

# Basic Photographic Sensitometry Workbook

**Kodak**

## A SELF-TEACHING GUIDE

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### A WORD ABOUT SENSITOMETRY...

Sensitometry is the science of measuring the sensitivity of photographic materials. As a photographer, graphic arts cameraman, cinematographer, or other user of photographic materials, you will use sensitometry in the control of operations involving exposing and processing photographic materials. Photographic manufacturers also use sensitometric methods in the control of manufacturing process.

### How to Use This Publication

Basic Photographic Sensitometry Workbook was prepared by Eastman Kodak Company for individual use on a self-study basis. This publication was written in a programmed instruction format, which will allow you to study and learn on your own and at your own pace.

You will first read a paragraph or two and then answer some questions in the spaces provided. Immediately afterward, check you answers to make sure they are correct. (All correct answers are provided at the back of the book.)

If your answer is correct, go right on to the next question. If your answer is incorrect, reread the material and correct your answer before going on.

If you will be studying this material within a regular school program, read only those pages assigned by your instructor. If you are studying on your own, read only those pages assigned by your instructor. Please go to page 2 and begin the program.

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### Acknowledgements

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*Bruce Ferguson, Editor, 1981 Edition*

## Introduction

Photography is part art and part science. The science part is called sensitometry. This book, Basic Photographic Sensitometry Workbook, leads one into the field of sensitometry, pausing occasionally to ask questions about the material presented. This book covers drawing a characteristic curve, determining D-min and D-max, determining film speed and Contrast Index, as well as figuring exposure latitude. Also included are sections on color negative and reversal sensitometry, paper sensitometry, and appendices on logarithms and slope. In the back of the book is a glossary of equivalent and preferred terms to help familiarize the student of sensitometry with both former and present notations (for example, what was once called one metre-candle is now called one lux).

This book is intended to be not only a teaching text but also a resource book to be referred to whenever the reader wants to refresh his or her memory. This book should give one an understanding of sensitometry, and an understanding of sensitometry is the key to better photographic quality.

## Names of Units

When you take a picture with your camera, the shutter opens and lets light strike the film. The film has then been exposed to light. When the film is developed, the areas where it has been exposed by the light will turn dark. The more light that struck the film, the darker that area will be when it is developed. What is needed is a way of measuring how much light and how much development it takes to darken the film a certain amount. In other words, we need to be able to assign numerical values to the amount of light, amount of development, and degree of darkening and then determine what the relationship is between them. The name of this method is sensitometry. Sensitometry tells us how sensitive the film is to light, and how development affects the exposed film.

1. What makes the film dark?  
\_\_\_\_\_
2. The more light that strikes the film, the \_\_\_\_\_ the film will get when developed.
3. The term which describes the method of evaluating the effect of light and development on film is \_\_\_\_\_.

The numerical value we assign to degree of development is called Contrast Index (CI). Contrast Index is affected by four variables: time, temperature, agitation, and developer activity. We will discuss Contrast Index and how to measure it later on (see page 9).

The unit for light (Illuminance) is called millilux. It is equal to one-thousandth of one lux (formally called a metre-candle). Exposure can be determined by multiplying Illuminance (in millilux) by Time (in seconds). The equation is:

$$\text{Exposure} = \text{Illuminance} \times \text{Time}$$

For example, Illuminance (measured by an illuminance meter) is 75 millilux, and the exposure time is 1/15 of a second.

What does the Exposure equal?

$$\text{Exposure} = (75)(1/15) = \frac{75}{15} = 5$$

Exposure = 5 millilux-seconds

4. The numerical value assigned to degree of development is \_\_\_\_\_.
5. What is the unit for Illuminance?  
\_\_\_\_\_.
6. What is the Exposure equation?  
\_\_\_\_\_.
7. In what unit is exposure expressed?  
\_\_\_\_\_.

## Density

The degree of darkening of film is called Density. Density is a measure of the light-stopping ability of the film. To determine the meaning of density, we must first get familiar with the terms transmission and opacity.

Transmission is how much of the light gets through the film, and opacity is how much of the light doesn't get through the film. Thus, opacity is the reciprocal of

transmission ( $O = \frac{1}{T}$ ). For example, if 100 lux of light is

falling on one side of the film, but only 25 lux gets through, then the transmission is 0.25. The opacity would then be 4. Notice that, like all reciprocal relationships, transmission multiplied by opacity equals 1.

Now, back to density. Density is the logarithm to the base 10 of opacity ( $D = \log_{10}O$ ). Since the only logs we will be talking about are to the base 10, we will omit the subscript from now on ( $\log = \log_{10}$ ). (If you are unfamiliar with logarithms, or just want to review them, turn to Appendix A in the back of the book.) The density of your film can be measured by an instrument called a densitometer.

If you use a densitometer, you do not need to figure transmission, opacity, or the log of the opacity, because the instrument will indicate the density on its scale (or readout).

8. What is the term for the degree of darkening?
9. To what other terms is it related?
10. How is it related to each of those terms?

## Densitometers

There are two types of densitometer: visual and photoelectric. Visual densitometers use the eye to compare a known density sample with an unknown density sample. You simply move a density wedge until its density looks like your sample. The density is then found by looking at the scale on the known density sample.

A photoelectric densitometer uses a photocell to read the density of the sample. The results are displayed directly onto a readout. Older densitometers have a readout that is a needle and a printed scale, newer ones make use of digital displays. Assuming that they are operated properly, they all are equally reliable.

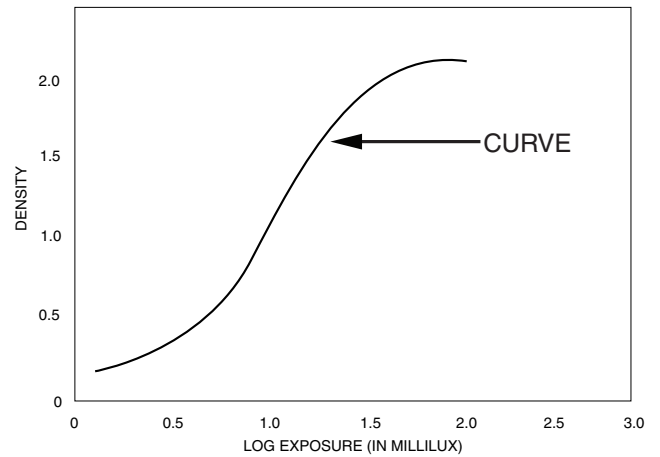
11. What makes the readings in a photoelectric densitometer? \_\_\_\_\_.
12. What makes the readings with a visual densitometer? \_\_\_\_\_.
13. If used properly, should there be any difference in the readings obtained by both types of densitometer?  
\_\_\_\_\_.

## Characteristic Curve

Now then, to relate density, exposure, and contrast index to each other, we use a graph. On the vertical axis is density, and on the horizontal axis is the log of exposure.

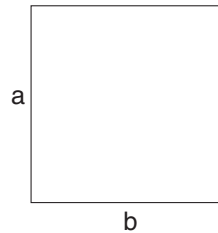


For negative-type films we know that the more exposure a film gets, the darker it gets. So now we will add a scale to the graph and sketch in a sample "curve." The "curve" shows that with increasing exposure, density increases.



Contrast Index is measured from this curve.

14. Label the sides of this graph:



- a) \_\_\_\_\_
- b) \_\_\_\_\_.

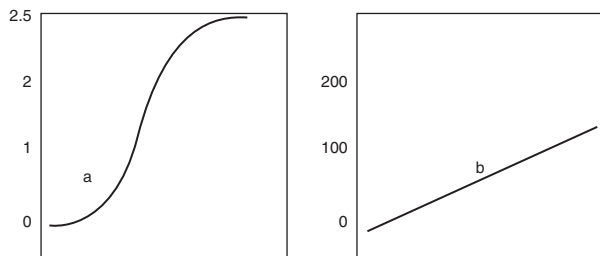
15. Contrast Index is measured from what?

\_\_\_\_\_.

## Why Logs?

By now you are probably wondering: why Logarithms? On one side we use density, which is the log of opacity, and on the other side we use the log of exposure (in millilux seconds). The reason is because logs can compact the information. It is a lot more compact to make a logarithm scale from 0 to 3, than it is to make an arithmetic scale from 1 to 1000. Another reason is that our eyes work "logarithmically." The change from 0 to 1 to 2 density units looks like equal brightness steps. If we use an arithmetic scale of  $1/10$  to  $2/10$  to  $3/10$ , they wouldn't look like even steps.

