The Adaptation of Light for Color Workers

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

The perception of color is subject to various peculiarities in the operation of the visual apparatus; and these have to be taken into account in considering the lighting conditions that will be most advantageous for any given purpose.

Colors vary with the intensity of illumination. There is a certain brightness at which the color of a surface appears most distinct. Increasing the brightness beyond this point dilutes the color with white; if the brightness is increased sufficiently only a dazzling white is seen. Reducing the brightness changes the chroma, or character of the color itself. The first effect is the reduction of the perception of red, which increases the brightness of green. With a sufficient reduction of the intensity the red will entirely disappear, and the orange will begin to fade. Further reduction in intensity extinguishes the orange and reduces the blue and violet. Still further reduction extinguishes all but the green, which is the last color to be seen; after which all surfaces appear a blue-gray.

When the whole visual apparatus is intact absolute darkness is not seen, even in the total absence of light; there is a sensation of blue-gray haze in the visual field. This is called the intrinsic light of the eye.

Intensities Required for the Discrimination of Different Colors

The intensity of illumination required for the accurate perception of color varies inversely with the brightness of the color; that is, the darker the color the higher the intensity required. Yellow is the brightest color, as shown by the illustrations in the preceding article.* Discrimination of tints of yellow, and light shades of hues in which yellow is predominant, therefore requires the lowest intensity of illumination. It requires very little excess light to extinguish the yellow in a light tint, and make it appear white. An intensity of ten foot candles is all that should be used for this purpose. By folding a piece of white paper, and then opening it to a sharp V, the color near the fold will appear much more distinct than the color of a flat piece. This is due to the several reflections which the light from the surfaces undergoes before reaching the eye, at each of which some light is absorbed by the yellow, thus making it appear darker in color.

What is called violet in the spectrum is called purple when seen on a surface, and is the darkest of the colors. Blue is the next darkest. This may seem contrary to common experience, but this is because the blue surfaces in nature are so largely diluted with white, as the sky, and most blue flowers. The discrimination of the real blues and purples, therefore, requires a high intensity, a hundred foot candle being a minimum for the darker hues. Green is of medium brightness, and requires a medium intensity, twenty to fifty foot candles being suitable.

When two surfaces differing in brightness are placed side by side, there is a very perceptible increase in contrast between the two for a narrow space each side of the dividing line. This may be seen by referring to Figure 4a in the preceding article. When the two surfaces are colored the effect is to increase the difference in color, as may also be seen in the same illustration. When very small surfaces are compared this may interfere with accurate discrimination. The difficulty may be overcome by using larger surfaces, or by slightly separating them.

Reflex Action of the Eye

Color sensations, like all sensory effects, are subject to fatigue. If light consisting of one color, or in which one color is predominant, falls upon the retina, the visual sensation of that color rapidly fades out, leaving only the sensation of colorless light. This effect is shown when a railway train enters a tunnel by daylight; at the first transition from the white daylight to the electric light the yellow color of the latter is plainly seen; but the color rapid-

*See THE MELLIAND, Oct. issue, p. 1078.

ly fades, and after a few moments is no longer perceptible. Even the red light in the photographic dark room soon loses its color to those working by it.

This fatigue resulting from light of a single color is connected with another physiological effect called *reflex action.* The nature of this action is as follows: when light of one color falls upon the retina of one eye it fatigues that eye for the sensation of that color, but increases the sensitivity of the other eye for the complementary color. The same reflex action takes place between the two halves of the retina, divided vertically, of the same eye. The result of monochromatic light falling upon both retinas is, therefore, to depress the perception of that color, and to increase the sensitivity to the complementary color. This reflex action of the visual nerve centers is a recent discovery, and goes a long way toward clearing up the contradictions and deficiencies in the various theories of color vision. It also furnishes a key to hitherto unexplained causes of glare.

Practical Application of Reflex Action

That this object may be turned to practical account is quite obvious. If different tints of the same chroma are to be distinguished, the eye should be kept sensitized for that color by frequent subjection to light of the complementary color. This can generally be done by providing colored surfaces in the immediate visual field. If it is not practical to provide such a contrasting background, the eye can be given frequent rest by closing the lids, or looking away from the work. This frequent resting of the eye for the particular color will expedite the work, since the actual judgments of color required can be made almost instantaneously, and the quicker they can be made the more accurate they will be.

