Measuring Paper Contrast

Contrast calibration to standard paper grades

After an appropriate print exposure time for the significant highlights is found, shadow detail is fine-tuned with print contrast. Without a doubt, the universally agreed units to measure relatively short durations, such as exposure time, are seconds and minutes. However, when it comes to measuring paper contrast, a variety of systems are commonly used. Many photographers communicate paper contrast in form of 'paper grades', others use 'filter numbers', which are often confused with paper grades, and some photographers, less concerned with numerical systems and more interested in the final result, just dial-in more soft or hard light when using their color- or variable-contrast enlarger heads. Nevertheless, a standard unit of paper-contrast measurement has the benefit of being able to compare different equipment, materials or techniques while rendering printing records less sensitive to any changes in the future.

The actual paper contrast depends on a variety of variables, some more and some less significant, but it can be precisely evaluated with the aid of a reflection densitometer or at least adequately quantified with inexpensive step tablets. In any case, it is beneficial to apply the ANSI/ISO standards for monochrome papers to measure the actual paper contrast.

Contrast Standards

Fig.1 shows a standard characteristic curve for photographic paper, including some of the terminology, as defined in the current standard, ANSI PH2.2 as well as ISO 6846. Absolute print reflection density is plotted against relative log exposure. The paper has a base reflection density and processing may add a certain fog level, which together add up to a minimum density called Dmin. The curve is considered to have three basic regions. Relatively small exposure to light creates slowly increasing densities and is represented in the flat toe section of the curve. Increasing exposure levels create rapidly increasing densities and are represented in the steep midsection of the curve. Further exposure to light only adds marginal density to the paper in the shoulder section, where it finally reaches the maximum possible density called Dmax. The extreme flat ends of the curve are of little value to the practical photographer. In these areas, relatively high exposure changes have to be made in order to create even small density variations. This results in severe compression of highlight and shadow densities. Therefore, the designers of the standard made an effort to define more practical minimum and maximum densities, which are called IDmin and IDmax. IDmin is defined as a density of 0.04 above base+fog, and IDmax is defined as 90% of Dmax, which is the maximum density possible for a particular paper/processing combination.

Please note that according to the ISO standard IDmax is a relative measure. At the time the standard was developed, the maximum possible density for any particular paper/processing combination was around 2.1, which limited IDmax to a value of 1.89. This is a reasonable density limitation, in order for the human eye to comfortably detect shadow detail under normal print illumination. Modern papers, on the other hand, can easily reach Dmax values of 2.4 or more after toning, in which case, a relatively determined IDmax would allow shadows to become too dark for human detection. Therefrom, a fixed IDmax value of 1.89 is a more practical approach for modern papers than a relative value based on Dmax.

While limiting ourselves to the textural log exposure range between IDmin and IDmax, we can secure quality highlight and shadow separation within the paper's density range. With the exception of very soft grades, the textural density range is constant for each paper and developer combination. However, the textural log exposure range will be wider with soft paper grades and narrower with hard paper grades. It can therefore be used as a direct quantifier for a standard paper-grading system.

Prior to 1966, photographic papers were missing a standard nomenclature for paper grades, because each manufacturer had a different system. The first standard concerned with paper grades was listed as an appendix to ANSI PH2.2 from 1966 (fig.2a). It divided the log exposure range from 0.50 to 1.70 into

