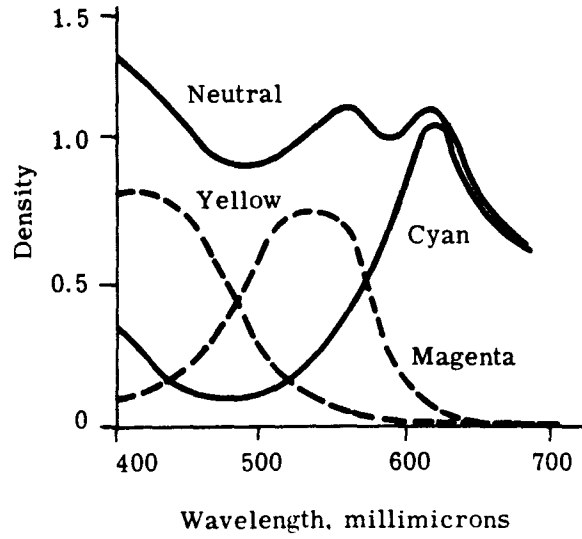
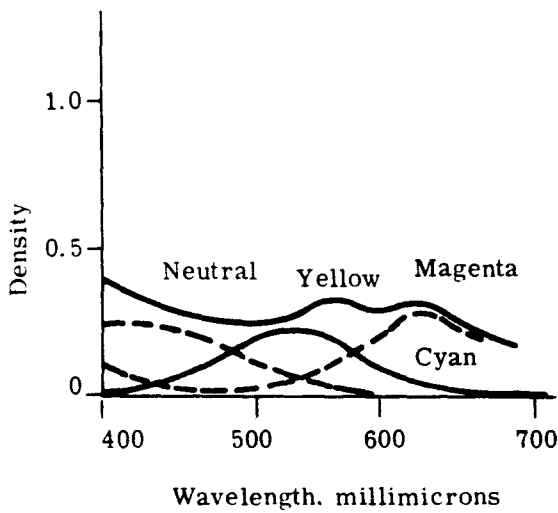


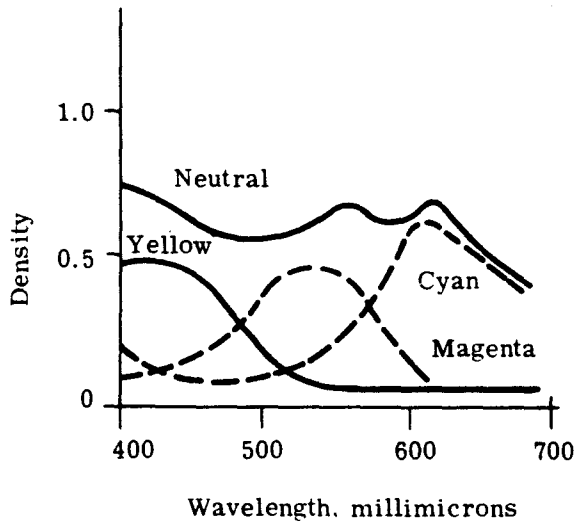
a. Not neutral density



b. Neutral density = 1.0



c. Neutral density = 0.3



d. Neutral density = 0.6

Fig. A-2 — Combinations of different amounts of dyes

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## 5. INTEGRAL DENSITIES AS A FUNCTION OF DYE SPECTRAL ANALYTICAL DENSITY

Assuming that for many applications the END's of a particular image are of most benefit, the question becomes how to determine such densities. It has already been shown that END's can be determined knowing the spectral analytical densities of the dye layers composing a particular image on the film. The problem is that spectral analytical densities are impossible to measure directly on a piece of color film after an image has been exposed and developed for the intended use. The type of measurements that can be made, however, are integral spectral densities. A later section will illustrate how one can determine the spectral analytical densities from the integral analytical densities, and then how the equivalent neutral density (END) can be determined from the integral spectral density. It is sufficient to point out at this time that these conversions are possible solely because photographic dyes used in color films obey within reason the log-D law, that is, as the concentration of a dye changes, its density changes linearly. For example, if the concentration of a dye in the color film is doubled, its density is also doubled.

