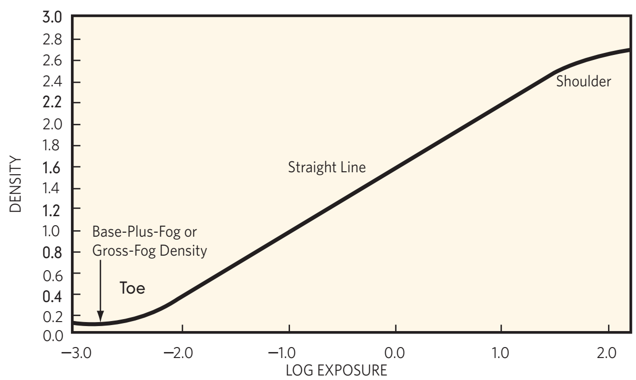
BASIC SENSITOMETRY AND CHARACTERISTICS OF FILM

BASIC PHOTOGRAPHIC SENSITOMETRY

Sensitometry is the science behind the art of filmmaking. It is the measurement of a film's characteristics. These measurements are expressed in numeric and chart form to convey how a film will react to the amount of light, the type of lighting, the amount of exposure, the type of developer, the amount of development, and how all these factors interact. In most cases, a cinematographer doesn't need a great depth of technical information to use motion picture films—using the right film speed and the right process will suffice. On the other hand, having a basic understanding of film sensitometry will help you in tasks as simple as film selection to as complicated as communicating the mood of a challenging scene.

THE CHARACTERISTIC CURVE

At the heart of sensitometry is the characteristic curve. The characteristic curve plots the amount of exposure against the density achieved by that exposure:



To create a characteristic curve, we first need some densities to plot, and they come from a sensitometric tablet exposed onto the film. Commonly called a step tablet, this highly calibrated tool consists of 21 equally spaced intervals of grey. When film is exposed through the step tablet, the resulting densities (darkness) of the 21 steps are measured on a densitometer. Density is placed on the vertical axis.

Exposure is placed on the horizontal axis. On a characteristic curve, the exposure numbers are converted to logarithmic values. One reason is to compress the amount of data into a usable space. Another is so that the curve shape looks like even steps.

The curve itself consists of three parts: toe, straight-line portion, and shoulder.

The dark portions (shadows) of a scene are the light (clear) parts of the negative. (The opposite would be true when looking at a characteristic curve of a reversal film.) These dark portions are represented as the toe part of the curve. We say the shadows "fall" on the toe.

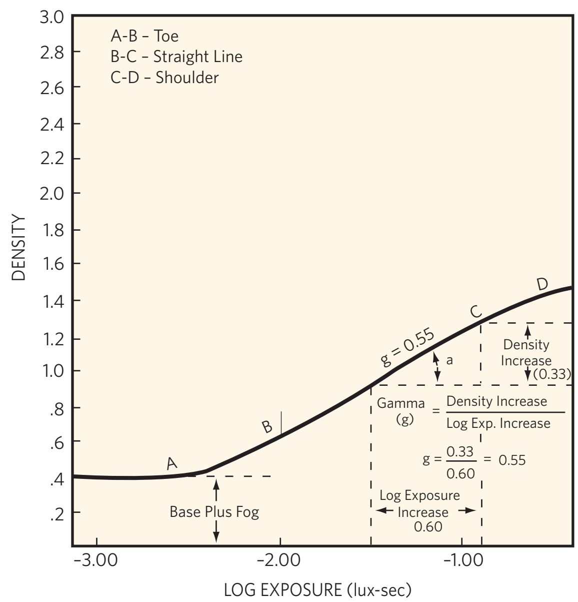
The light portions of a scene (white shirts, lights, bright reflections), called highlights, are the dark parts of the negative. These light portions are represented as the shoulder part of the curve. We say the highlights "fall" on the shoulder.

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

Characteristic curves take on an "S" shape for two reasons. One is that the arithmetic data has been compressed into logs. The other is that film does not reproduce extremely dark and/or extremely light areas in the same way as midtones. A film's ability to record detail in extremely dark subjects is called "shadow detail," and is reflected in the toe of the curve. Likewise, a film's ability to record detail in bright subjects is called "highlight detail" and is reflected in the shoulder of the curve.

What Can Be Learned From a Characteristic Curve?