16. Which scale is logarithmic? Arithmetic?



a) \_\_\_\_\_  
b) \_\_\_\_\_



c

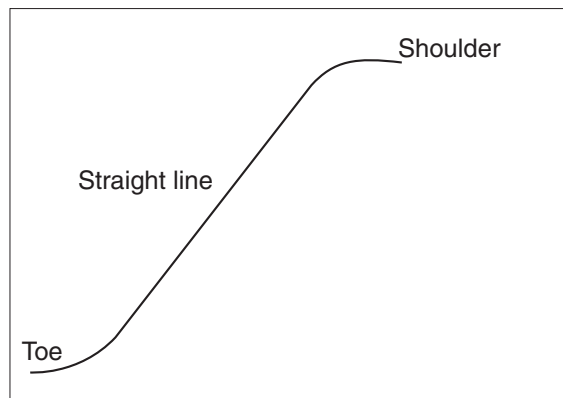


d

c) \_\_\_\_\_  
d) \_\_\_\_\_

## The Parts of a Curve

The curve is known as the characteristic curve, because it tells you a lot about the various characteristics of the film. The curve consists of three parts, the toe, the straight-line portion, and the shoulder, as illustrated below.



The dark portions (shadows) of a scene are the light (clear) parts of the negative. These dark portions are represented as the toe part of the curve. We say the "shadows fall" on the toe.

The light portions of a scene (white shirts, lights, bright reflections), called the highlights, are the dark parts of the negative. These light portions are represented as the shoulder part of the curve. We say the "highlights fall" on the shoulder.

The intermediate areas of a scene are called the midtones, and naturally they "fall" on the straight line part of the curve.

17. The curve is known as the \_\_\_\_\_ curve.
18. The shadows fall on the \_\_\_\_\_.
19. The \_\_\_\_\_ fall on the shoulder.
20. The \_\_\_\_\_ fall on the straight-line portion.
21. The shadows in a scene are \_\_\_\_\_ on the negative.
22. The highlights in a scene are \_\_\_\_\_ on the negative.

## Sensitometers

Where does the information to plot the curve come from? There is a device called a sensitometer, which exposes the film so that when the film is developed, it has a series of densities on it, varying from clear to dark. This is accomplished by putting the film in contact with a step tablet and exposing through the tablet.



(the step tablet)

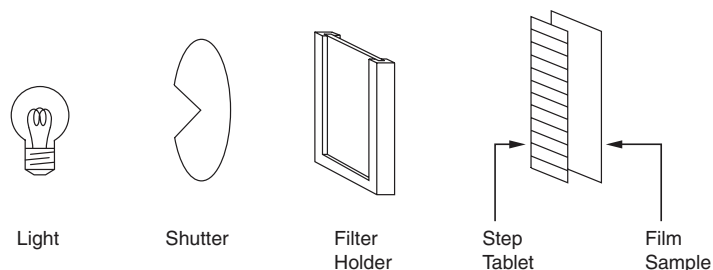
The dark areas on the tablet do not let much light through, so the developed negative is light (clear) in those areas. The light (clear) areas on the tablet let most of the light through so the developed negative is dark in those areas.

After the film is developed it looks like this:



(film sample)

This is a diagram of a sensitometer:



The steps are then read on a densitometer to obtain the density information.

23. What piece of equipment is used to print the step tablet onto the film sample? \_\_\_\_\_
24. Where the step tablet is dark, the developed film is \_\_\_\_\_.
25. Where the step tablet is light, the developed film is \_\_\_\_\_.
26. The instrument that measures the film densities is called a \_\_\_\_\_.

## Exposure

The densitometer gives us the density measurement for each step. Now we have to get the log exposure for each step so that we can graph the characteristic curve for our film sample. We can measure the amount of light that the sensitometer is putting out by using a lux meter (a light meter that measures lux. Lux and metre-candles are the same thing, but lux is the preferred term). So we try this and we get a reading of 100,000 millilux. The instruction manual for the sensitometer tells us that the exposure time is 1/5 of a second.

Exposure = Illuminance (in millilux) x Time (in sec)

Exposure = 100,000 x 1/5

Exposure = 20,000 millilux-seconds

Now we take the log of our exposure, 20,000 millilux-seconds, and get an answer of 4.3. Our log exposure is 4.3.

27. If the illuminance was 1,000 millilux, and the exposure time was 1/10 of a second, what would the exposure be? \_\_\_\_\_.
27. What would be the log exposure of the exposure in Question 27? \_\_\_\_\_.
28. The illuminance is 200 millilux, and the time is 1/5 of a second. What is the exposure? \_\_\_\_\_.

The characteristic curve is referred to by several names. Some call it the H and D curve, after Mr. Hurter and Mr. Driffield, two English gentlemen who created sensitometry. Hurter and Driffield were curious about how different films responded to different exposures and to different development times, and so they did a lot of research and came up with sensitometry to answer their questions. Many people call the characteristic curve the H and D curve out of respect for these two gentlemen.

The curve is also known as the D-Log E curve, which is short for "Density-Versus-the-Log-of-Exposure." Because it is so obvious, short, and to the point, it is the term that is used most often. Lastly the curve is sometimes call the D-Log H curve, because some scientists use "H" to mean exposure. They would use "E," but that is already being used to mean Illuminance. They would use "I" for that, but "I" is already being used to mean Intensity (which we don't deal with in this workbook, but which is used in some scientific terms). So: *D-Log E* is the same as *D-Log H*, which is the same as *H and D curve*. Also, the exposure equation  $E = I \times T$  (Exposure = Illuminance x Time) is the same as  $H = E \times T$ . If you see those various terms, there is no need to feel confused and worried; they are just different ways of saying the same thing.

30. The H and D curve is named after \_\_\_\_\_.
31. They created \_\_\_\_\_.
32. The H and D curve is also called \_\_\_\_\_ and
33. \_\_\_\_\_.
34.  $H = E \times T$  is the same as \_\_\_\_\_.

## Step Tablets

There are two types of step tablets used in sensitometers for printing the gray patches on the film sample. One type has 11 density steps, and the other has 21 density steps. Both tablets are the same size, and both have the same range of densities—about 0.05 to 3.05. It's just that the 21-step tablet uses more steps of gray to cover the same range.

The 11-step tablet uses a density increment of 0.30 for each step. The 21-step tablet uses an increment of 0.15.

11-Step

1	2	3	4	5	6	7	8	9	10	11
0.05	0.35	0.65	0.95	1.25	1.55	1.85	2.15	2.45	2.75	3.05

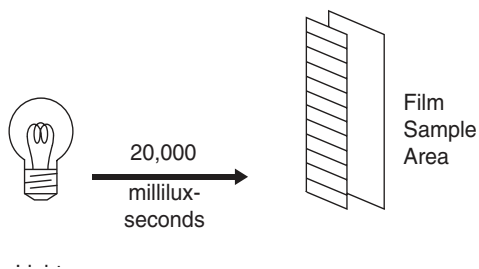
21-Step

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
0.05	0.20	0.35	0.50	0.65	0.80	0.95	1.10	1.25	1.40	1.55	1.70	1.85	2.00	2.15	2.30	2.45	2.60	2.75	2.90	3.05

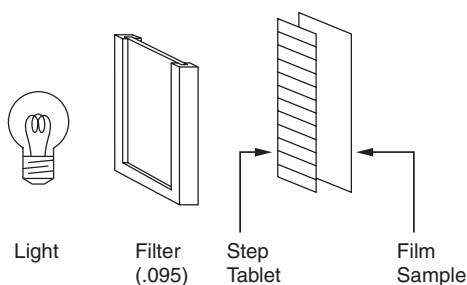
35. What is the lowest density of the two tablets? \_\_\_\_\_.
36. What is the highest density? \_\_\_\_\_
37. What is the density range (highest minus lowest)? \_\_\_\_\_.
38. What is the increment used for the 11-step? \_\_\_\_\_.
39. What is the increment used for the 21-step? \_\_\_\_\_.

