Avoidance of Color Troubles Caused by Electric Light

By E. LEAVENWORTH ELLIOTT, ITHACA, N. Y.

The cases in which color vision is required in industry are such a small minority that they may be considered properly as exceptions—and comparatively rare ones at that. This statement at once will be challenged by the average reader. Are not colors present in everything that is seen? Are not the commodities of commerce colored in nearly all cases?

Admittedly so. But the extent to which the workman must perceive colors in order to properly perform his task is being discussed. This at once rules out all consideration of color from the artistic, or esthetic standpoint. This is the field of the color artist, who is not classed as a workman. Turning to industry in its broadest sense, agriculture and mining also may be dismissed at once. Transportation involves the very special case of colored signals and beacons, which is distinct from the use of light to see by, which constitutes illumination, in the common meaning of the term. The iron industry requires no color vision, since the products involved are either black or gray; and this is true also for all other commercial metals except copper and its alloys, and gold. The cases in which the workman must distinguish different copper alloys by their color are exceptional. The textile trade is by far the largest division of industry in which color vision is required of the worker. But even in this only a small minority of the operatives need to distinguish colors. A survey will show that by far the largest part of the work is mechanical and has nothing to do with the color of the materials worked upon. The lesser divisions of industry, in which wood, leather, clay, chemicals, paper, and foodstuffs are the materials involved, all present some cases of color vision, which constitute special problems in lighting.

Altogether it is doubtful if much more than one-tenth of one per cent of those constituting what is generally included in the term "labor" are required to determine color in the pursuit of their tasks—the number certainly does not amount to one per cent. Probably also much less than one-tenth of one per cent of those travelling by water have to use life boats; but when they do need them, the lack is fatal. So with color vision; while the necessity for its use is exceptional, the want of the necessary facilities for it is disastrous, resulting in spoiled or damaged products. These life-boat cases in industrial lighting are to be considered.

The Fundamentals of Color Theory

The most important single fact in the whole subject of lighting is, that our minds see. The words "lighting" and "illumination" are used to signify the use of light to make objects visible—to enable them to be seen; and seeing is a mental act, a psychological experience.

In order to have an intelligent understanding of the subject, rather than a little rule-of-thumb knowledge, it, therefore, will be necessary to examine the theory of color vision to some extent. The subject is one upon which numerous investigators, in many fields, have spent years of labor, and upon which very many books have been written; so it is evident that only the most fundamental principles can be considered. Beyond these, in fact, the whole subject becomes more or less controversial, even among the specialists.

The first question that arises is: What is color? A little thought on the subject shows that the word "color" is used to signify three very different things. It may refer to a property of light; or to a property of a surface; or to a certain mental sensation. The last of these meanings is the one most commonly attached to the word, and to which our attention will be given first.

Referring to the colors of the solar spectrum as they appear in the rainbow as shown in Figure 1: beginning at the left, a sensation which is called "seeing red," is received or more simply, red. This is a distinct sensation, which can not be conceived of as the result of a combination of causes. It is what the

The Colors
of the Solar Spectrum

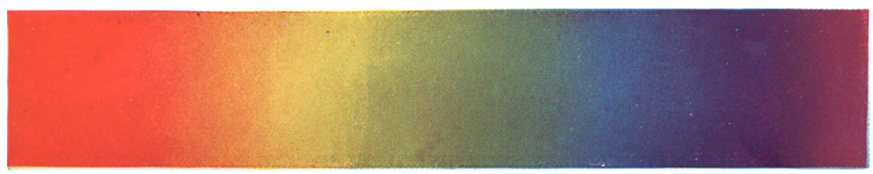

Figure 1

Solar or Daylight Spectrum, showing the colors
as they appear in the rainbow.

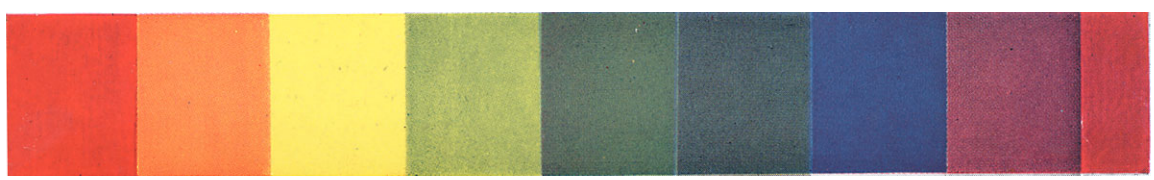

Figure 2

The four elementary or psychological colors in the spectrum:
red, yellow, green and blue, with intermediate colors.