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. A characteristic curve is like a film's fingerprint.



D-min

Lowest density is more often called D-min (density-minimum). It is a result of the transparent base and a slight chemical fogging of the film emulsion. Chemical fog occurs because a few silver halide crystals will spontaneously develop, even though they received no exposure. Because of this fogging, 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

D-max (density maximum) refers to a film's highest density, and measures the maximum darkness a film can achieve. Most black-and-white films' characteristic curves don't show the film's D-max; it's often beyond the scale printed from the step tablet. During normal use, films aren't typically exposed to D-max.

Speed Point

The speed assigned to any given film is derived from the exposure required to produce a certain minimum density. This "speed point" is generally 0.1 above base plus fog. There is no scientific basis for this value. Rather, it is the point at which the human perceives a noticeable increase in density.

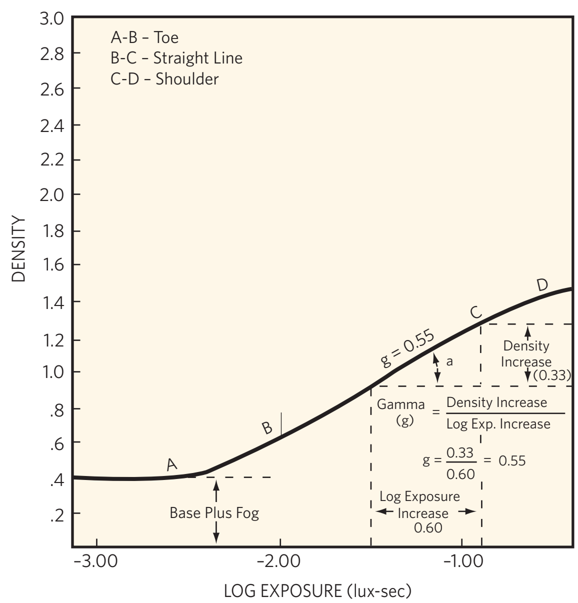
Contrast

Degree of developing affects the steepness, or contrast, of the curve. Adjectives such as flat, soft, contrasty, and hard are often used to describe contrast. In general, the steeper the slope of the characteristic curve, the higher the contrast.

There are two measurements of contrast. *Gamma,* represented by the Greek symbol γ, is a numeric value determined from the straight-line portion of the curve. Gamma is a measure of the contrast of a negative. Slope refers to the steepness of a straight line, determined by taking the increase in density from two points on the curve and dividing that by the increase in log exposure for the same two points.

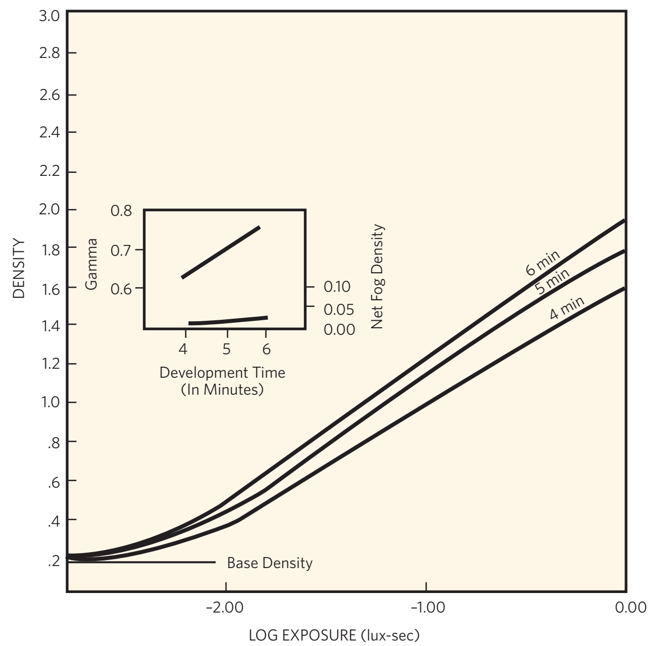
$$\gamma = \frac{\Delta D}{\Delta \text{ log exposure}}$$

The other means of measuring negative contrast is *Average Gradient.* Average Gradient is the slope of the line connecting two points bordering a specified log-exposure interval on the characteristic curve. The location of the two points includes portions of the curve beyond the straight-line portion. Thus, the Average Gradient can describe contrast characteristics in areas of the scene not rendered on the straight-line portion of the curve.