## Figuring Exposure

Remember from our previous example that our sensitometer was putting out 20,000 millilux-seconds, the log of which is 4.3.

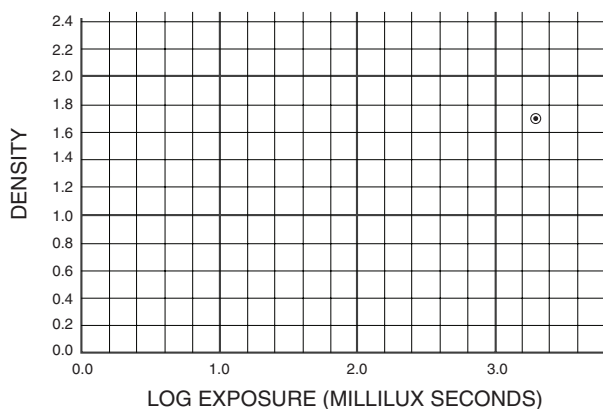


Our density step tablet (we will use the 11-step) is at the film sample location, but between the light and the film sample. There is also a filter in the light path to further reduce the amount of light that hits the film. The filter has a density of 0.95.



Thus, the light must go through the step tablet and the filter before it hits the film. The density step tablet and the filters will stop some of this light, thus creating a negative of the step tablet on the film. How much exposure has each patch of film received?

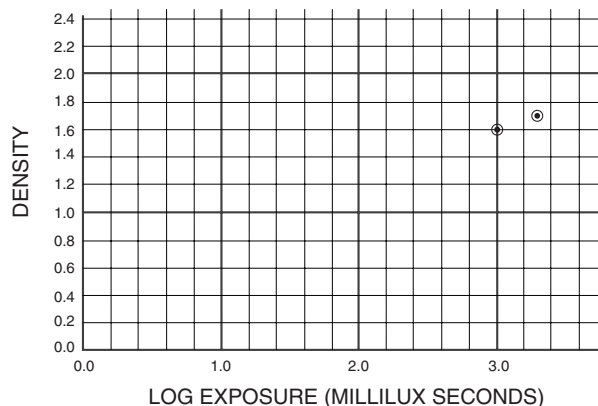
Well, the log exposure is 4.30, but the filter takes out 0.95 of that. So the light reaching the step tablet is  $4.30 - 0.95 = 3.35$  log exposure. The step tablet takes out some light, too. In the area where the step tablet has a density of 0.05, it takes out 0.05 of the light. Thus, the exposure in this area is  $3.35 - 0.05 = 3.30$ . The density of the developed film at that step would be plotted above that exposure. If that density is 1.70, the plot would look like this:



On the step that took out 0.35, the log exposure would be:

$$3.35 - 0.25 = 3.00.$$

If the density of that patch on the developed film was 1.58, the plot would look like this:

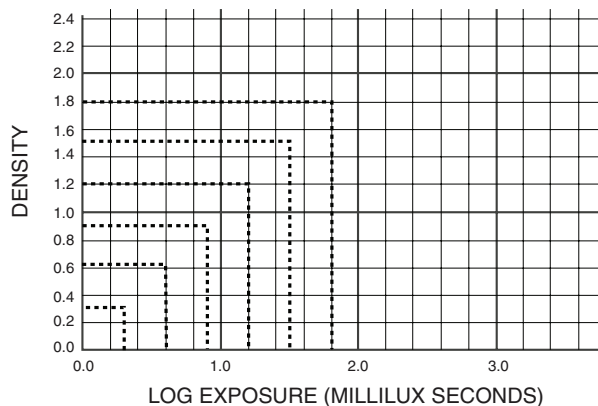


We take our exposed, processed film to the densitometer and read the densities at each step, and this is what we get:

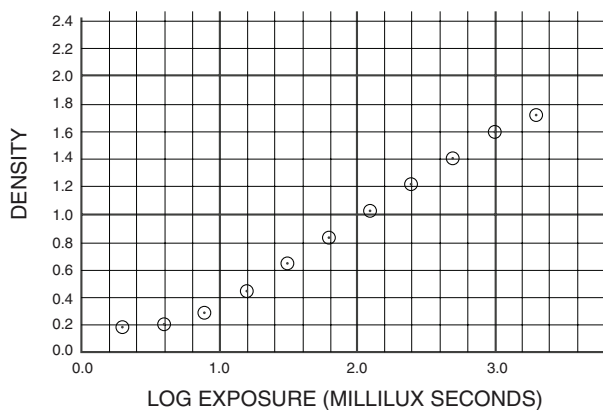
Step 1	0.18	Step 7	1.01
2	0.20	8	1.20
3	.028	9	1.39
4	0.45	10	1.58
5	0.64	11	1.70
6	0.82		

## Constructing the Curve

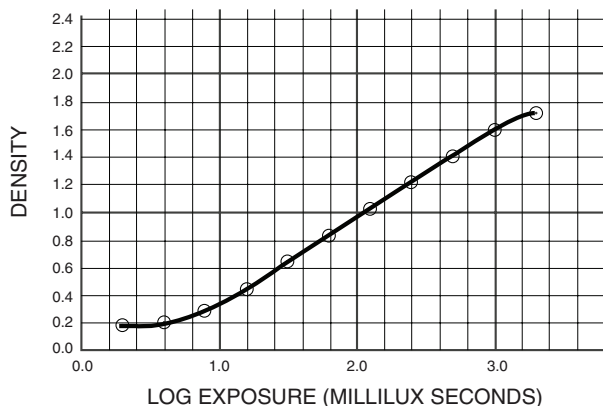
The exposures for each step can be determined by continuing the exercise in the previous illustration. Once we have all of the densities and their corresponding exposures, we can start to construct our graph. To get a proper-looking curve, we make the scales equal by having every 0.30 density change match evenly with every 0.30 log exposure change. The scales look like this:



So now we plot the points and our graph looks like this:



Once the points are plotted, we connect them together with a single, smooth, curved line. It is not necessary to hit every point exactly, because the idea is to show how the film characteristically responds to the exposure. It is very difficult to make a smooth line when drawing freehand. Use a set of French curves or a flexible curve for drawing your graphs. It should look like this:



40. To get the proper curve, the density scale and log exposure scale must be \_\_\_\_\_.
41. The points are connected with a \_\_\_\_\_,
42. \_\_\_\_\_ curved line.
43. Must the line go through every point? \_\_\_\_\_.

We have a characteristic curve of our film. What does it mean? Remember on page 2, when we said that what we needed was a way of relating amount of exposure and degree of darkening to each other? Well, that's what we have done.

There are many things we can learn from the characteristic curve, including lowest density, highest density, gamma, Contrast Index, and photographic speed of the film.

## D-min

Lowest density is more often called D-min, for density-minimum. It is a result of the transparent base and a slight amount of chemical fog of the film emulsion. Chemical fog happens because a few silver halide crystals will develop, even though they received no exposure. Because of this, D-min is sometimes referred to as base plus fog, and sometimes as gross fog. (In color films it is called base plus stain.)

## D-max

Highest density is often called D-max, for density-maximum. This is a measure of the darkest the film can be. With most black-and-white films, your characteristic curve may not show the film's D-max because it may be beyond the scale printed from the step tablet. This is not much to be worried about because in normal use the film never gets exposed enough reach D-max anyway.

44. What is the D-min of our film sample? \_\_\_\_\_.
45. What is the highest density shown? \_\_\_\_\_.
46. Does it seem to be a D-max? \_\_\_\_\_.
47. D-min is also called \_\_\_\_\_
48. and \_\_\_\_\_.

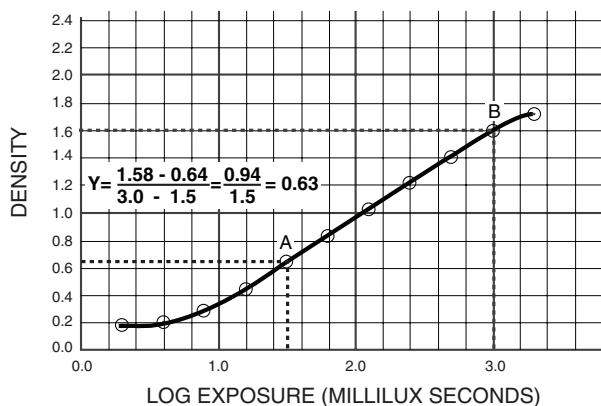


## Gamma

Degree of developing affects the steepness, or contrast, of the curve. So, if we change the degree of development, the relationship between exposure and degree of darkening also changes.

