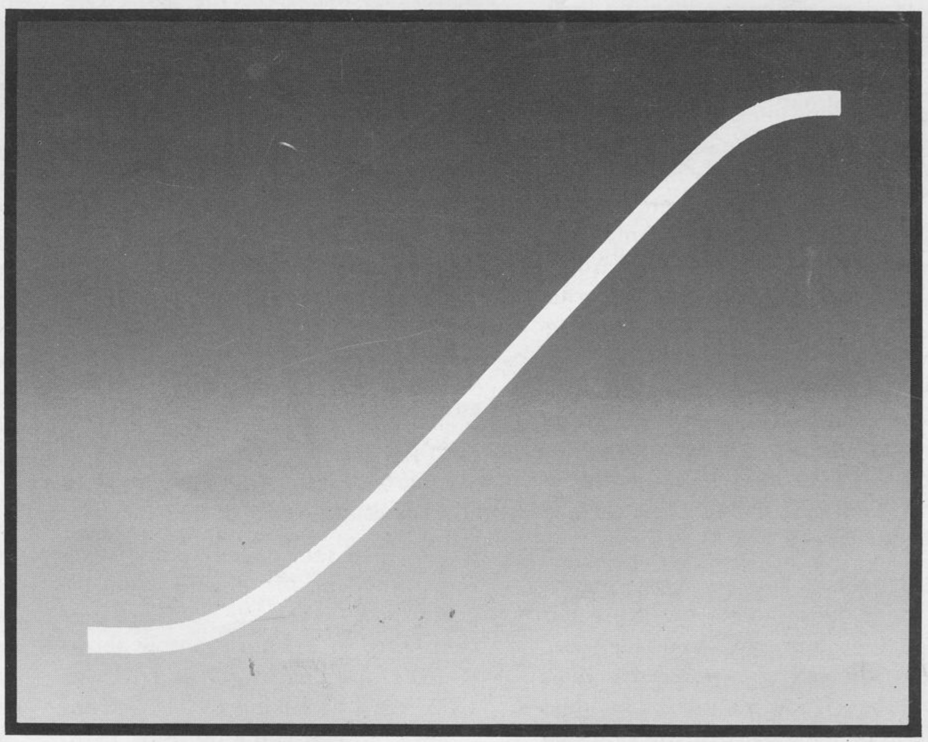
E-59

Kodak

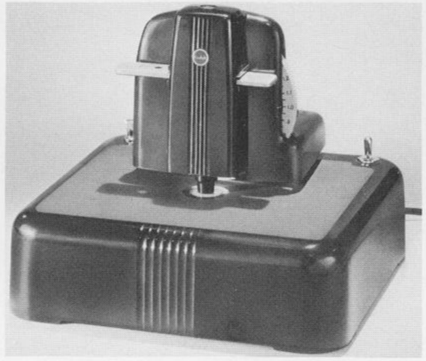
PRACTICAL DENSITOMETRY



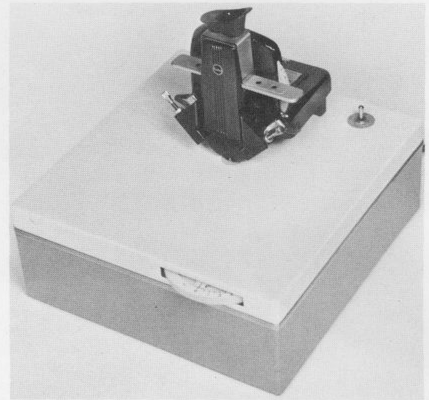
How to Use Density Readings in Black-and-White or Color Printing

This booklet is intended to acquaint you with the basic principles of plotting and interpreting densitometric data. In other words, it tells you how to make use of density readings obtained with an instrument such as one of those illustrated. You will probably find the information contained here of most value if you read it from the beginning, so that you understand each new idea as it is presented.

KODAK COLOR DENSITOMETERS



Model 1



Reflection-Transmission, Model 10-K

THE LANGUAGE OF DENSITOMETRY

Before tackling some of the practical uses of elementary sensitometry-densitometry, let's take a quick look at some of the terms—words and phrases—that you will be using regularly.

We have headed this section "The Language of *Densitometry*," and then in the first paragraph, we refer to *sensitometry*. We'd better explain that before going any further.

"*Sensi*tometry" is derived from two Latin words meaning "sensitivity" and "measurement." We're not talking Latin, so we'll use it to mean determination of the photographic characteristics of a light-sensitive emulsion. "*Densi*tometry" (density measurement) is the use of a densitometer to get the data that will let us determine the photographic characteristics of a film—or paper. (A *transmission* densitometer is used to measure the amount of light that passes through a film. A *reflection* densitometer is used to measure the light that reflects from the face of a print.)

Since we are going to show you how to use a densitometer, we'll use the term "densitometry" from here on. Really, the use of one word implies the other. Think about it like this: Densitometry is part of the practical application of sensitometry. It's a way you can use some photographic theory to improve your own photographs and save yourself some work. Now, as to some of the terms.

Density, the way we'll be using it, relates to the amount of developed silver (or dye) in any area of a negative, color transparency, or color negative. It's a measure of the "light-stopping power" of that area. The figures we use to express density—those on the scale of your densitometer—are derived like this:

TRANSMISSION = the amount of light that gets through any area **divided by** *the total amount of light that hits that area.*

Transmission is usually called "T" and is expressed as a percent, so you have to multiply the above fraction by 100. A transmission of 85 percent (T=85%) means that 85 percent of the light that hits any specific part of a negative or transparency gets through it.

OPACITY = the total amount of light that hits any area **divided by** *the amount of light that gets through that area.*

As you can see, opacity is transmission turned upside down. Stated algebraically, O=1/T. We don't use percent here; so, for our example above (T=85%), the opacity (O) is 1/0.85 or 1.175. We'll be talking about opacities quite a bit, and you'll be using them later. Remember: the higher the opacity, the less light gets through.

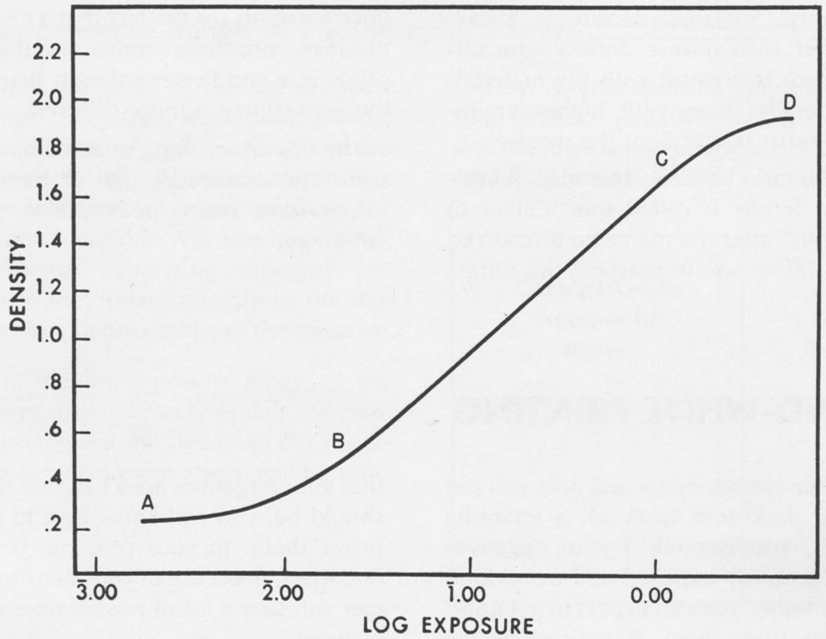
Now, density (D) relates directly to the opacity; it's the logarithm (to the base 10) of the opacity.

$$D=\log O \text{ (or } D=\log 1/T)$$

If you don't remember much about logs, don't let that equation scare you. For your reference when you do any figuring, we've included a Density-Opacity Table on page 15. Keep in mind that density and opacity actually mean about the same thing. They are written in different ways, that's all.