Can a Film's Contrast be Changed?

Yes, contrast can be varied to suit the filmmaker's needs. The usual method of varying contrast is to change the development time, while keeping temperature, agitation, and developer activity as unchanged as possible. The family of film in the following figure has three curves, but it could just as easily have had five or 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 nearly constant. Notice that all of the data that affects contrast is written on the graph.

EXPOSURE INDEX AND LATITUDE

Proper exposure depends on four variables: the length (time) of exposure, the lens opening, the average scene luminance, and the speed (Exposure Index) of the film.

Exposure Index

The film exposure index (EI) is a measurement of film speed that can be used with an exposure meter to determine the aperture needed for specific lighting conditions. EI is derived from the “speed point” on the characteristic curve—a point that corresponds to the exposure required to produce a specific optical density. The indices for KODAK Motion Picture Films are based on practical picture tests and make allowance for some normal variations in equipment and film that will be used for the production.

To keep film speed values simple, only certain numbers from the entire range are used, and speed points are rounded 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

Bold numbers show film speeds used on current KODAK Films.

In photography, the exposure system is based on the number 2. When we halve or double the camera settings, we make a one stop change in exposure. Thus films speeds 100 and 200 are one stop apart.

Standard film speed values are 1/3 stop apart. This is because the log of 2 is roughly 0.3 (the density change achieved by halving or doubling exposure). One-third stop increments result in a 0.1 log E change, which happens to be a convenient interval to work with.

Reciprocity

Reciprocity is the relationship between light intensity (illuminance) and exposure time, in the context of total exposure a film receives. According to the Reciprocity Law, the amount of exposure (H) received by the film equals the illuminance (E) of the light striking the film multiplied by the exposure time (T):

$$E \times T = H$$

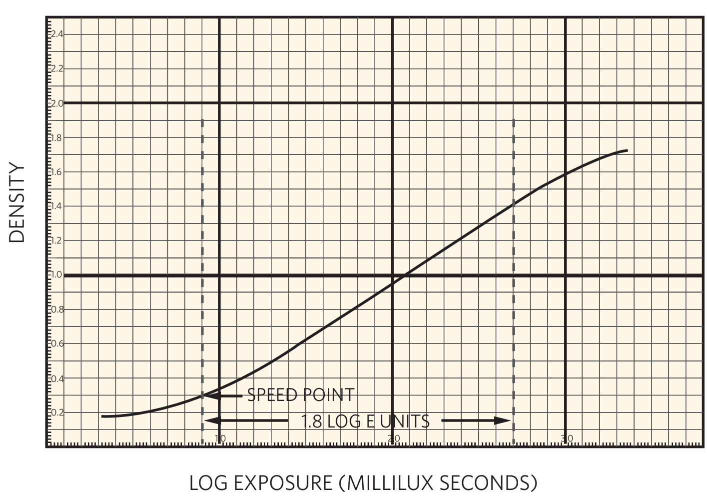
A film attains maximum sensitivity at a particular exposure (normal exposure at the film's rated exposure index). This sensitivity varies with the exposure time and illumination level. The variation is the "reciprocity effect." Film produces a good image within a reasonable range of illumination levels and exposure times. However, at extremely low illumination levels, the calculated increase in exposure may not produce adequate exposure. When this happens, the reciprocity law has failed. This condition is called "Reciprocity Law Failure" because the reciprocity law fails to describe the film sensitivity at very fast and very slow exposures.

The Reciprocity Law is usually effective for exposure times of 1/5 second to 1/1000 second for black-and-white films. Above and below these speeds, black-and-white films are subject to reciprocity failure, but their wide exposure latitude usually compensates for the effective loss in speed. Underexposure and a change in contrast result from Reciprocity Law Failure. The photographer must compensate for color film speed loss and color balance changes because the speed change may be different for each of the three emulsion layers. Contrast changes, however, cannot be compensated for, and contrast mismatches can occur.