Gamma is a measure of the contrast of a negative, and it is symbolized by the Greek character,  $\gamma$ . Gamma is the slope of the straight-line portion of the curve. Slope refers to the steepness of a straight line, determined by taking the change in density from two points on the curve and dividing that by the change in log exposure for the same two points.

$$\frac{\text{Density B} - \text{Density A}}{\text{Log E of B} - \text{Log E of A}}$$



In this example, point A has a density of 0.64 and point B has a density of 1.58. The change in density between those two points is 0.94. The log E of point A is 1.5, and the log E of point B is 3.0. This is a change of 1.5 log exposure units.

$$\text{The Gamma is: } \frac{0.94}{1.5} = 0.63$$

If you are uncomfortable with figuring slopes of lines, turn to Appendix B in the back of the book.

49. Gamma indicates?

\_\_\_\_\_.

50. It is measured on the \_\_\_\_\_ portion of the curve.

51. Gamma is the \_\_\_\_\_ of the straight line.

## Contrast Index

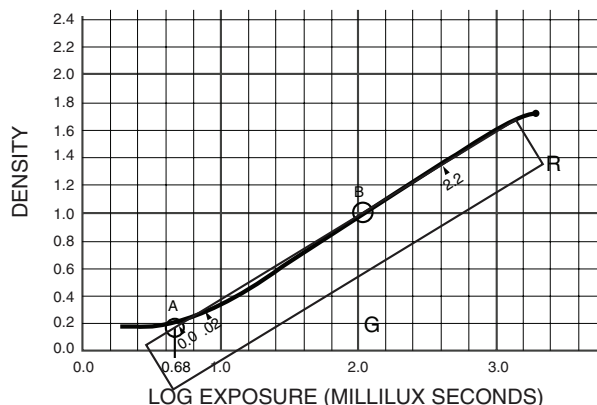
Another means of measuring negative contrast is called Contrast Index. Contrast Index is the slope of a line between two particular points on the D-Log E curve. These two points are the minimum and maximum densities on the curve that are normally used to make high-quality negatives. The minimum point falls somewhere on the toe of the curve, meaning that the shape of the toe influences Contrast Index. Thus, it is *unlike* gamma, which is the slope of the straight-line portion only.

To find out what these two points are, we need to make a marked straight edge—the edge of a piece of paper works fine. Place a mark on your straight edge and label it 0.0. Count over 0.2 log E units and place another mark and label it 0.2. Then count over 2.0 log E units from that point and make another mark and label it 2.2. Find D-min on the curve and draw a horizontal line at that density. Place the straight edge on the graph and move it about until the 0.0 mark touched the D-min line and the 0.2 and 2.2 marks both touch the curve. Draw a line along the straight edge. The slope of this straight line is the Contrast Index.

52. Contrast Index is a means of \_\_\_\_\_.

53. What affects Contrast Index that does not affect gamma?

54. The 0.0 mark on the straight edge must touch the D-min line. The other two marks on the straight edge must touch the \_\_\_\_\_.



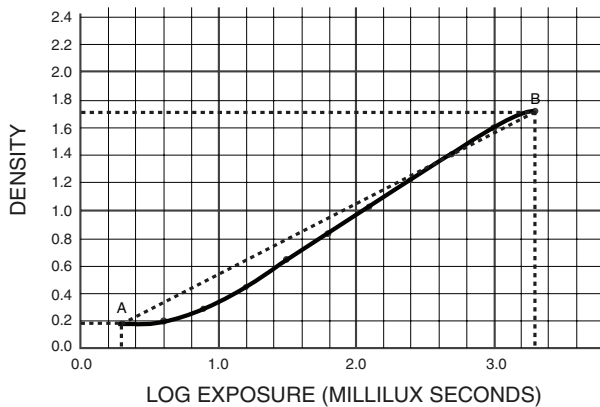
On the graph above, a marked straightedge has been drawn onto the curve. Note the horizontal line at the minimum density and how the 0.0 mark touches this line. The 0.2 and 2.2 marks touch the curve. Two points (A and B) have been marked off on the straightedge.

55. Using the points A and B, calculate the contrast Index of the film. \_\_\_\_\_.

## Average Gradient

Average Gradient ( $\bar{G}$ ) is also a measure of slope and is similar to gamma and contrast index, but it is not limited to the straight-line portion of the curve. Average Gradient can be measured from any one point on the curve, to any other point. If both points are on the straight-line portion of the curve, then average gradient and gamma are the same. It is customary to write the densities of the two steps as subscripts to the symbol  $\bar{G}$  so that anybody who looks at it can know which points you are referring to.

Let's go back to our curve and find the Average Gradient from the point that has a density of 0.18 to the point that has a density of 1.70. This is symbolized as  $\bar{G}_{0.18-1.70}$ .



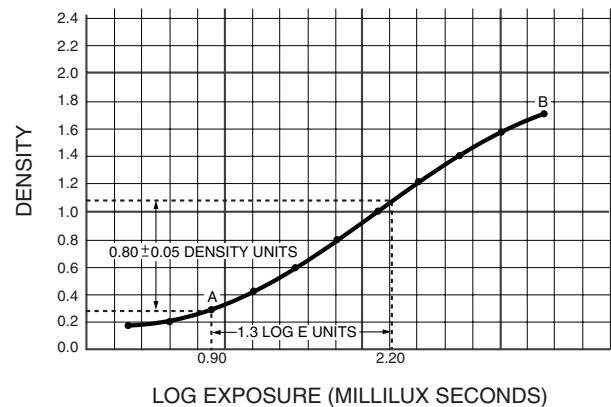
$$\frac{\text{Density B} - \text{Density A}}{\text{Log E of B} - \text{Log E of A}} = \frac{1.70 - 0.18}{3.3 - 0.3} = \frac{1.52}{3.0} = 0.51$$

56. Average Gradient is a measure of \_\_\_\_\_.
57. Is it limited to the straight-line portion of the curve?  
\_\_\_\_\_
58. What does  $\bar{G}_{0.25-1.50} = 0.60$  mean?  
\_\_\_\_\_

## Film Speed

Film speed is a bit complicated because it uses antilogs and Average Gradient. The American National Standards Institute (ANSI) has a method that is widely used for determining film speeds. ANSI, formerly American Standards Association (ASA) is a group that is dedicated to devising standard methods of doing things, thereby saving us the trouble of having to figure it out ourselves. The International Standards Organization (ISO) has adopted the ANSI method of determining film speed, so you might see film speed written as being either an ASA or ISO film speed (ASA/ISO). Don't fret. They're the same numbers.

Step 1 in the standard method is to be sure that the film has been properly developed. (Note that the different developers yield different film speeds. The developer specified by ANSI is similar to KODAK Developer D-76.) This is done quite easily. Find a point on the curve that is 0.10 density units above D-min and label it A. Make a note of the log exposure at this point. Count over 1.30 log E units, and mark this point. Draw a line from this point up to the curve, make a note of the density at this point, and label it point B. The film is properly developed if the density at this point is 0.80 ( $\pm 0.05$ ) more than the density at point A. For example, if D-min is 0.18, then the density at point B should be between 1.03 and 1.13. Point A is  $0.18 + 0.10 = 0.28$ . Thus,  $0.80 (\pm 0.05)$  units above point A is  $1.08 \pm 0.05 = 1.03$  and 1.13.



Let's look at our sample curve. D-min is 0.18, and we place point A at 0.10 above that. So point A is at a density value of 0.28. The log E at this density is 0.9. We count over 1.3 log E units to 2.2. We go up from this point until we reach the curve and mark that as point B. The density at point B is 1.08, exactly 0.80 above point A, so it is within the acceptable range of  $0.80 \pm 0.05$ . Now we are assured

that our film is properly developed and can be used to determine film speed.

59. If there is a change of 0.80 density units between points A and B, and the log E difference is 1.3, what is the Average Gradient of this film? \_\_\_\_\_.
60. The density difference for normally developed films must be within the range of  $0.80 \pm 0.05$ . What then is the range of Average Gradients?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

61. Point A is placed where on the curve?  
\_\_\_\_\_
62. How many log E units do we count over?  
\_\_\_\_\_.
63. Why must we do this before determining film speed?  
\_\_\_\_\_.

