

for hand-held photography in pictorial work are conveniently characterized by an exposure index number that is used in calculating the proper exposure setting from the light level of the scene, which is usually measured with an exposure meter. The numbers given under the heading "Speed" in table 4 are those given by the manufacturer for use with exposure meters calibrated by the American Standards Association system (the ASA has recently been renamed the "United States of America Standards Institute"). The sizes of the films, which are given in the table as either 35 mm or 70 mm, indicate the width of the film in millimeters.

NASA relied on commercially available films for the initial missions, but the desire for a much greater number of photographs on the later missions required photographic films constructed on a much thinner film base to reduce the bulk and weight.

The pictorial photographic experiments on the missions did not dictate a need for changes in emulsion technology, but they did stimulate the development of modern high-speed color reversal films with film emulsion speeds up to 50 times that of color films of 20 years ago. In this area the major significant advance fostered by NASA requirements was the development of modern color photographic emulsions on a thin, dimensionally stable polyester-film base with good optical properties. These provide for the low-bulk, low-weight film necessary for the large number of photographs required of the space missions.

In its selection of films, NASA has attempted to avoid diversity in order to simplify and standardize the purchase, storage, use, and processing of the films and to enjoy great flexibility with respect to the films available at all points required. While all types of normal commercial films can be used for Earth activities, some special considerations apply to space films. They are normally made on a polyester-film base. This film base is available on a number of commercial films. Now, due primarily to the stimulation of NASA in specifying its use on films to be exposed in the space environment, a high-strength polyester film is available. This allows a thinner base to be used, thus permitting more effective usable exposure area of film in a given space in a camera. As an example, a specific magazine which would hold 20 exposures of a normal film base may hold as much as 40 exposures on the thinner base film.

The polyester base has good dimensional stability, which is an important asset in the photogrammetric analysis of the pictures with the Lunar Data Camera. The polyester-base films are also

required in the low-pressure environment of space, because they have less tendency to give off solvent vapors than the normal cellulose-based film supports generally used for photographic films. Color negative films were used in early missions because of the extreme versatility of control in producing final prints, as well as the latitude of color negative films in permitting acceptable pictures to be obtained under a wide variety of adverse exposure conditions. It should be recognized, however, that within these capabilities, there lies a difficult technical deficiency in the program operations, that is, there is no control to permit proper printing of a color negative since one has no idea of the true color or expected color of the scene, as one does with pictures taken in the Earth-bound environment. For this reason, reversal films have been utilized for the color work taken from space.

In planning the Apollo missions, a hermetically sealed magazine was considered to maintain a suitable environment for the film. Many years of experience had included the use of photographic film in vacuum systems such as electron microscopy and electron beam recording, and this experience indicated that the disturbance caused by the vacuum environment should not prove too serious. This was confirmed by tests of extended exposure to vacuum conditions, and the Apollo 11 and Apollo 12 missions were carried out with a conventional unsealed magazine. Thus the film was exposed to the high-vacuum lunar environment. The results of these missions substantiated the validity of this decision and of the earlier observations.

#### FILM-HANDLING TECHNIQUES

The NASA centers use a wide variety of film-handling techniques, the choice depending on the film's use and ability to duplicate the pictures in the event that the film is lost or damaged. Obviously, the most critical films are those carried by the astronauts in flight. Approaching them in importance is the film used to record a nonrepetitive event, such as the liftoff of a launch vehicle. The level of critical conditions scales down through various levels to the simple case of publicity photos, which can be duplicated easily if something happens to the first set of exposures. The degree of control in film handling and processing is, therefore, a function of the subject of the photograph.

In the most critical cases, those of films used for the space missions, every effort is directed toward insuring positive control of flight films from the point of manufacture to archival storage.

The films are accepted directly at the manufacturer's plant by a courier who then transports them in special NASA-provided cases, which record humidity and temperature inside the case so that the courier can continuously monitor the environment of the film during transit. Upon receipt of the films at the Manned Spacecraft Center, random samples are given both physical and photographic tests. Until the films are used, these tests are repeated every 45 days so that the most subtle changes in film characteristics can be noted. Such testing is done in a clean room at the center.

