Densitometry

The densitometer is a precision tool to assist the craftsman in measuring tone values accurately. Densitometric measurements have a number of distinct advantages:

They eliminate the natural differences in human judgment. If you ask two men standing side by side on a street corner how hot or how cold it is, it would be most unusual for the two estimates of temperature to be the same. So it is with tone values. Two people will rarely judge tones with the same degree of accuracy; and no one person can judge them with the same accuracy all the time. But, a well-designed densitometer in the hands of a skilled craftsman gives readings which are precise. If you measure a tone with a densitometer, the reading will not change from day to day or from week to week within limits.

Densitometric readings are expressed in numbers. They can be recorded. They have the same meaning for all craftsmen. They can be incorporated in tables or plotted on graphs to show their relationships to exposure time and development of negatives and positives, and to ink density and dot size in proofs and press prints. Mere word descriptions obviously could not be used in this way.

Being expressed in numbers, densitometer readings make it possible to perform certain calculations. For example, relative exposure times can be accurately computed from densitometer readings. They can only be guessed at from visual estimates.

Density readings can be made on continuous-tone, halftone, transparent, or opaque images. Under proper conditions, the density will be a true measure of visual tone value and also of the light transmitting or reflecting power of the tone area. Making density readings need not be time consuming. Usually, only the important tones need to be measured.

When a craftsman or artist uses a densitometer to measure tone values instead of relying on estimates made by eye, it is certainly no reflection upon his ability. It would be as unreasonable to expect him to judge tone with precision as it would be to expect a photographer to estimate exposure times without a clock or watch, or temperature without a thermometer.

THE MEANING OF DENSITY

*Optical Density**, usually just called *density,* is a standard means of expressing the value of a tone in the form of a number. On positive prints, the density of highlights is set to around zero, while the density of heavy shadows will usually be somewhere between 1.4 and 1.9. The density of the most opaque portions of photographic negatives and positives may run as high as 3.0. Densities greater than 3.0 are seldom encountered in lithographic work.

The numbers used to designate density values are approximately proportional to visual tone values. If a halftone scale is printed with each tone having an increasing density of 0.1, the scale will appear to the eye as a uniform series of tones—a series in which there is the same difference in blackness between each pair of consecutive tones. This would also be true if the density difference from each tone to the next were 0.2 instead of 0.1. In fact, it would be approximately true regardless of how great or how small the difference in density between consecutive tones might be, so long as the difference was the same throughout the scale.

Density is really the degree of blackness of a tone area. This is another way of describing its light-stopping ability. The darker a tone, the higher its density. For positives, therefore, the words *high* and *low* mean exactly the opposite of what they mean to the artist. What the artist would call a *low* tone is a relatively black one of a high density. Likewise, what the artist calls a *high* tone (a highlight) has a low degree of blackness and therefore a *low* density.

When a density value refers to the proportion of light *transmitted* by a tone area, as through a photographic negative or positive, it is called *transmission density.* When it refers to the proportion of light *reflected* by a tone area, as from a drawing, painting, or print, it is called *reflection density.*

The numbers used to designate density values are derived from the relative intensity of light which is either transmitted or reflected by a tone area. But the relationship between density and light intensity is more complicated than a simple proportion. This

* The Term *optical* distinguishes this meaning of the word *density* from its other meaning; that is, the weight of a unit volume of a substance.

