

Density.

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1. Introduction.

On asking a student what might be the most valuable handout at the start of a darkroom lab class, he replied "something that explains Density and Densitometry". After a little library research, it seemed that these subjects were either dismissed in a relatively trivial manner, or went into depth on the subject - far more than is needed for even an advanced darkroom class. There should be "no fear" in using Density, Densitometry, and Densitometers. These are merely the darkroom equivalents of Light, Exposure, and Exposure Meters. I'll start with a simple description of each.

Density is the property of a print that describes how light or dark it is. Applied to film it is essentially a measure of how much light can get through the film. It can, with a little refinement, be applied to color prints and films.

Densitometry is the technology of measuring **Density**.

A **Densitometer** is the instrument used to measure **Density**.

Density is given as a number by the Densitometer (so you don't have to do the calculation). If you understand that Density is merely a means to give a number to what your eye assesses, you really may need not delve any deeper into the subject. (I will however hit you up with some more background - which you may choose to ignore.)

The human eye is a very accurate comparison instrument. We are able to see very small differences in two samples laid side by side. The brain can also assess what is the "right" darkness or lightness of a print, and we have methods for looking at film to decide if our exposure, and therefore density, is correct. The eye is not good at measuring. We can not remember exactly a depth or a shade of color. Some people have a greater skill at this than others, but, by and large, our ability to remember accurately is much less developed than our ability to compare.

At Austin Community College, Northridge campus, we have 3 Densitometers. Two are old, and were kindly donated to the Department. They are fully functional, but are more difficult to use than our third unit. The latter is a modern, version, able to measure films and papers, both black and white and color. It is all-electronic, and can be hooked up to a computer. Similar models are used in Minilabs to monitor the C41 and RA4 processes, and in Research Labs for the numerical evaluation of images.

I will restrict my comments on practice to the X-RITE 810 Densitometer.

2) What is Density?

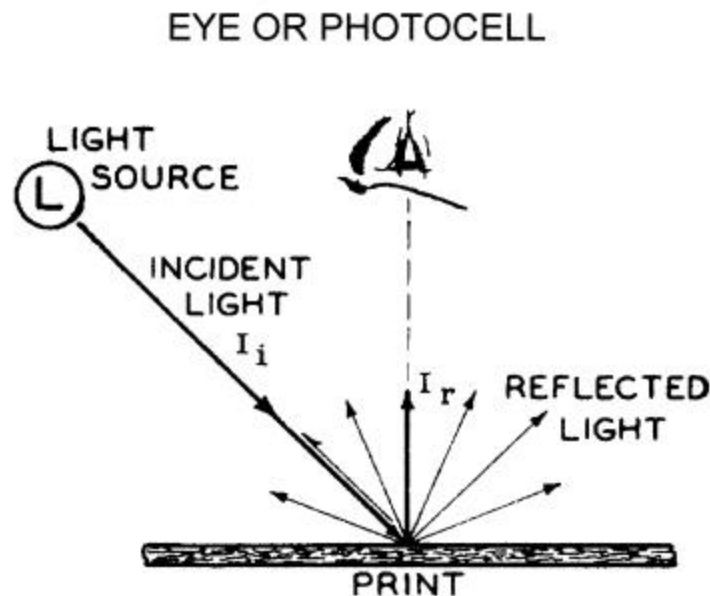
As we mostly use the Densitometer to measure prints, I will describe only what is properly referred to as "**Reflection Density**". (The other, film-applicable, measure is "Transmission Density".) Here we go. Figure 1 will help visualize the situation.

Figure 1.