A test section from the beginning of every roll of film is given a series of precisely controlled exposures, each consisting of an exact quantity of light of a specific color. After the film is used and processed, scientific measurements of these test exposures, known in the trade as sensitometric strips, are compared with standards to determine any existing variations.

Prior to a given mission, the film is again transported by courier and special packages from the Manned Spacecraft Center in Houston to the Kennedy Space Center in Florida. Very strict rules specify the amount of time that film can be held in controlled storage, in an uncontrolled environment, or in actual cameras between loading and use.

After a spacecraft returns to Earth, cameras and film magazines are taken from it as soon as it is put aboard the recovery ship. The technician in charge of the photographic operation at that point inspects the films and repacks them in one of the special film-handling cases that are monitored for both humidity and temperature. The astronauts also give him any special information about the film and the exposures used and some estimations of the most significant pictures. These are given priority in processing. The film is again transported under the watchful eyes of the courier. At the Manned Spacecraft Center, the package is opened in the presence of senior personnel and the film magazines are inspected for physical damage. Next the magazines are opened and the exposed film transferred to special storage cans to await processing.

Processing may involve both specially designed equipment and standard commercially available machines. Prior to receipt of the film, all processing facilities are prepared for critical demands of the program. Before a mission, the equipment is disassembled, cleaned, and overhauled. After it has been reassembled and the chemicals prepared, samples of the type of film from the same roll used on the mission, again with the test exposures or sensi-

tometric strips, are processed so that the chemicals and equipment are at predetermined optimum operation. Such test strips are processed and evaluated immediately before space film is processed, the procedure being repeated at frequent periodic intervals to insure the continued stability of the chemical solutions. The test exposures used while the actual space films are processed represent those on film taken directly from storage, as well as those made before the flight. In this way, compensation can be made for differences due to carrying the film through the various environments of space.

Even though all processing takes place in a completely darkened room, trained technicians in the processing units know the exact location of a film at any time and are ready to take corrective action should a problem arise. As soon as the film has been completely processed, a master reproduction is made from the original, which is then committed to storage. This master, or first generation, reproduction is used to produce all the prints in the transparencies released to the press and public. Some of the steps used in making multiple sets of reproductions to produce duplicate and release copies with opportunities for editing are outlined in figure 56.

All films which require special processing by reason of overexposure or mishandling by the astronauts are generally processed last. If there is any doubt as to the effects, duplicate films are prepared and put through the same conditions as those reported by the astronauts, and a processing technique developed for them.

For pictures taken on the Moon, cameras, magazines, and films were put through a decontamination procedure at the Lunar Receiving Laboratory. Control films, again with the special test exposures, were also put through the decontamination procedures and checked for adverse effects so that necessary corrections could be introduced in the processing.

A magazine loaded with highly sensitive film was confused with one loaded with low-speed film during the Apollo 8 flight. The high-speed film received nearly 1000 times the required amount of exposure. Special development procedures were worked out nevertheless, which permitted the recovery of usable images on this overexposed film.

In addition to basic laboratory processing, film may be processed aboard space vehicles. References 28 and 29 describe systems that have been used by the military for a number of years. They are designed to expose film and put it through some sort of rapid processing system for immediate evaluation by onboard reconnais-