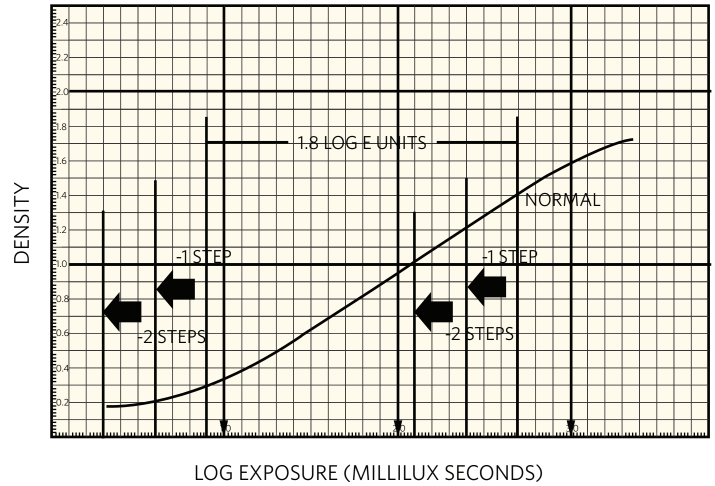
Exposure Latitude

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

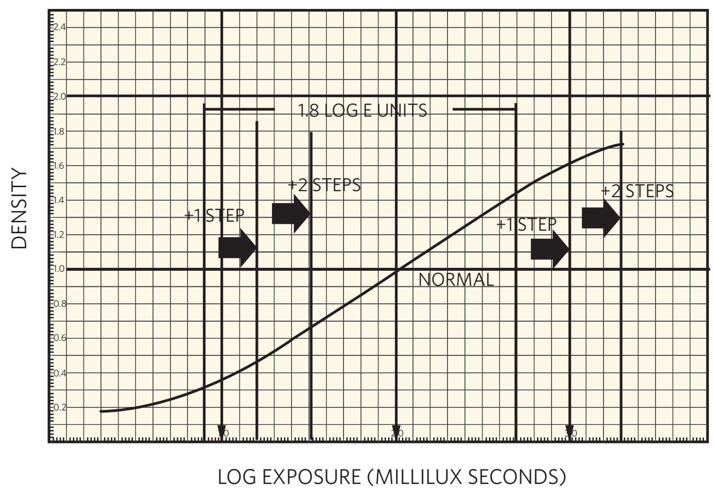
If the range of brightness (difference between the darkest and lightest objects in the scene) as recorded on film is 60:1, then the brightness range, expressed as a log, is 1.8. A typical characteristic curve covers a log E range of 3.0. A range of 1.8 can fit inside that range easily with some room (latitude) to spare. A normal exposure would be placed at the speed point.



Moving in steps of 0.3 log E units, (one stop), we see that we can move the brightness range left two times before running off the curve.



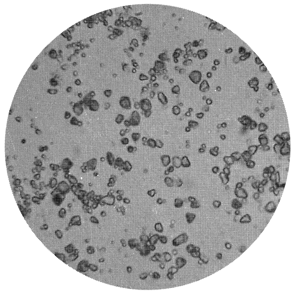
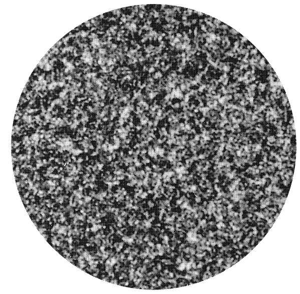
Similarly, we can move right two times before running off the curve.



In this particular case, our underexposure latitude is two stops and our overexposure latitude is two stops.

GRAININESS AND GRANULARITY

The terms graininess and granularity are often confused. They refer to distinctly different ways of evaluating image structure. When a photographic image is viewed with sufficient magnification, the viewer experiences the visual sensation of **graininess,** a subjective impression of a random dot-like pattern. This pattern can also be measured objectively with a microdensitometer. This objective evaluation measures film **granularity.**

	
Grains of silver halide are randomly distributed in the emulsion when it is made. This photomicrograph of a raw emulsion shows silver halide crystals.	Silver is developed or clouds of dye formed at the sites occupied by the exposed silver halide. Contrary to widely held opinion, there is little migration or physical joining of individual grains. Compare the distribution of silver particles in this photomicrograph with the undeveloped silver halide in the unexposed film at left.

Speed of the film is relative to grain surface area (in sensitized films)—the fastest or most sensitive grains are also the largest grains. Graininess is more obvious in shadow areas and underexposed areas because the fastest, largest grains are predominantly exposed. Camera films are the fastest type of motion picture film; laboratory films, used in more controlled settings are substantially slower and less grainy.