Large fields of color appear less vivid than small fields, down to a certain limit. If the field becomes very small, such as a mere dot, the color disappears altogether.

Contrasting colors appear brighter and purer when seen in juxtaposition. Even a neutral gray may appear colored with the contrasting color when seen on small surfaces intermingled with patches of color. These effects are shown in Figure 5. This effect may be produced by introducing contrasting lines, which are very effective because of the perfect contrast of the apparent colors.

Colors are subjects of memory, rather more accurately than sounds. The accuracy of the memory, however, varies with the individual; some can "carry a color in the eye" with almost the same accuracy as they can discriminate colors actually seen. When we speak of how a colored object looks we always refer to its appearance by good daylight, and it is the memory of these colors that attach to objects when we visualize them.

Variation in Daylight Color

It is a common knowledge that daylight varies with various conditions that are constantly met in the regular course of factory operation. These are: direct sunlight; indirect sunlight from a clear sky; light from a clouded sky, varying from light, fleecy clouds to heavy storm clouds; the time of day; and the clearness of the atmosphere.

The lighting conditions under which the workman commonly performs his task are often very far from the ideal conditions for the accurate discrimination of color; daylight may be of low intensity on account of weather conditions, or distance from windows, or dirty and insufficient windows. Electric lighting may be inadequate in amount, and the color of the light changed by dirty lamps and reflectors. And he may have to see his work in deep shadows. It is, of course, unreasonable to require accurate color discrimination under such conditions. Where colors must be accurately matched such of these conditions as exist must be corrected.

It is an established fact in the psychology of color that difference in brightness can be detected with greater accuracy than difference in chroma, or color. If color be added to a white or neutral surface, a difference in brightness will appear before a difference in color becomes visible. The rapid fading of color from visual fatigue, in conjunction with the above fact, renders the discrimination of tints and shades a detection of difference in brightness rather than a difference in chroma. In fact, the cases in which two surfaces of different chroma are exactly the same in brightness are comparatively rare.