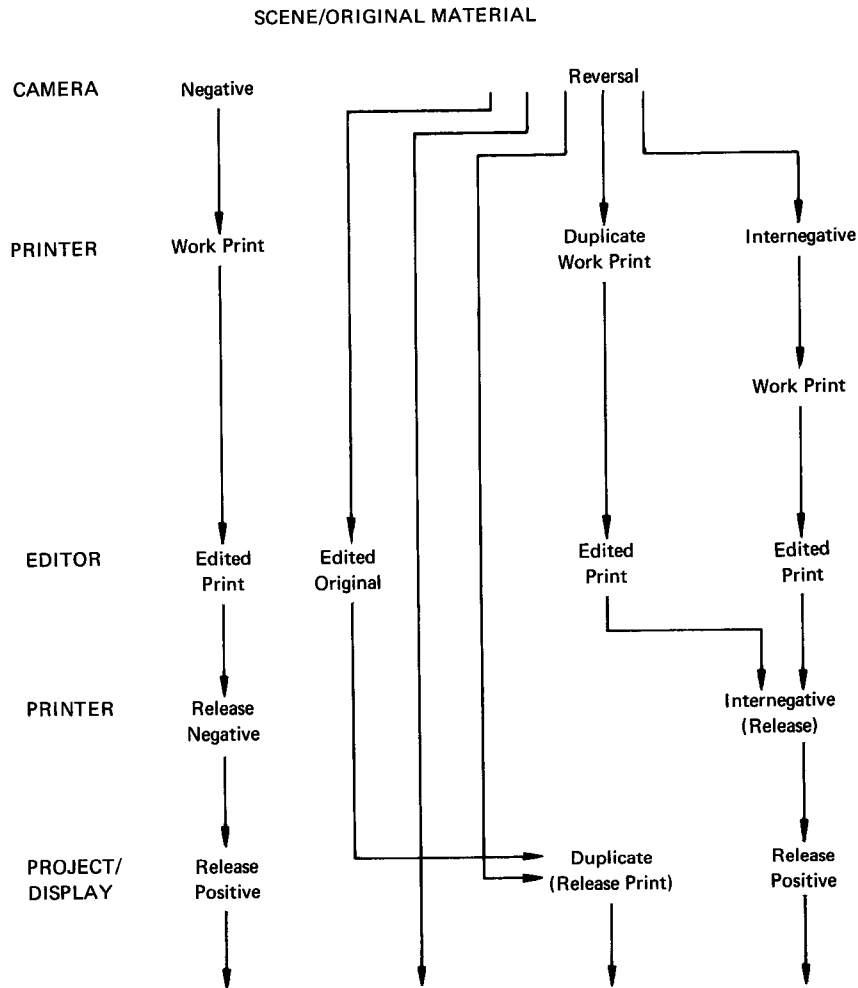


FIGURE 56.—Some of the alternate steps in preparing final pictures in both motion picture and still photography. The steps apply to both black and white and color, except that internegative processes have primarily been used in color.

sance officers. Such systems have been used for high-resolution or high-information capacity photorecording systems. The image is recorded on film, then put through a rapid processor for immediate scanning. The image is scanned with a low-bandwidth system which transmits large amounts of information over a longer period of time than the camera could focus on the subject for adequate scanning by video systems. The photographic film, in essence, becomes a time compression system and the video

transmission becomes a time expansion system. The references describe such a system that is under investigation for use on planet-reconnaissance systems in the late 1970's.

#### SUMMARY

This survey of photographic systems in NASA programs may suggest to others what photography may do for them.

Some general contributions to photographic technology that have resulted from the NASA program are:

The development of techniques for making cameras more utilitarian in restricted operational environments, specifically leading to the development of techniques for one-hand operation by persons wearing heavy gloves. This could lead to a more general use of photography under adverse conditions.

The development of high reliability systems which may have significant applications in other scientific and technical fields, such as oceanographic studies, terrestrial exploration, and archeology, when cameras must be left in remote areas for extended periods and remain functional, or must be operated remotely for long experimental time periods.

The stimulation of the development of the high-speed color reversal films, which culminated in films having sensitivities 50 times those of the versions of 20 years ago.

The expanded development of the lightweight, low-bulk photographic films for applications where a large number of photographs must be acquired despite constraints on weight and bulk.

The development of effective equipment and techniques to provide acquisition of cartographic data from hand-held cameras where the usual techniques are not feasible.

The development of camera systems capable of being operated in, and recovered from, remote environments in unmanned vehicle exploration programs.

The development of stabilization systems for vehicle-mounted cameras.

Improvements in the design, installation, and operation of multi-camera systems for multispectral photography.

Improvements in long-range theodolite and tracking photographic systems and the development of suitable reference bases for engineering analysis.

Design, development, and implementation of a large number of

diverse systems and equipment for quantitative analysis in support of engineering research programs. This has led to the use of such photographic systems as a valuable instrumentation technique.