Reflection Density.

$$\text{Reflectance} = I_r / I_i$$

$$\text{Reflection Density} = \text{Log}_{10} (I_i / I_r)$$



If you can imagine a beam of light striking a print surface, at some part of your image, some of it will be reflected, and some will be absorbed. The Densitometer is going to measure this for you, but first of all we need a standard. This is usually a piece of white ceramic tile, easily cleaned, and unchanging over the years. As this tile is as white (reflecting) as the ceramics industry can produce, this will be said to reflect "most" of the light falling on it, and have a density of 0.0X – the "X" number being supplied by X-RITE. (A deposit of magnesium oxide, formed by burning magnesium near a surface, is the whitest surface known, but no way is such a thing convenient to prepare or use, so we go with the tile. X-RITE compared their tile with the Magnesium Oxide standard.) During the set up procedure, which I do about once a month, I measure the standard tile, and adjust the densitometer. The electronic memory of the densitometer retains this measured value (even if turned off) and uses it as the "white" reference until I re-calibrate the unit. It will use that number to measure every print sample that is placed under it. The tile also has a grey patch and a black patch, so I can check that the instrument is behaving itself at other densities. There is a slight "drift" to the instrument, and people sometimes press the wrong buttons, which can throw it off. Therefore my check.

Now if a gray sample is put under our imagined beam of light, less light will be reflected than with the white tile. The densitometer will measure this amount of reflected light. The ratio of reflected light to the 100 % value is called the **Reflectance**, and it is a pretty useless number,

except as a starting point to calculate density. The Reflection Density is the logarithm to the base 10 of the reciprocal of the Reflectance. There, you really wanted to hear that didn't you? Given a Scientific Calculator, this is easy to calculate, but no need, the Densitometer will do this for you, and display the result. It won't even give you the raw data you need to make the calculation for yourself.

After understanding Reflection Density, it should be no problem understanding Transmission Density. This time it is the light that gets through that is measured. Again the Densitometer will perform the calculation for you. Figure 2 shows the general arrangement.

Figure 2.

Transmission Density.

$$\text{Transmission} = I_t / I_i, \text{ Opacity} = I_i / I_t$$
$$\text{Transmission Density} = \text{Log}_{10} (I_i / I_t)$$

EYE OR PHOTOCELL

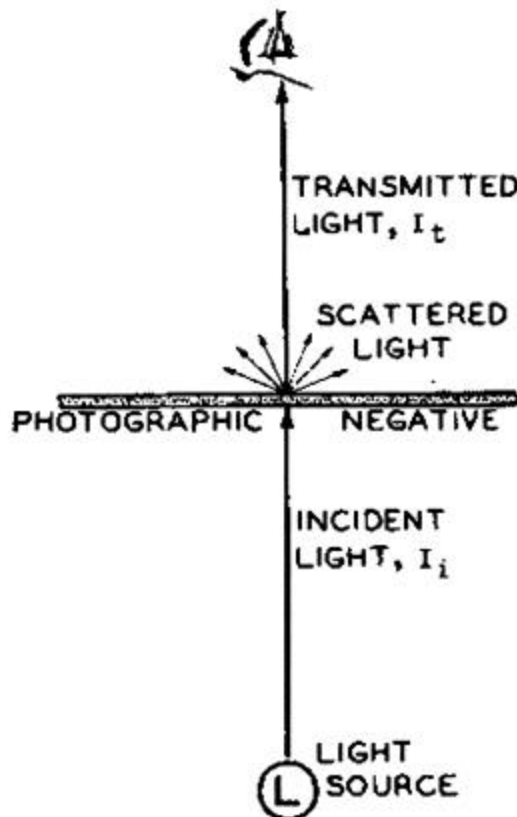
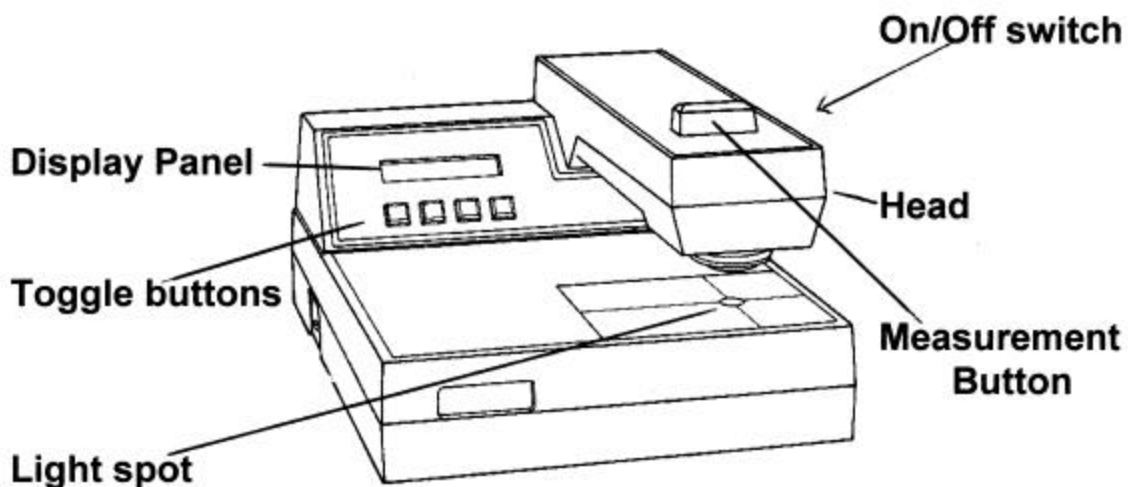