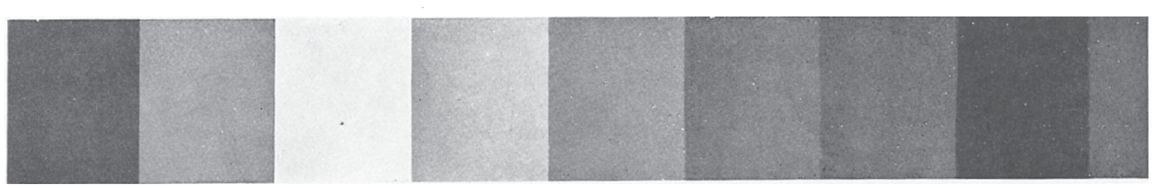

Figure 3

Relative brightness of the four elementary and intermediate colors represented by neutral, or gray, surfaces of respectively equal brightness.

psychologists call "a unique experience;" it can not be described in terms of any other experience. The only way to tell what is meant by seeing red is to show a red object.

Passing the eye along to the right, the red sensation is changed by a new sensation mingling with it; and as the line of sight continues to move a point is reached at which the red sensation has entirely vanished, and the new sensation stands alone. This is called yellow. Again proceeding, the yellow becomes fainter, another new sensation appears, which finally becomes distinct and unique, this is called green. Still continuing, another unique sensation is reached which is called blue. Beyond this the red sensation begins to appear again, intermingled with the blue, this is called purple; and farther on violet. If eyes are particularly sensitive, and the visual conditions are especially favorable, it is possible to go still farther, until the blue nearly or quite disappears, and a red is seen which is designated as "crimson." Thus four colors have been found which mentally cannot be resolved into components, and which, therefore, may be called elementary colors: namely, red, yellow, green, and blue. These four elementary colors with the intermediate ones, are shown in Figure 2. To further distinguish them they may be called the psychological colors.

It may be objected that green is a composite color, consisting of a mixture of blue and yellow. This opinion is based upon familiarity with the fact that a mixture of blue and yellow pigments produces a green pigment. This is quite a different matter from mentally recognizing blue and yellow in green, which the untrained mind cannot do. The green pigment resulting from a mixture of blue and yellow is due to certain physical properties of the pigments, which will be explained later.

The difference in the kind, or quality of color—what commonly is meant by the color of an object—technically is called chroma.

Looking at the spectrum, which is the technical term for the rainbow colors, as a whole, it is seen to vary in brightness, being brightest near the center, and becoming darker quite rapidly toward the ends. The relative brightness of the four elementary and intermediate colors is represented in Figure 3 by neutral, or gray, surfaces of respectively equal brightness. The violet at the far end of the band also is represented. Brightness is, therefore, one of the visual properties of color.

The brightness of a color, and the coloring power of light, however, are two entirely different things, and must not be confused. The violet at the end of the spectrum is the darkest of all the colors; while violet light has the highest coloring power. If this coloring be ascribed to the dye, let it be remembered that the color of the dye is the color of the light it reflects, and, therefore, its coloring power is that of the light; the chemical substance of the dye does not reach the eye, much less the mind, where the seeing takes place. The red at the other end of the spectrum is the next lowest in brightness, and the next highest in coloring power; and so on for the other colors. This general relationship, of course, holds only for the pure spectral colors.

There is a peculiar vividness in the colors of the actual rainbow which is missed when they are compared with colored surfaces. It will express the feeling fairly well if it is stated that the rainbow is all pure color, while colored objects show more or less dilution with colorless, or white light, or adulteration with other colors or with black. The degree of freedom of color from dilution or adulteration is called its degree of saturation.

