THE PHOTOGRAPHIC NEGATIVE

The
PHOTOGRAPHIC NEGATIVE

by

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IN FOUR VOLUMES

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Table of Contents

VII Chemical After-Treatment **40**

Negative Characteristics; Methods of After-Treatment; Intensification; Reduction, Handwork; Use of Glass Plates for Enlargements; Retouching with a Brush, Retouching with a Pencil; Retouching to Get Cloud Effects.

VIII Characteristics of the Negative.......... **46**

Development and Contrast; Defining the Terms; The Soft Negative; Detail, Texture; Color; Resolving Power and Grain; Negatives to Fit Your Needs; Thin vs. Heavy Negatives; Experimenting with New Techniques; More About the Emulsion; Color Sensitivity; Basic Nature of the Spectrum; Types of Color-Blind Emulsions, Types of Orthochromatic Emulsions; Types of Panchromatic Emulsions.

IX Sensitometry **533**

Some Definitions; The Densitometer; The Characeristic Curve; Reading the Curve, Gamma; Gamma Infinity; Exposure Range; H & D Value; Some Further Considerations of Sensitometry; The Comparison Scale; The Gray Scale; The Photographic Image; Film-Speed Ratings; The Eder-Hecht Sensitometer; Scheiner Film-Speed Ratings; Other Systems of Sensitivity Rating; Curves and Their Interpretation; Wedge Spectrograms; The Filter Curve

VII.

CHEMICAL AFTER-TREATMENT

VII.

Chemical After-Treatment

A WIDE gap exists between the work of the average photographic amateur and that of the salon exhibitor. The fact itself is obvious, but many amateurs do not have the slightest idea as to how the gap can be bridged. There is a large volume of amateur work of highly creditable quality both as regards technique and esthetics, which, nevertheless, falls way short of the salon standard. One of the most valuable training aids that any amateur can gain is that which comes from examining a salon print and comparing it with a contact print from the original negative.

A photographic negative has often been likened to a stencil, and this is true insofar as documentary and record photography is concerned. However, in the process of picture making by photography the negative is nothing more than the raw material from which the final picture is made. It is not too farfetched to compare the negative and the original subject. The original is arranged and lighted by the photographer to the end that he may obtain, in a mechanical reproduction, the specific effect he desires. The negative, although it permits no alteration of pose and lighting, is subject to a wide variety of controls. This may and very often does result in a positive which bears only a basic resemblance to a straight contact print.

The actual procedure of controlling the print production may be divided into three parts. The first of these is the removal of certain actual blemishes, or correction of other technical deficiencies of the negative. The second is the alteration of the values of the negative, which includes decreasing or increasing the depth of the tone, the emphasis of the lighting effect, the removal or addition of complete images or portions of such images, and a similar definite alteration of the main image itself. The third step is that in which the effect of the projected image upon the sensitive paper is controlled by various means during the actual process of projection. The first two activities lie within the province of our present discussion. The third, being a subdivision of print making, does not fall within the province of our subject, the photographic negative.

One of the characteristics noted in the completed negative is its general density and contrast. It must be borne in mind that we have several combinations of four basic conditions. These are underexposure, overexposure, underdevelopment, and overdevelopment. A negative may be underexposed and underdeveloped. It may be underexposed and overdeveloped. It may be overexposed and underdeveloped, or it may be overexposed and overdeveloped (see Fig. 71).

Negative Characteristics.