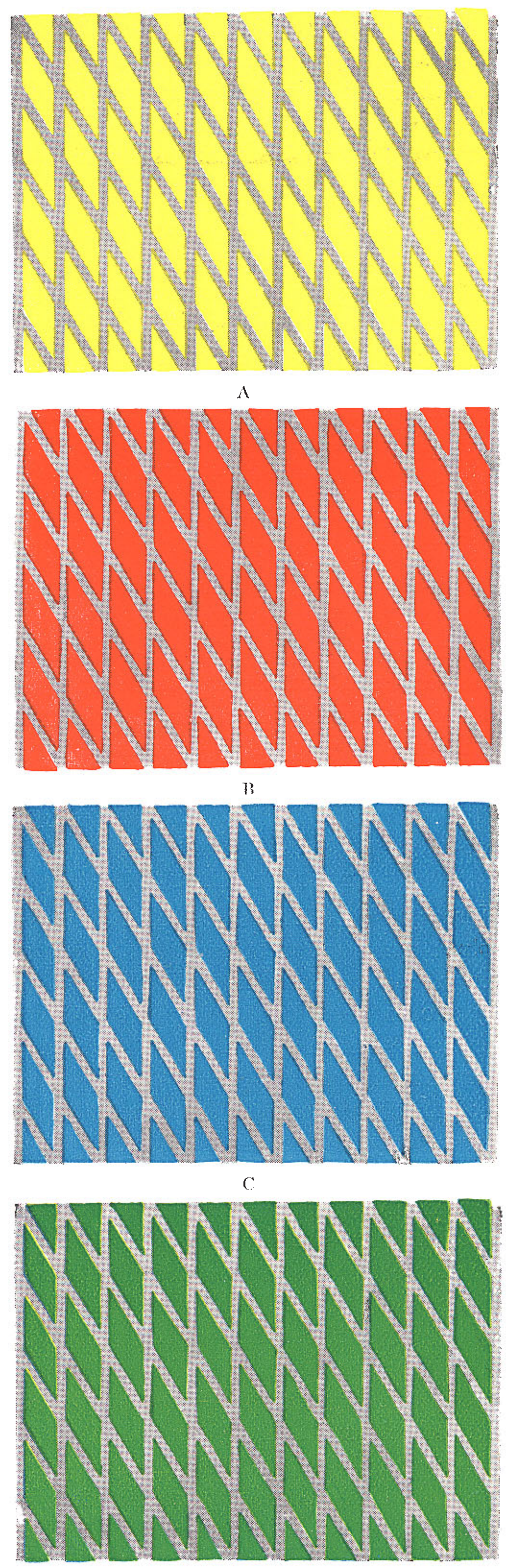
Differences in Color Vision

Colors do not look alike to different individuals. Since it is impossible to tell in words how a color looks, these individual differences in color perception go entirely unnoticed by the individual himself, unless his vision is decidedly defective. He may be made aware of his defects by mistaking a red signal for a green, that being the most common form of color blindness. In rare cases, said to occur only in men, there is total inability to see color. Color perception is less subject to variation in women than in men, and changes more or less with age.

Differences in color vision can be very accurately determined by means of the instruments designed for the analysis of color previously mentioned, and which will be more fully treated in a subsequent article. The point is, that the color vision of the individual can be even more accurately determined than the optical defects for which glasses are worn. It is a rather curious thing, when the facts are considered, that operatives who have to use color discrimination are almost never subjected to tests of their color vision—it is even more curious than the general neglect of employers to test the eyes of employees for optical defects. A beginning has been made to removing this anomaly, however. A few concerns are employing occulists regularly, and making periodical examinations of the eyes of the operatives. The practice should be made universal. No other equal expenditure of money by large concerns would bring such satisfactory returns.

Color Discrimination by Mercury Light

Different shades or tints of the same order of chroma, that is, nearly the same proportions of the primary colors but with varying amounts of black or white, can be determined quite as accurately by mercury light of the proper intensity as by full spectra light. As a practical example, the case of a manufacturer of full fashioned hosiery may be cited. A large proportion of such hosiery is of the hues commonly called flesh-color, in which red is prominent, and the hue largely diluted with white. The



Figures 5 a-d
Effect of contrasting colors on neutral gray.

two stockings in any one pair must be accurately matched for color, while slight differences between pairs are negligible. It was found that the pairs could be more accurately matched by mercury light than by incandescent light, and with accuracy equal to daylight.

The cases in which mercury light renders color discrimination impossible are those in which chromas of different orders must be distinguished. Red may be confused with chocolate brown; and orange with either brown or olive green. A warm brown may be confused with a cold brown, or with maroon. Blue may be confused with purple, and yellow with greenish-yellow.

Under incandescent light blue and purple, and their tints, may be confused; and brown hues cannot be sharply discriminated.

The textile industries in which complete discrimination of colors must be performed by the operatives are the weaving of woolens and worsteds, and certain kinds of carpets, and in knitting fabrics with colored patterns. In these cases mercury light alone cannot be used.

Combination of Mercury and Incandescent Light

Mercury light contains no red, and an excess of blue; while incandescent light contains an excess of red, and is deficient in blue and violet. They should, therefore, mutually correct each other's color defects. This is true to a certain extent; but it does not follow that a combination of the two lights will form true white light. As previously stated, physical white light contains all the wave-lengths from red to violet, in certain proportions. It is, therefore, impossible to produce such light by any combination of band spectra, or separate colors. A combination of mercury and incandescent light, however, can produce results that are unobtainable with either light alone, and so serve the practical purpose of white light for the discrimination of colors. Thus, the hues included under the general term "maroon" appear brown by mercury light and red by incandescent light. The addition of a certain amount of incandescent light to the mercury light will show them in their exact daylight chroma.

It does not follow, however, that the proportion of incandescent light requisite for showing maroon, or any other particular hue in which red is a prominent component, will show hues in which the other primaries are dominant in their daylight value. But even in the cases in which it is necessary that no two chromas be confused by the workman, it is not necessary that all chromas appear in their daylight values. While no mixture of mercury and incandescent lights will produce physical white light, such a mixture will enable the operative to avoid the confusion of colors, and thus serve the practical purpose of white light.