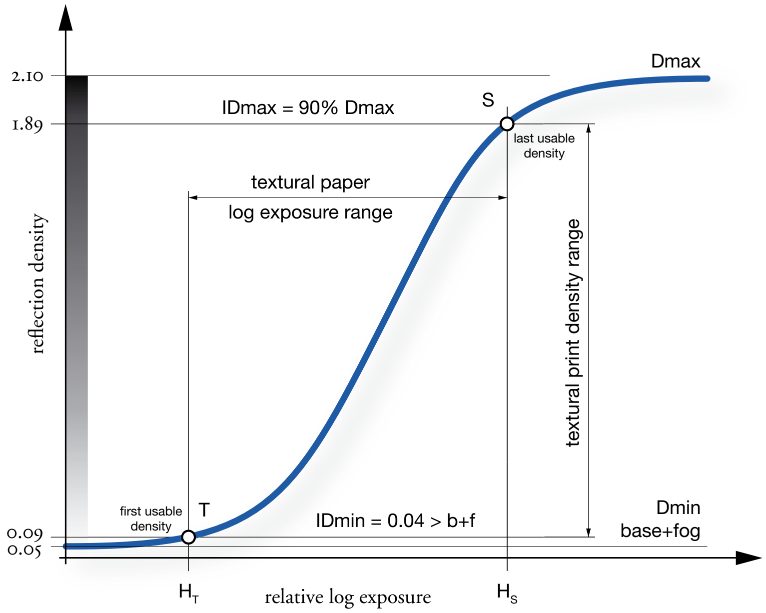

fig.1 The paper characteristic curve shows how the paper density increases with exposure. The textural log exposure range and the textural density range, between points 'T' and 'S', ignore most of the flat toe and shoulder portions of the curve to avoid compressed highlights and shadows.

six grades, which were given numbers from 0 through 5 and labels from 'very soft' to 'extra hard'. Agfa, Ilford and Kodak had used very similar systems up to that time. A never-released draft of the standard from 1978 added the log exposure range from 0.35 to 0.50 as grade 6 without a label. In 1981, the standard was revised, and the numbering and labeling system for grades was replaced. In this ANSI standard as well as the current ISO 6846 from 1992, different contrast grades of photographic papers are expressed in terms of textural log exposure ranges. In fig.1, we see that the textural log exposure range is defined by $H_S - H_T$, which is determined from the points 'S' and 'T' on the characteristic curve. In the standard, the textural exposure ranges are grouped into segments referred to as paper ranges, which are 0.1 log units wide and expressed as values from ISO R40 to ISO R190 (see fig.2c). In order to avoid decimal points in expressing the ISO paper ranges, the differences in log exposure values are multiplied by 100.

$$R = 100 \cdot \left(H_S - H_T\right)$$

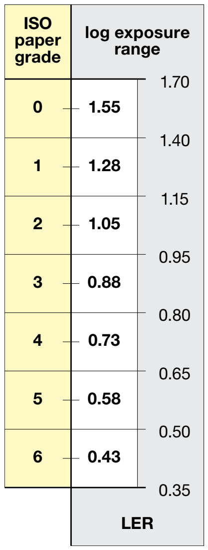

fig.2a The ANSI/ISO paper grade standards divide the log exposure range from 0.35 to 1.70 into seven grades, which are given numbers from 0 through 6.

