FUNDAMENTALS OF Photographic Theory

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Outline of the Photographic Process. Terminology

The steps normally involved in the making of a photograph are (1) exposure of the sensitive material in a camera or other suitable device, (2) development of the exposed material to give a *negative,* (3) fixing, (4) washing and drying, (5) exposure of a second sensitive material through the negative, and (6) development of this material to give the positive, which is then fixed, washed and dried as before.

The theory of these steps will be considered in some detail in subsequent chapters of this book. It will facilitate the presentation of the theory, however, if these steps are considered briefly at the outset and definitions are given of certain terms commonly used in the literature.

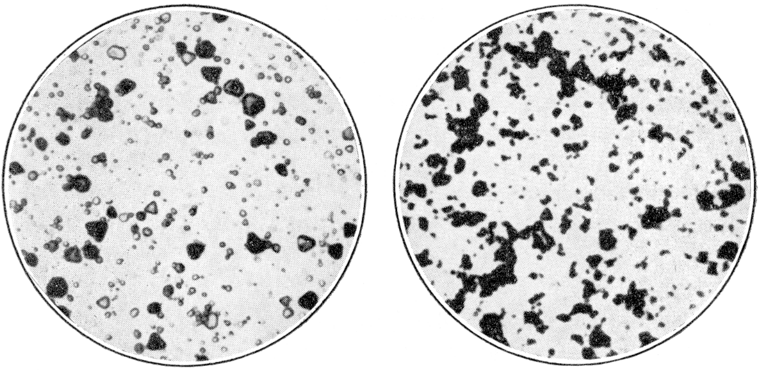
The Light-Sensitive Material (the Emulsion)

The normal sensitive layer consists of a very large number of tiny crystals (*grains*) of silver halide embedded in a layer of gelatin. Figure 1 · 1 (*a*) shows the appearance under the microscope of some of the grains of a typical photographic material.

The combination of grains and gelatin is often referred to as the *photographic emulsion,* or simply the *emulsion.* It is not a true emulsion, but the terminology is firmly fixed in the photographic literature, and no useful purpose can be served by trying to change it here. In this book, where it is clear that the sensitive photographic layer is being referred to, the simple term *emulsion* will be used.

The silver halide most commonly employed is the bromide, with or without the addition of small amounts of iodide. Some slow photographic emulsions, however, contain only silver chloride, and some contain a mixture of chloride and bromide.

The emulsion is coated on some suitable support before it is used to "take a picture." If a photographic film is desired, the support is a sheet of cellulose ester, e.g., acetate. If photographic paper is wanted, the support is a sheet of suitably sized paper. If photographic plates are desired, the emulsion is coated on glass. Other supports may be used for special purposes.



(a) (b)

Fig. 1·1 Photomicrographs of undeveloped and developed grains. Magnification 1125×. (a) Undeveloped grains of a typical photographic emulsion. (b) The same grains after exposure and development. (Loveland.)

The Latent Image

Any light that produces a photographic effect must be absorbed by the sensitive material. In ordinary practice the photographic effect is not revealed by any visible change in the appearance of the emulsion, unless the exposure to light has been excessive. The exposed emulsion, however, contains an invisible *latent image* of the light pattern which can be translated readily into a visible silver image by action of a *developing agent.*

Development

Development is possible because certain agents react with the exposed silver halide in preference to the unexposed, reducing the former to metallic silver in a substantially shorter time. Thus, the developing agent is simply a reducing agent which differentially attacks the exposed grains first. The developing agent is used in a solution containing certain other ingredients which facilitate or mediate the reaction. The complete solution often is referred to simply as the "developer."

When the developed image is examined under the microscope it is seen to consist of tiny particles of metallic silver, as shown in Fig. 1·1 (*b*). This figure represents the same portion of the emulsion as that shown in Fig. 1·1 (*a*), except that now the grains have been exposed and developed. For the most part, each silver particle corresponds to the development of a single silver halide grain, although it is apparent that in some places two or more grains are closely aggregated.

Fog

If the development process is continued for a sufficiently long time, all the silver halide, unexposed as well as exposed, will be converted to silver. Even during normal development, some unexposed grains may be reduced, some silver may be deposited rather uniformly over the emulsion, or both may occur. This unselective, and generally undesirable, action constitutes the formation of photographic *fog*, and the silver formed is often referred to as *fog silver.*

Fixing

After development, the unreduced silver halide is dissolved out in a *fixing bath.* The principal ingredient of this solution is a thiosulfate, usually sodium thiosulfate ("hypo") or ammonium thiosulfate.