The visual sensation of grain in projected motion picture images is different than in still photographs. Film images are captured on a mosaic of randomly distributed silver halide grains. Those grains then form an image of tiny dye clouds. If the image has fine detail, you'll have difficulty finding the detail in any single frame. Show 24 frames per second and the cumulative effect of the detail caught on each frame is delivered to the eye. When these images are processed in the brain, an incredible amount of detail is perceived.

Diffuse rms Granularity

Microscopic examination of a black-and-white photographic image reveals particles of metallic silver suspended in gelatin. The subjective sensation of this granular pattern is called graininess. The measurement of the density variations is called granularity. (In color films, the sensation of graininess is the result of dye formation where silver halide particles existed in the unprocessed film.)

Granularity measurement begins with density readings from a microdensitometer (a densitometer with a very small aperture, usually a 48-micron diameter) at a net diffuse density of 1.00 above base density. The small aperture measures fluctuations in density, and the standard deviation from average is called root-mean-square (rms) granularity and is expressed in terms of diffuse granularity. Since standard deviation numbers are very small, they are multiplied by 1000, which yields a small whole number, typically between 5 and 50. Diffuse rms granularity numbers are used to classify graininess. The graininess classifications are:

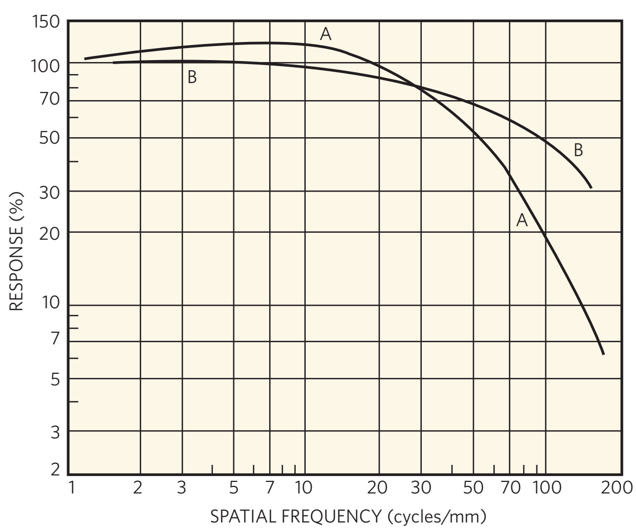
Diffuse rms Granularity Value	**Granularity Classification**
45, 50, 55	Very coarse
33, 36, 39, 42	Coarse
26, 28, 30	Moderately coarse
21, 22, 24	Medium
16, 17, 18, 19, 20	Fine
11, 12, 13, 14, 15	Very fine
6, 7, 8, 9, 10	Extremely fine
Less than 5, 5	Micro fine

SHARPNESS AND MODULATION-TRANSFER CURVE

The “sharpness” of a film is the subjective perception of good edge distinction between details in a photograph. However, the boundary between dark and light details is not a perfectly sharp line. The dark areas in a negative tend to bleed over into the light areas because of light scattering (or diffusion) within the emulsion. This effect varies with different types of emulsions, the thickness of the film base, overprocessing, as well as the anti-halation properties of the base and its backing. These factors all affect our perception of a good edge.

The objective measure of a film’s sharpness is expressed as an MTF curve (for Modulation Transfer Function). Basically, MTF shows the loss of contrast caused primarily by light scattering within the emulsion during exposure. The curve represents the contrast between light and dark areas relative to the original light and dark areas on a test target. A perfect reproduction would result in a horizontal line at 100%, even as the space between the light and dark areas decreases (represented by a movement from left to right on the horizontal axis). In reality, as the space between the light and dark areas decreases, the film’s ability to make the distinction between light and dark fails, and the percentage drops accordingly.

In the example below, film A provides sharper results when the distance between light and dark areas is higher, but decreases more rapidly than film B.



Note that in some cases, an MTF curve actually shows a response greater than 100%. The most common cause for this is “developer adjacency effect,” where fresh developer washes over onto dark areas, and exhausted developer washes from dark areas (where it was working hard) to lighter areas.

MTF curves should be used carefully, keeping in mind that additional factors influence the sharpness of a finished film, including camera movement, lens quality, and scene contrast. All other factors being equal, the comparison of one film’s MTF to another’s is a very useful tool.