Figure 3 shows the X-RITE unit, and naturally it doesn't look much like the arrangements in Figures 1 and 2. The actual components need not be very large, and the ingenious engineers of X-RITE have managed to incorporate both Transmission and Reflection units in one small package. Please don't take it apart to see how it is done.

Figure 3.

The X-RITE 810 Densitometer.

This unit is a combined Reflection/Transmission unit and will measure both Color and Black and White materials. It can be computer interfaced for routine data collection.



So why do we use density? Well, there are three good reasons. Firstly Density corresponds closely to what our eyes see. The same change in density (i.e. the number) anywhere on the white-to-black scale looks the same to our eyes. (As an aside, people can detect a density difference on a side-by-side comparison of between 0.007 and 0.02.) I have a Radiologist friend who sees smaller changes than I can, perhaps he has a trained eye. People vary, and some males are color blind to a degree, (ladies: you carry the gene, we men suffer the consequences. Only 0.1 % of women are color blind.) This detectable difference carries over into Digital Imaging - using 24-bit color may give steps (Posterization) in the image that you won't see with 32-bit color. The second reason is that we have a recordable number for the appearance of a print. This is useful for process control. If a standard exposure is made on a sheet of photographic paper, and a strip processed every day for a week, we have a means to check on the uniformity of our processing machine. (Yes I've done it and the RA4 machine does vary somewhat.) Similarly if we expose strips of paper on several enlargers, we can measure just how different are the enlargers. (I haven't done it, but Don and Chris have. Enlargers vary too, as you already know if you have to change from one to another.) Thirdly, density is an

accurate measure of the amount of dye in an image. This ties density in to a whole field of chemistry that is important in the research into color materials - accurate concentration measures are very important to the Techies who make film. If you are thinking of going into that side of the business, you need to understand the third item, but otherwise skip it. In the "To dig deeper" section, I'll give references.

As I said, Figures 1 and 2 show the details of densitometers, somewhat idealized. In the place of the eye, there would normally be a photocell. I've added a few bits of my own to the figures, which came from a GATF manual. (Graphic Arts Technical Foundation.)

3) Using the X-RITE 810.

Again, Figure 3 is a picture of the X-RITE unit. I have annotated the features referred to below. It does the Reflection and Transmission measurements in one instrument - very ingenious. First look at the display panel. If nothing is visible, the unit is turned off. Turn it on. (Switch is on the back.) It will perform a self-check, and probably tell you it's OK, even if it isn't.

On the left side of the display is a letter. It will be **R** or **T**, depending on if the unit is preparing to measure Reflection density or Transmission density. You can toggle this with the button below the display. (Go to **R**, we're going to measure a print.)

The next button should be toggled until **VIS** appears (if you are measuring a B & W print, or **Red, Green, Blue** if you are working with a color print). We're going the color route. To perform a check, place your print, back uppermost, under the densitometer head. (Where the spot of light is.) Depress the button above the head until the display flashes numbers. Release the button. If the back of the print is truly white, the numbers displayed should all be less than 0.10

Now take your print and position the area that you wish to measure under the spot of light. Depress the button and hold. The three numbers that come up on the display are the Red density (corresponding to the amount of Cyan dye in your print), the Green density (i.e. Magenta) and Blue (Yellow). The color is above the number,

Write these numbers down. You've used the Densitometer.