The density in any part of a negative depends on the exposure which that part of the negative received and the amount of development given the film. In any negative, the density differences we see are there because the different areas received different amounts of exposure. We can say that, with any given degree of development, the density anywhere in the negative depends on the exposure at that point.

Let's draw a picture of that relationship. To do it, we need to get a piece of film, give it a series of exposures (like a test strip), and develop it. Then we'll read the densities in the developed strip, and plot them against the logarithms of the exposures we used to produce them. (We use the logarithms of the exposures because the density is logarithmic.) Here is the resulting graph:



That ought to look familiar to you. It is the characteristic curve, or H & D curve (after Hurter and Driffield, the men who devised it), or D-log E curve, or whatever you know it by. We'll call it the "characteristic curve."

This curve actually describes the photographic characteristics of the film for the development given. Densities falling on the "toe" portion (A-B) of our curve are not directly proportionate to the log exposures. Neither are the "shoulder" (C-D) densities. That doesn't mean that we shouldn't use these two parts of the curve. We do. In a really good negative, we often use the toe. The main thing here is to know what the "toe," "shoulder," and "straight-line" portions of the curve are, and what they mean to us in our picture-taking. (We're going to draw our own curves later, so we'll need to be familiar with these terms.)

B-C is the "straight-line" portion of the curve; the density in the film increases proportionately with the log of the exposure. Extend the straight-line part of the curve so that it meets the log E scale at the bottom of the graph. The slope of the line (tangent of the angle between the line and the log E scale) is "gamma." Generally, the longer you develop any film, the higher the gamma will be, until it **finally reaches a limit. We can say this** another way: The higher the gamma, the greater the contrast of the negative *due to development*. That italic phrase is important. The total—or printing—contrast is due to quite a few factors: subject contrast, development contrast, flare in the optical systems of camera and enlarger, etc. So, when we talk about gamma, we are referring to *development* contrast only.

Contrast index is also a measure of development contrast of a film. It indicates the *average slope* of that portion of the characteristic curve commonly used in a particular picture-taking application, such as portrait, press, or amateur photography. To measure contrast index for most general-purpose films, a point is selected on the characteristic curve where the density is 0.2 above fog and base density. This usually falls on the toe of the curve and represents the minimum density used in most negative making. A straight line whose length is equal to 2.0 log E or density units is drawn between this point and another point on the curve where it intersects at a higher density. The slope of this straight line is the average gradient, or "contrast index."

Contrast-index values have replaced gamma in the data sheets for most Kodak general-purpose black-and-white films. This makes it easier to obtain consistent results from the variety of films which are suitable for a given application. However, for purposes of control with the film-developer-paper combination you use in your darkroom, you will probably find gamma measurements more desirable.

Remember that, in the straight-line portion, the density in the film increases an equal amount for each log exposure increase; therefore, we say that we have "good tone separation" in those areas of our pictures that are composed of straight-line densities.

In the toe and shoulder regions of the curve, though, equal log exposure differences don't produce equal density differences, so we can say that the tones in our pictures are *compressed* in the shadows and highlights. *The tone separation is never as great in the toe and shoulder regions as it is in the straight-line portion.*

The highlights in our negatives shouldn't fall on the shoulder any more than we can help. If we overexpose very much, more of the densities will be in this shoulder region. We'll then have very poor highlight tone separation in our prints. As we said, part of our shadow densities will normally be on the toe of the curve; if we underexpose quite a bit, we use too much of this toe portion, and our shadow tone separation will be poorer than it should be.

In the case of gross over- or underexposure of the negatives, our prints are apt to be flat (low in contrast), with the important tones in either highlights or shadows showing far too little separation.

If we expose and develop our negatives so that as few densities as possible fall on the toe and shoulder, we're all right—we have "good" negatives.

Before closing this basic theory section, we want to clear up a point that is bound to arise sooner or later. There are two kinds of density, differing in the geometrical arrangement of the optical system in which measurements

◀ **Punched to fit the Binder for Kodak Technical Information (W-4), sold by photographic dealers.**

are made. If *all* of the light passing through the film sample is collected and measured, the value is *diffuse* density.

On the other hand, if the light incident on the sample is restricted to a narrow beam and only a narrow beam of the transmitted light is collected and measured, the value is *specular* density. Specular density is always higher than diffuse density; the difference is greatest with the materials (generally those with higher graininess) that scatter light the most.

The ratio between specular and diffuse density is called the "Callier Q Factor," after the man who discovered the difference. In practice, this difference accounts for the fact that a given negative produces more contrasty prints in a condenser enlarger than if the light source is more diffused.

The important thing in all comparisons is to make sure that all density values have been measured in the same way.

DENSITOMETRY IN BLACK-AND-WHITE PRINTING

Now, let's consider some practical problems. For a start, we'll take up the question of exposure, development, and printing of black-and-white pictures.

Your densitometer will help you put your darkroom work on a scientific basis. You can tell if your negatives are properly exposed and developed —whether you can expect to get good prints from them. If indications are that your negatives aren't all that they should be, you will know how to improve them. In your printing, you'll find that correct use of your densitometer will save a lot of wasted time and materials.

Judging Negative Exposures

First of all, check up on yourself: You've been making good negatives, but let's see if we can't improve them a bit. Get a few of your negatives together—some that are representative of your work.

Take a density reading of the clear edge of the film. Write it down. (Always keep a scratch pad and pencil with your densitometer, or, better still, start keeping a notebook. Never trust your memory.) Next, read the density of the shadow area—the lightest part —of the image in the negative. Now, subtract the first reading from the second. Is the difference at least 0.05? If it's lower than that value, your negative is probably so underexposed that you'll never get a really good print from it.

The first reading you took indicated the density of the film support (*base density*) and the small amount of fog that is always present due to development. Such a measurement is called a "base-plus-fog" density determination.

We've said that the difference in density between the deepest shadow in a negative and the base-plus-fog should not be less than 0.05, and preferably is should be a little greater. So, if your shadow densities are consistently lower, increase your exposures by using a lower film speed. On the other hand, the difference between the shadow density and base-plus-fog shouldn't be too great—not more than about 0.25. If it is consistently more than this, reduce your exposures by using a higher film speed. You'll notice an improvement in your prints and in the ease of printing your negatives. We haven't mentioned changing your development yet. Don't. Shadow-density measurements are used to check on proper exposure level. That's a very important point to remember.

Density Range of Negatives

Let's measure the density range of a negative. Here we don't need to measure the base-plus-fog density unless we want to for some special purpose. We're going to compare two densities in the negative, and the base-plus-fog will be part of each; it will cancel itself in any calculations we make.

