Sensitometry Primer
Part I: The Numbers and Graphs

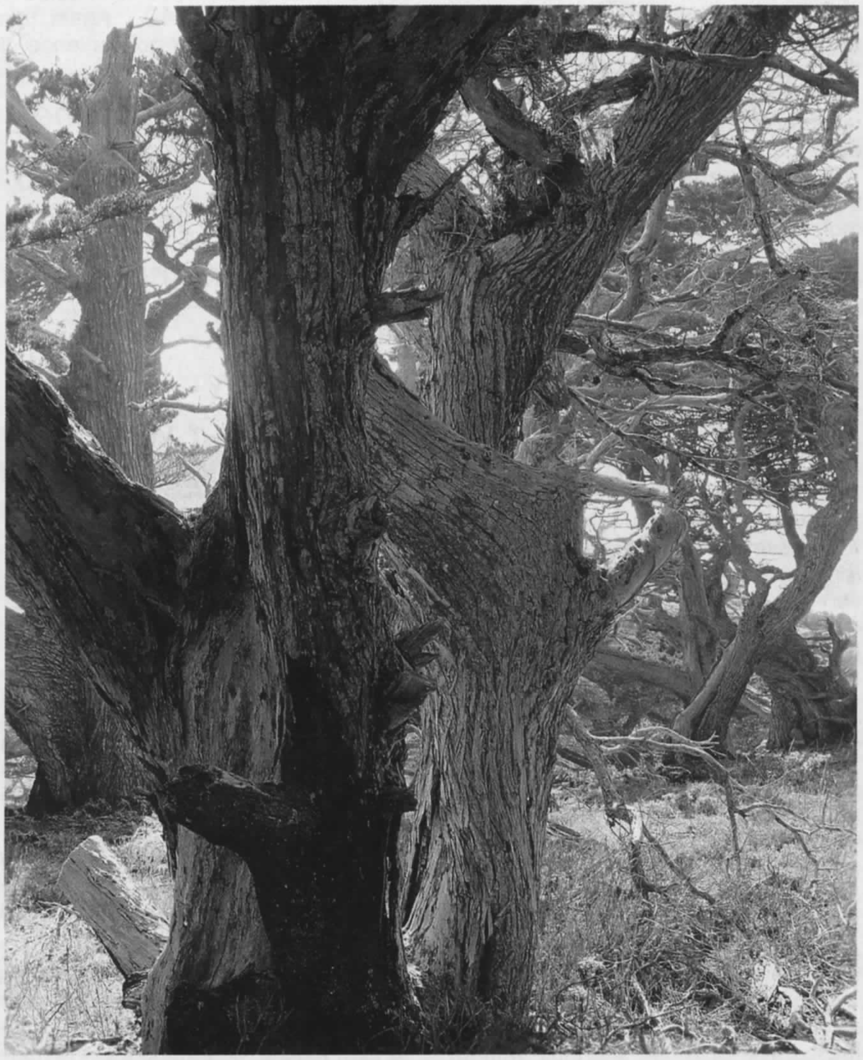
By Phil Davis

For the first 50 years after photography was invented photographers had to rely on intuition, painful experience and luck to expose their plates and papers satisfactorily. The quality of sensitized materials was only partially predictable and the fundamental relationship between exposure and development was not well-understood. In fact, photographers generally considered the effects of exposure and development to be essentially similar.

To Dr. Ferdinand Hurter, however, this haphazard approach was intolerable. In 1876 Hurter, a chemist, and his friend and colleague Vero C. Driffield, an engineer, began a series of experiments to investigate and measure the chemical effects of light. Before long they were also involved in measurements of lens transmission and image density, and by 1890 they had formulated procedures that were to become known as "sensitometry." Their researches were summarized in the now-famous paper entitled "Photochemical Investigations and a New Method of Determination of the Sensitiveness of Photographic Plates," which Dr. Hurter read at a meeting of the Society of Chemical Industry in Liverpool on May 31, 1890.

Sensitometry is now a well-established science that manufacturers use to monitor the quality of the materials they produce, so we can thank Hurter and Driffield for the fact that our modern photographic materials behave predictably. We should be especially grateful to them, though, for identifying and defining the various factors that influence the characteristics and appearance of the photographic image. As working photographers we can use the procedures they formulated to discover how the photographic process works and to predict what our favorite materials can be made to do under actual field conditions.