Step 2 in the method is determining the film speed. The formula for speed is:\*

$$\text{film speed} = \frac{800}{\text{antolog of A}}$$

\*This equation uses millilux-seconds as the unit for exposure. When we use lux-seconds as the unit for exposure, the formula changes to:

$$\text{film speed} = \frac{0.8}{\text{antolog of A}}$$

We already know where point A is (see Step 1). The EXPOSURE at point A is 0.9. The antilog of 0.9 is 8;  $800/8 = 100$ ; the ASA/ISO is 100. Bingo! It's that easy.

64. If point A was at 0.6, what would the ANSI film speed be? \_\_\_\_\_
65. If point A was at 1.2, what would the ANSI film speed be? \_\_\_\_\_

## Standard Film-Speed Tables

If the film speed came out to 105, would we report it as 105 or 100? Answer—we report it as 100. Why? Well, to make things easy for the camera user, the ANSI standard specifies that only certain numbers of the entire range of numbers are used as film speeds and that we must round our answers to the closest standard number. Below is part of the table of standard film-speed numbers:

32	64	125	250	500
40	80	160	320	650*
50	100	200	400	800

\*This number and the next full step, 1250, do not follow the general pattern.

You probably noticed that there is a pattern to this table. Going across the table, every number is the double of the previous one (650 and the next full step, 1250, are exceptions to the rule). Going down the table, every number is approximately 1.25 ( $1\frac{1}{4}$ ) times the previous one. Where does this table come from?

In photography, the exposure system is based on the number 2. By changing the settings on the camera we either halve or double the exposure. Each time we do this, we make a one-step change in the exposure (note, the preferred term is "step," not "stop," since "stop" refers only to changes in lens opening. "Step" refers to change in exposure by any means). Thus film speeds 40 and 80 are one step apart. So are film speeds 125 and 250. The change between speeds 32 and 40 is  $1/3$  of a step.

Why are steps broken down into thirds? Well, the log of 2 (because we halve or double exposure) is roughly 0.3. Remember in the previous exercise where you had to figure film speed, that at the log exposure that was 0.3 lower than the example, the film speed doubled? If we went down only by 0.1 log E, then the film speed would have changed only by  $1/3$  of a step. One-third step changes result from 0.1 log E changes as nice neat intervals to work with.

66. Complete the table above down to a film speed of 4.

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

67. Complete the table up to a film speed of 3200.

\_\_\_\_\_

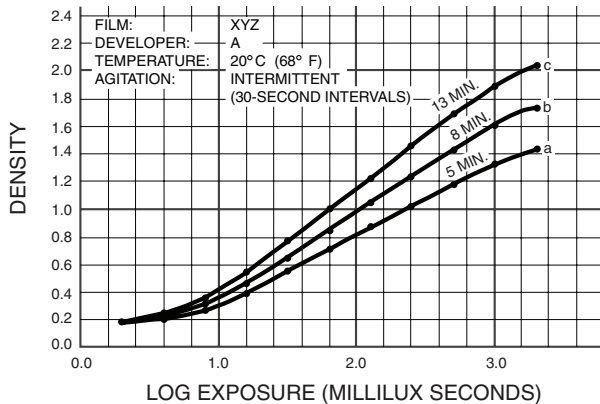
\_\_\_\_\_

\_\_\_\_\_

68. The photographic exposure system is based on what number? \_\_\_\_\_.
69. Why is the interval of film speed changes  $1/3$  of a step? \_\_\_\_\_.

## Family of Curves

In the previous example, we checked the film to make sure that it has the right amount of development. In that exercise, we specified that the film had to have an Average Gradient in the range of 0.58 to 0.65 to be considered properly developed so that we could determine its speed. Depending upon the use that the photographer intends for the film, contrast can be varied to suit those needs. The usual method of varying contrast is to change the development time, while keeping temperature, agitation, and developer activity as nearly unchanged as possible. Below is what is known as a "family of curves." This family has three curves, but it could just as easily have had five or only two.



Notice that the longer the development time, the steeper the slope of the curve. Most of the change is in the straight line and shoulder of the curve, and the toe remains basically the same. Notice that all of the data that affects contrast is written on the graph.

70. Figure the Contrast Indexes for curves

a \_\_\_\_\_

b \_\_\_\_\_

c \_\_\_\_\_

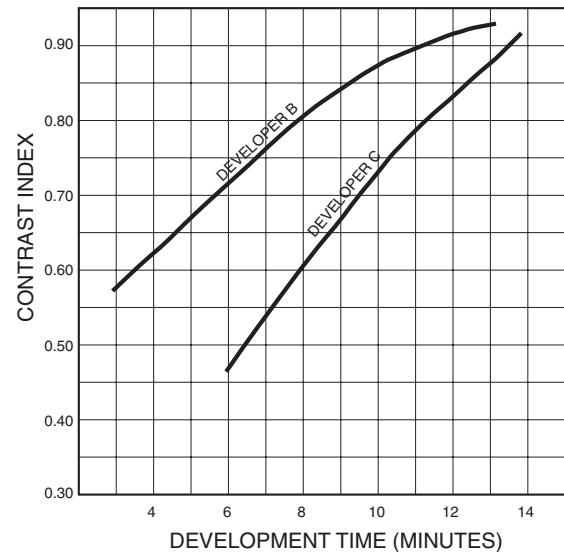
71. What 4 factors affect Contrast Index?

\_\_\_\_\_, \_\_\_\_\_,

\_\_\_\_\_, \_\_\_\_\_.

72. Which one is being varied in this example? \_\_\_\_\_.

The family of curves gives rise to another graph, called the Time-Contrast Index Curve, which shows Contrast Index versus development time for a developer-temperature-agitation combination. Below are Time-Contrast Index Curves for two developers. Usually film manufacturers show several curves on a graph so that it is easier to compare information from one developer to the other. The purpose of this graph is to make it easy to find the proper development time for any desired Contrast Index.



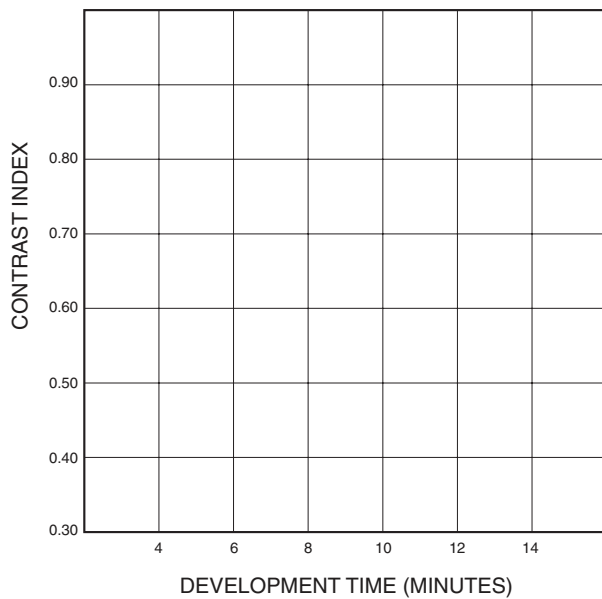
73. Using the information gained from the last exercise, and the additional data below, construct a Time-Contrast Index Curve for Developer A.

Additional Data: 6-minute CI = 0.55

10-minute CI = 0.67

12-minute CI = 0.72

74. What is the purpose of this graph?



\_\_\_\_\_

\_\_\_\_\_.

75. If we wanted a Contrast Index of 0.70, what would be the required development time? \_\_\_\_\_

76. For a Contrast Index of 0.58? \_\_\_\_\_.

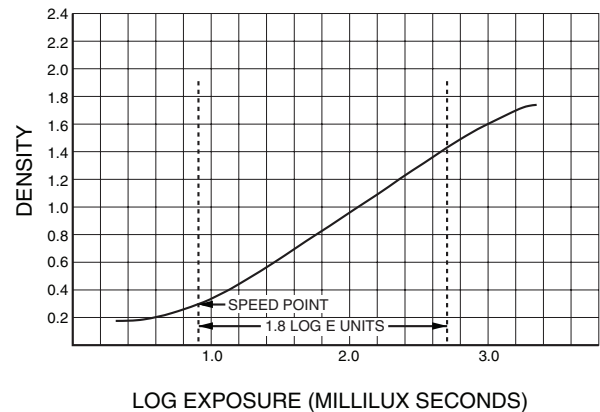
## Exposure Latitude

Latitude in exposure is the permissible change in camera exposure that can be made without significant effect on image quality. We can determine latitude from our characteristic curve.