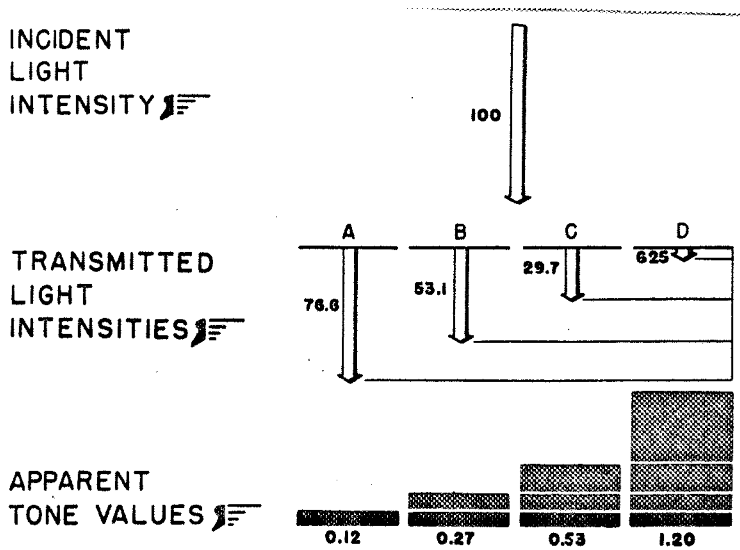

Figure 61. Equal Differences in Light Intensity Do Not Produce Equal Differences in Tone Value

is because the human eye does not interpret tones in simple terms of light intensity. The following will clarify this point.

Suppose we consider a positive transparency containing four different tones: A, B, C, and D. In Figure 61, the intensity of the light *striking* the transparency is indicated by the upper arrow. The intensity of the light *transmitted* through each of the four tone areas is indicated by the lower arrows. In each case, the numerical value of the intensity is shown beside the arrow.

The arrows have been drawn so that the length of each arrow is proportional to the light intensity it represents. The difference in length between arrows A and B is the same as the difference between arrows B and C, or between arrows C and D. In other words, the arrows decrease in length in equal steps.

The values of these tones as the eye sees them are indicated by the black blocks beneath the arrows. The optical density of each tone appears beneath the blocks. Since a highlight has a *low* density value, the blocks *increase* in height as the arrows become shorter. But the heights of the black blocks do *not* increase in equal steps. The increase from B to C, for example, is much less than the increase from C to D. In other words, equal *differences* in light intensity do *not* produce equal differences in tone values.

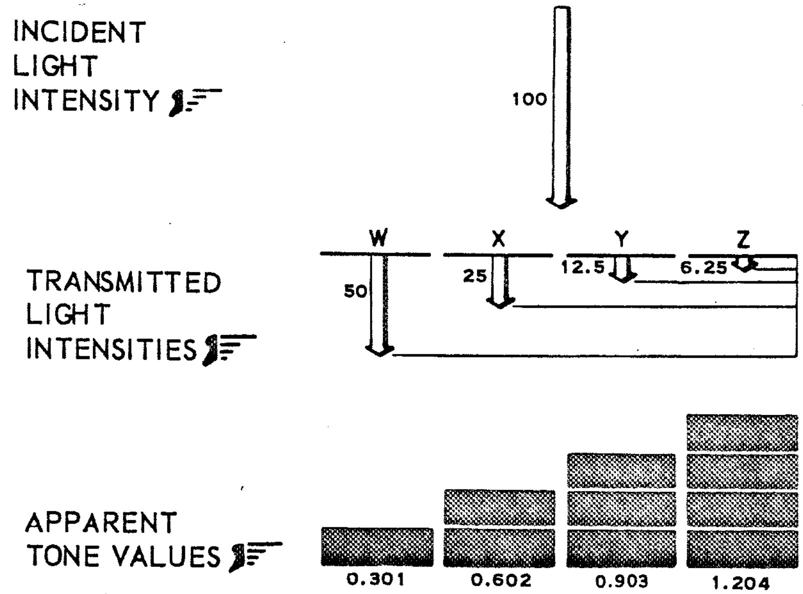

Figure 62. Equal Ratios of Light Intensity Produce Equal Differences in Tone Value

Now consider a different subject containing tones, W, X, Y, and Z. Here the arrows do *not* decrease in length of equal steps. Arrow X is only half as long as arrow W. In turn, arrow Y is only half as long as arrow X. Each arrow is just half as long as the one on its left.