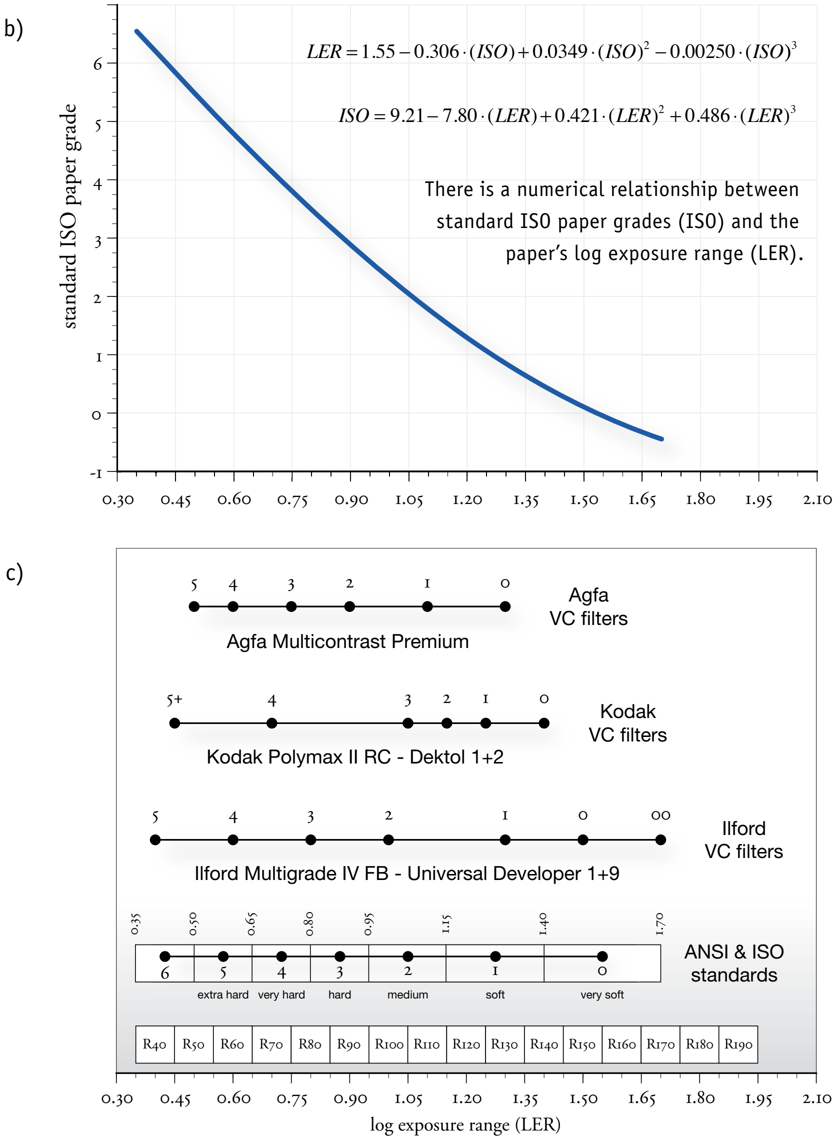

fig.2b-c The ANSI and ISO standards specify commonly used paper grades and ranges. There is a numerical relationship between standard paper grades and the log exposure range of the paper (top), but variable-contrast (VC) filter numbers have only a vague relationship to standard paper grades (bottom).

Fig.2c shows a comparison of the variable-contrast filter numbers used by Agfa, Ilford and Kodak, with the two standards. It is easy to see that there is only a vague relationship between filter numbers and the old standards. Manufacturer dependent variable-contrast (VC) filter numbers should not be confused with standard paper grades. They should always be referred to as 'filters' or 'filter numbers', to eliminate any possible misunderstanding.

In this book, we use both the paper-grading system of the old ANSI appendix and the standard ISO paper ranges, to measure and specify paper contrast, for several reasons. Manufacturers do not use their own grading systems anymore, but they have not switched completely to the new standard either. Graded papers are still available in grades from 0 to 5, even though standard paper ranges are typically also given for graded and variable-contrast papers. In addition, photographers seem to be much more comfortable communicating paper grades than paper ranges, and the confusion between filter numbers and paper grades has not helped to speed up the acceptance of standard paper ranges. Consequently, we continue to use the old paper-grading system, and we take the liberty of incorrectly referring to paper contrast, measured according to this once proposed standard, as 'standard ISO paper grades'.

Variable-Contrast (VC) Paper

The advantages of variable-contrast paper over graded paper have made it the prime choice for many photographers today. The ability to get all paper grades from one box of paper, and even one sheet, has reduced darkroom complexity and provided creative controls not available with graded papers.

Variable-contrast (VC) papers are coated with a mixture of separate emulsions. All components of the mixed emulsion are sensitive to blue light but vary in sensitivity to green light. When the paper is exposed to blue light, all components react and contribute similarly to the final image. This creates a high-contrast image because of the immediate additive density effect produced by the different components (see fig.3). On the other hand, when the paper is exposed to green light, only the highly green-sensitive component reacts initially, while the other components contribute with increasing green-light intensity. This creates a low-contrast image because of the delayed additive density effect produced by the different components (see fig.4). By varying the proportion of blue to green light exposure, any intermediate paper contrast can be achieved.

There are several options to generate the proper blend of light required to achieve a specific paper contrast. The simplest way of controlling the color of the light is the use of filters, for example a mixture of blue and green filtered light using a Wratten 47b (deep blue) and a Wratten 58 (green) filter. However, inexpensive filter sets, optimized for VC papers and numbered from 0 to 5 in increments of 1/2, are more practical and available from most paper manufacturers. They can be used in condenser or diffusion enlargers, either below the enlarger lens or in a filter drawer above the negative. The numbers on these filters correspond only approximately to paper grades, because of a missing standard between manufacturers (see fig.2c), and because contrast differs from paper to paper and according to the type of light source used.

Finer contrast control of up to 1/10-grade increments is available with dedicated VC heads. They come with their own light source at a modest price, but are typically only calibrated for the more popular paper brands on the market. Their light source consists of either two cold cathode bulbs or two filtered halogen bulbs, both providing independent intensity controls, to alter paper contrast. With some of these products, a full contrast range may not be achievable, and contrast is unlikely to be evenly spaced.