Read the density in the negative of the blackest highlight in which you expect some detail in your print. Then read the shadow density, or the lightest part of the negative in which detail is required. Subtract the shadow density from the highlight density; the difference between them is the density range of the negative. For example:

Highlight density	= 1.18
-Shadow density	= 0.13
Density Range	= 1.05

That's all there is to that. One word of caution:

Some things you photograph may contain shiny objects—metal, glass, etc—that reflect light brilliantly. The "highlights" in your negative will not be these very bright reflections. They contain no detail at all and should reproduce in the print as white. The highlight you measure should be the densest part of your negative in which you want to be able to see detail in the print. This is the type of area sometimes referred to as a "diffuse highlight."

Now that we know how to find the density scale of a negative, let's put it to practical use.

Log-Exposure Range of Photographic Papers

When we speak of the log-exposure range of a paper, we're talking about the difference in the amounts of exposure to light necessary to produce the full range of tones of which the paper is capable. We use logarithmic units for expressing exposure because they relate directly to the logarithmic density range of the negative.

If the log-exposure range of the paper approximately equals the density range of the negative, the resulting print, in many cases, will be satisfactory. A table showing the relationship between negative density range and the log-exposure ranges of Kodak papers appears below.

However, in pictorial or portrait printing, you may want to use a paper with a higher or lower contrast to achieve a particular effect.

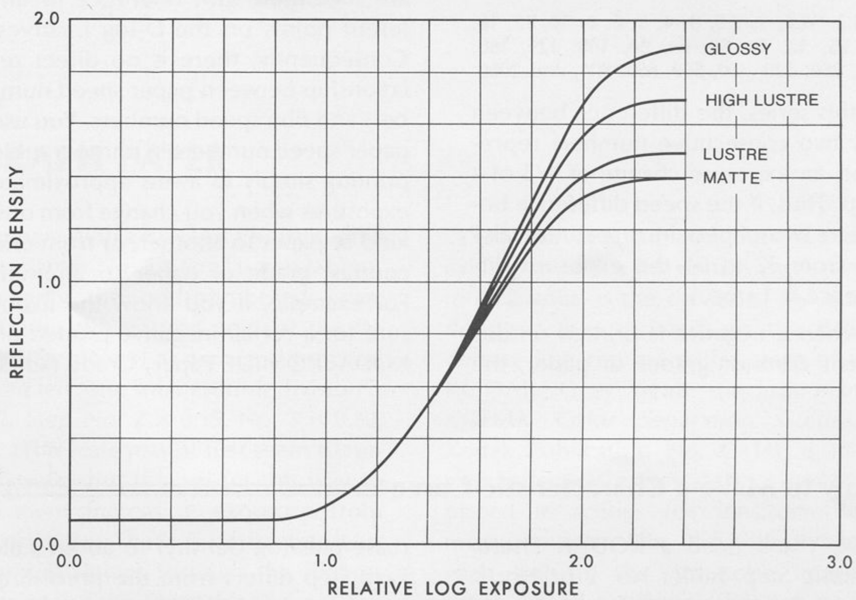
Contrast-Grade Number of Paper	Log-Exposure Range of Paper	Density Range of Negative Usually Suitable for Each Log-Exposure Range or Grade Number
0	1.40 to 1.70	1.40 or higher
1	1.15 to 1.40	1.20 to 1.40
2	0.95 to 1.15	1.00 to 1.20
3	0.80 to 0.95	0.80 to 1.00
4	0.65 to 0.80	0.60 to 0.80
5	0.50 to 0.65	0.60 or lower

Contrast-Grade Number and Log-Exposure Range

The contrast numbers 0, 1, 2, 3, 4, and 5 are broad indications of the log-exposure ranges of the papers, and thus, of the types of negatives that can be printed satisfactorily on each contrast of paper. A negative with a very long density range will print best on grade 0 or grade No. 1 paper, both of which have long log-exposure ranges. Conversely, a negative with a very short density range will print best on contrast grade No. 5 paper, which has a short log-exposure range. Similar contrast grades of Kodak papers have similar log-exposure ranges, but papers having similar log-exposure ranges, with different surfaces, have different apparent density ranges in the print. For example, the log-exposure ranges of KODAK AZO Paper F and KODAK AZO Paper E are practically the same, but a print on the E (matte) surface will appear to have less contrast because of the diffuse reflection of light from the matte surface.

If you know the density range of a negative, you can pick the contrast grade of paper that suits it by matching the log-exposure range of the paper with the density range of the negative. However, this will be only an approximation in many cases, because of the subjective nature of pictures, and because of your own personal preference for a higher or lower contrast print.

Since there will be a difference between the actual density range of a negative as determined on a densitometer and the effective density range at the enlarger easel, because of the enlarger optics, it is preferable to read the density range of negatives to be enlarged directly on the easel.



TYPICAL SENSITOMETRIC CURVES FOR CONTRAST GRADE 2 KODAK PAPERS WITH VARIOUS SURFACES

Finding Exposure Times for Prints

Pick a negative, measure its density scale, and select the right paper grade. Then, by trial, find the exposure time required to make the best print you can–a "straight" print. (Don't do any dodging or printing-in yet.) Now record the exposure time and the highlight density of the negative.

Suppose our test negative has a density range of 1.10. That means we'll pick grade No. 2 (See the table on page 5.) The highlight density of the negative measures 1.40, and the exposure time was 12 seconds at the magnification we used. Now that we know these things, we're all set.

We can take any other negative and, if the density range is right for No. 2 paper, get the right exposure for it from its highlight density, with no further tests. To do it, we'll either use the Enlarging Computer in the *KODAK Master Darkroom DATAGUIDE*—that's the easiest way—or calculate our new exposure from the Density-Opacity Table on page 15.

Opacities are directly proportional to exposure times. Let's assume that our new negative has a highlight density of 1.30 and our test negative measured 1.40 in the highlight area. From the Density-Opacity Table we find that the corresponding opacities are 19.95 and 25.12. The exposure time for our test print was 12 seconds, so, to find the exposure time for the new negative, we just make a little computation: Exposure time for new negative = 19.95 x 12 =239.40 ÷ 25.12 = 9.5 seconds.

Remember that exposure times are directly proportionate to opacities, and you can figure exposures for any number of negatives from just one test if the negatives can all be printed on the same type and grade of paper.

American National Standards Institute Paper Speeds

The speed of Kodak papers is given in accordance with the ANSI Standard titled *Sensitometry of Photographic Papers, PH2.2-1966* (Available from American National Standards Institute Inc., 1430 Broadway, New York, N.Y. 10018). This standard method provides a simple way to express paper speed with one number. These speed numbers indicate the relative speed of different papers. The series of ANSI paper speed numbers is as follows:

1, 1.2, 11.6, 2, 2.5, 3, 4, 5, 6, 8, 10, 12, 16, 20, 25, 32, 40, 50, 64, 80, 100, 125, 160, 200, 250, 320, 400, 500, 650, 800, and 1000.

In this series, the difference between any two consecutive numbers represents an exposure change of 1/3 of a stop. Thus, if the speed difference between two papers in three intervals–say from 32 to 64–the exposure difference is 1 stop.

