work reaches its highest state in the practice of dyeing. The artist is concerned only with the esthetic values of color combinations. This field is again divided into pure art, and applied, or decorative, art. In point of economic value the latter is by far the largest field.

Color, in the usual sense of the term, is a property of visual sensations. Visual sensation is the effect produced by a certain range of ether vibrations which is designated by the term *light*. There is no color where there is no light, or even where there is insufficient light—"in the night all cats are gray." Color vision in all its aspects is therefore basically a question of light.

So far as its action in the production of vision is concerned, light is a simple matter of mechanics, easily understood, and susceptible of accurate measurement in terms of the common physical units. The visual apparatus, however, is complicated in the highest degree, and its construction and method of operation but imperfectly understood. Herein lie the many difficulties that beset the work of the colorist.

Analogy Between Light and Sound

The further we can go in unraveling the ultimate causes of phenomena the more clearly we can see our way in directing the phenomena in accordance with our own wills. We acquire

* THE MELLIAND, Sept. issue, p. 904; Oct. issue, p. 1076; Dec. issue, p. 1351.

knowledge by reasoning from the known to the unknown. The causes of sound are of a much grosser nature than the causes of vision, and easily appreciated by the senses. The familiar phenomena of sound thus afford many analogies which are helpful in enabling us to visualize the relation of light to color.

Sound and light are both wave motions, and both follow the mechanics of this form of energy, or power transmission. A wave has two fundamental properties: length, and amplitude. In a given medium, wave length has a direct relation to the rate of the vibrations by which it is produced; the more rapid, or frequent, the vibrations, the shorter the length. This fact has become very familiar in the use of radio receivers. In a given medium waves of all lengths move with the same velocity.

The two fundamental properties of wave motion give rise to the two fundamental properties of sound and color; viz. loudness, and pitch, in sound; and brightness, and color, in vision. Mental sensations cannot be measured. The nearest we can come to measuring them is to measure their physical causes. Such measurements are based upon the assumption that equal amounts of physical force, or stimulus, produce equal amounts, or intensities, of sensation. This assumption accords with experience.

There is no common measurement for loudness of sound, although it could be readily made. Brightness, however, is the basis of all measurements of light, the amount of the physical cause being expressed in terms of intensity. The unit of intensity is the light received upon a surface one foot from a light-source of one candle-power, and called the foot-candle.

Quality Can Not Be Measured

Pitch cannot be measured, since it is a quality of the mental sensation of sound; but it can be accurately defined by stating the frequency to which it is due. In an exactly similar manner, color can be defined by stating the wave length of the light. This method of defining pitch and color by wave length or frequency is applied only to simple wave forms, representing pure tones and colors. Such tones do not exist in nature; but pure colors are found in the rainbow, and in thin films, as of soap bubbles and oil scum on water.

Besides loudness and pitch, we recognize a difference in the quality of sounds. It is by this quality that we distinguish the sounds of different musical instruments. Musical quality is commonly known as timbre, also as tone. The quality of a musical tone is due to the form of the sound wave. The wave is produced by a fundamental wave whose frequency determines the pitch, upon which are superposed waves of shorter length and less amplitude, which represent "overtones." It is possible by devices called "resonators" to identify each of the overtones, and determine its relative loudness. In Figure 1 are shown diagrams representing the wave-form of the tone of a pipe organ, and the various simple waves which constitute the overtones.

The analogy between sound and color is very close in this respect. The colors that we commonly see are due to complex wave forms, resulting from a combination of a predominant wave length, upon which are superposed various wave lengths of less amplitude. By passing the light from a colored surface through a prism the different components of the wave can be separated, and their wave lengths and relative amplitudes determined.

Differences Between Light and Sound

From this point the differences rather than the similarities, between sound and color phenomena are noteworthy. In sound the waves are received by the ear in the same form as they left the source, being changed only in loudness by reflection from various surfaces; while the light waves that reach the eye have been changed in form at every surface from which they were reflected, except the surfaces which we call white. This is one of the peculiarities of light which render its phenomena so exceedingly complex—there are others.