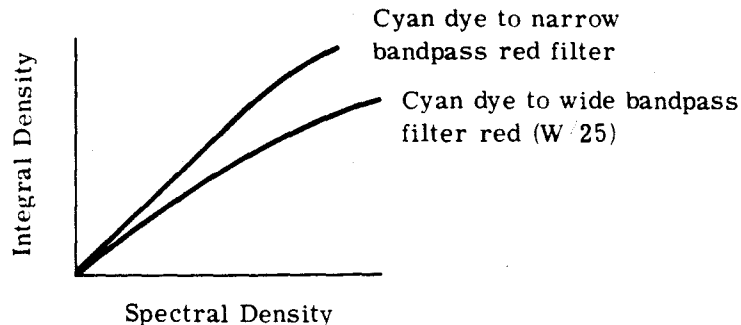


Fig. A-3 — Relationships between the spectral analytical density of a cyan patch and the integral spectral density

It is extremely important to understand first, however, that integral densities (spectral or otherwise) are not strictly valid when measured with wide bandpass filters, due to the nonlinear density response when compared with pure spectral (monochromatic) light densities. For example, Fig. A-3 illustrates the relationships between the spectral analytical density of a cyan patch and the integral spectral density when the integral density is measured with filters of differing bandwidth. As indicated in Fig. A-1, the integral spectral density of a color film at a given wavelength is simply the sum of the spectral analytical densities at that wavelength. This additivity of spectral densities does not hold, however, for wide bandpass filters but only for very narrow bandpass filters. For example Fig. A-4 illustrates the spectral density distributions of three different red filters, each of which was used to measure the densities on a series of patches on a cyan strip and a magenta strip, and then to measure the densities of the same patches with the two strips superimposed.

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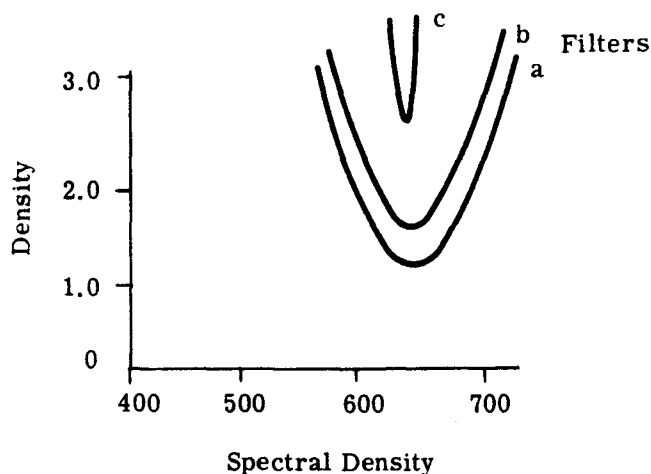


Fig. A-4 — Spectral density distributions of three different red filters

The next series of figures (Fig. A-5) compares the sum of the individually measured densities against the deviation from these densities as measured when the strips were superimposed. Only filter c (the narrow bandpass filter) approaches the ideal of no deviation between predicted (or sum) and actually measured integral spectral density.

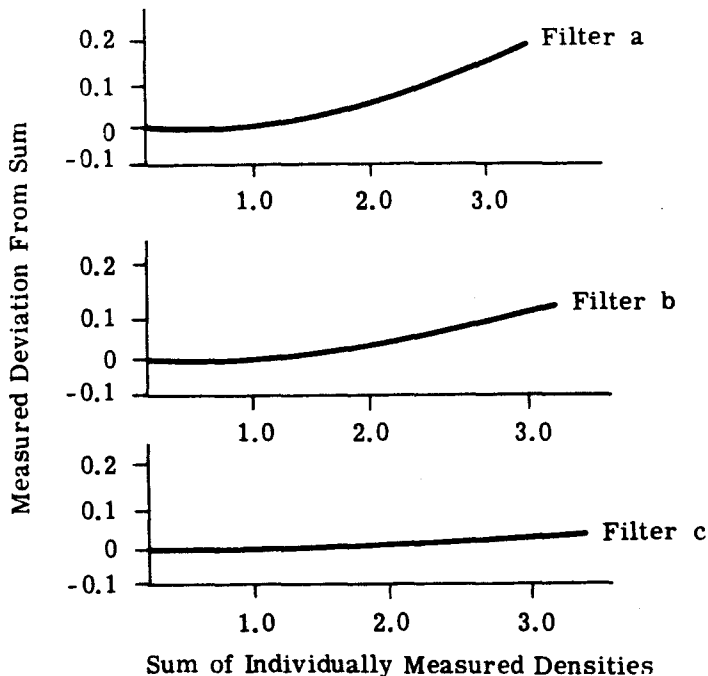


Fig. A-5 — Sum of individually measured densities versus the deviation from these densities when the strips were superimposed