When a negative is printed on different contrast grades of paper, the prints can easily be compared when a midtone is matched in the prints. Consequently, ANSI paper speeds are measured at a midtone (0.6) according to this formula: $S = \frac{10^3}{E_{0.6}}$ where $E_{0.6}$ is the exposure in meter-candle-seconds required to obtain a density of 0.6 above "base-plus-fog" density.

Since a useful speed number for any photographic material must be related closely to its principal use, the speed numbers for films and papers are measured with reference to different points on the D-log E curves. Consequently, there is no direct relationship between paper speed numbers and film speed numbers. You use paper speed numbers in photographic printing simply to assess approximate exposures when you change from one kind of paper to another, or from one contrast grade of paper to another. For example, if you know the exposure for a certain negative printed on KODABROMIDE Paper, Grade No. 3, the approximate exposure for another grade can be calculated. Just multiply the known exposure by the speed number of the paper used, and then divide the result by the speed number for the paper you wish to use.

The paper speed numbers given in the instruction sheet packaged with the paper are for the average product. Exposures calculated by means of these numbers may not be exactly correct, because exposure in printing is critical, and because aging or adverse storage conditions may alter the characteristics of an emulsion. Further, the subjective nature of print density may require that more or less exposure be given to obtain a desired effect. Consequently, speed numbers are intended to provide a starting point in determining correct exposure, and a basis for comparing the relative speeds of different papers.

How to Make a Characteristic Curve

First, you'll need a KODAK Photographic Step Tablet No. 2 or No. 3. This is a "step wedge" consisting of 21 densities running from about 0.05 (base-plus-fog density) to about 3.05. Each step differs from the preceding step by a density difference of about 0.15, corresponding to an actual exposure difference of 1.414 (square root of 2). Read all the densities of the steps and record them. You have "calibrated" your step tablet.

(Actually, the steps on a KODAK Photographic Step Tablet are so close to being 0.15 apart that you don't really need to calibrate it. If you just assume that the steps run from 0.05 to 3.05, they'll be easy to lay off on graph paper, and any little deviations from these values won't matter in making comparisons.)

Now, make a contact print of this calibrated step tablet (which we'll call the "original" step tablet from now on) on the black-and-white film you normally use. Use a printing frame, but be sure to back up the film with black paper. Sheet film is the easiest to handle, but you can also work from roll film (including 35mm) or film packs.

An enlarger is an excellent light source to use in making your exposures, since most contact printers are too "fast." You need an exposure long enough to control easily. If you have an exposure meter, measure the light intensity on the baseboard. Change the magnification of the enlarger to obtain a reading of 3 to 5 footcandles with the lens at *f*/4.5 Then, after the lens has been set at *f*/16, the exposure time should be about 10 seconds.

Exposure here is *not* critical except that all the 21 steps of the original should show in the reproduction. Don't use an exposure that's too great; try to get a density of about 0.1 or a little less in the reproduction of the densest step of the original. You can do it easily after a couple of trials. (If you need to or want to read wet negatives, wipe them off as you usually do before drying them, and then fold a sheet of clear KODACEL Sheet, cellophane, or some other waterproof transparent material around them. You won't get exactly the same readings as with dry negatives, but, as a quick check, the results are accurate enough.) Don't work for *exactly* 0.1 in your lightest step, just something close to that value. The idea is to include all the steps of the original in your reproduction *without* getting too much density in the lightest steps. We want some "toe" in our curves – that's where the deepest shadows in a scene fall in a normal negative.

Develop your "test scale" just exactly as you normally do your films and at whatever temperature you use regularly. If you usually use a tank, use it here. If you tray develop, do so now. *Follow your normal procedure until you make a few curves.* You'll then know whether you need to change your routine or not.

Fix, wash, and dry your test scale in the normal way; then read the densities of the steps. Write them down beside the densities of the original step tablet, but *backwards*. That is, start with the heaviest densities of your test scale, and write them opposite the lightest densities of the original as shown below.

Now make a graph. Use regular graph paper, which is divided up into little squares, not log paper, which has uneven divisions. Or, if you wish, you can use KODAK Curve Plotting Graph Paper, which is made for this purpose.

STEP NO.	ORIGINAL DENSITY	DENSITY OF TEST
1	0.08	2.19
2	0.26	2.12
3	0.41	2.02
4	0.57	1.93
5	0.73	1.82
6	0.86	1.73
7	1.01	1.63 and so on.

KODAK CURVE PLOTTING GRAPH PAPER

This specially designed graph paper provides a quick and easy way of plotting step-tablet or gray-scale images made on black-and-white and color films. The semitransparent paper stock enables two or more sheets to be superimposed for easy direct comparison. The vertical lines marked 1 through 21 along the bottom of the graph represent the 21 steps of the KODAK Photographic Step Tablet No. 2 or No. 3. Plot the density of each step in the step-tablet image on the vertical line corresponding to the step number. With a KODAK Photographic Step Tablet No. 1A (an 11-step tablet), use only the odd-numbered lines. Consider the starting point at the far right (Step No.1) as zero and proceed to the left. The smallest unit division is 0.02. Step No. 2 is 0.15, No. 3 is 0.30, etc. (The scale may at first seem to run backward, but it is set up this way to represent increasing exposure from left to right. That's because the least exposure comes through the highest densities of the step tablet.)

The horizontal axis of this graph is called the abscissa and the vertical axis, upon which the density increases in 0.02 units, is the ordinate. The ten density values printed on the 0.20 density line represent the steps of a KODAK Gray Scale (included in *KODAK Color Separation Guides*, Kodak Publication No. Q-14), a 10-step reflection gray scale that can be placed in scenes for sensitometric measurements. Plot the density of each step in the gray-scale image (from negatives containing the gray scale) along vertical lines drawn from these points. You can order *KODAK Curve Plotting Graph Paper,* Kodak Publication No. E-64, in envelopes containing 25 sheets at $1.00 and *KODAK Color Separation Guides,* Kodak Publication No. Q-14, at $1.95 from your photo dealer or from Eastman Kodak Company, Dept. 454, Rochester, N.Y. 14650. Please include remittance plus any state or local tax with your order. Prices are subject to change without notice.