The Negative and The Positive

Exposure and development of the usual photographic sensitive material yield a photographic *negative,* in which the light and shadow values of the photographed object are reversed. In order to obtain a *positive,* another sensitive material (usually having different characteristics from the first) is exposed through the negative, developed, fixed, washed and dried as before.

Density

The photographic effectiveness of light is measured by the image which can be developed. The developed image, in turn, can be evaluated in terms of its ability to block the passage of light. The most direct measure is either the *transmittance* or the *opacity*. The former is defined by the ratio I_t/I_o, where I_t is the intensity of the transmitted light and I_o that of the incident light. Thus, the transmittance gives the fraction of the incident light transmitted through the material. Opacity is simply the reciprocal of the transmittance, that is, I_o/I_t.

For most purposes, it is prefarable to use the common logarithm of the opacity as a means of evaluating the developed image. The logarithm of the opacity is termed the *optical density*, photographic density, or simply the *density* of the developed image. (For a more complete definition of density, see Chapter 10.) The use of density, which was introduced by the founders of photographic sensitometry, Hurter and Driffield, is dictated partly by the convenience of the logarithmic scale, but also by the relationship which exists under certain conditions between the density and the mass of developed silver per unit area. This relationship can be seen from the following considerations.

If a layer of developed silver particles in a transparent support is placed in front of a light source, it will reduce the intensity of the transmitted light to $1/m$ the value of the incident light. If a second, identical layer of silver particles is placed against the first, the intensity of the transmitted light falls to $(1/m)^2$ because the second layer blocks the passage of the same *fraction* of the light incident upon it as does the first layer. If n layers are used, the intensity falls to $(1/m)^n$.

If a developed photographic emulsion containing n grains of uniform size per unit volume is sliced into n layers in such a way that each layer contains only one grain, in effect n superposed layers will have to be dealt with. A single grain absorbs or prevents the passage of the fraction b of the incident light. The intensity of light transmitted by each layer, then, is given by $1-b$ of the light incident upon that particular layer, and the intensity transmitted by all n layers is $(1-b)^n$. Since b is very small, the quantity $(1-b)^n$ can be replaced to a good approximation by the quantity e^{-nb}. The opacity, therefore, is equal to e^{nb}, and the density is given by

$$D = nb \cdot \log_{10}e = 0.434nb$$

Thus, when the size of the individual silver particles is approximately uniform, the density is nearly proportional to the number of such particles per unit volume.

The Characteristic (H & D) Curve

When the intensity and the quality of the light to which the emulsion is exposed are kept constant, the photographic effect (developed density) increases with increasing time of exposure,

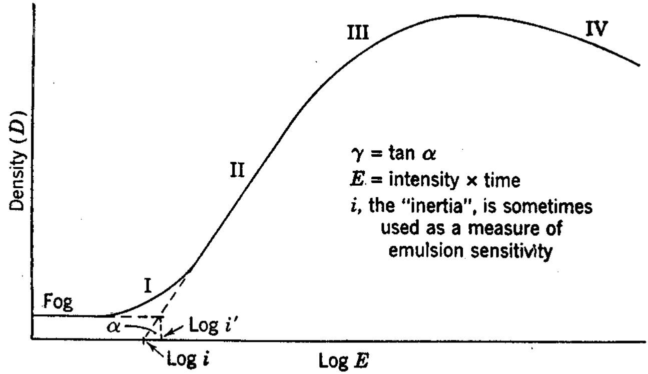


Fig. 1·2 The characteristic curve of the photographic emulsion. I, the toe region; II, the straight portion; III, the shoulder; IV, the region of solarization.

up to a certain limit. Conversely, if the time and quality are kept constant, the photographic effect increases with the intensity of the exposing light, again up to a limit. The relationship between the density and the amount of exposure is commonly represented by the *characteristic curve,* which is also known as the H & D curve because it was first employed by Hurter and Driffield. This curve is obtained by plotting the density against the common logarithm of the exposure, where exposure E is determined by the product It of the light intensity I and the time of action t. Figure 1·2 shows the typical form of the characteristic curve.