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If the new values of  $D_r$ ,  $D_g$ , and  $D_b$  are measured or known, and the coefficients  $B_m$ ,  $G_y$ , etc., are also known (from the previous table) then the above equation can be solved for  $c'$ ,  $m'$ , and  $y'$  by matrix algebra. As an example, using the previous dye set and substituting in the above equations we obtain:

$$D_r = c' + 0.059m' + 0.013y'$$

$$D_g = 0.220c' + m' + 0.048y'$$

$$D_b = 0.254c' + 0.154m' + y'$$

Solving the above equations by matrix algebra allows the determination for any new set of integral spectral densities of the amount of each individual color former (i.e., the spectral analytical densities), the above equations become:

$$c' = 1.015D_r - 0.058D_g - 0.010D_b$$

$$m' = -0.213D_r + 1.019D_g - 0.046D_b$$

$$y' = -0.225D_r - 0.142D_g + 1.010D_b$$

The determination of the equivalent neutral densities (END) from the integral spectral densities is equally straightforward. A sample of the color film is exposed to produce a neutral.\* The integral spectral densities of this neutral are determined, and using the above equations, the spectral analytical densities are calculated. By definition the END of each of the dye layers forming the neutral is equal to the luminous density of the neutral, regardless of the spectral analytical density of the dye layers. As an example consider a sample exposed to produce a neutral image with a luminous density of 1.0. The END of the cyan, magenta, and yellow layers is by definition 1.0. Even though the spectral analytical densities in all probability will be different, say for this example:

$$c' = 1.052$$

$$m' = 0.751$$

$$y' = 0.826$$

## 6. RELATIONSHIPS BETWEEN INTEGRAL AND ANALYTICAL DENSITIES

As has already been mentioned, the images in a color film are a result of the separate actions of the three dyes, and the integral and analytical densities are both a measurement of this action by the dyes. Because of the fact that both measurements (i.e., integral and analytical) are a

---

\* The exposure of a piece of color film to produce a neutral is not always simple. However, by definition for the purposes of determining the END's of color dye layers, a neutral exposure is commonly accepted as the exposure of the color film to a neutral wedge (such as type 3 carbon) with the colorant of illumination the film is intended to be used with (such as daylight, tungsten, flash, etc.)

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measure of the action of the dyes, and since the dyes follow the log-D law, it follows that there is a correlation between the two types of density measurement.

Curve s of Fig. A-6 represents the integral spectral densities of an image consisting of three dyes. An increase or decrease in the amount on any one of the dyes in this image would result in a corresponding increase or decrease in density at all wavelengths. The combined density of the three dyes at any one wavelength does not, therefore, indicate the extent to which any one of the dyes contributes to this density, unless the spectral absorption characteristics of the dyes are known. If these characteristics are known, the extent to which each dye contributes to the integral spectral density measurement can be determined.