Another popular option is a standard color enlarger, which can also be very useful to control contrast in monochrome printing. A color enlarger is typically equipped with a dichroic filter head, containing yellow and magenta filtration. The yellow filter absorbs blue and transmits green light, and the magenta filter absorbs green and transmits blue light. These filters successfully alter the contrast in VC papers, and no additional investment is required. Even minute but precise contrast changes are simple with this setup. The maximum contrast will be slightly lower than that achievable with filter sets optimized for variable-contrast paper. However, this is of little practical consequence, since full magenta filtration typically achieves a maximum standard ISO grade. Manufacturers of enlargers and papers often include tables with yellow and magenta filter recommendations to approximate the paper contrast.

To the down-to-earth monochrome printer, it is commonly of little importance which paper grade was required to fine-tune the final image as long as it helped to achieved the desired effect. However, to the discerning printer, it seems reasonable after a long darkroom session, to spend a few moments, scribbling down filter numbers or filtration settings needed to render image detail appropriately. This gives the satisfaction to pick up a negative, and start printing where you left off several months or years ago. Nevertheless, a dependable method to measure

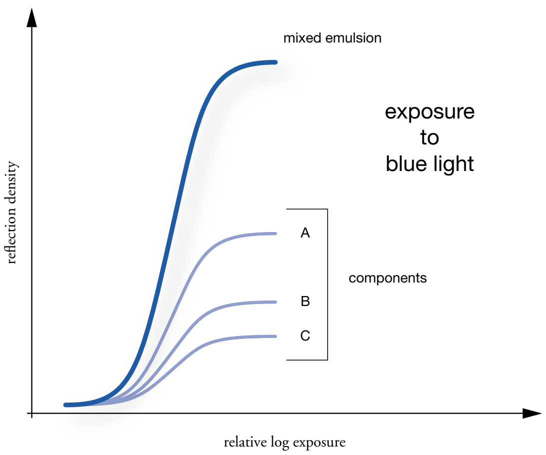

fig.3 When the paper is exposed to blue light, all components of the mixed emulsion react and contribute similarly to the final image. This creates a high-contrast image because of the immediate additive density effect produced by the different components.

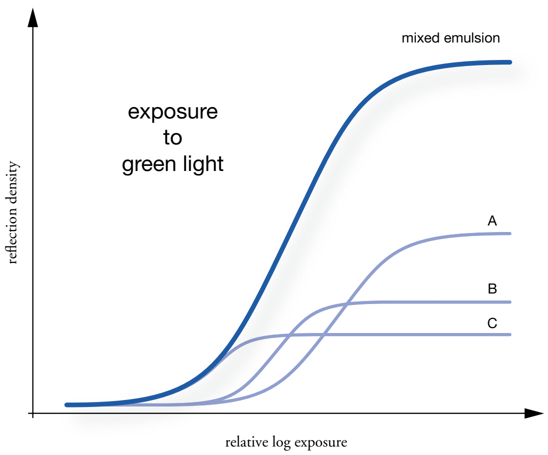

fig.4 When the paper is exposed to green light, all components react and contribute differently to the final image. This creates a low-contrast image because of the delayed additive density effect produced by the different components. (graphs based on Ilford originals)

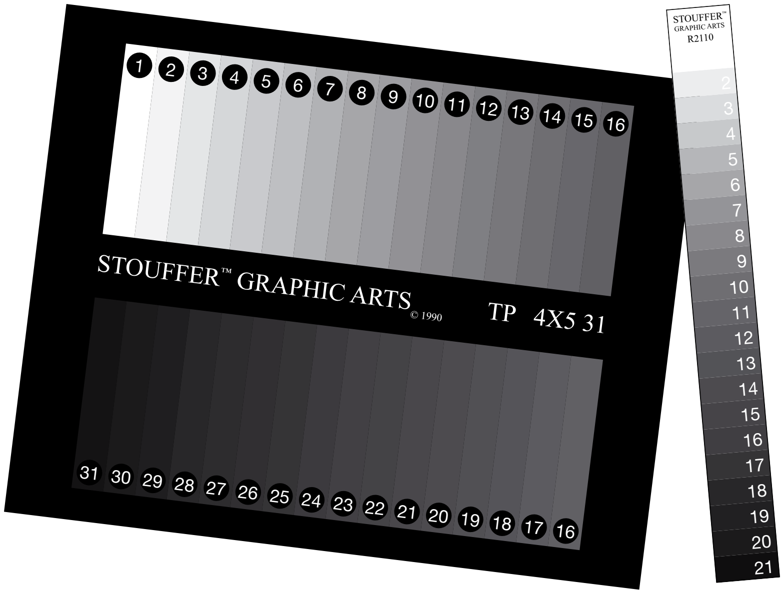

fig.5 A transmission step tablet (left) is required for the test. It should fit the enlarger for projection and have at least 31 steps. The optional reflection step tablet with 21 steps (right) is an ideal visual aid, if a densitometer is not available. Both photographic scales feature a step-to-step density increase of 0.1 and sold for about $40 a pair in 2006.