Improvements in systems and techniques for the examination of the Earth from remote locations above the surface and in outer space.

The accomplishments of NASA in photographic recording and documentation can also be considered an example of visual communication for social ends.

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## A Summary of the Photographic Process\*

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### THE PHOTOGRAPHIC PROCESS

The word "photograph" is a combination of two Greek words: "photos" meaning light, and "graphos" meaning to write. A photographic film is literally a "light-writing" film or one which records the pattern of light that strikes it. Photographic material in common use today is so highly sensitive to light that it must be manufactured and stored in almost complete darkness. Since it can be thoroughly examined only after it has recorded an image and has been chemically processed, the structure and mechanism of photographic films in common usage are not known to the average user.

#### **Construction**

The light-sensitive element of photographic materials consists of one or more extremely thin coatings of silver halide microcrystals embedded in a colloidal medium-like gelatin. These coatings or photographic emulsions are generally less than a thousandth-of-an-inch thick and are exceedingly delicate and susceptible to damage by abrasion and scratching. The emulsion is coated on top of a material whose primary function is to support and strengthen the delicate light-sensitive element. The support for roll-films and motion-picture films is usually colorless, transparent, and flexible, and the support is many times thicker than the emulsion. The overall thickness seldom exceeds five- or six-thou-

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\*Excerpted from NASA Report NAS CR-92015; B3076 (1965); CFSTI N68-19742 (Contract NAS9-3613).



sandths of an inch and, for special applications, is sometimes less than three-thousandths of an inch. Glass plates serve as the support for certain applications, while different types of paper are used to support photographic-printing emulsions.

The silver halide microcrystals, or grains, are the actual light-sensitive elements of photographic emulsions. These very small grains of silver chloride, silver bromide, silver iodide, or mixed salts range in size from one-half to several microns in diameter and tend to be flat or platelike in shape. Their function is to absorb radiant energy and undergo a change in state which can be amplified millions of times by subsequent treatment in the proper chemical solutions.

Clear gelatin is used to control the quality of the microcrystals and to hold them in suspension. At the same time, the retaining gelatin must be inert to processing procedures and yet permit liquid chemicals to penetrate and to react with the suspended crystals. Emulsions generally have a greater volume of gelatin than silver halide grains and are somewhat elastic besides being capable of absorbing liquids.

The support or base material generally does not participate in the mechanism of image formation, recording, or processing and serves essentially as a means of mechanical support for the delicate emulsion. The transparent flexible support for sheet, roll-type, and motion-picture films consists of an acetate material which is strong and dimensionally stable. Another support material, introduced a few years ago, is often used in applications where overall film thickness must be minimized; this polyester material has many times the shear strength of acetate and provides sufficient strength for a photographic emulsion with a thickness of only two-thousandths of an inch. Because of difficulty in splicing pieces of this material, it is not widely used for motion-picture films.

#### ***Theory of the Photographic Process (refs. 1, 2, and 3)***

The light-sensitive elements of a photographic film consist of microcrystals of certain silver salts. Emulsions with high photographic speed have large grains of silver bromide containing small amounts of silver iodide. Smaller grains of the same silver halide combination result in films with less speed. Materials used for making photographic prints are generally made with silver chloride grains of very small dimensions.

### The Latent Image

The action which takes place when light impinges upon the photosensitive emulsion is basically one involving energy absorption. The lattice structure of the silver halide crystals contains impurities which constitute a structural weakness. After exposure to light and subsequent immersion in the proper chemical solution, conversion of the grains to free metallic silver appears to commence at the points of structural weakness. These points, or sensitivity centers, contain small amounts of silver sulfide and are often located at many places throughout the crystal. Grains which do not contain such centers do not appear to be sensitive to light. Thus, it is assumed that the silver sulfide specks act as catalysts to collect silver atoms, liberated by the action of light upon the silver halide crystal. The average sensitivity usually increases with the size of the grain because the number of sensitivity centers is usually increased in direct proportion to grain size.