Again, there is nothing in sound comparable with the sensations which we know as black and white. Black is the physical counterpart of silence; but black is as distinct a color sensation as red, while silence is merely complete absence of sensation. White is likewise a distinct sensation, which has no counterpart in the wave-form that produces it. When not referred by the mind to a definite surface, gives only a general sensation of light, without any accompanying sensation of color. So-called "white light" would be more accurately designated as neutral.

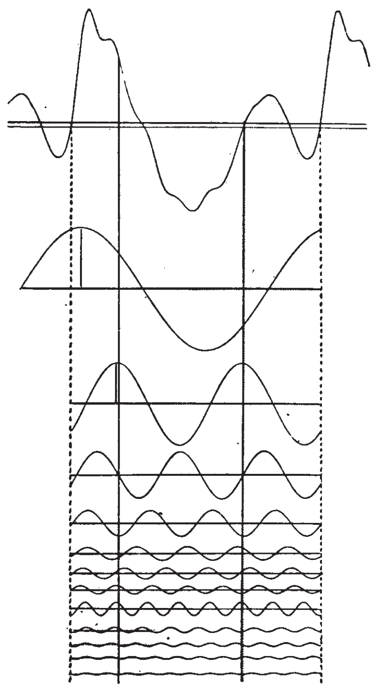

Figure 1

The functioning of the apparatus by which sound is converted into sensation is presumably much simpler than the apparatus for the translation of light into vision. It is the peculiar functioning of the latter that puts the final complication into the phenomena of color. The auditory apparatus consists essentially of a set of resonators which respond to the different wave lengths within the range of hearing, connected with nerve centers in the brain which convert these nerve forces into the sensations of tone.

The Color Mechanism of the Eye

From what is known of the action of the visual apparatus, it appears that the receiving apparatus, called the retina, contains only three sets of "resonators," and that these conjointly are capable of picking up the entire range of wave lengths found in light. Each set singly, however, responds most vigorously to a narrow range of wave lengths, and more or less feebly to wave lengths beyond the limits of this band. These three narrow bands fall in the pure red, the yellow-green, and the violet-blue. Light having a wave form compounded of these three wave lengths is picked up by the resonators, and transformed in the optical nerve centers in the brain into white, and all other colors, according to the relative intensities of the different colors. The diagrams in Figure 2 illustrates this theory.

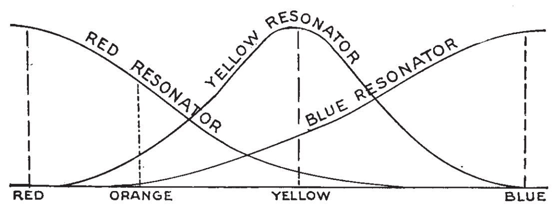

Figure 2

It will be interesting to see how this theory explains the fact that the same color sensation can be produced by light of a single wave length, and by a wave-form resulting from two components. Let us take orange, which we know can be produced by a band in the spectrum between the red and the yellow, and also by a combination of red and yellow light. Referring to the diagram in Figure 2, it will be seen that the band in the orange is picked up by both the red and yellow resonators, which therefore send a composite impulse to the brain, which produces the sensation of orange color. The final result is thus the same as if the red resonator had picked up waves of red, and the yellow resonator waves of yellow. In each case both resonators have been simultaneously stimulated and produced a composite result.

The production of white by the combination of two colors is explained in the same way. Take red and green, for example. The red resonator picks up frequencies extending into the yellow; the yellow resonator picks up frequencies extending into both the orange and green; and the blue resonator picks up frequencies extending into the green and violet. Red and green light, therefore, act upon all three resonators; and the composite result is white. It is, of course, understood that the relative intensities of the red and green must be in a certain definite proportion. The production of any given color can be accounted for in a similar way by this theory. A theory that accounts for the known facts is presumably true.