4) Matching a specific color.

If you have included a gray card in your picture, it can be used to obtain an accurately balanced print. The procedure is as follows: measure your gray card. It should give values of about 0.75 for all three colors. (It need not be exactly these numbers, it is only important that you know what it records.) Now measure the gray card reproduction on your print. Unless you are phenomenally lucky, you won't get the same values as the gray card gave. The differences will tell you what corrections you must make to the enlarger filters. If the Red reading is too high, there is too much Cyan in your print. If the Green reading is too low, you have too little Magenta in your print. Now if the Blue reading is too high, what does it tell you about the Yellow in the print?

If all values are too high, your overall exposure is too much, and you will have to cut your exposure time down. To do this correctly, one step at a time, adjust your exposure time so that the Cyan density is correct. (Now you know why we want to do this, but can you remember?) Now the change in filtration can be calculated approximately.

The Cyan density is now spot-on, but Yellow and Magenta are off. Multiply all three numbers by 100. (Take away the decimal point.) Now subtract the Cyan value from each of the other two and then divide each number by 2. This gives you the amounts you will have to alter your enlarger filters to produce a closer match to the gray card.

Actually this is not quite correct, because photographic dyes are not perfect. (The Magenta dye absorbs Blue light, and interferes with the Yellow reading). The result on your corrected print should be very much closer to the gray card results. It is possible to make allowances for each of the dyes, but it isn't worth the effort unless you're the National Bureau of Standards.

You now use the values on your corrected print to calculate as before the filter changes - which should now be small. You will not be able to obtain an exact match most of the time because there are sources of variation between each print that we can't quite eliminate.

Again, a gray card need not be used. If you have a color in the picture, that you also have a sample in hand, a direct comparison is possible, by the method above. **This can be important.** Corporate Ad. Directors can insist that your photograph matches their product.

Usually the Corporate logo color must be accurately reproduced.

(Now I throw a wrench in the machine. Research by Eastman Kodak, some years back, indicated that people don't always want an accurate reproduction. Often they want a slightly lower overall density print. For artistic reasons therefore, the final reproduction is yours to decide upon!)

5) Process control using a densitometer.

All minilabs and pro printing shops maintain tight control of their processes. It results in consistent output and high quality. They use the other side of the densitometry coin, which is called **Sensitometry**. This is the technology of accurately and consistently exposing photographic materials to light. At ACC we do not have the needed equipment to do this, but we can do something close with what we do have. (An alternative is to purchase pre-exposed film strips, and that is what most minilabs do.)

You need a 21-step wedge. This is a strip of film with 21 steps in density, each step differing by a known amount from its neighbor. Usually this is 0.15 density units. This wedge should be contacted printed onto your test material, also in strips. Make a dozen or more. Process one, and put the rest in a black bag in the freezer. Each day, take a strip out and process it. Refreeze the remainder. When you are out of strips to develop, take all the processed strips, select a step that is in the mid-tone range, and measure that step on each strip. Plot a graph of color density against time. You now know how the processor is varying day by day. Should you do something about it? May be not. You will also pick up deterioration of chemistry, which you should do something about, or at least bring it to the attention of Faculty.

As an exercise, leave a sheet of color paper in a dark container, in the back of your car, for a few Texas summer days. Then run a comparison between that sheet and a refrigerated sheet. This should warn you not to leave color materials in your car! Incidentally, people are always asking me about this, so let me know the results, so I can quote real data.

5) Do your prints fade?

Expose a sheet of paper uniformly. Cover one half with truly black paper, and leave it out in the sun for a few days. When you remove the black paper, there will probably be a line where fade has occurred. Measure both halves on a densitometer, and you have quantified the result.