In this case, the black blocks—the tone values—*do* increase in equal steps. Equal *ratios* of light intensity *do* produce equal differences in tone value.

The ratio between the various light intensities does not necessarily have to be one-half. If arrow X had been only one-third as long as arrow W, arrow Y one-third as long as arrow X, and so on, the black blocks would still have risen in equal steps. The only difference is that the steps would have been bigger. To the eye, the gradations between the tones would still have seemed uniform, but the jumps in tone value would have seemed larger.

What Density Is. To anyone who understands what a logarithm is, the relationship between the optical density of a tone and its light intensity will be fairly easy to grasp. And a speaking acquaintance with logarithms can be picked up in a few minutes.*

The logarithm of any number is simply the number of times 10 must be multiplied by itself to obtain the number. For example, 10 x 10 equals 100, so the logarithm of 100 is 2. This is usually written: Log 100 = 2. In the same way, 10 x 10 x 10 equals 1000, so the logarithm of 1000 is 3. Log 1000 = 3. The logarithm of 10,000 is 4.

Logarithms are not necessarily whole numbers. In fact, most

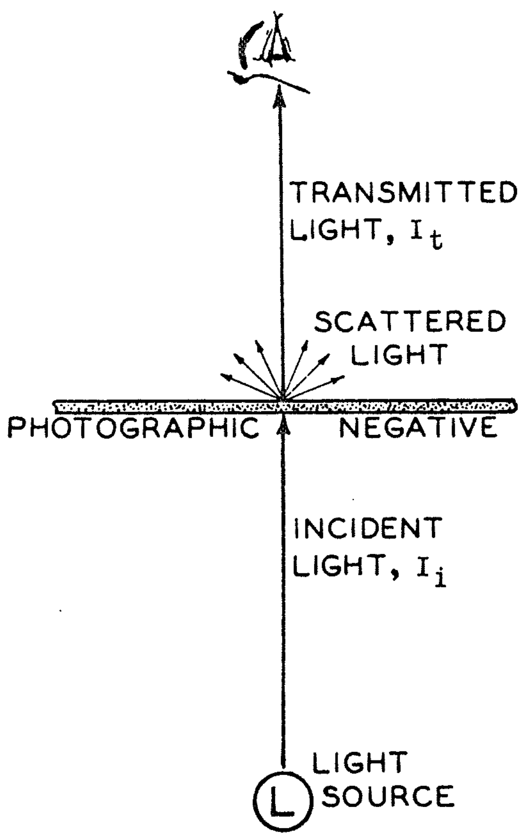

Figure 63. Transmission Density

* The mathematics on the next few pages is presented in simple form. However, one can use density readings in practical work without understanding the mathematical theory behind them. Anyone who prefers to omit the mathematics can ignore the equations and calculations which appear in these pages and concentrate on the comment instead.

logarithms are fractions. To say that the logarithm of a number is ½, or 0.5, means that you must take the square root of 10 to get the number. To say that the logarithm of a number is 1/3, or 0.33333, means that you must take the cube root of 10 to get the number. To say that the logarithm of a number is 4/3, or 1.33333, means that you must raise the cube root of 10 to the fourth power to get the number. However, you don't have to bother with all this to use logarithms.

You can look up the logarithm of any number in logarithm tables. For all numbers greater than 10, the logarithms are greater than 1. For numbers between 1 and 10, the logarithms are between 0 and 1.

Transmission Density. When light strikes a photographic negative or positive, part of the light is absorbed by the plate or film. If the image is an ordinary silver type, part of the remaining light is scattered out of its original path by the small silver particles which make up the image. The rest of the light is transmitted through the negative or positive in its original direction.

Dye images and other images which are not made up of small particles do not scatter light in the way silver images do. All of the light which is not absorbed by a dye image is transmitted through it without any change in direction.

More light is transmitted through the light portions of an image than through the dark areas. These differences in the amount of light transmitted through various sections of the negative or positive are responsible for the different tones of the image.