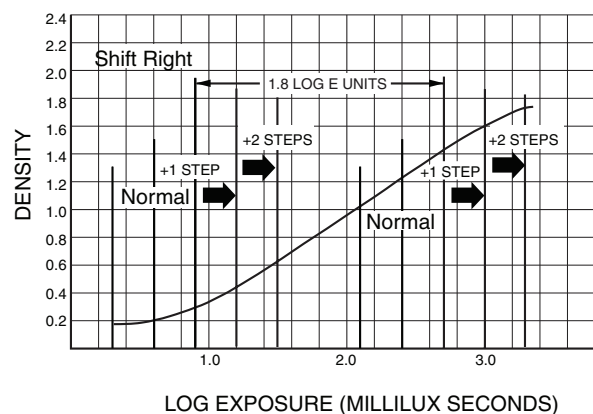
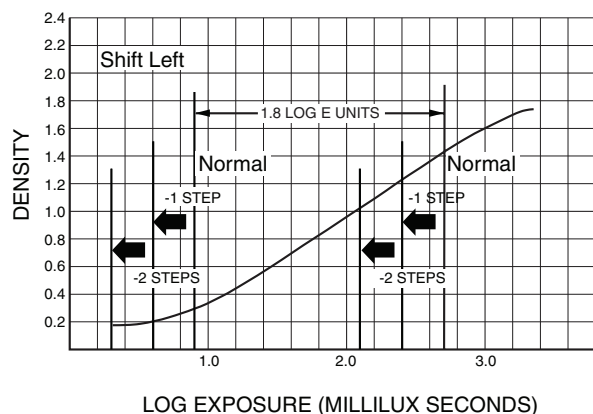
If the range of brightness (difference between the darkest and lightest objects) on our film is 60:1, that is, the brightest object is 60 times brighter than the darkest object, then the brightness range is 1.8 (the log of 60. Remember, on our characteristic curve, we deal with log exposures). A quick inspection of the scale on the curve shows that the entire curve covers a log E range of 3.0. A range of 1.8 can fit inside that range easily with some room (latitude) to spare. What is our latitude in terms of exposure steps? How much can we underexpose and overexpose and still get a printable image?

First we must figure out where in the entire range of 3.0 we want to put in the scene brightness range of 1.8. Normal exposure is affected by film speed, and film speed is figured from the speed point of our curve, so we place one end of our brightness range on the speed point and the other end near the shoulder (we count 1.8 log E units for the speed point) and call this position NORMAL exposure.

The speed point of our film was at log E = 0.9.



Moving in steps of 0.3 log E units (one step), we see that we can move the scene brightness range left two times before we run off the curve. Similarly we can move right two times before we run off the curve there.



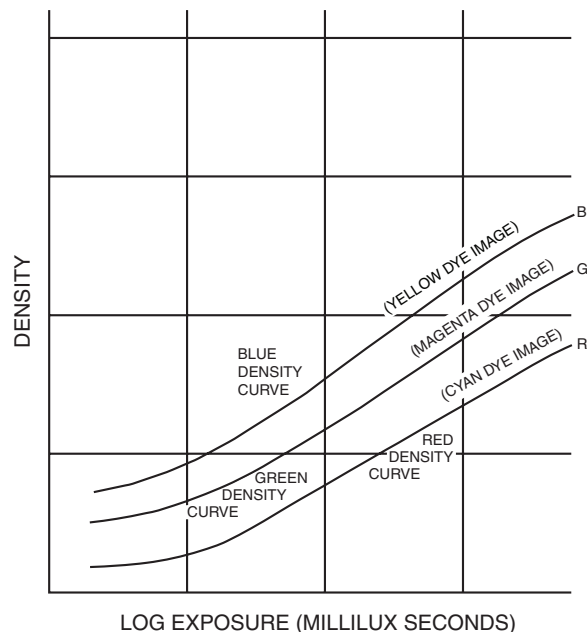
We have an underexposure latitude of 2 steps and an overexposure latitude of 2 steps, also.

77. If our scene brightness range was 1.5, what would be the underexposure latitude? The overexposure latitude? \_\_\_\_\_

78. What would the over- and underexposure latitudes be if the scene brightness range was 2.1? \_\_\_\_\_  
\_\_\_\_\_

## Color Negative Sensitometry

Color negatives are very similar to black-and-white ones except that color films have three superimposed emulsion layers of black-and-white film, each to control a different color: red, green and blue. It is important that the three curve shapes are as similar to each other as possible, indicating that all three color layers respond to light equally. Below is an example of what the characteristic curves for a sample color negative look like.



The color associated with each of the curves is the color of the densitometer filter that is used in reading the densities.

Notice that the three curves are spaced a bit apart from each other. This is due to the orange mask. If the orange mask wasn't there, the blue and the green curves would be "lying" on the red curve.

The images in color negatives are made up of yellow, magenta, and cyan dyes. The color filters in the sensitometer are used so that you can know how much of the overall density is being caused by each dye. Each filter reads its opposite color: a blue filter for yellow dye, a green filter for magenta dye, and a red filter for cyan dye. A color densitometer also has a visual filter that is used for reading the total density. The orange mask is incorporated in the film to compensate for dye characteristics. Its presence results in better quality color prints.

79. How many emulsion layers are there in color negative film? \_\_\_\_\_.

80. Each layer responds to different color of light. What are these three colors?  
\_\_\_\_\_

81. The negative image is made up of dyes; what are the colors of these dyes? \_\_\_\_\_, \_\_\_\_\_, and \_\_\_\_\_

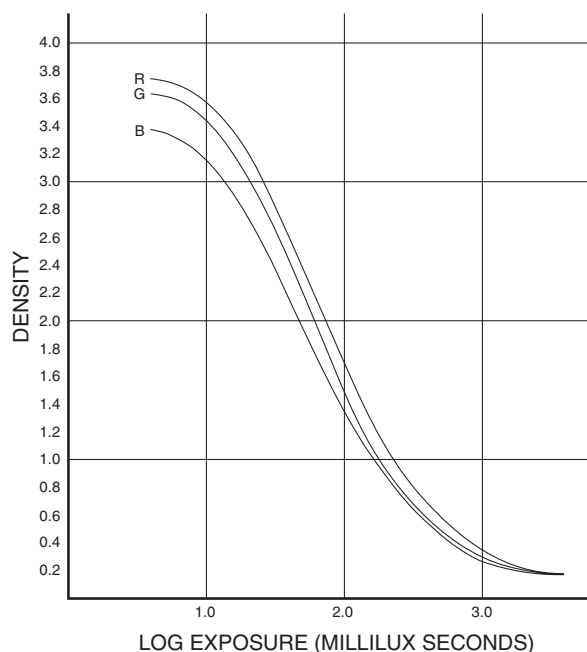
82. The densitometer uses red, green and blue filters to read the cyan, magenta, and yellow densities of the negative. Match the color filter with the color dye it measures.

Filter	Film Dye

83. Why do negative films have that orange mask?  
 \_\_\_\_\_ and  
 \_\_\_\_\_.

### Reversal Film Sensitometry

The characteristic curve for reversal films is like a mirror image of the curve for negative film. This is not hard to understand if you think about what a reversal (transparency) film images looks like. The dark areas of a scene do not reflect much light to the film (small log E). These areas come out dark (high density) just as they should. The light subject areas reflect a lot of light to the film (big log E). These areas come out light; practically clear (low density). Look at the curve shown below. At small log E exposures, the densities are high. At large log exposures, the densities are low. One further note — if you are plotting a color reversal film, it also has three separate curves, one each for the cyan, magenta, and yellow dye layers. Because there is no orange mask, all these curves lie almost on each other.



84. How does the curve for a reversal film look compared with that for a negative film?  
 \_\_\_\_\_.
85. Why do all three curves lie almost on each other?  
 \_\_\_\_\_.