(Stouffer Graphic Arts, www.stouffer.net)

variables		insignificant	significant
method of control	fixed	batch variability baseboard reflectivity normal flare reciprocity latent image stability drying method	light source paper emulsion paper surface developer dilution temperature agitation time
	tested		filter settings
	ignored	normal material aging equipment aging mechanical hysteresis	outdated materials high flare toning bleaching

fig.6 Multiple variables are responsible for the final paper contrast. How they are controlled during testing depends on how significantly they influence contrast.

standard paper contrast is needed in order to compensate for equipment and materials changes reliably, while rendering printing records less sensitive to any changes in the future.

Equipment and Test Procedure

The equipment required to measure standard paper contrast includes a transmission step tablet, a reflection densitometer or a reflection step tablet, some graph paper and the typical darkroom equipment to expose and process photographic paper. Fig.5 shows the photographic scales supplied by Stouffer Graphic Arts. The transmission tablet on the left is used to generate the required density data. Precise measurements rely on a densitometer, but in the absence of such equipment, the reflection scale on the right, can be used as a visual aid to quantify paper contrast adequately. References to this alternative method are made at the end of this chapter.

There are many possible variables controlling the paper contrast. Fig.6 shows how the variables can be separated into their level of significance and my suggested control method for them. In this test procedure, we concentrate solely on the variables of high significance. Variables with low significance are either assumed to be fixed or are ignored. The goal of this test procedure is to determine the standard paper-contrast grades achieved with your favorite filtration method and materials. Other variables, which influence contrast significantly, need to be closely controlled and are therefore assumed to be fixed. In addition, some significant variables are considered undesirable but avoidable, and therefore, they are ignored as well. Be aware that conditions in your darkroom may change over time, necessitating an occasional control test.

For the sample test described here, the following significant variables were fixed, tested or ignored. The light source was an Omega D2V variable condenser enlarger with filter drawer. I used Kodak's Polymax VC filters, and Polymax II RC-E paper was tested. The developer used was Kodak's Dektol at a dilution of 1+2 and at a temperature of 20°C (68°F). The agitation was accomplished by constantly rocking the tray for 1.5 minutes, followed by normal processing without toning. The paper was air dried after washing.

Generating Your Data

Select the paper and paper surface you would like to test, and have it available in a practical size, so that the transmission scale from fig.5 can be printed onto it. I always have a box of 5x7-inch paper for these types of tests in stock. Project the transmission scale, so that it fits comfortably on the paper, with some room to spare. Start with the softest filtration to produce the lowest grade possible. Expose the paper such that the whole tonal range fits on the paper. The highlight area should have several paper white wedges and the shadow area should have several maximum black wedges before any tonality is visible. Record the filtration and the exposure time on the back of the print. Then, process the paper normally, keeping development time, temperature and agitation constant. For RC papers, the development time can be fixed to 1.5 minutes, but for FB papers, the total development time should be about four to eight times (6x is normal) the 'emerging time' of the mid-tones. Ansel Adams referred to this as the Factorial Development. Repeat the process for all remaining filters or significant filtrations. Be sure to keep all other variables constant, including the exposure. This will allow us to create an exposure compensation table, as discussed in the chapter 'Exposure Compensation for Contrast Change'.

With the help of a reflection densitometer, all step wedges can be read and charted as shown in fig.7. The x-axis shows the relative log exposure values, which have equivalent log densities in the transmission tablet of fig.5. Just remember, that step number 1 has a relative transmission density of 0.0 and that number 31 has a density of 3.0. To convert the step-tablet values into paper exposures, take a step number, subtract 1, divide by (-10) and add 3.0. The result is the relative paper log exposure value of that step. The y-axis indicates the reflection densities as read with the densitometer. Use a copy of the blank record sheet from 'Tables and Templates' to collect and chart the paper density data. The result, in fig.7, shows the paper characteristic curve of our test with filter number 2.