Color Terminology

Between the elementary colors in the rainbow, or spectrum, there are bands which easily are recognizable as compound colors, consisting of various mixtures of the two colors at each end. It obviously is possible to compound colors of three, or all four of the elementary colors, in varying proportions. In fact, it is in this way that all the different colors which can be distinguished, numbering perhaps twenty thousand, are formed. In order to designate these colors it is necessary to classify and name them in some way. Unfortunately, the terms used with reference to colors have not been reduced to a fixed system. It, therefore, will be necessary to define the terms that we employ, and adhere to these definitions, regardless of how others may use the terms.

The four elementary colors are plain colors.

A color formed by the mixture of two elementary colors is a tone of the predominant color. Thus, tones of red are formed by the presence of either blue or yellow in varying amounts. Red tones containing blue are referred to by various names, as "cerise," "cherry," "rose," "carnation," etc. Tones containing yellow are called "orange-red" or "flame-red," sometimes "deep orange."

Tones of yellow are formed by additions of either red or green. Orange is a visually equal mixture of red and yellow and often is classed as a plain color; as is also purple. Yellow tones will be referred to as orange-yellows and green-yellows.

Tones of green are formed by additions of either yellow or blue, forming yellow-greens and blue-greens.

Tones of blue are formed by additions of green, forming blue-greens. Additions of red to blue form tones of purple or purple-blues.

Additions of red to purple form tones of violet, or red-purples. If the red largely predominates the color becomes crimson.

Plain colors or tones diluted with white form tints; if darkened with black they become shades.

Mixtures of more than two colors form hues. Hues may be lighter or darker according as they are diluted with white, or adulterated with gray or black. They are designated by names given arbitrarily, as "ashes of roses," "old gold," etc.

There is a radical difference in practice between the scientific and the commercial uses of the terms black, white and gray. The psychologist generally, but not invariably, considers black, white and gray as colors; but in commerce they are treated as distinct qualities. The expression, "piece goods in black, white and colors," is a familiar form of statement. It simplifies the subject to consider black and white as elementary colors, and gray as a tint or shade.

It must be remembered that these different colors are visual colors, and the separate colors of which they are composed are likewise color sensations, and not pigments or dyes.

Color as a Property of Light

Attention is turned now to the external cause of the mental sensation of color. Color being an element of visual experience, the fundamental facts concerning vision will have to be considered. It is a matter of common knowledge that the eye—meaning the eyeball—is a small photographic camera, with a sensitive film at the rear, called the retina, upon which the picture of the thing seen is thrown by the lens in front. The retina contains something over a hundred million of special nerve cells, which are connected with other special nerve cells in the brain by a cable of nerve fibers. The light falling on the cells in the retina sets up nerve-currents, which pass through the nerve lines to the brain, where they act upon the special nerve cells at that end of the line, and produce the consciousness we call seeing, or vision. The visual apparatus as a whole is thus a combined television, motion picture camera and projector, which produces the changing scene in all its colors.

The ultimate cause of visual experiences is the thing which is called light. According to the prevailing theory, light is a wave motion of the ether. This statement now has a familiar sound, from the general interest in "radio." It is known that light waves and radio waves differ only in length, the former being some yards long, and the latter only a small fraction of a millionth of an inch in length. According to the wave theory of light, the different sensations of color are due to light-waves of different length, or frequency. If a beam of colorless light, such as sunlight, be passed through a glass prism, it spreads out fanshaped; and if this spreading beam be intercepted by a white surface, the colors appear in the same order, and of the same kind, as in the rainbow. It is a simple matter to measure the wave lengths in any part of this color band, or spectrum. Such measurements show that the red contains the longest waves, and the violet the shortest, with the lengths varying regularly from one to the other. The difference from the extreme limit of the visible red to the utmost visible crimson at the other end, is very nearly in the ratio of two to one.

In sound waves a difference in length of two to one includes eight musical notes, and is called an octave. Out of the entire range of ether waves, therefore, one particular octave furnishes all visual experience. In the case of sound the range of the ear is more than eight octaves. It is probable that more different colors can be distinguished than different sounds; which shows that the eye is a much more sensitive apparatus.