Testing of materials is not a new idea, but sensitometric testing in the personal darkroom is only beginning to become popular. There are at least two reasons for this: first, laboratory sensitometry requires expensive instrumentation that is beyond the means of many photographers—only recently has it become apparent that sensitometric procedures can be implemented quite satisfactorily with relatively inexpensive equipment. Second, sensitometry has had a lot of bad press. For years we've been told that art and technique are antithetical and that any interest in process theory will inevitably inhibit creativity. That issue can be debated, I suppose, but given the choice of extremes, I'm inclined to believe that skill is always preferable to ineptitude, and knowledge is generally better than lack of knowledge.



***POINT LOBOS, CALIFORNIA* was photographed by the author with a Sinar 4 × 5 view camera equipped with a Zeiss 6⅜ inch convertible Protar, series VIIA on Kodak Super-XX Pan film, developed in D-76.**

Some photographers object to "all the numbers and graphs" that are involved in sensitometry. I won't try to deny that numbers and graphs can be a problem for some people at first, but they're no cause for panic. Although the number systems may seem a little confusing initially, there's almost no mathematical calculation involved and the graphs and charts are really quite simple. If you can handle ordinary arithmetic and a little elementary algebra, and if you're willing to think a little, you're adequately prepared to take the plunge.

"But why get involved in this at all?" you may be asking. There are two excellent reasons: first, you'll learn a great deal about the photographic process in general—and your chosen materials in particular. Second, because the testing procedures are very efficient you'll save time and money, and get much more (and more reliable) information than is possible with conventional trial-and-error test methods.

Honestly, I can't think of any good reasons why you *shouldn't* get involved. So let's begin.

There's one fundamental difference between this scientific approach and the more conventional "try-it-and-see-if-it-works" methods. The "try-it" approach defines things subjectively and often ambiguously. Sensitometric definition is relatively objective and factual. For example, you might describe some print tone as *dark gray*, which is not very helpful. Sensitometric measurement will assign some specific number to that tone, defining its reflection density with much greater precision. Similarly, it's difficult to describe the printing contrast of a negative in words, but the economical *language* of sensitometry can identify it very accurately with a single number. With very little practice you can learn to recognize these numbers and use the information that they convey.

Whether you recognize them or not, you're forced to deal with several systems of numbers in photography. Counting off the seconds of a print exposure uses numbers in arithmetic sequence, which means that the number series increases by the addition of some constant—typically the number 1. For example, if you count "1, 2, 3, 4, 5..." it's apparent that each number is 1 greater than the preceding one.

Geometric sequences are more common in photography and you've used at least three of them, perhaps without realizing it. Geometric series numbers progress by multiplication or division by a constant. The familiar series of shutter speed numbers is a case in point: 1, 2, 4, 8, 15, 30... Here the constant is 2 and the series is only approximate: The number following 8 should really be 16, but it's convenient to stay with even multiples of 5. The series can obviously be extended in either direction. Simply multiply any number by the constant 2 to find the next higher one, and divide any number by 2 to find the next lower one.

Relative aperture numbers are in a geometric series, too, but the constant in this case is the square-root of two (approximately 1.41). Because of this, every second number in the series is either doubled or halved (depending on which way you're going): f/1.4, **2**, 2.8, **4**, 5.6, **8**, 11, **16** ... To find the next number multiply 16 by 1.41 (22.63) and drop the decimal to get f/22. Similarly, divide 1.4 by 1.41 to find the next smaller number (larger aperture), f/1.

The ISO film speed number sequence is also a geometric series, but its constant is the cube-root of 2 (about 1.26). For this reason, every *third* number in the ascending sequence is doubled—**10**, 12, 16, **20**, 25, 32, **40** ... Again, this series is simplified for convenience. It can also be extended in either direction by multiplying or dividing any number by 1.26 to find the next number. For example, you can determine that the number following 40 is 50 (approximately) by multiplying 40 by 1.26 or by doubling 25 (to skip over two number spaces).

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Table I. Number System Equivalents

Exposure Ratio	*Stops*	*Log*
1:2	1	0.3
1:4	2	0.6
1:8	3	0.9
1:16	4	1.2
1:32	5	1.5
1:64	6	1.8
1:125	7	2.1
1:250	8	2.4
1:500	9	2.7
1:1,000	10	3.0

This ISO number series is a very important one, not only because it identifies the various film speeds, but because it progresses in *third-stop* intervals. This relates it directly to calibration intervals on both the exposure meter's calculating dial and to the more useful log numbers that are used extensively in sensitometry. Yes, unfortunately you'll have to deal with log numbers but there's no higher math involved. The ISO number series is also important because it is an exposure measuring system with which photographers are already familiar. Commit at least a portion of the ISO film speed sequence to memory and, I promise you, handling the log numbers will be relatively painless. You really need to memorize only three consecutive numbers. From those you can construct the entire sequence. Learn these numbers. You'll be glad you did.