Quantum mechanics explains latent-image formation by assuming that the absorption of light quanta by silver halide grains injects electrons from the halide ions into conduction bands where they are free to wander throughout the crystal lattice. Some of these electrons become trapped in the sensitivity centers and produce a negative charge which prevents additional electrons from entering the center until the negative charge is reduced by recombination with interstitial silver ions. The silver ions which migrate throughout the crystal enter the sensitivity centers and use the trapped electrons to form neutral atoms of silver. When a sufficient number of neutral silver atoms have coagulated, a stable latent image is established.

A quantum of light liberates only one electron if it is absorbed. Experiments have shown that a grain requires absorption of several quanta if developability is to be achieved. High-energy particles, such as alpha particles, release thousands of electrons into the conduction bands while passing through an emulsion. Many small latent-image centers are established throughout the grain with which the high-energy particles have collided. Further collisions by high-energy particles increase the number of the silver atoms in the centers, producing larger centers which develop more readily.

The incidence of a large amount of energy over a short time period on a silver halide grain produces an avalanche of electrons and appears to favor the formation of many small latent-image centers. A single high-energy particle or a large number of light quanta can liberate a surplus of electrons. The effect of the surplus

negative charge on the sensitivity center which is produced by the first few trapped electrons prevents additional trapping. By the time a sufficient number of interstitial silver ions have migrated into the centers, neutralizing the charge by forming neutral silver atoms, the avalanche of electrons has dissipated. This gives rise to a nonlinear effect which is termed "short exposure time" or "high intensity reciprocity failure." The latent-image centers, although plentiful in number, do not trap a sufficient number of silver atoms to permit formation of a developable center. Prolonged development will minimize the effect but often at the expense of increased-background density.

Quanta arriving at a lower rate and corresponding to a low intensity over a very long time period tend to produce large latent-image specks but fewer in number. This is termed "long exposure time" or "low intensity reciprocity failure." Thermal motion causes some of the silver atoms formed in the specks to break up. Latent-image specks are not stable until they contain a critical number of silver atoms. When the rate at which the light quanta arrive is so low that the breakup rate of the silver aggregates exceeds the rate of addition of new silver atoms, the latent image never attains a stable level. With insufficient numbers of silver atoms in the single speck, the grain is not capable of development. The exposure effect is an apparent loss of sensitivity as the low-intensity reciprocity failure manifests itself.

#### Processing

The latent image produced in a photographic emulsion by the action of sufficient radiant energy becomes detectable as a darkened image on an otherwise light-colored background of silver halide. The use of developing agents reduces by millions of times the radiant energy required to produce the same darkening, making the photographic process a most sensitive and practical recording system.

The process of development is one of reducing the silver halide grains to free metallic silver which is readily detectable as a black deposit. Because developing agents will ultimately reduce all grains, a practical developer is one which will reduce exposed silver halide grains to the free metallic state at a greater rate than those grains which have not been exposed. Thus, practical development is a rate-dependent phenomenon which affords a means of discrimination between exposed and unexposed portions of the photographic emulsion. Development is terminated by the simple procedure of inactivating the developing agents before the

unexposed grains are significantly affected. At this point, the remaining unreduced silver halide grains may be removed by immersion in silver halide solvents known as fixing agents, or development may be continued by reactivation of the developing agents. If the remaining silver halide is removed by a fixer, further reduction will not take place and the film may be examined in the light.

There are two distinct types of development processes which will allow discrimination between exposed and unexposed silver halide grains. One is termed physical development in which many silver atoms are deposited from solution onto those few silver atoms comprising the latent-image centers. The other process is referred to as chemical or direct development and, for many practical reasons, is the one in common use. Physical development undoubtedly accompanies, to some extent, the process of chemical development. In a chemical developer containing a silver halide solvent, the main part of development appears to be an intensification reaction. Silver dissolved in the developer solution is deposited on grains which have already been partially reduced to free-silver and thus intensifies and increases the size of the original grains.