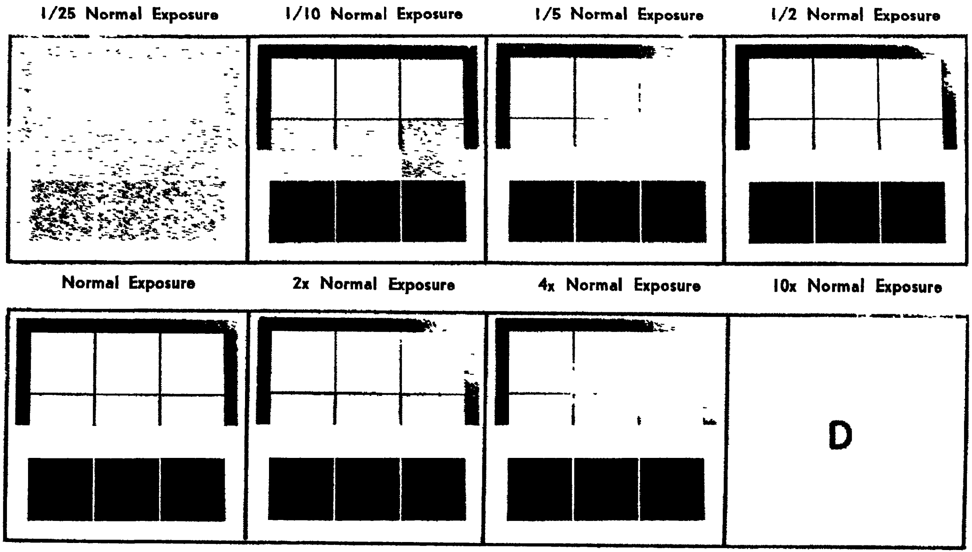
Underexposed-Underdeveloped. The image of this negative is thin throughout. Most of the shadows are non-existent, while the highlights are considerably less than normal in density. If the conditions are extreme, this negative must be abandoned and replaced by another exposure. It would be desirable to build up the image to a greater density, but this cannot be done unless there is at least an infinitesimal deposit upon which to build. When shadows are completely transparent—containing no deposit whatsoever—it is hopeless to try to remedy the condition.

Underexposed-Overdeveloped. This negative has an image in which the highlights probably are opaque and the shadows without detail. If the shadows are completely clear there is no possible remedy, just as in the preceding case. However, if the condition is one in which there is detail in the shadow but it is unavailable because no printing paper will accommodate the range of the negative, it would be desirable to build up the shadow detail and cut down the highlights. This can be done to a limited degree by a process of intensification followed by selective reduction.

Overexposed-Underdeveloped. This negative often appears to have very high quality. It is full of detail both in the shadows and in the highlights which are not blocked. The difficulty with this negative is that it produces a gray or flat print—that is, the shadows are not dark enough and the highlights are not white enough. This negative would be greatly improved in an extreme case by removing the silver deposit to the point where shadow detail was barely visible, and then building up the contrast by disproportionately increasing the highlight deposit. This is a very simple matter, as it involves simple reduction followed by straight intensification.

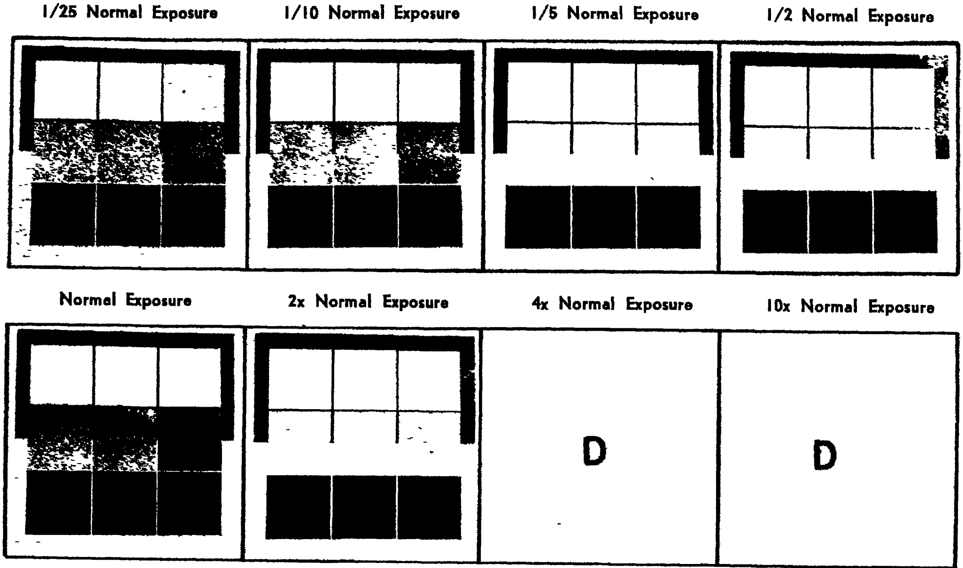
Overexposed-Overdeveloped. This negative is extremely dense, and in many cases the highlights through a range of several tones exhaust the emulsion. However, it is only the extreme case in which this is true. Reduction of the image will usually result in a

Fig. 71. The Effect of Exposure and Development on Tonal Range



Developed in p-diamine-glycin for 25 minutes at 68° F.