The light striking the negative or positive is called the *incident* light. The *transmittance*—sometimes known also as *transmission*—of any tone area is simply the fraction of the incident light which is transmitted through the area, without being absorbed or scattered. A tone area which allows half the incident light to pass through it without any change in direction has a transmittance of ½, or 50%.

In the form of an equation, where T is the transmittance, I_t

$$T = \frac{I_t}{I_i}$$

(which is called I-sub-t) is the intensity of the transmitted light, and I_i (called I-sub-i) is the intensity of the incident light.

The *transmission density* of the tone area is the logarithm of the reciprocal of the transmittance.* If D_t stands for transmission density,

$$D_t = \log \left[\frac{1}{T} \right]$$

The density values of the tones in Figures 61 and 62 were computed by using these equations. The practical man never has to make such computations. If he knows the transmittance of a tone area, he can look up its density in a table like the one in the appendix of this text. But merely to show the relationship between light intensity and tone value, it may be interesting to follow the computation of the density of a tone in one of the figures—for example, tone B in Figure 61.

1. Find the intensity of the light transmitted by tone B. This is the number next to the arrow: 53.1.
2. Calculate the transmittance of the tone by dividing the intensity of the transmitted light, 53.1, by the intensity of the incident light, 100. The result is 0.531.
3. Find the reciprocal of 0.531—in other words, divide 1 by 0.531. The quotient is 1.88.
4. Look up the logarithm of 1.88 in a logarithm table. The answer is 0.27. This is the density shown for tone B.

In this example, the intensity of the light striking the image is 100 units. Suppose the intensity of this incident light were doubled. The upper arrow in the figure would become twice as long as it is now. But with the illumination twice as strong, each of the tone areas would transmit twice as much light as before. Consequently, each of the other arrows would double in length also.

In other words, as the intensity of the incident light increased to 200, the intensity of B would increase to 106.2. The transmittance of tone B—106.2 divided by 200, or 0.531—would remain unchanged. And since density depends on transmittance, the density of tone B would likewise remain unchanged. So also with tones A, C, and D.

This illustrates the fact that density values are *relative*. A densitometer reading does not express the value of a tone in terms of light intensity. Instead, it tells how much darker the tone is than some other tone. In Figure 61, the density value of tone B really tells how much darker tone B is than tone A. The same thing is true for the other tones in the figure.

* To get the reciprocal of any number, divide one by the number. For example, the reciprocal of 2 is ½, or 0.5.

The tones on photographic negatives and positives ordinarily have density values somewhere between zero and 3.0. Zero would be the density of an extreme highlight in a positive or a deep shadow in a negative—a tone area which permitted *all* of the incident light to pass through it. 3.0 would be the density of an extremely black tone area in a color transparency. Intermediate tones would, of course, have densities in between these two extremes.

At first glance, this range of density values may seem rather small. Actually, it is quite large. The relationship between density and light intensity is *logarithmic*. To say that a tone has a density of 3 means that the logarithm of one divided by the transmittance of the tone is 3, or, in the form of an equation,

$$\log \frac{1}{T} = 3$$

In turn, this means that in order to find the value of the fraction $\frac{1}{T}$ you must multiply 10 by itself three times.

$$\frac{1}{T} = 10 \times 10 \times 10 = 1000$$

Consequently: $T = 0.001$

But T (the transmittance) is the fraction of the incident light which passes through the tone area without being absorbed or scattered. A tone with a density of 3, in other words, transmits only 1/1000 of the light which strikes it. In contrast, a tone with a density of zero transmits *all* of the light which strikes it. The density range from zero to 3.0, therefore, represents a thousand-fold range in light intensity.

For practical purposes, the meaning of density values can best be understood by remembering that if the difference in density between two areas is 0.3, it means that one area transmits or reflects twice as much light as the other. A difference of 1.0 means that one area transmits or reflects ten times as much light as the other.