Each grain suspended in the gelatin is surrounded by a negatively charged barrier layer of absorbed gelatin and halide ions which present a retarding force to the penetration of developer to the grain. Those grains which have been exposed contain potentially weak points in the barrier at the latent-image centers. Silver ions from the crystal lattice which are put into solution by the liquid of the developer penetrate the charge barrier and soon become absorbed on the silver specks of the latent-image centers. Once such adsorption occurs on the crystal, the protective charge barrier layer is broken, and the developing agent can then easily penetrate the grain, thus allowing reduction of the entire grain to proceed.

The protection afforded the silver halide grains by the gelatin produces a further complication in restricting the transport of chemicals in and out of the emulsion. Once reduction of a grain commences, the chemical complexes formed by the interaction must be removed and replaced by fresh chemicals if further reduction is to proceed. The transport of these chemicals through the gelatin depends for the most part upon diffusion. Within the gelatin emulsion, the transport is limited by internal pressures and temperature effects. At the boundary between the gelatin emulsion surface and the developer solution, the complexes which are

formed at the grain sites and which have diffused to the surface present a boundary-layer barrier to incoming fresh solution. This barrier severely restricts the interchange of chemicals and slows down the process of silver reduction of the exposed grains. The unexposed grains, on the other hand, are not so restricted and in time will be reduced to free silver, resulting in a high fog value.

Agitation of the film during processing tends to break up the emulsion surface barrier of the developer complexes, permitting fresh solution to be transported by diffusion into the emulsion. The complex byproducts removed from the surface are then diffused into the remaining developer solution and, to a degree, exhaust the developer. With sufficient concentration of these byproducts, the developer action becomes ineffective and must be replaced with fresh chemicals.

Silver reduction is most active in highly alkaline-developer solutions and slows down as the developed pH is lowered. At a sufficiently low pH, usually an acid condition, development activity ceases. Thus, development of a latent image can be brought to an abrupt halt by a rapid reduction of the solution pH. A common practice in the processing cycle includes immersion of the films in an acid stop bath after the desired developing time has expired. Further reduction of silver halide ceases immediately in the acid stop bath. The film is then placed in a fixing bath which removes the remaining silver halide grains and leaves only a visible black silver image in those areas where light struck the emulsion. The black image will ultimately be attacked and destroyed by the dissolved chemicals if not removed by water-washing to leave only the permanent image in the emulsion.

#### Exposure Response Characteristics

The previous paragraphs have described the general mechanisms, leading to the production of black silver deposits in photographic emulsions which have been exposed to radiant energy and treated in suitable chemical solutions. The response of silver halide grains to absorbed energy varies with the size of the grain, the larger grains being more sensitive. Most photographic emulsions consist of a random mixture of different-sized grains resulting in different degrees of blackening as a function of exposure. The exposure is further attenuated as the light is absorbed in traversing the emulsion. Both factors are instrumental in producing the different degrees of sensitivity in a photographic emulsion.

### Negative film

The photographic response to varying amounts of exposure can best be described by means of a graph which plots the degree of blackening as a function of exposure. Exposure is defined as the product of intensity of illumination,  $I$ , and exposure time,  $t$ . The degree of blackening is represented by the term density  $D$ , which is the logarithm to the base 10 of the ratio of the incident to the transmitted light of the developed image. Practical reasons dictate that the exposure should also be expressed logarithmically to the base 10. The resulting graph, shown in figure A-1, is known as an *H and D, characteristic* or *D-log E curve* and represents the response of a typical negative photographic film to the action of different amounts of exposing energy when processed with a fixed set of processing conditions.

At the left of the graph, the resulting density is uniformly low and represents that value produced by development action without benefit of exposure to light. It is referred to as "fog density," but is more appropriately termed "background density," since it includes any discoloration or density of the emulsion and its support. At a threshold level, the film starts to respond to greater exposure by a measurable increase in density. Additional exposure produces greater amounts of density, resulting in an upswing to the