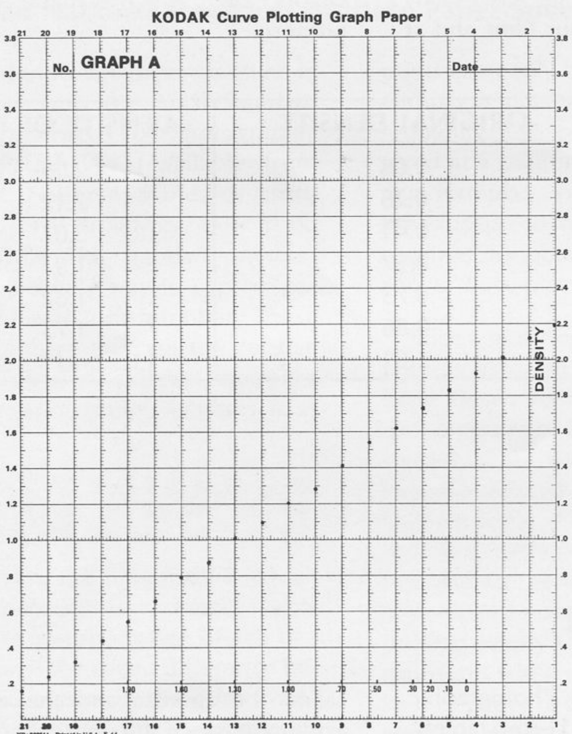
Plotting the Characteristic Curve

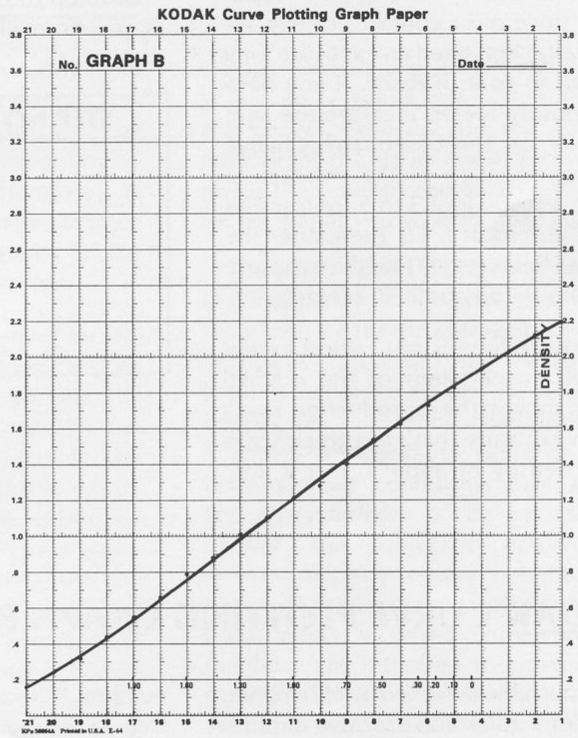
If you use KODAK Curve Plotting Graph Paper, plot the densities in the test scale above the 21 points on the abscissa that represent the steps of the tablet. If you use regular graph paper, start the abscissa scale at the right with 0.0 and then plot the densities of the test scale above the actual densities of the original step wedge. In either case, the shape of the resulting curve will be the same.

For example, if Step No. 1 has a density of 2.19, that means you make a dot at this density level on the vertical line over the figure "1" on the KODAK Graph Paper, or right over the density of original Step No. 1 (which is 0.08) on the abscissa of the regular graph paper. Step No. 2 plots at the 2.12 density level over figure "2" on the Kodak Paper, or over 0.26 on the regular paper, and so on. When you've plotted all the steps, you should come out with something like graph A as shown below.

Now, draw a smooth curve through the *average* of these points. Don't try to connect each individual point to the next one, because they never line up perfectly. Your first curve ought to look like graph B as shown below.

That's it. A characteristic curve that shows what you are getting out of your film under *your* working conditions.



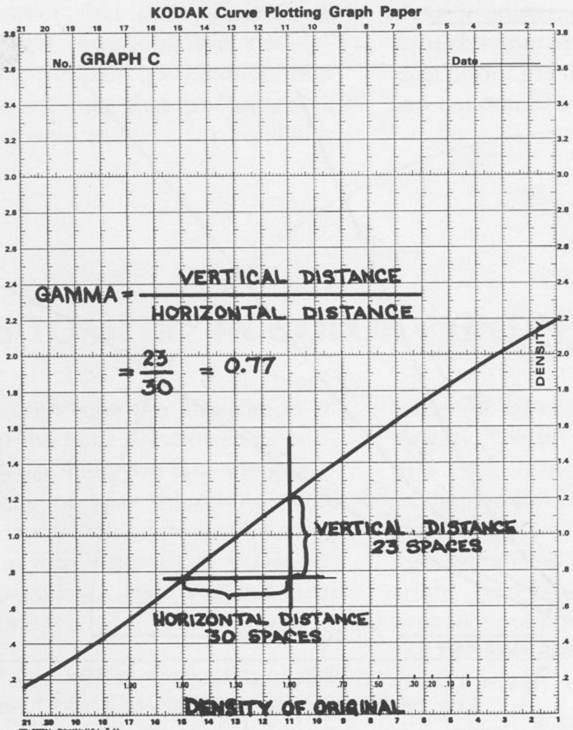


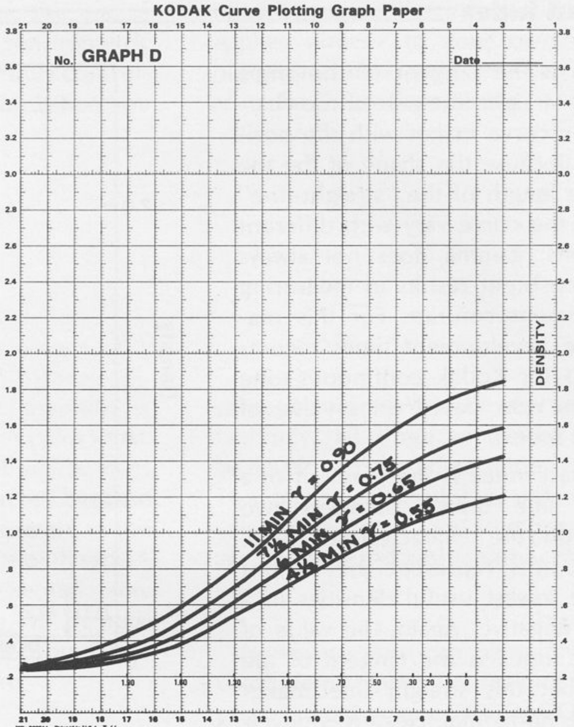
Gamma

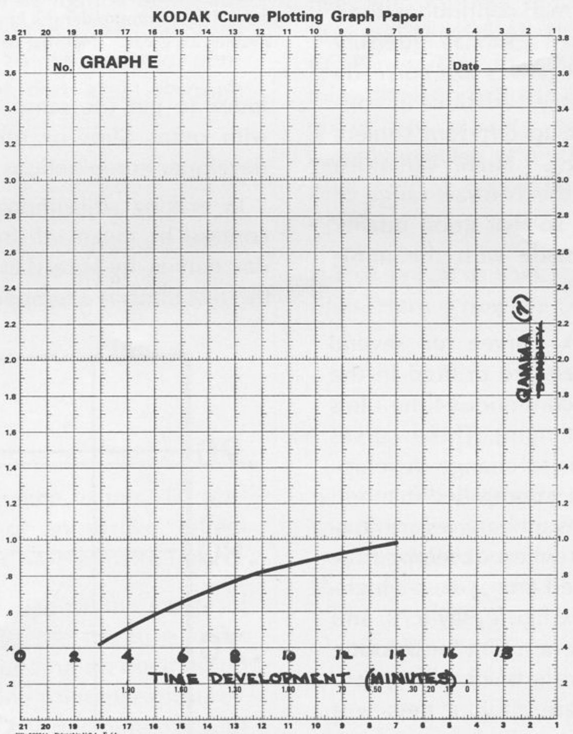
In figuring gamma, you don't need to use trigonometry. Pick any point on the straight-line portion and count to the right 30 small units (0.6 on the lower axis). Now count the small units up to the curve (on the vertical axis). Let's say there are 23 of them. Then *GAMMA = the vertical distance* **divided by** *the horizontal distance = 23* **divided by** *30 = .77.* (As shown in graph C.)