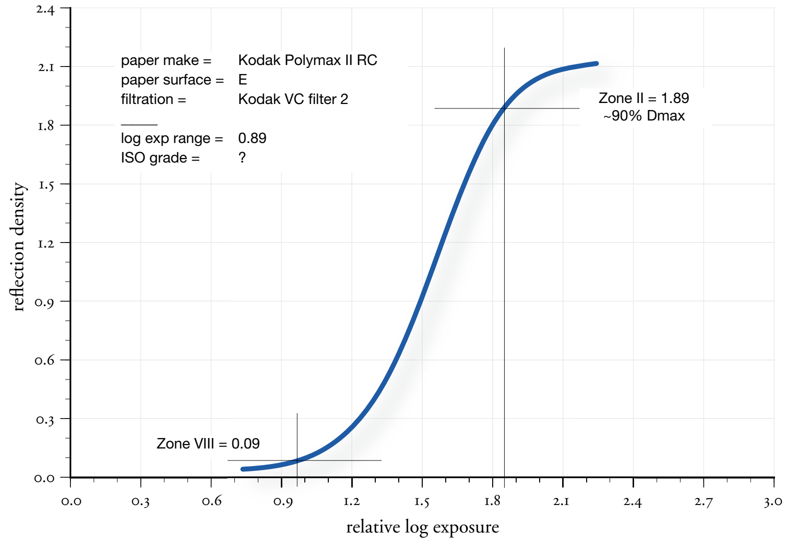

fig.7 Charting the test densities results in a typical paper characteristic curve.

Measuring Contrast

Now, we are interested in the textural log exposure range. From fig.1, we remember that it is the delta between the first usable density and the last usable density, or also referred to as IDmin and IDmax, respectively. The ISO standard defines these two densities in relative terms, but we need absolute values for a quantitative analysis. I have chosen a reflection density of 0.09 for IDmin and 1.89 for IDmax for reasons that are explained in more detail in 'Fine-Tuning Print Exposure and Contrast'. We will use the log exposure range between 0.09 and 1.89 reflection density for the rest of this sample test.

The chapter 'Tables and Templates' includes an overlay called 'Paper Range and Grade Meter', which is a handy measuring tool based on the ANSI/ISO standard. The use of the meter overlay is shown in fig.8, as it is applied to the sample test data. The curve has been highlighted for clarity. The overlay is placed on top of the graph so the 'base+fog density' line is parallel to the grid, but tangent to the toe of the curve. The overlay is then moved horizontally until the vertical origin and IDmin (0.09) intersect with the curve in point 1. At the same time, IDmax (1.89) intersects with the curve in point 2. A vertical line drawn down from point 2 allows for the measurement of ISO grade

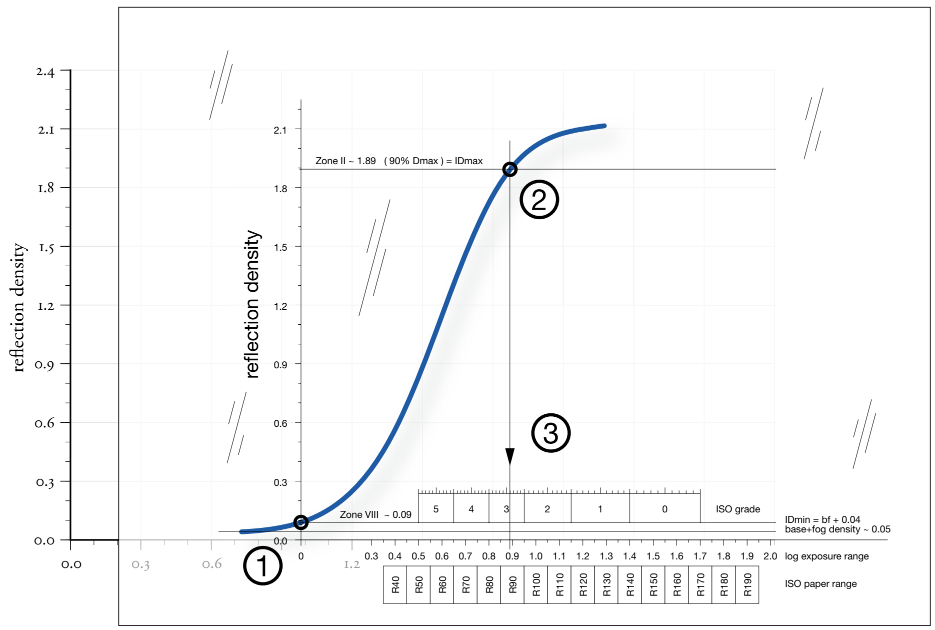

fig.8 In this example, the paper characteristic curve, obtained with a number-2 filter, is plotted and measured to determine the exposure range and ISO grade for this paper/filter combination.