NOTE: The modulation transfer function values published by Kodak are determined using a method similar to that of ANSI Standard PH2.39-1977 (R1986).

RESOLVING POWER

Resolving power is a film emulsion's ability to record fine detail. It is measured by photographing resolution charts or targets under exacting conditions. Spaces and lines identical in width separate the parallel lines on resolution charts from each other. The chart contains a series of graduated parallel-line groups, each group differing from the next smaller or next larger by a constant factor. The targets are photographed at a great reduction in size, and the processed image is viewed through a microscope. The resolution is measured by a visual estimate of the number of lines per millimeter that can be recognized as separate lines.

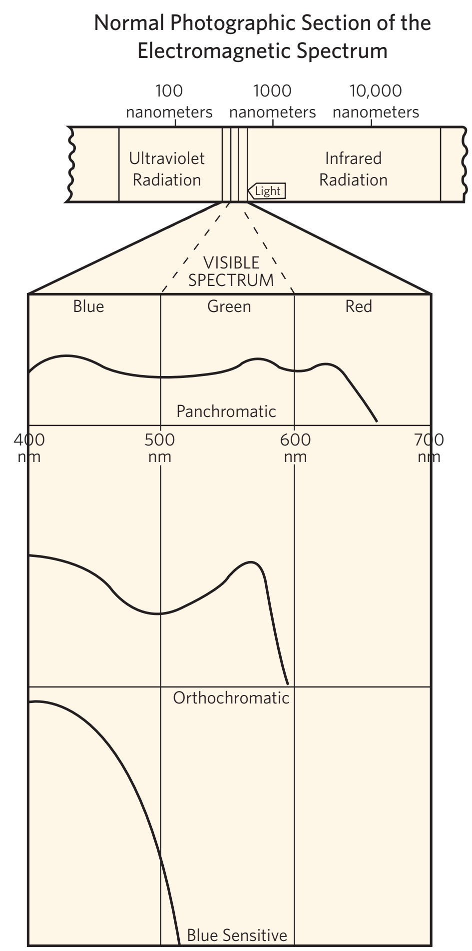
The measured resolving power depends on the exposure, the contrast of the test target, and, to a lesser extent, the development of the film. The resolving power of a film is greatest at an intermediate exposure value, falling off greatly at high and low exposure values. Obviously, the loss in resolution that accompanies under- or over-exposure is an important reason for observing the constraints of a particular film when making exposures.

In practical photography, system resolution is limited by both the camera lens and the film; it is lower than the resolution of the lens or film alone. In addition, other factors such as camera movement, poor focus, haze, etc., also decrease maximum resolution. Resolving power values can be classified as follows:

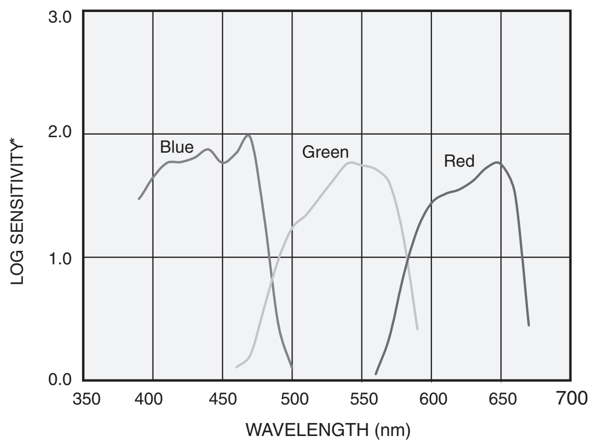
(High Contrast Values in lines/mm)	ISO-RP Classification
50 or below	Low
63, 80	Medium
100, 125	High
160, 200	Very High
250, 320, 400, 500	Extremely High
630 or above	Ultra High