Logs are used in sensitometry for the same reason they're used everywhere else. They simplify the process of dealing with large numbers. You'll work mostly with so-called "common" logs—that is, logs based on the number 10. Simply speaking, a log number represents the number of times that 1 must be multiplied by 10 to produce the number. For example, to produce the number 10, it's necessary to multiply 1 by 10 only once, so the log of 10 is simply 1. To get 10,000 you have to multiply 1 by 10, 4 times so the log of 10,000 is 4. You can find the log of even multiples of 10 easily. Just count the zeroes: 10, 100, 1000, 10,000, 100,000, 1,000,000. A million has six zeros, so the log of 1,000,000 is 6.

Logs of other numbers can't be found quite so easily but, fortunately, we use only a few of them. One that you *must* remember is 0.3 which is (approximately) the log of 2. This is important because the number 2 represents one stop.

It's an interesting characteristic of logs that adding them is the same as multiplying the numbers they represent (their "antilogs"). For that reason, if 1 stop represents an exposure change of 2×, and 0.3 is the log equivalent of 2, then a 2-stop interval must equal 4 × (2×2) and its log equivalent is 0.6 (0.3 + 0.3). Table I shows how these three number systems relate in a longer sequence.

Again, the numbers in Table I are simplified for convenience. Notice that you can convert stops to logs by multiplying the number of stops by 0.3. Also, of course, you can divide any log number by 0.3 to find the number of stops it represents.

Converting stops to exposure ratios is only a little more complicated. Use your fingers to count off the ratios, beginning with 2, like this: 2, 4, 8, 16, 32, 64... In this case you've counted six times, so 64 must represent a range of 6 stops. If you have a calculator you can do this mathematically: Six stops is equivalent to 2×2×2×2×2×2, or 2 to the sixth power, so key in 2, then hit the "Y^x" key, then 6, then =. You should get 64, although some calculators will display 63.999, which is certainly close enough. Incidentally, if you're using the Radio Shack PC-6 pocket computer for this calculation, the key sequence is 2, ↑, 6, EXE, and the screen will display 64.

A calculator can also simplify converting logs to exposure ratios. For example, to find the equivalent of the log number 2.2, key in 2.2, then hit the 10^x key and the answer 158.489 should appear. The PC-6 uses different key strokes to get the same result: type 10, ↑, 2.2, EXE, and you'll get 158.4893192. We consider this number to be 160, for convenience.

You can also do this conversion without a calculator. Remember that the ISO number sequence identifies third-stop intervals. Also, since the log of 2 (one stop) is 0.3, the log of ⅓ stop must be 0.1. Armed with these two bits of information you can find the exposure ratio equivalent of *any* third-stop interval.

Using the numbers from the example I just gave, first convert the log number 2.2 to stops by dividing it by 0.3, which yields 7⅓. Then find the exposure ratio by counting 7 times: 2, 4, 8, 16, 32, 64, 128. The next full stop number is 256, but we're after the value of the first ⅓ stop. Here's where the ISO numbers come in handy. There are two ISO numbers between 125 and 250 and you'll notice immediately that the number we want is the next one after 125, which is 160.

Try some other numbers. What's the arithmetic equivalent of the log number 1.4? It's 0.2 (two-thirds stop) greater than 1.2, and 1.2 is equivalent to 4 stops or an exposure ratio of 1:16. In the ISO sequence the second number above (⅔ stop greater than) 16 is 25, so 1.4 must equal 4⅔ stops or 25. Similarly you can discover that a ratio of 1:80 equals 6⅓ stops or 1.9; and 8⅓ stops is equivalent to a ratio of 1:400 or 2.6 in log terms. Practice these number conversions until you're comfortable with them.

Numbers are important in sensitometry but the information they convey is not always obvious. To make numerical data more easily recognizable we usually present them in graphic form. Graphs, especially line graphs, are valuable because they display numerical relationships visually. They can also provide a lot more data than we put into them.

A graph's most valuable feature is its ability to display all the data at once so that the trends are obvious and the entire series of relationships can be perceived at a glance.