Reflection Density. Reflection density is very much like transmission density. When light falls on an opaque image, a paper print for example, part of the light is absorbed. The remainder is reflected in various directions (see Figure 64).

How much light is reflected in each of the different directions by a given tone area depends on two factors. The first factor is the tone density of the area. A highlight reflects more light than a shadow tone. The second factor is the nature of the surface of the image. A glossy surface reflects a beam of light largely in one direction, as though the surface were a mirror. A rough or matte surface reflects the light more nearly equally in all directions.

In measuring reflection densities, the standard practice is to illuminate the tone area at an angle of 45 degrees, and to measure the amount of light reflected at 90 degrees to the surface. This arrangement corresponds roughly to average viewing conditions. Anyone reading a book or a magazine holds the page more or less perpendicular to his line of sight. The source of light is usually somewhat to the side. The reader sees only the light which is reflected into his eyes—at roughly 90 degrees to the page. Any light reflected in other directions is lost so far as the reader is concerned.

Just as *transmission* density is based upon the *transmittance* of a tone area, so *reflection* density is based upon *reflectance.* But there is one important difference between transmittance and reflectance. Transmittance is the fraction of the *incident* light which passes through a tone area without being absorbed or scattered, in

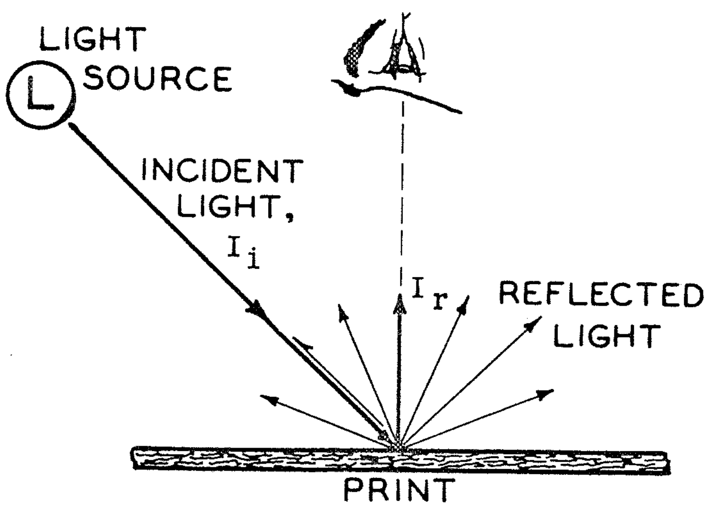

Figure 64. Reflection Density

other words, the ratio between the intensities of the original *incident* light and the amount of it that is *transmitted.* In the case of *reflectance,* the *incident* light is not considered in a measurement. Reflectance is the ratio between the amount of light reflected from a given tone area and the amount reflected from a comparison standard. In graphic arts this standard is usually an unprinted area on the same paper. For checking paper whiteness or absolute color, the reference standard is usually a block of magnesia. As an equation,

$$R = \frac{I_r}{I_{rw}}$$

where R stands for reflectance, I_r is the intensity of the light reflected by the tone being measured, and I_{rw} is the intensity of the light reflected under the same conditions from the surface of the reference standard.

Reflection density has the same relationship to reflectance that transmission density has to transmittance. Reflection density is the logarithm of the reciprocal of the reflectance. If D_r represents reflection density,

$$D_r = \log \frac{1}{R}$$

Reflection density readings express the values of tones in an opaque image, like a photographic print or a lithographed press proof, in exactly the same way that transmission density readings express the values of tones in a transparency. Reflection density values, like transmission density values, are proportional under most viewing conditions to visual tone values. Like transmission density readings, reflection density readings are relative. They are not affected by changes in intensity of illumination. They do not express the value of a tone in terms of light intensity. Instead, they tell how much darker one tone is than another. The whitest area on the sheet (the unprinted margin) has a zero density. All of the other readings on the print are expressed in relation to this value.