Kodak Polymax II RC		
filter number	ISO	
	grade	range
-1	0.1	152
0	1.5	116
1	2.3	99
1.5	2.5	96
2	2.9	89
2.5	3.2	85
3	4.0	73
3.5	4.4	66
4	5.4	51
5	6.2	36

fig.9 (top) The results of all tests are compiled into a reference table, enabling us to work with standard ISO paper contrast values and objectively comparing different materials and methods.

and paper range at point 3. Fig.8 shows the overlay in this final position to take the contrast readings. For this paper and filtration, I measured an ISO grade of 2.9 and a log exposure range of 0.89 (ISO R90).

Measure ISO grade and paper range for all of your test curves and record the readings. When finished, list the results in a reference table, similar to fig.9, showing the entire test data. Now, we are able to work with standard ISO paper contrast values and objectively compare different materials and methods.

The Alternative Method

A densitometer is still a luxury item in most amateur darkrooms. Fig.8a shows how the reflection scale from fig.5 can be used, in the absence of a densitometer, to determine the log exposure range of the sample test. Just take each filtration test, and find the wedge that has the best matching density with step number 2 and 20 on the reflection scale. These are the wedges with a reflection density of 0.15 and 1.95, respectively. I suggest conducting this evaluation in a well-lit area. Otherwise, it may be too difficult to see the difference between the dark steps. Counting the steps from highlights to shadows gives us the exposure range. In this sample test, 9 steps (23-14) are equal to a 0.9 log exposure range, since each step is equivalent to 0.1 in density increase. The bottom scales in fig.2c, or the Paper Range & Grade Meter, reveal that a 0.9 log exposure range is equivalent to an ISO paper range of R90 and a grade of just under 3. This method is not as precise as using a densitometer, but it is sufficient to get useful measurements.

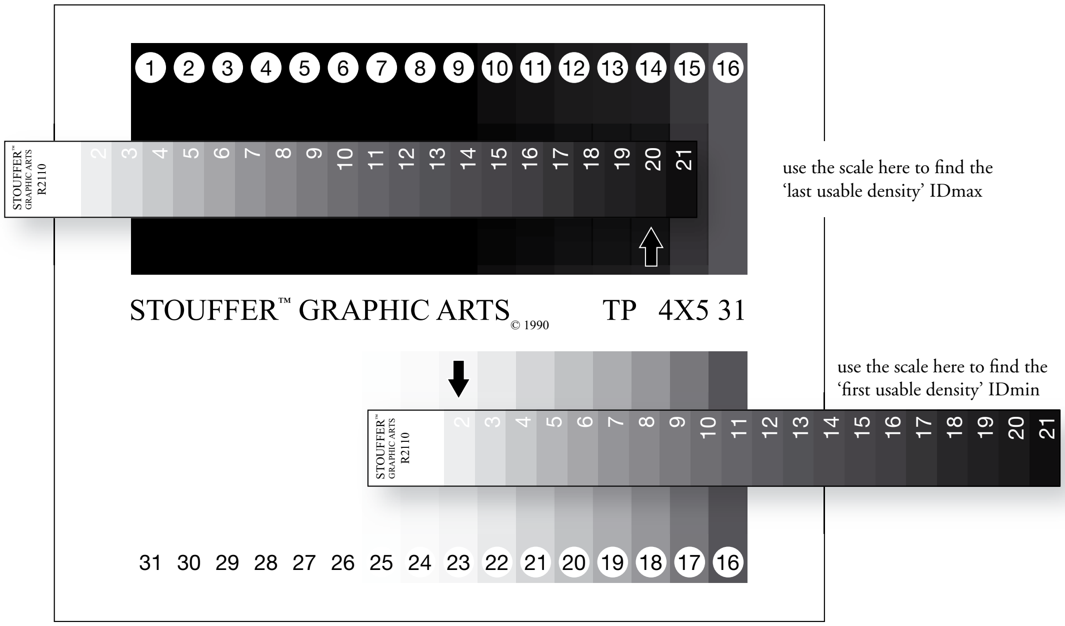

fig.10 (right) A reflection scale can be used to determine the log exposure range and paper contrast adequately, if a densitometer is not available.