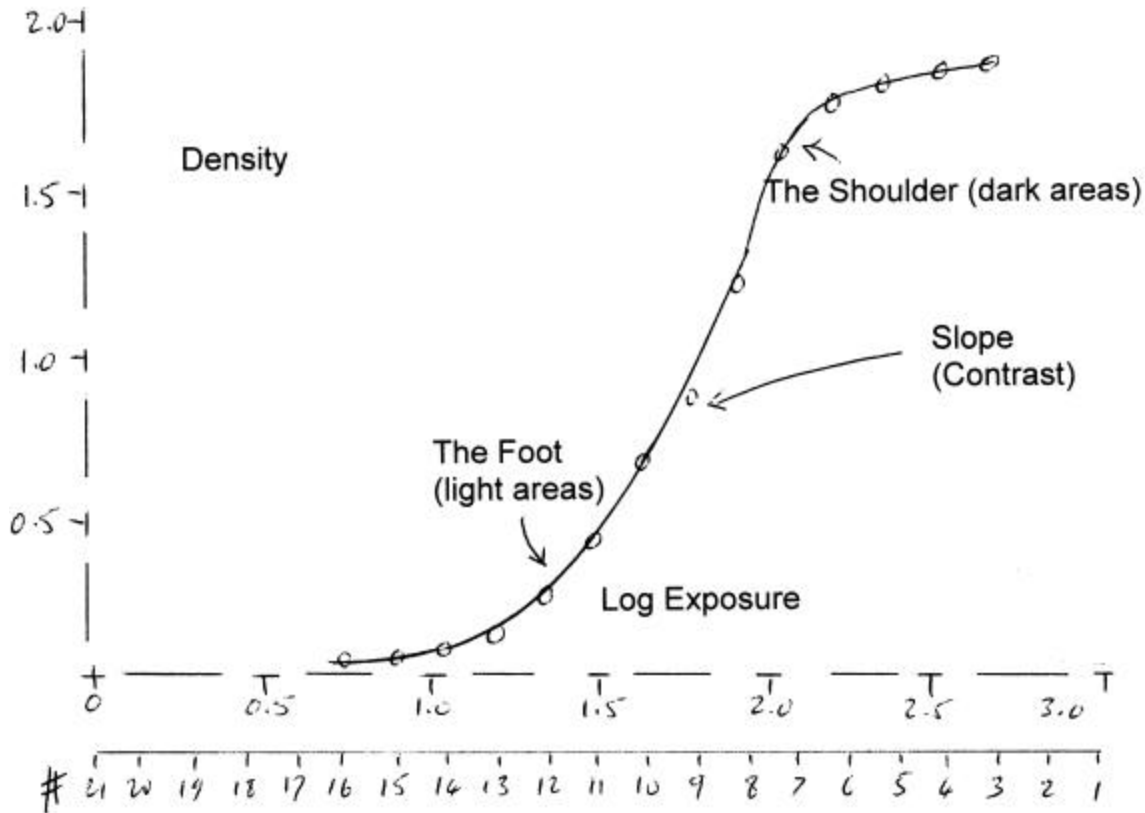
Scientific rule. He who has the best data wins the argument. If you have actual numbers, and the other guy says "some" or "quite a bit", you win. If you have four times as many numbers and a nicely-plotted graph, you win. Got the idea?

6) Generating a Characteristic Curve.

The Characteristic Curve is the basic piece of information needed to understand the behavior of a photographic material. It is a graph that plots the amount of light that falls on the material versus the density that results after development. You have already observed that as development proceeds, the image appears. After a certain length of time the image doesn't change any further. If you work with Multigrade RC and FB you've probably noticed that development does not proceed at the same rate, although these are supposedly the same emulsion layer. It's probably the fiber base making the difference. The optimum development time for one is not the optimum for the other.

A Characteristic Curve is in fact the graph of the Logarithm of Exposure, plotted against the Density that results from that Exposure. Sometimes you hear them called D LogE curves (for the obvious reason), or H and D curves. The latter names them after two early workers in the field, Hurter and Driffield. Exposure is defined as the product of Intensity x time. The reason for using this somewhat arcane combination of variables is, that when plotted this way, the Characteristic Curve comes out pretty much as a straight line.

Figure 4.
Generation of a Characteristic Curve.