(Fig. 71. Continued from preceding page.)



1/25 Normal Exposure

1/10 Normal Exposure

1/5 Normal Exposure

1/2 Normal Exposure

Normal Exposure

2x Normal Exposure

4x Normal Exposure

10x Normal Exposure

Developed in D-76 for 12 minutes at 65° F.

reseparation of the highlights to a degree which will make the highlight detail thinner. As there is an abnormal degree of contrast produced by the overexposure in this negative, it would be desirable to decrease the contrast as well as the density; and this, too, is a practical laboratory step.

These are the extreme cases of negative faults resulting from incorrect exposure and development. It may as well be stated frankly that the best remedy for any of them is to make the negative again. As long as a photograph can be duplicated without the expenditure of too much time and effort, it is always very much easier and gives a higher degree of satisfaction. It is, as a matter of fact, easier to develop a negative than it is to intensify or reduce it. In addition, the negative which is correctly exposed and developed has a quality which cannot be expected from one which was made incorrectly in the first place, and upon which remedial devices have been employed.

There are cases, however, in which the error is slight, and corrective measures may be employed easily and with complete satisfaction simply because the amount of change from the original condition is comparatively slight. It is one of the remarkable characteristics of the photographic process that a slight absolute change in the negative will result in a marked apparent change in the positive.

Correct Exposure-Underdevelopment. This negative is complete in all detail, but it is inclined to be thin and lacks the necessary contrast to give a good print. The image is characterized by satisfactory detail in the shadow. A negative of this kind often can be made to give just as good a print as a perfectly processed negative by the use of simple intensification.

Correct Exposure-Overdevelopment. This is a very common fault among amateurs who do not conscientiously watch the temperature of their darkrooms.

The shadows are just about right, but the highlights are so opaque that they cannot be printed. This is the type of negative which produces the mediocre snapshots in which hands and faces, and to a greater degree light-colored clothing, appear blocked up and chalky. Many negatives can be rendered completely satisfactory by the use of a reducing bath whose action is restricted largely to the highlights and which has a minimum effect upon the shadows.

Underexposure-Correct Development. This negative has extremely thin or even blank shadows, while the highlights appear normal. The transition from highlight to shadow is more abrupt than it should be, and half-tones in the print are considerably darker than they should be. As we have stated before, shadows which are non-existent on the original negative cannot be brought into the picture by any method short of actually sketching them in with brush or pencil. Of all errors of exposure and development in the photographic process, we may regard underexposure as the single one for which there is no satisfactory remedy. The only thing to be done is to duplicate the negative by making the exposure again—and this is substitution rather than remedy. If an underexposure has been correctly developed and will not give a satisfactory print on any grade of paper available, it is ordinarily hopeless. When the fault is slight, intensification may help, but the result will not be first class.

Overexposure-Correct Development. This negative is heavy and requires a long printing time. But unless the error has been extreme, a prolonged printing exposure will usually give a fairly satisfactory positive. Negatives of this kind are quite easily remedied by submitting them to the action of a reducer which attacks the various deposits **proportionately,** so that while the normal contrast is retained the over-all density is reduced considerably.

Methods of After-Treatment.