How does your gamma check out against what you thought you were getting? If your negatives print best on No. 2 paper, don't change the development time for your picture negatives, even if the gamma isn't what you thought you were getting.

While you're experimenting with the step tablet, though, why don't you make your own time-gamma chart? Expose four test scales from







the original. Expose them just alike. Then develop them like this:

Develop one of them for 3/4 of the time that is recommended; another for the recommended time; another for 1 1/4 times the recommended time; and the last for 1 3/4 to 2 times the recommendation.

For example, suppose you're using KODAK PANATOMIC-X Film and KODAK MICRODOL-X Developer at 75 F. Cut up a roll of the film and expose four test scales. Develop them (if you use a roll-film tank regularly, use it here) for 4 1/2, 6, 7 1/2, and 11 minutes.

Now plot all four curves on one sheet of graph paper and measure the gamma produced by each developing time(see graph D).

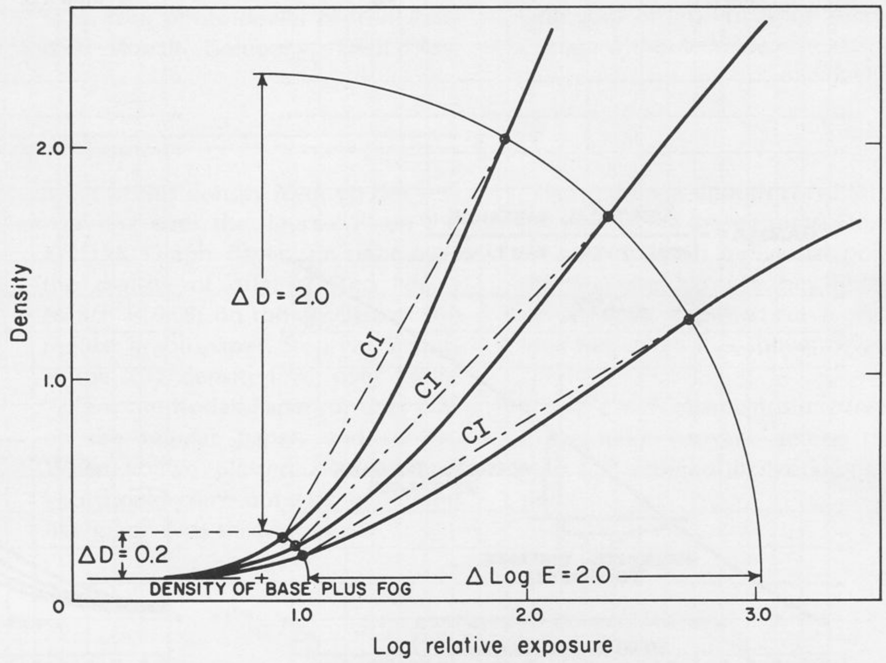
Take a fresh sheet of graph paper and plot time of development (on the horizontal axis) against gamma on the vertical axis. Draw a smooth curve through these points, as shown in graph E.

If you want to use any particular gamma for any reason, find it on the "gamma" axis. Then draw a horizontal line over to the curve. From that point on the curve, draw a perpendicular line down to the "time" axis. Develop for time indicated, and, provided you do everything as you did when you made the time-gamma curve, you'll get pretty close to the gamma you want. You never will come out exactly right unless you do everything exactly the same way each time, but you ought to be within ±0.04 of the predicted value. If you're not, standardize your technique some more!

Contrast Index

Gamma is the tangent of the angle that the straight-line part of the characteristic curve makes with the horizontal. Because the shape of the toe and the length of the "straight-line" part of the curve vary with different emulsions, gamma does not always yield consistent results in measuring development contrast. For this reason, the development times recommended for Kodak continuous-tone films are now based on a value of contrast index.

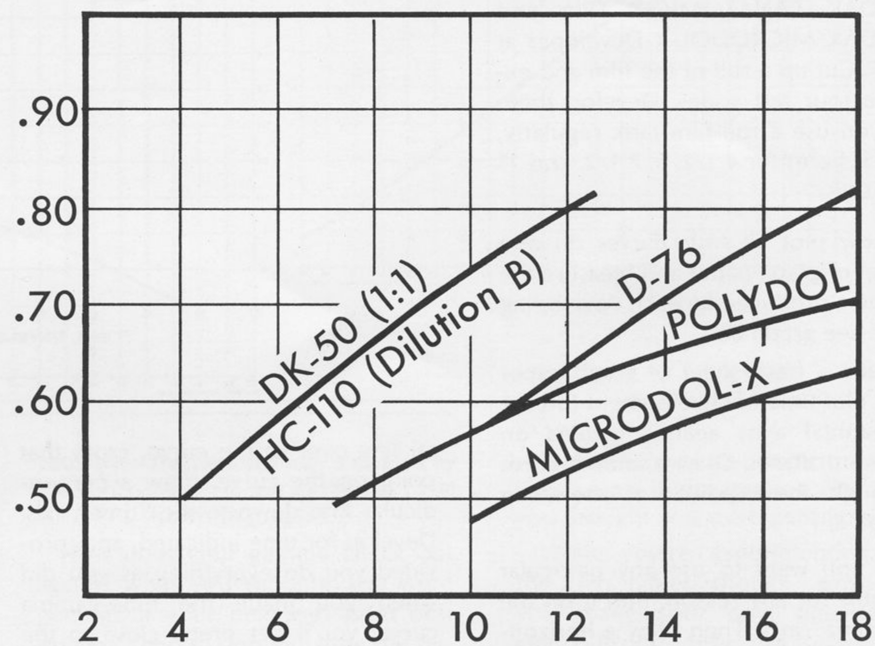
Contrast index is the gradient of a straight line drawn between two points on the characteristic curve. These points represent the highest and the lowest useful densities in a normal negative. Again, the value of contrast index is the tangent of the angle that this straight line makes with the horizontal. Negatives developed to a given contrast index—0.56 to 0.60 for normal continuous-tone work—will have similar density ranges. If the negatives are correctly exposed, noticeable variations in contrast will be due to different subject brightness ranges. Such variations are well within the contrast range of printing papers, so that good quality prints can be made with the minimum of difficulty.



Contrast index (CI) is the slope of a straight line joining selected minimum and maximum densities on the characteristic curve. The minimum density lies on the arc of a circle having a radius of 0.2 in density units. The maximum density lies on the arc of a larger circle concentric with the smaller one and having a radius 2.0 greater than that of the smaller circle.

Contrast-index curves for several Kodak developers are printed in the data sheets for continuous-tone films (see example at right). These curves provide a means to change development contrast in a controlled manner. For example, if your negatives are consistently too flat when developed for the recommended time, select a higher contrast index figure, say 0.70, and then develop the test film for the time shown on the scale below the graph. On the other hand, if your negatives are consistently too high in contrast, select a contrast index value below 0.60, say 0.50, and develop for the shorter time indicated by the time scale. You may need to make more than one trial to arrive at the contrast that best suits your conditions. When this has been done, however, you can then use the most suitable contrast index to get the same density range with other films or other film-and-developer combinations.