Using a step wedge as described in the previous section, and a densitometer, it is possible to quantify the development of a material, and select the best time to use. I found that after a minute's development at room temperature, Multigrade RC was fully developed. The FB product needed two minutes. On testing my (free) packet of Forte paper I found that density was continuing to increase after 5 minutes in the developer. If you don't quite give enough exposure to the Forte product, development can be extended to wring out a little more density. This doesn't work with Multigrade. These effects are small, but by using densitometry, can be seen. Once a development time experiment has been conducted, you are unlikely to pull a print out early - you know it won't have reached full maximum density. Try it.

Going back to generating the Curve (I digressed). The material being tested must first be exposed under the 21-step wedge, to such an exposure that one end develops to maximum density (shortened to D_{max}), and the other has no detectable image (D_{min}). You will have to determine this by testing a strip, and adjusting exposure. Then the actual experiment is conducted, and the dry strip measured, step by step, on the densitometer. Each step permits a 0.15 increase in Log Exposure, so all you have to do is to plot the step number on the horizontal axis of your graph, each step number being separated by 0.15. The reason for this is related to the step wedge being made in logarithmic steps (Density is a logarithmic quantity). Believe me it works, and if you're not into logarithms, don't worry, the process is what you need to learn.

For a negative-acting material the low densities should plot on the left hand side, and the high densities on the right. See Figure 4, on which I have added some of the common terms thrown around by those who use Characteristic Curves frequently.

7) An example of the use of step wedges.

This experiment was to see what was the effect on the Characteristic Curve of Multigrade IV on varying the Contrast filters. I did it first in the normal way, but then decided to use a variation. I set my exposure time to 20 seconds, and switched from a # 4 1/2 filter to a # 1/2 filter at various points in the exposure. For example on the third strip, I exposed for 12 seconds to the # 4 1/2 filter and 8 seconds for the # 1/2 filter. All in all, I made 6 strips, (20/0, 16/4, 12/8, 8/12, 4/16, and 0/20 seconds). All strips were processed for 1 minute at 24° C in Dektol 1+3. The best way to see the changes that resulted, was to lay the dry strips alongside one another with the steps aligned. (The same result was found by measuring densities, but for the full effect, in this case, viewing was very instructive.)

My finding was that up to a density of 0.65, (a little lighter than the standard gray card), the curve shape did not alter. Above that density, the contrast steadily dropped. What does this mean in practical printing terms?

It means that if you wish to alter the contrast in the foot region - the light tones, variation of the contrast filters will not help you, but if you want to see greater detail in the shadow areas, going to a lower filter number will.

How can this aid you? Well, it demonstrates how to change shadows, and it tells you that you can't change foot detail, at least not by this method.

However I would be remiss in my job if I didn't at least make some suggestions as to how you might alter the light tones while leaving the dark tones the same. The obvious method would be to burn in the high light areas - double the exposure in that area, using a card with a hole in it. You might also try pre-flashing the paper, which is to give the paper a slight overall exposure, almost enough to fog it, but not quite. This alters the foot shape. Some papers may also respond differently to Multigrade IV, so there is another area to experiment. I don't have any proper data on these last methods, just a few quick tests, so I'm only suggesting what might be done. You could start off by uniformly exposing strips on which you have placed a coin. The pre-exposure should be the one just before you start to see the image of the coin. It will be a very low exposure in comparison to the main exposure.

8) Conclusions.

I hope I've enlightened a little. If you have the concept of Density as a measure of the eye's response to the lightness or darkness of your image, you have the basics. If you can walk up to a Densitometer with an image, and measure it, you're up and running. If you can plot a Characteristic Curve, you're ahead of the pack. Then, only if you wish, you can dig deeper into one or other of the texts given in Section 9.

9) To dig deeper.

Color Separation Photography, GATF, Chapter 10.

The Theory of the Photographic Process, any edition has what you need.

Ansel Adams' The Negative, p85. He doesn't say much, but the book is easy to find!

Post Exposure, by Ctein. He assumes that if you are going to read and use his book, you already know about Density and the rest.

Science and Technology of Photography, editor, Karlheinz Keller. Don't bother with this one unless you're up on Integral Calculus.