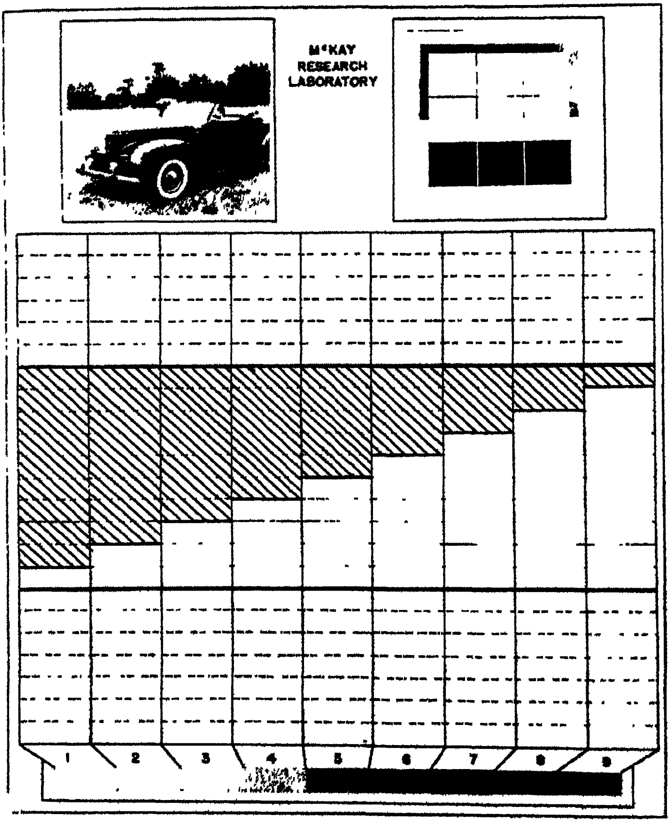
The intensification of a negative can be produced by various chemical agencies in which the opacity of the deposit is increased and the color of the deposit is changed, or in which a supplementary deposit is made upon the exisiting one.

The one big advantage of after-treatment lies in the fact that by a careful selection of the method used the degree of the result can be controlled and the contrast of the negative altered by using a solution which acts more strongly upon the highlights or the shadows respectively. Although it is ordinarily understood that intensifiers are not subject to this control, it has long been recognized that such a control is easy with reducers. As a matter of fact, there is such a control obtainable in intensification, so that a wide range of different conditions may be compensated.

Also when we are concerned with the removal of silver from the deposit to make it less opaque, we have similar control.

There are reducers which act upon the shadows more quickly than upon the highlights, and thus increase the contrast of the negative while reducing its density. Other reducers act uniformily throughout the image, and do not alter the original specific contrast of the negative. A third type of reducer acts more rapidly upon the highlights than upon the shadows, and thus reduces the contrast as well as the density of the negative as a whole.

It must be understood that any after-treatment endangers the negative to a certain extent, and this is particularly true in the case of reduction. To prevent the losses often encountered, care should be taken to use only pure chemicals of the best grade and to make sure they are fresh. In some cases it is also advisable to harden the negative before giving it any additional



Negative fault and remedy chart used in laboratory shows effect of various combinations of exposure and development. Upper left, print from negative being considered; upper right, photo of 9-step wedge; bottom, wedge showing theoretical result if print were limited to 9 tones. This chart was made for a negative which was given 1/10 normal exposure and twice normal development.

chemical treatment. Both intensification and reduction should be done when the negative is first removed from the wash water. If the negative has been dried, it should be soaked thoroughly before undergoing any further chemical treatment.

Intensification and reduction were once almost routine steps in negative processing because there were only one or two types of emulsion available and only one printing medium. This made it necessary to bring everything to a uniform quality. Today, with the wide variety of emulsions and printing media, the need for after-treatment is much less. While every photographic technician should be familiar with the processes, they should be avoided except when absolutely essential. This means, as stated before, that the best way to intensify or reduce is to make a new exposure and give it correct processing.

Intensification.

Before considering chemical intensification in detail, we will examine superficially some of the methods of intensification which are not chemical in the ordinary sense of the word.

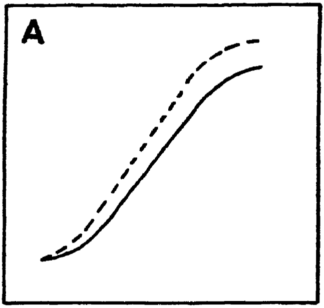
One of the simplest methods of mechanical intensification is to make a positive transparency from the negative, using the thinnest obtainable film for the purpose. From this film a second negative is made through the back of the film so that it will register with the original negative when they are placed face to face, This second negative should be made on glass—a lantern slide plate can be used. The two images are carefully registered, the original film is backed by a second sheet of glass, and the whole bound together. This is a somewhat clumsy device, and when any degree of enlargement is to be used, accurate registration becomes almost impossible.

A similar method consists in making the best possible positive transparency from the negative. This positive image is intensified or reduced as may be necessary, and from it a duplicate negative is made. This method is widely used when the original negative is of such value that possible damage cannot be risked by submitting it directly to chemical treatment.