In providing such a mixed light for shop use it is neither necessary nor desirable to attach the incandescent lamps to the reflector of the mercury lamp, which makes a cumbersome contrivance. The light will mix sufficiently if the incandescent lamps are hung near the mercury lamps, and at the same height. They should, preferably, be provided with deep bowl enameled reflectors, so that the lamps will be hidden from general view as much as possible. The lamps should consume about one-third the wattage of the mercury lamps for general purposes. While some of the advantages of the mercury light are lost by this combination, color perception is rendered practically equal to that under white light, and the glare of incandescent light is reduced by two-thirds, which is an item well worth considering. There is also an increase in economy of light production as compared to straight incandescent light.

It is possible in some cases to confine the incandescent light to a small area in which the color discriminations can be made. The knitting of seamless hosiery in colored patterns furnishes an example. The practice in some mills is to provide a narrow bench—say a foot wide—between two rows of machines set facing each other, to serve as a receptacle for the pieces as they come from the machines. The operatives give each piece an inspection for dropped stitches as they place it on the bench. A few incandescent lamps in deep reflectors are hung low over the benches, the light of which mingles with the mercury light, used for general illumination when the inspection takes place, but does not extend to the machines, which are thus lighted entirely by the mercury light.

Why Use Mercury Light?

The question will naturally arise with those unfamiliar with mercury light, why take the trouble to provide these special arrangements for lighting in order to have this particular kind of light? A full answer would necessitate a complete review of the optical, physiological, and psychological, principles involved in vision. The facts may be briefly stated as follows:

Owing to the fact that mercury light contains no light-waves longer than the yellow, and to the fact that the lens of the eye is incapable of focusing all the colors at the same time on the retina, mercury light produces on the retina a sharper image of the objects seen. The objects seen thus appear more distinct in outline, and smaller objects are made visible.

Owing to certain physiological actions in the visual process, mercury light increases the contrast in light and shade. This increases the distinctness of details in dim illumination, and, therefore, makes them visible in shadows.

As a result of the principle of reflex visual action, previously explained, mercury light produces no glare under normal conditions of use.

Recent investigations seem to show that the ultra violet rays in mercury light may exert a distinctly beneficial effect upon the general health, particularly in preventing colds.

For equal visual results, mercury light is considerably more economical to produce.

Where these properties of the light have been demonstrated by actual use it is not surprising that all practicable means will be employed to retain them.

The gas filled incandescent lamp, generally known as the Mazda B, if operated at full voltage, gives a continuous spectrum from red to violet inclusive. The violet is very weak, and the blue somewhat less so, compared to normal sunlight. Since it is impossible to add color to a light-source—a fact often uncomprehended—the only way in which the proportions of the different color-rays can be made to match daylight is by reducing all the other colors so as to bring them down to the level of the violet. This can be done by the use of a color filter having a slightly violet-blue color. Since the yellow and green rays produce ninety per cent of the total visual effect, the suppression of these colors enormously reduces the seeing-power of the light. To produce a complete daylight match from 80 per cent to 90 per cent of the light has to be absorbed. It is obvious that the production of pure white light by this method is impracticable for any but very special uses. However, it is not necessary to produce pure white light for general factory use. An approximation to whiteness that is sufficient for many purposes can be obtained by screening off a half of the red and yellow. This can be done by the use of the blue bulb Mazda B lamp. Such lamps have only about half the life of the clear bulb lamp, which, together with cutting the quantity of light in half, materially increases the cost of illumination. Where it is desired to use this method of lighting it is better practice to use a blue globe over the lamps, which will not shorten their life.

Blue bulb lamps have been recommended in some cases on the assumption that the whiter light gives greater visual acuity, and less glare. The second assumption is measurably true. Yellow and red are the most glaring of the different colors, and there is not sufficient blue and violet in incandescent light to give a balanced direct and reflex retinal action; hence the glare that accompanies this form of light. Reducing the relative amounts of yellow and red, therefore, reduces the glare, which increases the acuity of vision by reducing visual fatigue.

The selection of a white light to be used as a standard is a matter that has been much discussed and investigated; but no single definite standard has been universally agreed upon. So far as the workman is concerned, however, the colors which he has to discriminate must be wide enough apart so that he will not confuse them, not only under all of these varying conditions of daylight, but of still greater variations of electric light.

Light is the cheapest of all the facilities essential to factory operation; to economize on light is to practice the traditional economy of saving at the spiggot and wasting at the bung.