It is customary to refer to light-rays of different lengths, or colors, proceeding through space, as if each travelled alone, and was a distinct wave-system. It requires but little observation of water waves to discover the fact that when a number of waves of different lengths and heights spread out from the same place, they coalesce to form a single wave system. This fact is shown still more convincingly by a phonograph record; all the different sounds produced by a symphony orchestra are represented by a single wavy line, which is capable of reproducing all the sounds combined, as heard by the ear. Such wavy lines represent the wave form of the composite sounds.

In a similar manner, any color of light may be represented by a single wave-form. Since the entire range of lengths is scarcely an octave, the wave-forms necessarily are very simple as compared to sound waves. Color, as a property of light, is thus the form of the ether waves. The different hues and tints correspond to musical sounds of different quality, or timbre. It is from this analogy that "tone" is used to denote the character of a color. The form of a wave depends upon the different heights of the waves that it contains, as well as upon the different lengths. The height, or amplitude, determines the brightness in light, as it determines loudness in sound. It is the infinite number of possible combinations of length and amplitude that enables us to recognize so many different colors and sounds.

Color as a Property of Surfaces

The sensation of color always is connected more or less definitely in the mind with a surface. It is difficult to imagine "red" without thinking of a red surface. It is one of the commonest tricks of language to call a thing by the name of the mental impression it produces. To speak of "red apples" is entirely natural, referring the sensation red to the surface of the apple. The property of the surface which causes it to produce the red sensation is a matter of physical science, determined only by investigation.

It must be understood that the wave-form belonging to the color that is seen pertains to a given wave system; that is, the waves coming from a particular place of origin. So far as the eye can determine, the origin of the waves is the surface of the object seen. Thus, when light falls upon a surface, that particular wave-system is extinguished, and another wave system takes its place, of different form, and proceeding in another direction. This new wave system is what we call reflected light.

The wave-form of sunlight is commonly called white light, because a surface which reflects it without changing the form, but causing only a uniform reduction in amplitude, is known as a white surface. A surface which so changes the wave-form of white light that the reflected wave gives the sensation of red is called a red surface; and similarly for other colors. A surface that reflects the wave of white light without change of form, but reduces its amplitude, or brightness, nearly to extinction, is called black. When the reflected wave-form varies in amplitude between black and white, the surface is called gray.

From the fact that ether waves of different lengths combine to form a single complex wave system, it must not be inferred that the composite wave can not be "unscrambled." The experiment of passing waves of white light through a prism is the most familiar proof of this; the wave components of different lengths take different directions, and thus separate the different color radiations.

Some substances have the property of absorbing light of one color, and sending out light of another color. Thus certain aniline dyes, when exposed to mercury vapor light, which contains no red light, show a brilliant rose-red; while others show a red-blue. Some colorless, or white, substances show a light of greenish-yellow. This effect is called fluoresence. Fluorescent bodies may also show their color by ultra-violet rays.

In order to change its wave-form light must penetrate the substance of the body to some extent. Light reflected from the actual surface is simple specular reflection, such as takes place from a mirror. The result of such reflection is to hide the surface and show the light-source. Perfectly specular and perfectly mat surfaces are never found in practice. The proportion of the amount of light specularly reflected to the amount of incident light determines the degree of gloss or polish of the surface. This can be measured by instruments designed for this purpose.

The surfaces of bodies are colored either by pigmenting the surface or dyeing the material of the body. In either case the color of the surface is due to the suppression of some of the component wave-frequencies (colors) of the incident light by its passage through the particles of pigment, or dyed fibers, lying near the surface, before the light is turned back by reflection. In other words, the apparent color of an opaque object is due to the filtering out of some of the rays of the original light by passing through the particles or fibers at the surface. The object appears colored for the same reason that a stained glass window appears colored.

The result of mixing pigments or dyes is precisely the reverse of mixing colored lights. Thus, a mixture of red and green dyes or pigments will produce black, while a mixture of red and green lights will produce visually white light. This is theoretical, but can be approximated very closely in practice by gauging the brightness and chroma of the red and green dyes or pigments with sufficient accuracy. In any case the result of such a mixture is a hue of much less brightness than either color. The explanation of the result of the mixed pigments is simple enough; the red pigment nearly extinguishes all light but the red, including the green; and the green, all light but the green, including the red; so that the result is the practical extinction of all the color rays.

(To be continued)