The characteristic curve may be divided, somewhat arbitrarily, into four regions: a toe (I), a straight portion (II), a shoulder (III), and a region of solarization (IV). The toe portion is sometimes termed the region of underexposure, although the upper part of it can be quite useful for photographic purposes. The straight portion is a region of linear increase of density with log E. This portion is quite extensive in some curves, but may be small or almost nonexistent in others. The shoulder is the region of overexposure, where an increase in exposure produces only a relatively slight increase in density. The curve bends away from the straight line and toward the exposure axis, eventually becoming parallel to it. Beyond the shoulder lies the region of solarization, where an increase in exposure actually results in a decrease in developed density.

The density obtained by a standardized development of a given photographic material, however, is not uniquely determined by the value of E; it usually depends to some extent upon the individual values of I and t. If E is obtained by high-intensity light acting for a short time, or by low-intensity light acting for a long time, the result usually will not be the same as that produced by light of moderate intensity acting for an intermediate time, even if the product It is identical in every case. This phenomenon is *reciprocity law failure*. Because of it, a characteristic curve obtained by plotting densities corresponding to constant light intensity and varying exposure time will not, in general, coincide with one obtained by plotting densities corresponding to varying light intensity and constant exposure time.

Gamma (γ)

In the region of the straight portion of the characteristic curve, where the change in density is proportional to the change in the logarithm of the exposure, the density is given by the relation

$$D = \gamma\,(\log E - \log i) \qquad (1\cdot 1)$$

In this equation, $\log i$ is the point where the extrapolated straight line cuts the $\log E$ axis (see Fig. 1 · 2) and γ is the proportionality factor, that is, the slope of the straight line. Numerically, the value of γ is equal to the tangent of the angle α.

The value of $\log i$ is sometimes taken as a measure of the *sensitivity* of the photographic emulsion. If the fog is appreciable, suitable fog corrections are applied, or the $\log E$ value corresponding to a density on the straight line equal to the fog density is used instead of $\log i$ itself. This point is represented as $\log i'$ in Fig. 1 · 2. The actual sensitivity values in this system are expressed in terms of $1/i$ (or $1/i'$) or some multiple thereof, and the value of the sensitivity will increase numerically as i diminishes. In Chapter 11 a more elaborate and, for many purposes, more useful method of determining sensitivity will be discussed. Knowledge of the characteristic curve, however, is essential to that method as well as to the simpler one given here.

The characteristic curve depends upon both the nature of the photographic emulsion and the development process. Different emulsions may vary greatly in the form and position of their characteristic curves. The time and temperature of development, the composition of the developing solution, and the way in which

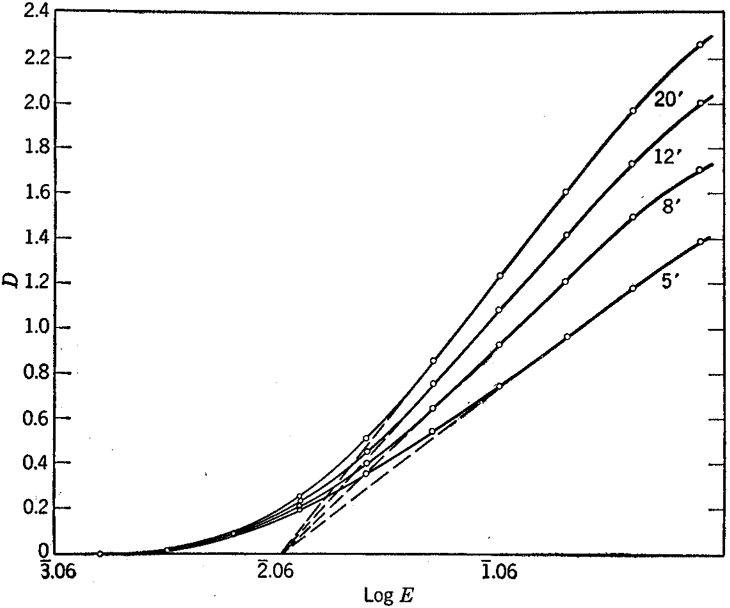


Fig. 1 · 3 A family of characteristic curves, showing variation with development time.

development is carried out likewise play important parts in determining the shape and position of the curve. Figure 1 · 3 shows a series of characteristic curves obtained by varying the time of development and keeping all the other factors constant. It will be noted that gamma increases with the time of development. For this reason, gamma is sometimes referred to as the "development factor."