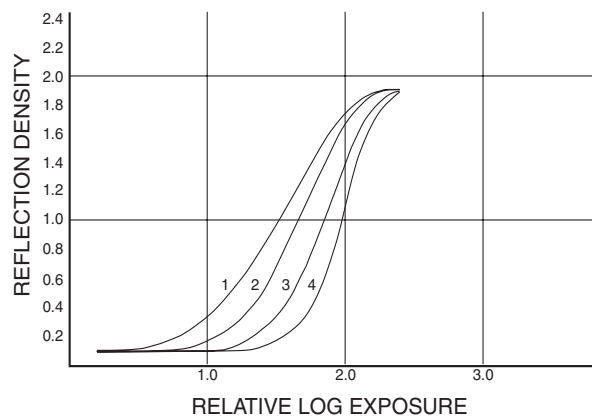
### Paper Sensitometry

Negatives are meant to be printed onto photographic paper. For this reason, negatives and paper are thought of as a system. The final result, the print, is what is important. Negative curves have slopes well below 1.0 (typically around 0.45 to 0.65) to give the photographer more exposure latitude. To compensate for the low slope of negative, printing papers have a slope greater than 1.0 (from about 1.5 to 3.5, depending upon the grade of the paper). The paper grade number gives you an idea as to the slope of the paper. Grade 2 paper is considered normal and has a slope of around 2. The higher the grade, the higher the slope.

86. Negatives and printing paper are considered a  
 \_\_\_\_\_.
87. Why do negatives have a small slope?  
 \_\_\_\_\_  
 \_\_\_\_\_.
88. What do papers do to compensate? \_\_\_\_\_  
 \_\_\_\_\_.

Paper densities are not read with a regular transmission densitometer, such as is used to measure negatives and transparencies. To measure paper densities, a reflection densitometer is necessary. This is because light does not pass through the paper but is reflected from its surface. Therefore, the densitometer must be designed so that it can measure reflected light. Sensitometric exposures are made on paper the same as they are on film, except that papers require more exposure because they aren't as fast as film. There is a separate method of figuring out the speed of paper because paper is not exposed like film.

Other than that, the curves for paper are plotted the same as for film. If the paper is a color paper, then there are three curves, one for each emulsion layer (there are no paper grades for color paper). Below is a typical family of black-and-white paper curves for grades 1, 2, 3, and 4.



89. What type of densitometer is used for reading paper densities? \_\_\_\_\_.
90. Papers are faster or slower than films?  
\_\_\_\_\_
91. Do we figure paper speed the same as film speed? \_\_\_\_\_
92. How many curves are there for color paper? \_\_\_\_\_
93. What are they? \_\_\_\_\_, \_\_\_\_\_ and \_\_\_\_\_.



## APPENDIX A

### Logarithms

Some people feel a little uneasy when they hear the word "logarithms." Actually logarithms (logs) are just shorthand forms of other numbers. The basic number in logs is 10.

$10 \times 1 = 10$	$10^1 = 10$ exponent is 1	$\log$ of 10 = 1.0
$10 \times 10 = 100$	$10^2 = 100$ exponent is 2	$\log$ of 100 = 2
$10 \times 10 \times 10 = 1000$	$10^3 = 1000$ exponent is 3	$\log$ of 1000 = 3

Note that the small number written above the 10 (exponent) is the same as the number of zeroes in the answer.  $10^5$  means 100,000. The log of 100,000 ( $10^5$ ) is 5. If the number 10 is raised to any exponent, the exponent is the log of that term.

For example:

$10^2 = 100$	The log of 100 = 2.0
$10^{2.6} = 398$	The log of 3.98 = 2.6
$10^3 = 1000$	The log of 1000 = 3.0

Based on this, what would you say are the logs of:

94. 1,000,000

95.  $10^5$

96. 10,000

There are positive exponents and negative exponents. Negative exponents are used to express numbers less than 1. The log of 1 is 0 because  $10^0 = 1$ . The log of 0.1 ( $10^{-1}$ ) = -1.

What are the logs of:

97. 0.01

98. 0.0001

99.  $10^{-6}$

This works well for numbers that have a whole number exponent of 10, but what about other numbers like 200, 63, and 0.41? Logs are actually two numbers, the whole number part (like 1, 2, 3, etc.) and the decimal part (like 301, 145, and 80). Just look at this table:

The log of 2	= 0.3
The log of 20	= 1.3
The log of 200	= 2.3
The log of 2000	= 3.3

Notice that the decimal part (.3) never changes because the number 2 is being multiplied by 10 in each example, and that the whole number part (1, 2, and 3) shows how many 10s are being multiplied by the number 2. Look at this next table:

$6.3 = 6.3 \times 1$	The log of 6.3 = 0.8
$63 = 6.3 \times 10$	The log of 63 = 1.8
$630 = 6.3 \times 100$	The log of 630 = 2.8
$6300 = 6.3 \times 1000$	The log of 6300 = 3.8

Notice that we broke all of the numbers down to how many times the number is multiplied by 1, 10, 100, or 1000, depending on how large the number was to begin with.

100. Complete the table:

$4.17 = 4.17 \times 1$	The log of 4.17 = 0.8
$41.7 = (a) \times 10$	The log of 41.7 = (b)
$417 = 4.17 \times 100$	The log of 417 = (c)
$4170 = 4.17 \times (d)$	The log of (e) = 3.620
$0.417 = (f) \times 0.1$	The log of 0.417 = -1.620

The whole number part of a logarithm is called the characteristic, and it tells you how many whole powers of 10 are in your number. The decimal part is called the mantissa, and it tells you how many fractional powers of 10 are in your number.

What are the characteristics of the following logarithms?

101. 1.7

102. 5.14

103. 3.98

What is the mantissa of the following numbers?

104. 9.01

105. 7.2

106. 0.323

Negative characteristics are used quite often in sensitometry. Note that in this book the unit for exposure is millilux-seconds. The former standard unit was lux-seconds. Five hundred millilux-seconds equals 0.5 lux-seconds. The log of 500 millilux-seconds is 2.7 but the log of 0.5 lux-seconds is a negative number (-1.7). All characteristic curves that used lux-seconds as the unit for exposure use negative characteristics.

Be prepared for this when looking at most characteristic curves because the change to using millilux-seconds is fairly recent and most published curves use lux-seconds as the unit for exposure.

### Bar Logs

When you are writing negative characteristics, the conventional way of doing it is to put the minus sign over the characteristic, like this:  $\bar{2}.23$ . This is because the negative sign refers only to the characteristic, not the mantissa. It is referred to as "bar notation" because if you say the number, it is done like this: "bar two point two three."

107. Complete the table:

The log of 4.1	= 0.613
The log of 0.41	= $\bar{1}.613$
The log of 0.041	= (a)
The log of 0.0041	= (b)
The log of -0.0041	= (c)

### Using a Table of Logarithms

The number 87 falls between 10 and 100, which have logs of 1.0 and 2.0, respectively, so the log of 87 must be 1 plus some decimal quantity. To find that decimal, we go to a table of logarithms, which is really a table of decimal numbers, and look up the number 87 in the left-hand column. The decimal is given to us in four or five digits (depending on the table). In the case of 87, we find the

decimal .9395, but we notice that the same decimal also applies to the numbers 870, 8700, 8.7, 0.87, etc. However, since we have already said that the log of 87 must be 1+, then the actual log of 87 is 1.9395, accurate to the fourth decimal. The log table reproduced below shows how this decimal was found. Can you guess what the log of 870 would be?

**COMMON LOGARITHMS**

N	0	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774
60	7782	7789	7796	7803	7810	7817	7825	7832	7839	7846
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506
71	8531	8519	8525	8531	8537	8543	8549	8555	8561	8567
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996

This table is a bit hard to understand at first. It's not as complicated as it seems! Let's pick a number on the left-hand edge, say 60. This is really 6.0; the table leaves out the decimal point because it is assumed that you know it should be there. Now let's take a number from the top, say 5. The intersection of 60 and 5 is 0.7818. 6.0 and 5 together mean 6.05.