The visual apparatus is the counterpart of the receiving set in radio; but no physical similarity must be assumed. The visual receiving set has many peculiarities, as was pointed out in the previous discussions. The ether waves that reach the receiver have been entirely re-formed by reflection from various surfaces. Their final form thus depends upon two physical conditions: the wave-forms sent out by the light source; and the kind of modification they have suffered by reflection. Both of these variables are subject to control; the control of the former is within the province of the illuminating engineer; the control of the latter is the special field of the technical colorist.

Necessity for a Light of Standard Color

It is an axiom in science that the control of variables can be studied only by considering one variable at a time, while the others are kept constant. The colorist must, therefore, be able to secure a light of constant quality. What quality shall be chosen for this constant light? The obvious answer is, the light which is most used; namely, sunlight. But sunlight is highly variable, both in intensity and color, in the reflected form in which it reaches our eyes, familiarly called "daylight." If the matter is to be handled at all scientifically some means must be found of specifying the quality of light within the limits of accuracy common to science.

Method of Specifying the Color of Light

In order to establish a light of specified quality, or color, it will first be necessary to develop a method of reducing color comparisons to some kind of numerical scale. The analogy of musical tone and color will again be helpful. We have seen how the tone of the organ was analyzed by means of resonators, which picked out each of the overtones, and enabled their relative intensities and frequencies to be measured. By passing light through a prism it can be spread out into a band of colors, which represent the different frequencies of which the original wave-form was composed. It is possible to measure these frequencies, or wave lengths, and also to compare their intensities, on a numerical scale. A statement of these two measurements will evidently form a definite specification of the quality, or color, of the light.

The proof of analysis is synthesis. If the elements as determined by analysis reproduce the original substance or phenomenon when combined, the analysis is correct. By combining simple sounds of frequencies and relative loudness as shown by the resonators, the tone of the organ can be exactly reproduced. An analysis of color will give the data for producing the color, which can be put to practical use. Instruments for analyzing color in this way, called spectrophotometers, have been brought to a high degree of efficiency. The principle of their operation is simple. Light from a source which gives a continuous spectrum of the order of sunlight, such as a tungsten electric lamp, is reflected from a white surface through a prism, and the spectrum received upon another white surface. The color to be analyzed is, in practice, the color of light reflected from a given surface. Light reflected by the white surface in the instrument is again reflected from the colored surface, passed through the prism, and its spectrum projected on the screen by the side of the standard spectrum. Means are provided by which the spectra can be so shifted on the screen as to bring any narrow band of one spectrum opposite the same color in the other spectrum. The colors having been thus matched, the brightness of the standard spectrum is then varied until the two bands are of equal brightness, and the degree of brightness read off on a scale provided for the purpose. The wave length at the center of the band is then read on another scale. In this way any number of separate bands can be measured, and the results plotted as a curve by laying off the wave lengths along the base, and the corresponding intensities as vertical distance.

For the comparison of the colors of surfaces the actual quality of the standard light used does not effect the measurements so long as it remains the same. By this means color is expressible by the most generally useful implement of the mathematician, the curve, or graph. While such curves form perfect records of colors, and provide an infallible means of reproducing the original, their meaning is by no means apparent at sight. Only long experience in their use will enable the color represented to be visualized, and then more or less vaguely. They do, however, afford a means of detecting differences in color well beyond the ability of the eye to perceive by direct inspection.

A spectrophotometer has been developed, and is soon to be placed upon the market, which is automatic in its action. The given surface being properly inserted and the machine set going, the color curve is drawn upon a card. The apparatus utilizes the photo-electric tube and microphone, those uncanny devices which have made television, and the talking picture possible.