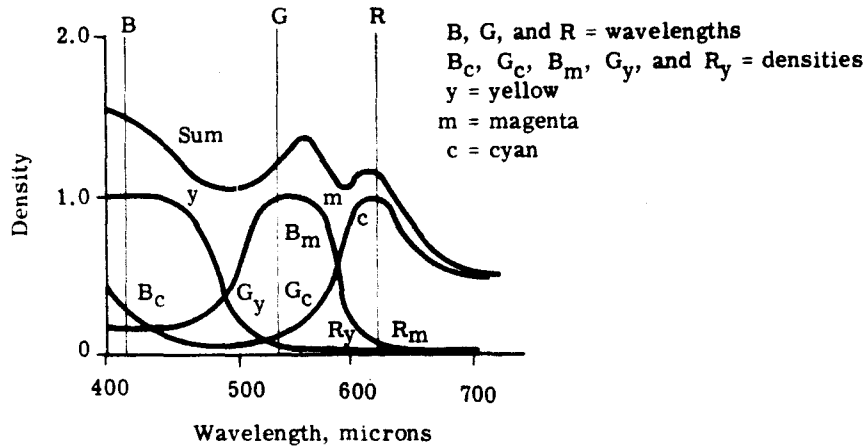


Fig. A-6 — Integral spectral densities of an image consisting of three dyes

The amounts of the dyes will be specified in terms of the spectral analytical densities  $c'$ ,  $m'$ , and  $y'$ . By definition, a unit concentration of dye is when the spectral analytical density is 1.00 at the peak absorption of the dye. The wavelengths are labeled R, G, and B for the cyan, magenta, and yellow dyes respectively. Besides the amount of the primary dye absorption at a given wavelength, the amount of "unwanted" absorptions from the other dyes must also be known. There are six such densities and they are designated as  $G_c$ ,  $B_c$ ,  $B_m$ ,  $R_m$ ,  $G_y$ , and  $R_y$ . These densities are noted in Fig. A-6, and their numerical values for the particular dyes illustrated in Fig. A-6 are tabulated below. The letters R, G, and B are used to denote the color of the measuring light. The letters c, m, and y are used to denote the dye layer being measured. On this basis it is evident that  $R_c$ ,  $G_m$ ,  $B_y = 1.00$ .

Density, millimicrons	Spectral Analytical Densities		
	(c) Cyan Dye	(m) Magenta Dye	(y) Yellow Dye
(R) 620	1.000	0.059	0.013
(G) 540	0.220	1.000	0.048
(B) 410	0.254	0.154	1.0000

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Let us now consider these dyes in amounts which differ from those given in Fig. A-6. For any given amount of cyan dye  $c'$ , the density of this dye to red light would be  $c'$ , to blue light  $B_C c'$ , and to green light  $G_C c'$ . The same relationships hold for the other dyes. The integral spectral densities  $D_r$ ,  $D_g$ , and  $D_b$ , to red, green, and blue light respectively, of any combination of these dyes, is simply the sum of the spectral analytical densities contributed by each dye component as shown in the following equations:

$$\begin{aligned}D_r &= c' + R_m m' + R_y y' \\D_g &= G_C c' + m' + G_y y' \\D_b &= B_C c' + B_m m' + y'\end{aligned}$$

The END of each layer (c, m, y) is thus related to the analytical spectral density by the equations:

$$\text{END's } \begin{cases} c = \left(\frac{1}{1.052}\right) c' = 0.951c' \\ m = \left(\frac{1}{0.751}\right) m' = 1.332m' \\ y = \left(\frac{1}{0.826}\right) y' = 1.211y' \end{cases}$$

By combining the above relationships between END and ASD with the equations for the determination of analytical spectral density (ASD) from integral spectral density, one can solve directly for the END of a dye layer from the integral spectral density. Thus:

$$\begin{aligned}c' &= 1.015D_r - 0.058D_g - 0.010D_b \\m' &= 0.213D_r + 1.019D_g - 0.046D_b \\y' &= 0.225D_r - 0.142D_g + 1.010D_b\end{aligned}$$

From the END equations above:

$$\begin{aligned}c' &= \frac{c}{0.951} \\m' &= \frac{m}{1.322} \\y' &= \frac{y}{1.211}\end{aligned}$$

Substituting  $c/0.951$ ,  $m/1.322$ , and  $y/1.211$  for  $c'$ ,  $m'$ , and  $y'$  respectively, we obtain:

$$\text{END's } \begin{cases} c = 0.965D_r - 0.055D_g - 0.010D_b \\ m = -0.284D_r + 1.357D_g - 0.061D_b \\ y = -0.272D_r - 0.172D_g + 1.223D_b \end{cases}$$

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Thus, to obtain the END's of any combination of the above set of color formers, it is only required to measure the integral spectral density. Once the above equations are established there is no need to recompute them for the same color film, as long as the type of dye used remains the same.

7. REFERENCES

1. Overhage, C. F. J. et al, "Principles of Color Sensitometry," SMPTE, 1951.
2. Evans, R. M., Hanson, W. T., and Brewer, W. L., "Principles of Color Photography," John Wiley and Sons, New York, 1953.
3. Mees, C. E. K., "The Theory of the Photographic Process," MacMillan Co., New York, 1954.

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