COLOR SENSITIVITY AND SPECTRAL SENSITIVITY

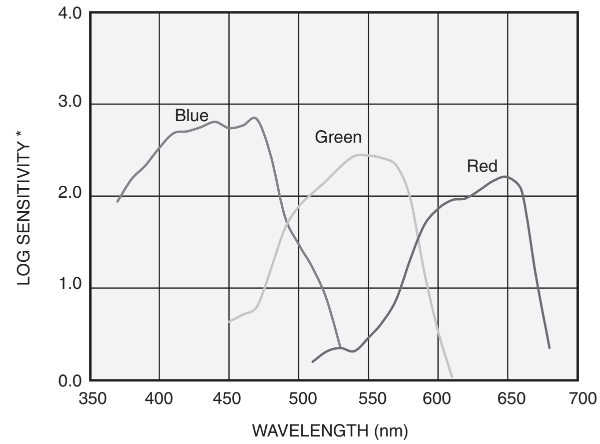
The term *color sensitivity,* used on black-and-white film data sheets, describes the film's sensitivity to the visual spectrum. All black-and-white camera films are panchromatic (sensitive to the entire visible spectrum). Orthochromatic films are sensitive mainly to the blue-green portions of the visible spectrum. And blue-sensitive (only) films are used to receive images from black-and-white materials.



Panchromatic black-and-white films and color films, while sensitive to all wavelengths of visible light, are rarely equally sensitive to all wavelengths. Spectral sensitivity describes the relative sensitivity of the emulsion. This is especially evident when you compare the spectral sensitivity curve of a tungsten-balanced film to a daylight-balanced film:



This daylight-balanced film is approximately equal in sensitivity to blue, green, and red wavelengths.



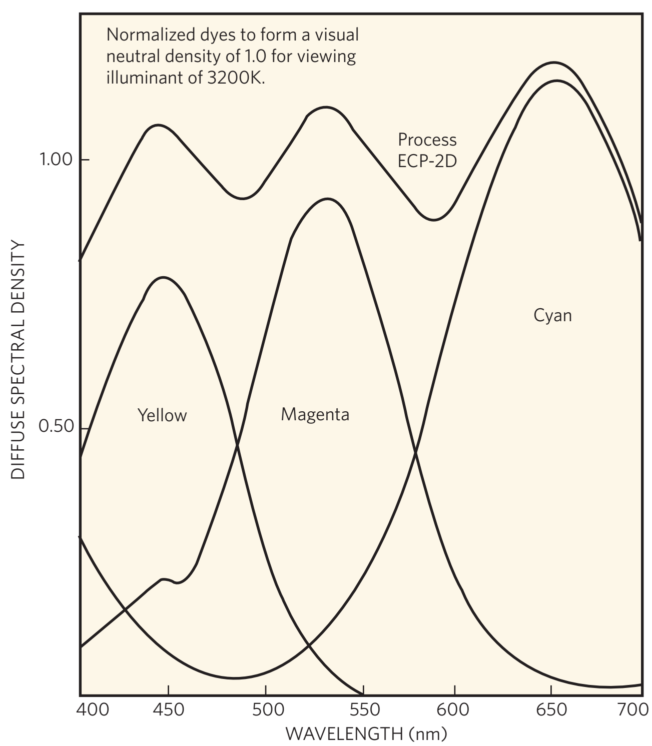
This tungsten-balanced film has a higher blue sensitivity and lower red sensitivity to compensate for the spectral output characteristics of tungsten light.

SPECTRAL DYE DENSITY

Processing exposed color film produces cyan, magenta, and yellow dye images in the film's three separate layers. The spectral-dye-density curves indicate the total absorption by each color dye measured at a particular wavelength of light and the visual neutral density (at 1.0) of the combined layers measured at the same wavelengths.

Spectral-dye-density curves for reversal and print films represent dyes normalized to form a visual neutral density of 1.0 for a specified viewing and measuring illuminant. Films which are generally viewed by projection are measured with light having a color temperature of 5400K. Color-masked films have a curve that represents typical dye densities for a mid-scale neutral subject.

The wavelengths of light, expressed in nanometers (nm), are plotted on the horizontal axis, and the corresponding diffuse spectral densities are plotted in the vertical axis. Ideally, a color dye should absorb only in its own region of the spectrum. However, all color dyes absorb some wavelengths in other regions of the spectrum. This unwanted absorption, which could prevent unsatisfactory color reproduction when the dyes are printed, is corrected in the film's manufacture.



In color negative films, some of the dye-forming couplers incorporated into the emulsion layers at the time of manufacture are colored and are evident in the D-min of the film after development. These residual couplers provide automatic masking to compensate for the effects of unwanted dye absorption when the negative is printed. This explains why color negative camera films look orange.