108. The log of 7.54 is?

109. The log of 5.5 is?

110. The log of 7.27 is?

## Antilogs

Simply put, antilogs are the numbers that logs represent. Let's go back to our common logarithm table and find the antilog of 0.9058. First we search the table until we find 0.9058. Then we look to the left to see which row it is in. It is in the row for 80. Then we look above it to see which column it is in, and find that to be column 5. Thus the antilog of 0.9058 is 8.05. If our number was 2.9058, we would multiply 8.05 by 100, because the antilog of 2 is 100. thus the antilog of 2.9058 is 805.

Determine the antilogs of the following numbers.

- 111. 0.804
- 112. 1.8142
- 113. 2.7619
- 114. 1.9299
- 115. 2.8882

If you use a calculator that has a log key, figuring logs and antilogs is quite easy. However, if you are working with bar logs, you will find that the calculator adds the negative characteristic and the positive mantissa together to yield a single negative number.

$$\begin{array}{r} \bar{2}.3 \text{ is added together: } -2.0 \\ +0.3 \\ \hline -1.7 \end{array} \text{ to yield -1.7 on the calculator display}$$

So if you are going to use a calculator, you will probably find it best to make separated calculations, one for the characteristic and one for the mantissa, and add them together.

One of the great things about logarithms is that multiplying two numbers together is the same as adding their logarithms. Solve the problem  $2 \times 2 = 4$  using logs.

The log of 2 is 0.3; the log of 4 is 0.6:

$$2 \times 2 = 4 \quad 0.3 + 0.3 = 0.6 \quad \text{antilog of } 0.6 = 4$$

### Helpful hint:

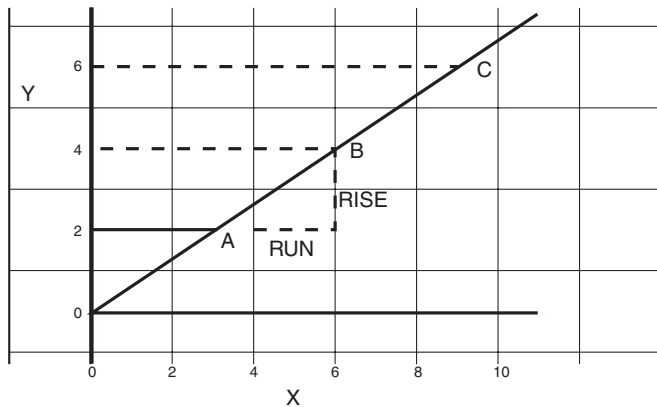
Because the factor 2 is very popular in photography (doubling exposure, halving exposure), its log (0.3) gets used a lot in sensitometry.

## APPENDIX B

### Slope

Slope in sensitometry is figured the same as it was in your old geometry class:

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}} \text{ (the rise over the run).}$$



Point A is at 2 on the Y scale and 3 on the X scale.  
Point B is at 4 on the Y scale and 6 on the X scale.

$$\text{Slope} = \frac{\text{Rise}}{\text{Run}}$$

Between two points, the line has risen 2 units. also, the line has run 3 units. the slope is 2/3 or 0.67.

116. Determine the slope between points A and C.

Notice that in the above question, the slope was the same as that in the example. On a straight line, it doesn't matter which two points you pick, because the slope of the line will always be the same.

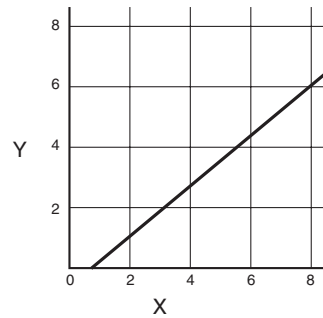
You might see this formula for determining slope:

$$\frac{\Delta Y}{\Delta X}$$

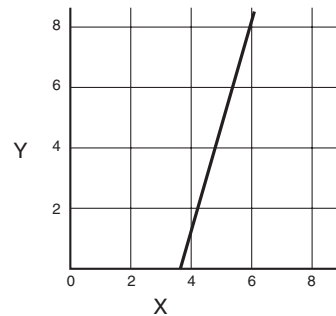
The triangle  $\Delta$  (Greek—delta) is the symbol meaning "change."  $\Delta Y$  means "the change in the Y." In the example, point A is at 2 on the Y scale and point B is at 4.  $\Delta Y$  then = 2, (4 - 2 = 2);  $\Delta X$  would be 3, (6 - 3 = 3). It

doesn't matter how you write it  $\Delta Y / \Delta X = \text{Rise} / \text{Run} = \text{Slope}$ , it all means the same.

117. Figure the slope on the following:



118. Figure the slope on the following:



## GLOSSARY OF EQUIVALENT TERMS AND PREFERRED TERMS

ANSI	American National Standards Institute (formerly ASA). An institute that devises and publishes standard methods for conducting scientific work, including sensitometry.	H & D Curve	The graph made by plotting the density of a film sample against the log of the exposure that made that density. Named after Messrs. Hurter and Driffield who created the science of sensitometry. Also known as D-Log E and D-Log H. D-Log H is the technically correct term, but for this book, we are using D-Log E because it is clearer. See H, E, and I.
ASA	American Standards Association—now called ANSI. See ANSI.	H	(Exposure) The international symbol for Exposure (units are lux-seconds), also known as E.
ASA Speed	The speed of photographic materials as determined by the method published by ANSI.	$H = E \times T$	(Exposure = Illuminance x Time) The exposure equation. Illuminance is in lux and time is in seconds so exposure is expressed in lux-second (millilux- and microlux-seconds can also be used). Also known as $E = I \times T$ . $H + E \times T$ is technically correct because it uses the correct international symbols for Exposure and Illuminance.
Base + Fog	The density of the base of the film plus the density of the fog in the emulsion. Also known as D-min and gross fog. D-min is the preferred term. See D-min.	I	1. International symbol for intensity. 2. Although not technically correct, we use it in this book to symbolize Illuminance. The technically correct symbol for Illuminance is E.
D-Log E	D-Log E (Density vs. the log of exposure). The graph made by plotting the density of a film sample against the log of the exposure that made that density. Also known as D-Log H and H and D curve. D-Log H (H for exposure) is the technically correct term, but for this book we are using D-Log E because it is clearer. See H, E, and I.	ISO	International Standards Organization. The international version of ANSI. See ANSI.
D-max	(Maximum density) This is a measurement of the darkest a film can be. For most black-and-white films, the D-max is not shown on the characteristic curve because it is beyond the scale printed from the step tablet. If a piece of film is exposed to sunlight for a few second and then developed, the resulting density will be D-max.	Lux	Unit of illuminance, equivalent to one lumen per square metre and to one metre-candle. Preferred term is Lux.
D-min	(Minimum density) The smallest possible density a film has. There is always some density to even the most transparent of things. In clear film, D-min is the density of the clear acetate base of the film plus a little bit of "fog" in the emulsion. thus, it is also known as base plus fog, and sometimes as gross fog. D-min is the preferred term for black-and-white film and papers. In color it is called base plus stain.	Metre-Candle	Unit of illuminance. The light received at a point one metre away from a point light source having an intensity of one candela (formerly candle). Equivalent to Lux, which is the preferred term.
E	The international symbol for Illuminance. In this book we use I for Illuminance because it is clearer, but the technically correct symbol is E.	Millilux	One thousandth ( $10^{-3}$ ) of one lux. This unit is sometimes used instead of Lux so that when figuring log exposure, the result is not a neegative log, thereby avoiding the use of bar notation. With very slow films, occasionally the unit is changed to microlux (one millionth [ $10^{-6}$ ] of one lux) to avoid using bar notation.
$E = I \times T$	(Exposure = Illuminance x Time) The exposure equation. Illuminance is in lux and time is in seconds so exposure is expressed in lux-seconds (millilux- and microlux-seconds can also be used). Also known as $H = E \times T$ . $H = E \times T$ is technically correct because it uses the correct international symbol for Exposure and Illuminance.	Step	1. An exposure increase or decrease, usually by a factor of 2. The same as "Stop," except stop specifically refers to lens aperture. Preferred term is Step. 2. A patch of a step tablet used for sensitometer exposures, as in "11-step tablet."
Gross Fog	The density of the base of the film plus the density of the fog in the emulsion. Also known as D-min and base + fog. D-min is the preferred term. See D-min.	Stop	An exposure increase or decrease by a factor of 2 associated with varying of lens aperture. For a general term meaning exposure increase or decrease, not necessarily associated with lens aperture, the preferred term is Step.