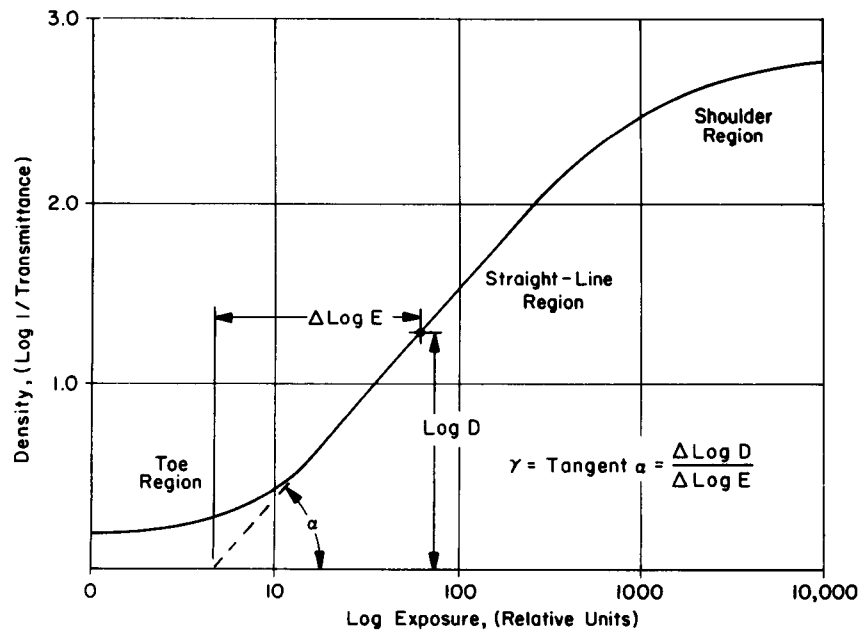


Figure A-1.—*D-log E* curve for a typical photographic negative film.

curve, finally reaching a point where density becomes uniform with increasing exposure. The upswing in the curve, or the toe region, shows an increasing effect of the response system. Beyond the toe region, the system attains a uniform rate of change in response in the straight-line portion and density changes linearly with the logarithm of exposure. The slope of the angle  $\alpha$ , formed by the exposure axis and the straight line is termed gamma  $\gamma$ , and its value is determined by the ratio of  $\Delta D/\Delta \log E$ . Ultimately all grains become exposed and no additional density is produced. The gradual reduction in slope beyond the straight line is termed the shoulder region.

The slope of the straight-line region or gamma is affected by the amount of development the film receives. Prolonged development increases gamma up to a limiting value, gamma infinity, which, while not mathematically infinite, is the greatest slope which the emulsion is capable of attaining. Prolonged development beyond this point produces excessive background density with no increase in maximum density and effectively reduces the slope of the straight line. Values of gamma approaching gamma infinity tend to compress the exposure range over which the film is responsive thus creating a narrow-latitude film. For purposes of scientific data reduction on the original negative, this is often an advantage because of the increased measuring precision. Relatively large differences in density are produced by small changes in exposure or scene luminance. The precise value of gamma desired is dictated by the intended use for the negative.

Negatives for which the primary purpose is pictorial must be printed onto a positive-type photosensitive material and require low gamma values. Both optical and photographic characteristics of positive-printing materials restrict their exposure latitude to narrow limits. Since the density contained in the negative image serves as the exposure modulator for the narrow latitude positive print material, it is necessary to maintain a low gamma in the negative in order to make a print of acceptable range. A gamma of 0.6 to 0.8 is best suited for pictorial negatives, while a value of 1.0 is used for scientific films. The latter value is a compromise value which permits satisfactory prints from the original negative.

#### Reversal film

Modifications of the processing procedure will permit most negative photographic films to be developed into direct positive images. Called reversal processing and yielding a positive image, the negative image has been destroyed during the chemical treatment.

For optimum results with reversal processing, the construction of the film is usually altered and produces a positive image with somewhat finer grain than the negative image. The exposure response of a film processed by reversal processing can be described by a  $D$ -log  $E$  curve whose general shape exhibits the reverse characteristics of the curve for negative materials. A typical reversal positive  $D$ -log  $E$  graph is shown in figure A-2. Maximum density for reversal-processed films occurs below the threshold value where no exposure is received. A threshold exposure for reversals is the value at which reduction in maximum density commences and the shoulder region corresponds to the toe region of a negative  $D$ -log  $E$  curve. Density changes linearly with the logarithm of the exposure in the straight-line region but opposite in slope to that of the negative material. The actual slope for reversal processing is considerably greater than that for a negative film. The toe region represents saturation or the leveling-off in exposure response beyond which the film is no longer effective.