In making adjustments to negative contrast by means of the contrast index curves, be sure that you develop the test films at a temperature of 20 C (68 F) or as indicated and that you use the agitation procedure recommended for the method of development in use. Also, be sure that the developer is at proper working strength. Obviously, any departure from standard conditions would make the tests valueless.



Remember that such projects as we've been discussing are not intended to replace the development information, etc, that photographic manufacturers provide for use with their products. However, the manufacturers obtain their sensitometric data under the most carefully controlled conditions imaginable. When you need to get similar information that applies directly to your own techniques and darkroom, you can do it as we have just described.

DENSITOMETRY IN COLOR PRINTING

You've seen how the application of some of the basic principles of densitometry can help you take the guesswork out of your black-and-white photography. You can do the same thing in your color work—take out the guesswork, the trial-and-error methods.

Black-and-white films have one emulsion. Color films have three—one sensitive to red light, one to green light, and the third to blue light. After processing, these three emulsions contain images consisting of dye alone. The image in the layer that was sensitive to red is composed of cyan dye; in the green-sensitive layer, magenta dye; and in the blue-sensitive layer, yellow dye.

A photographic silver deposit absorbs light of all colors about equally, so it makes very little difference what color of light is used to measure its density. This is not so with color films. The cyan, magenta, and yellow dyes in the dye layers are selected because their maximum absorptions are in the red, green, and blue parts of the spectrum, respectively. A neutral gray area in a color film, then, will be neutral because just the right proportions of all three dyes are there.

So how can you find out how much red, green, or blue light is being absorbed by the dyes in a "neutral" area of a color film? You take tricolor density readings of that area, through red, green, and blue filters.

Let's digress for a moment. We've covered how densitometry can help you control your black-and-white film development as you wish. You can't do this with color films. Why not? Because if colors are to be reproduced faithfully, all three emulsions must be developed to predetermined values. This can be accomplished only if development times and temperatures are standardized within rather narrow limits.

However, you can certainly use color densitometry in making color prints from your KODACOLOR, VERICOLOR, and EKTACOLOR negatives with KODAK EKTACOLOR Professional or KODAK EKTACOLOR 37 RC Paper. The objective is to determine the approximate filter pack required for printing each negative, thereby arriving at a satisfactory final print with a minimum of trial and error.

That brings us back to tricolor densities. Here is how we use them:

The Gray-Card Image — Why?

First, you need a "standard" area to measure. This is the reason we recommend that the image of the gray side of a KODAK Neutral Test Card be included in color negatives that people are going to print themselves. The *KODAK Neutral Test Card*, Publication No. R-27, available at photo dealers, is designed to provide a reference area of know reflectance for making exposure-meter readings in scenes, for inclusion in pictures (as an aid in controlling their reproduction), and for use in precision printing of color negatives. Manufacture of the Test Card is controlled within close limits to produce neutral surfaces of standardized reflectance values. To prevent specular or mirrorlike reflections, both sides have a matte finish.

The required size of the image of the Test Card on the negative varies somewhat, depending on the method used to determine printing exposures. In general, the shorter dimension of the image should be about 1/4 inch.

Place the card at the center of interest, where it receives the full subject lighting. Do not, however, locate the card near colored objects that reflect colored light onto it, because the control patch in the negative will then be misleading. Make another negative without the gray card. This negative can then be used to make print exposures based on measurements of the gray-card negative.

Occasionally, it may be possible to place the card along the edge of the scene area in such a position that it does not interfere with the actual picture and can be trimmed off the final prints. Particularly in artificial light, however, it may be difficult to obtain the full subject lighting along the edge of the scene. For this reason, it is generally easier to make an extra negative with the card at the center of interest.

A gray-card negative must, of course, be made on film of the same emulsion number, and if possible, the film should come from the same package. The film must also be processed with the other film exposed under the same lighting conditions.

Let's assume for the time being that each color negative you're going to print has a gray-card image in it. Now, if you can get that image to reproduce the same in each print, it logically follows that the rendering of other colors should stay the same, doesn't it?

The Basic Filter Pack

As your first step, choose one of your negatives as a "master."* Pick a *good* negative of the same type as the negatives you are going to print. Preferably, it should contain not only the gray-card image, but other colors as well, including, by all means, a flesh tone.

Next, print that negative, selecting the filters by trial and error, until the print really satisfies you. (The image of the gray card may not be exactly neutral when the subject colors are rendered in the most pleasing way.)

Third, record the filter pack you used for that print. As an example, suppose that the pack was 50M + 70Y. That's your basic pack.

Fourth, read the red, green, and blue densities of the gray-card image in the master negative. Write them down in columns headed *Cyan*, *Magenta*, and *Yellow*, respectively. Let's assume values of 1.10C, 1.20M, and 1.30Y.

Finally, add your basic filter pack to the Magenta and Yellow columns as shown in the table below.

The sum of these values represents the color of the light that must be used in order to obtain good color balance with that emulsion of paper. This is, therefore, the key (or master) set of values you work for when predicting filter packs for other negatives with that paper.

The procedure for finding the new filter pack when changing from one emulsion number to another is outlined in the instruction sheet packaged with the color paper.

*A 120/620-size KODAK EKTACOLOR Standard Negative, Part No. 513412, can be ordered through your photo dealer.

	CYAN	MAGENTA	YELLOW
Gray card densities in negative	1.10	1.20	1.30
Basic filter pack	—	.50	.70
Sum	1.10	1.70	2.00

Predicting the New Filter Pack

Just read the tricolor densities in the gray-card images of the other negatives to be printed, and subtract them from the key (master) values. What you have left represents the filter pack required for printing each negative. Let's predict an approximate pack for a negative having densities of 1.00, 1.10, and 1.50 when measured through red, green, and blue filters, respectively.

	CYAN	MAGENTA	YELLOW
Master values (master negative densities plus printing filters)	1.10	1.70	2.00
New negative densities	–1.00	–1.10	–1.50
Differences	0.10	0.60	0.50

It appears that the filter pack required to print this negative is 10C + 60M + 50Y, but we have one thing left to do:

Getting Rid of Neutral Densities

Equal densities in all three colors add up to gray (neutral density), which does nothing but increase the required exposure, and therefore should be eliminated. In our example, we have 10 units of neutral density (10C + 10M + 10Y). To eliminate this, all we do is subtract 0.10 from each of the columns:

	CYAN	MAGENTA	YELLOW
Density differences	0.10	0.60	0.50
Less neutral density	−0.10	−0.10	−0.10
Printing filter pack	0	0.50	0.40

The filter pack for the new negative is *50M + 40Y*.

Note that the 0.10 neutral density we cancelled out is the amount by which the new negative is *lighter* than the master negative. That's why we subtracted to eliminate neutral density. Let's suppose that the next negative is *darker* than the master.

	CYAN	MAGENTA	YELLOW
Master values	1.10	1.70	2.00
Unknown negative densities	−1.50	−1.60	−1.70
Differences	−0.40	0.10	0.30

So we'll *add* 0.40 to all three columns:

−0.40	0.10	0.30
+0.40	+0.40	+0.40
	0.50	0.70

The pack for this negative is *50M + 70Y*.

Where Do We Go from Here?