The most common graphs in sensitometry display the relationships between exposure, development and the resulting image density. The plotted data points form characteristic curves of the tested material. A typical family of characteristic curves is shown in Figure 1. It demonstrates the effect of varied exposures and varied development times on T-Max 400 sheet film, developed in D-76, diluted 1:1. Printing paper's characteristics can be displayed graphically, too. Figure 2 illustrates the response of Multigrade FB paper, exposed with a condenser enlarger through a No. 2 filter, and developed in Dektol for 2 minutes. These characteristic curves contain all the information you need to know about these materials. When you learn to read them they can provide you with accurate working data for use in the field.

Fortunately, learning to read the curves is fairly easy because the graph format is standardized. The horizontal graph axis (the x-axis) is always calibrated in units of exposure, increasing from left to right. The vertical axis (the y-axis) is always calibrated in units of image density, increasing from bottom to top. Each curve in the family represents a single

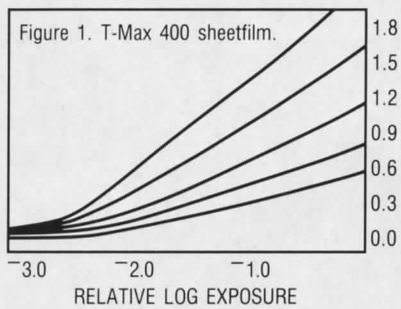


Figure 1. T-Max 400 sheetfilm.

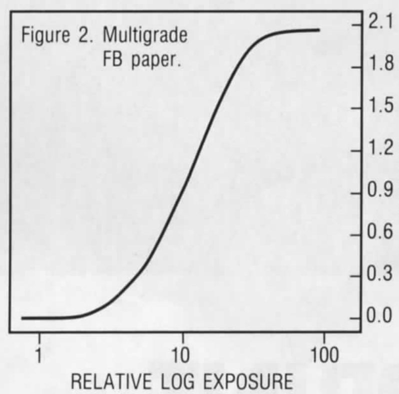
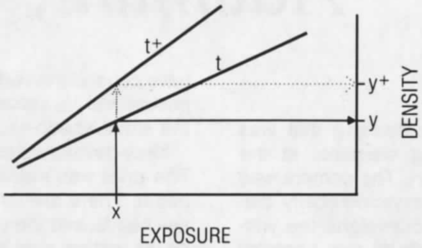


Figure 2. Multigrade FB paper.

Figure 3. Comparing development time and density.



development time so it's not at all difficult to see, as shown in Figure 3, that a test film given x units of exposure and developed for t time, will yield an image tone of y density units. It's also obvious that the same film, exposed for the same time but developed for t+ time, will produce a greater density of y+ units.

The exposure effect on any sensitized material is approximately geometric rather than arithmetic: Doubling an exposure time of 1 second by adding 1 more second will produce an obvious change in image tone, but if the original time is 30 seconds, simply adding one more second will have only negligible effect. To obtain the same increase in image tone, you'll have to *double* the original 30 second exposure. This is the reason we use stops so frequently to describe the exposure adjustments. A 1-stop increase in exposure always doubles the previous exposure and produces a predictable change in image density whether the original exposure time is a fraction of a second or a many-second time exposure.

Log numbers also express exposure and density changes geometrically but because they represent actual values, rather than just ratios, they're more informative than stops. For example, notice the x-axis calibration of the graph in Figure 2. The numbers are minus logs, indicating fractional values of the exposure unit, whatever it was. The standard exposure unit in published graphs is typically the lux-second or sometimes the meter-candle-second or mcs. These terms refer to the total exposure effect that a film (or paper) will receive if (in the mcs example) a *standard candle* is held one meter away from the film surface for one second.

This is obviously a lot more exposure than is necessary to fog a film, so the test exposures must begin with very small fractions of the basic unit. The log numbers express these fractions: ⁻3.0 equals $\frac{1}{1000}$ of the unit; ⁻2.0 equals $\frac{1}{100}$; and ⁻1.0 equals $\frac{1}{10}$. Notice, there is no *log equivalent* for zero. The 0.0 that appears on the graph axis is really the log equivalent of the number 1.

Density values are also log numbers (by definition). The arithmetic numbers that they're derived from describe the opacity of the negative (or print) image—that is, its ability to block or absorb light. The opposite of opacity is transmittance (of a negative) or reflectance (of a print). For example, if a negative area transmits ¼ of the light that strikes it, its transmittance is 25-percent. Its opacity is the reciprocal of transmittance ($\frac{100}{25}$), or 4, and its density is the log of its opacity (4), or 0.6. Similarly, the standard gray card has a reflectance of 18-percent which is equivalent to the fraction $\frac{1}{5.556}$. Its opacity is, therefore, 5.556, and its reflection density (the log of 5.556) is approximately 0.75. I'll let you figure out how many stops that represents. □

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