The major advantage of reversal processing is that it produces a direct positive image suitable for projection onto a screen. Due to the optics of image projection, a great deal of unwanted non-image-forming light is present with such systems. Undesirable

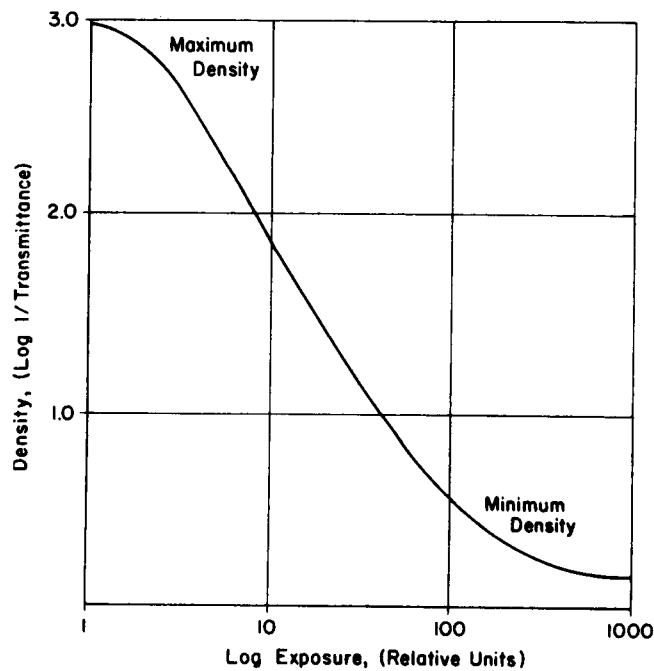


Figure A-2.— $D$ -log  $E$  curve for a typical reversal film used for projection.



scattered light reduces the maximum density of the projected image resulting in a washed-out and tonally distorted facsimile of the original scene. Such tone distortion may be effectively reduced by producing an intentional increase in contrast of an image intended for projection. Inspection of the characteristic curve of figure A-2 shows that the gamma is considerably higher than the corresponding value for a negative film. This is accompanied by a greater maximum density and results in a film image of increased contrast. The scattered light produced during projection of the image on the screen has the effect of reducing the maximum density. The screen-image contrast is thus reduced and the projected image appears to be a faithful tonal representation of the original scene.

#### Sensitivity

Photographic films undergo changes upon the absorption of radiant energy and only that energy which is absorbed will cause a photochemical change to occur. Silver halide grains have peak absorption at short wavelengths. However, because the grains are held in place by gelatin, the energy contained in the short ultraviolet will not expose the grains because it is absorbed by the gelatin before reaching the silver halide crystals. The transmission of gelatin, plotted in terms of density as a function of wavelength in figure A-3, shows that appreciable attenuation occurs at 2900 Å and that almost complete absorption takes place below 2500 Å (ref. 4). Hence, ordinary photographic film exhibits little or no sensitivity to ultraviolet below 2500 Å, without special sensitization. Application to the surface of the emulsion of a layer of ultraviolet fluorescing material extends the sensitivity to wavelengths considerably shorter than 2000 Å, but the magnitude of the added effective sensitivity is no more than 1/100 the sensitivity at 3000 Å. The curve in figure A-4 shows the spectral sensitivity response of a high-speed emulsion with the extension to very short wavelengths affected by a fluorescing sensitizer (ref. 5). Short-wavelength energy is absorbed by the material and causes fluorescence which emits a very-low-level blue light. The visible light emission is responsible for the exposure of the film even though the exciting radiation was ultraviolet.

Spectral sensitivity curves of the various silver halides characteristically show peak sensitivity in the ultraviolet and blue portions of the spectrum. Toward the red end of the spectrum, the photochemical effect for unsensitized films monotonically decreases, becoming very small above a wavelength of 5000 Å.