Since color reversal films and print films are usually designed for direct projection, the dye-forming couplers must be colorless. In this case, the couplers are selected to produce dyes that will, as closely as possible, absorb only in their respective regions of the spectrum. If these films are printed, they require no printing mask.

DIMENSIONAL STABILITY

Film dimensions are influenced by variations in environmental conditions. Films swell during processing, shrink during drying, and continue to shrink at a decreasing rate, to some extent, throughout their life. If film is properly stored, dimensional changes can be kept to a minimum.

Dimensional changes are either temporary or permanent. Both are largely dependent on the film support. However, humidity changes can have a marked influence on the film emulsion, as it is far more hygroscopic than the base.

Temporary Size Changes

Moisture

Relative Humidity (RH) of the air is the major factor affecting the moisture content of the film, thus governing the temporary expansion or contraction of the film (assuming constant temperature). In camera films, the humidity coefficients are slightly higher than in positive print films. For ESTAR Base films, the coefficient is larger at lower humidity ranges, and smaller at higher humidity ranges. When a given relative humidity level is approached from above, the exact dimensions of a piece of film on cellulose trial support may be slightly larger than when the level is approached from below. The opposite is true for ESTAR Base films, which will be slightly larger when the film is preconditioned to a lower humidity than it would be if conditioned to a higher humidity.

Temperature

Photographic film expands with heat and contracts with cold in direct relationship to the film's thermal coefficient.

Rates of Temporary Change

Following a shift in the relative humidity of the air surrounding a single strand of film, humidity size alterations occur rapidly in the first 10 minutes and continue for about an hour. If the film is in a roll, this time will be extended to several weeks because the moisture must follow a longer path. In the case of temperature variations, a single strand of film coming in contact with a hot metal surface, for example, will change almost instantly. A roll of film, on the other hand, requires several hours to alter size.

Permanent Size Changes

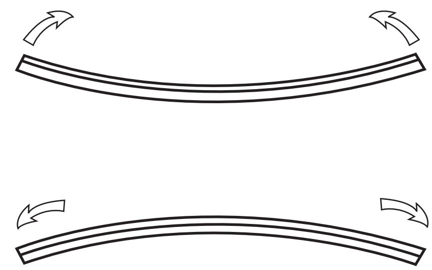
Age Shrinkage

It is important that motion picture negatives, internegatives, and color prints have low aging shrinkage for making satisfactory prints or duplicates even after many years of storage. In positive film intended for projection only, shrinkage is not critical because it has little effect on projection. The rate at which age shrinkage occurs depends on storage and use conditions. Shrinkage is hastened by high temperature and, in the case of triacetate films, by high relative humidity that aids the diffusion of solvents from the film base.

Processed negatives made on stock manufactured since June 1951 have the potential for lengthwise shrinkage of about 0.2 percent, generally reached within its first two years; thereafter, only inconsequential shrinkage occurs. This very small net change is a considerable improvement over the shrinkage characteristics of negative materials available before 1951 and permits satisfactory printing even after long-term storage.

Curl

Curl toward the emulsion is referred to as positive. Curl away from the emulsion is negative. Although the curl level is established during manufacture, it is influenced by the relative humidity during use or storage, processing and drying temperatures, and the winding configuration. At low relative humidities, the emulsion layer contracts more than the base, generally producing positive curl. As the relative humidity increases, the contractive force of the emulsion layer decreases—the inherent curl of the support becomes dominant. Film wound in rolls tends to assume the lengthwise curl conforming to the curve of the roll. When a strip of curled film is pulled into a flat configuration, the lengthwise curl is transformed into a widthwise curl.



Buckling and Fluting

Very high or low relative humidity can also cause abnormal distortions of film in rolls. Buckling, caused by the differential shrinkage of the outside edges of the film, occurs if a tightly wound roll of film is kept in a very dry atmosphere. Fluting, the opposite effect, is caused by the differential swelling of the outside edges of the film; it occurs if the roll of film is kept in a very moist atmosphere. To avoid these changes, do not expose the film rolls to extreme fluctuations in relative humidity.

"This film (KODAK VISION2 Color Negative Film) definitely proves that the "film look" is not about grain but exposure latitude. There's no grain to speak of—it's the finest-grained film I've ever seen, with perfect color rendition, natural skin tones, a huge range of exposure, highlights that don't burn out, and shadows that are rich and dark but with visible subtle detail."

—Jon Fauer, ASC