By measuring the brightness of a sufficient number of spectral bands of the given light, a color curve can be obtained which is independent of any particular form of light. This is a task for the trained scientist, working under laboratory conditions. Much work of this kind has been done, and the results recorded in scientific literature. The characteristic color curves for noon sunlight, and the gas filled tungsten lamp (Mazda C) are given in Figure 3.

It will be noted offhand that the curve of the lamp, while similar to the sunlight curve in general form, is shifted bodily toward the lower frequency, or red, end of the spectrum, which shows that the light is orange in comparison with white light. Such a general shift of the color is characteristic of the differences in color of incandescent light, that is, light produced by solid bodies at high temperatures.

Color Defined in Terms of Temperature

The difference in color of bodies at different temperatures is a more or less familiar phenomenon. If an iron rod, for example, be heated sufficiently it glows with a dull red. As the temperature is increased the red becomes orange, then yellow, and finally at the welding point it becomes "white hot." Its whiteness, however, is due to the dazzling

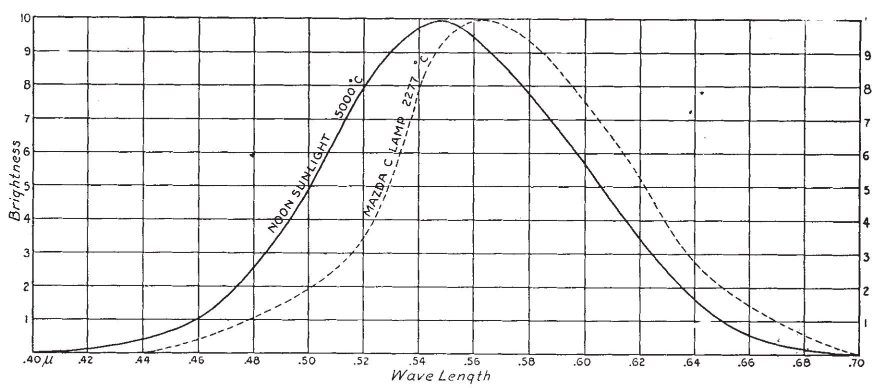

Figure 3

effect; a color curve of its light would still be shifted well toward the red. Tungsten in a vacuum may be heated much higher, causing a marked shift toward the violet end. In

It is apparent from the preceding description that the spectrophotometer can be used to compare the color composition of light from various sources, and the variations in daylight.

the gas filled electric bulb it runs still hotter, with the curve as shown.

It is apparent from these observations that a definite color of light can be designated by reference to the temperature of the incandescent body. Conversely, the temperature of incandescent bodies can be measured by observing their color. This is the principle of the optical pyrometer, of which there are a number of forms on the market. The color of an incandescent body depends somewhat upon the material, but the variation is not very great for the common substances. For scientific accuracy the temperature colors are referred to as a "theoretical black body," or "perfect radiator." The temperatures are usually given in centigrade degrees, but sometimes in Kelvin, or absolute, which is the centigrade plus 273°. However, the scale is entirely arbitrary, both as applied to color and temperature.

The average of many observations by many different observers has shown that clear noon sunlight corresponds to a temperature of 5000°C, while the Mazda C lamp gives 2277°C. Knowing the law of color change with temperature, it is possible to continue the scale far beyond the temperature at which any known substance will retain the solid or liquid form. Such temperatures exist in the sun, but not on earth. By means of an instrument specially designed for the purpose, the color temperature of the sky under various conditions has been determined, giving the following results: Overspread with light clouds, 6,000° to 7,000°; blue sky, from 12,000° to 15,000°; extremely clear blue sky before noon, 24,000°. All of these temperatures represent color curves shifted toward the violet from the noon sunlight curve; in other words, they are all various tints of blue.

It will be seen from the preceding discussion that the physical elements of color are now capable of treatment to a very high degree of mathematical accuracy. This scientific method of treatment offers a wide field of application to the practical work of the colorist, both technical and artistic. We shall study some of these applications in the subsequent discussion.