All we have to do now is calculate the exposure necessary for each negative, and we can do that from the amount of neutral density we cancel out in each case. Just use this table:

Value added or subtracted to cancel out neutral density:	Multiply master-negative* exposure time by:
+0.40	2.5
+0.30	2.0
+0.20	1.6
+0.10	1.25
0	1
−0.10	0.8
−0.20	0.65
−0.30	0.5
−0.40	0.4

What would be the exposure times for the two "new" negatives we used as examples? (In the first case, we subtracted 0.10 to cancel the neutral density; in the second, we added 0.40.) Assuming 20 seconds as the exposure for the master negative, the new printing times are 16 and 50 seconds, respectively.

*As mentioned in other publications (for example, Data Book No. E-77, *KODAK Color Films*), it may also be necessary to allow for changes in film sensitivity with illumination level (reciprocity effect).

What If There's No Gray-Card Image?

While a gray-card image is excellent, the same system will work in reference to any common type of density in negatives to be printed; for example, a flesh tone. The only catch is that all flesh tones will then look alike in the final prints. This is usually not too disturbing, unless wide differences in flesh tones are to be expected. For instance, predicting the filter pack for a negative of an Indian chief from a negative of a baby might lead to a rather startling effect — to say the least! Just use common sense in picking reference densities, that's all. Remember that the densitometric system is based upon the reproduction of similar tones, and you should get along all right.

For Additional Information

If you are really serious about your color work, you should be quite interested in the *KODAK Color DATAGUIDE* (Kodak Publication No. R-19). The procedure we've just outlined is included in it, as well as a wealth of other practical information. As an example, the KODAK Color Printing Computer in the DATAGUIDE will be particularly valuable to you in relating densities, filters, exposures, and magnification changes. Another Kodak publication concerning color printing is *Printing Color Negatives,* Kodak Publication No. E-66. It is a comprehensive discussion of the subject for both the beginner and the professional photographer. Your photo dealer will be glad to show you these publications.

Densitometry can be used in a great many ways. Standard photographic tests describe these uses, and ideas will no doubt occur to you from time to time.

Keep in mind that your densitometer is a measuring instrument. Use it whenever you think density measurements will help you.

It is beyond the scope of a booklet such as this to go any deeper into theory, and so we've had to skip many important parts of what can be a really fascinating study. For more complete information, read any of the texts on photographic theory, such as "This is Photography," by Miller and Brummitt, published by Doubleday & Co., Inc., New York, N.Y.; "Fundamentals of Photographic Theory," by James and Higgins, published by Morgan & Morgan, Inc., New York, N.Y.; "The Theory of the Photographic Process," by C.E.K. Mees, published by the Macmillan Co., New York, N.Y.; or "Photography, Its Materials and Processes," by C.B. Neblette, published by D. VanNostrand Co., New York, N.Y.

In the field of production-processing of both black-and-white and color photographic materials, densitometry is the vital tool used in monitoring the condition of the processing solutions so that they yield the best results. Kodak has devised a number of monitoring systems for use in various situations. A list of the manuals describing these systems is titled *Index to KODAK Process Monitoring Systems,* Kodak Publication No. J-33. Single copies are available from Eastman Kodak Company, Department 412-L, Rochester, N.Y. 14650.

DENSITY-OPACITY TABLE

DENSITY	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	1.00	1.02	1.05	1.07	1.10	1.12	1.15	1.18	1.20	1.23
.1	1.26	1.29	1.32	1.35	1.38	1.41	1.45	1.48	1.51	1.55
.2	1.59	1.62	1.66	1.70	1.74	1.78	1.82	1.86	1.91	1.95
.3	2.00	2.04	2.09	2.14	2.19	2.24	2.29	2.34	2.40	2.46
.4	2.51	2.57	2.63	2.69	2.75	2.82	2.88	2.95	3.02	3.09
.5	3.16	3.24	3.31	3.39	3.47	3.55	3.63	3.72	3.80	3.89
.6	3.98	4.07	4.17	4.27	4.37	4.47	4.57	4.69	4.79	4.90
.7	5.01	5.13	5.25	5.37	5.50	5.62	5.75	5.88	6.03	6.17
.8	6.31	6.46	6.61	6.76	6.92	7.08	7.24	7.41	7.59	7.76
.9	7.94	8.13	8.32	8.51	8.71	8.91	9.12	9.33	9.55	9.77
1.0	10.00	10.23	10.47	10.72	10.96	11.22	11.48	11.75	12.02	12.30
1.1	12.59	12.88	13.18	13.49	13.80	14.13	14.45	14.79	15.14	15.49
1.2	15.85	16.22	16.60	16.98	17.38	17.78	18.20	18.62	19.05	19.50
1.3	19.95	20.42	20.89	21.38	21.88	22.39	22.91	23.44	23.99	24.55
1.4	25.12	25.70	26.30	26.92	27.54	28.18	28.84	29.51	30.20	30.90
1.5	31.62	32.36	33.11	33.88	34.67	35.48	36.31	37.15	38.02	38.90
1.6	39.81	40.74	41.69	42.66	43.65	44.67	45.71	46.77	47.86	48.98
1.7	50.12	51.29	52.48	53.70	54.95	56.23	57.54	58.88	60.26	61.66
1.8	63.10	64.57	66.07	67.61	69.18	70.80	72.44	74.13	75.86	77.63
1.9	79.43	81.28	83.18	85.11	87.10	89.13	91.20	93.33	95.50	97.72
2.0	100.0	102.3	104.7	107.2	109.6	112.2	114.8	117.5	120.2	123.0
2.1	125.9	128.8	131.8	134.9	138.0	141.3	144.5	147.9	151.4	154.9
2.2	158.5	162.2	166.0	169.8	173.8	177.8	182.0	186.2	190.5	195.0
2.3	199.5	204.2	208.9	213.8	218.8	223.9	229.1	234.4	239.9	245.5
2.4	251.2	257.0	263.0	269.2	275.4	281.8	288.4	295.1	302.0	309.0
2.5	316.2	323.6	331.1	338.8	346.7	354.8	363.1	371.5	380.2	389.0
2.6	398.1	407.4	416.9	426.6	436.5	446.7	457.1	467.7	478.6	489.8
2.7	501.2	512.9	524.8	537.0	549.5	562.3	575.4	588.8	602.6	616.6
2.8	631.0	645.7	660.7	676.1	691.8	708.0	724.4	741.3	758.6	776.3
2.9	794.3	812.8	831.8	851.1	871.0	891.3	912.0	933.3	955.0	977.2
3.0	1000.	1023.	1047.	1072.	1096.	1122.	1148.	1175.	1202.	1230.

To find the opacity corresponding to a given density, locate, in the vertical column on the extreme left, the density to the first place of decimals. Then, in the top row, find the correct figure for the second place of decimals. The corresponding opacity is found in the horizontal row to the right of the first part of the density value and in the column directly below the second part of the density value. To find the density corresponding to a given opacity, locate the value, in the body of the table, that is closest to the given opacity. Then, find the density to the first place of decimals at the extreme left of the same row, and find the second place of decimals at the top of the same column.

Professional, Commercial, and Industrial Markets Division
EASTMAN KODAK COMPANY • ROCHESTER, N.Y. 14650

Practical Densitometry
Kodak Pamphlet No. E-59
Pub. Pt. No. 837733

6-72-CX Major Revision

Printed in the United States of America