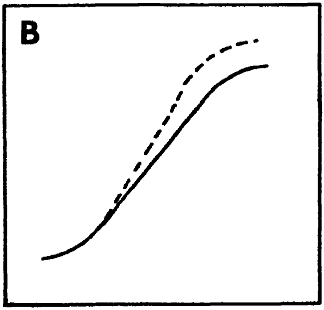
Quite satisfactory results have been obtained by making a series of duplications in this way, alternating negative and positive and adding to the density and contrast of each image through control of development and exposure. This method really works and is practical. Another method, which is mentioned merely as a curiosity because it is too involved for practical application, consists of giving the negative a coat of waterproof varnish. A coat of bichromated gelatin is applied and exposed through the negative, which is then placed in warm water. The exposed gelatin remains hard, while the unexposed areas swell. This relief image is treated with a pigment such as lamp black, which adheres only to the swollen gelatin. Variations of this process include one which practically amounts to making an oil print (negative) on the surface. All these methods are simply variations of pictorial pigment processes.

Another group of intensification methods includes those in which intensification is obtained by changing the color of the deposit. For example, a negative which is toned by the ordinary sulfide sepia toning process will become considerably intensified, although its visual appearance would not suggest such a condition. Dye toning can be used; in fact, any process which alters the color of the deposit within the gelatin to one that is less actinic than the original will prove effective.

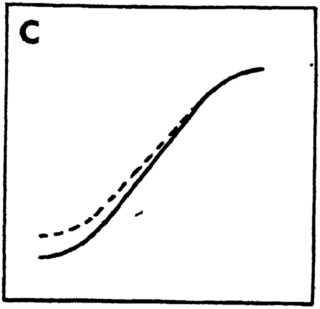
Of these methods the repeated duplication and the sulfide toning are the only ones actually worth a trial. Serious intensification is based largely upon addition



Contrast-retaining type, such as chromium.



Superproportional type, such as lead, which increases contrast.



Flattening type, such as mercuric iodide, which has greatest effect on shadows.

Fig. 72. Curves showing typical action of various intensifiers.

to or substitution of the original silver image. This may be accomplished by first bleaching the silver, which really means that the metallic silver is converted into silver chloride or silver bromide. After bleaching, the bromide or chloride is converted into some substance which, by reason of its greater mass, altered color, or both, has a greater density than the original.

Mercury Intensification. This process of intensification is based upon the use of mercury as the bleaching agent. The method works very well, but when miniature negatives are involved it should be avoided. Most intensifiers which employ a mercury bleach produce a new image in which the grain is excessive.

The amount of intensification is not as great as most people believe—visual inspection is not a reliable guide! While the usual mercury bleach followed by ammonia blackening will, under ideal conditions, produce an intensification of from about 30 to 70 per cent, depending upon the original density of the deposit, as ordinarily practiced it will give an over-all increase of between 20 and 25 per cent. If the various densities are measured individually, the lighter halftones will be found to have gained proportionally more than either the extremely light areas (shadow areas) or the very dense deposits (highlights). In contrast to this, the mercuric iodide bleach followed by sodium thioantimoniate will, under ideal conditions, give upwards of 100 per cent increase, approaching or even exceeding 150 per cent, with the greatest increase in those areas somewhat darker than medium. There is no particular point in discussing every variation of the process of intensification, so we will consider only those more commonly used.

The ordinary mercuric bleach contains approximately 130 grains of mercuric chloride and 25 minims of either hydrochloric or nitric acid in 10 ounces of water. This is roughly equivalent to 30 grams of mercuric chloride and 5 cubic centimeters of acid in one liter of water.

Mercuric chloride is the poisonous chemical ordinarily known as bichloride of mercury or corrosive sublimate. It should be handled with extreme care and the use of rubber gloves is advisable, particularly if there are any scratches on the hands. The mercury bleach is preferably used only in glass or hard rubber trays. Mercury attacks ordinary metals so vigorously that minute cracks in an enamel tray might cause difficulty. For the same reason articles of gold, silver, aluminum, etc., must not be allowed to come in contact with the solution or they will be blackened.

When the negative is immersed in the bleach it appears to become darker, and if examined by holding it up to the light it will appear to have a bluish or even purplish color. However, this stage soon passes, and the image takes on a more or less white color. It is during this period that the first degree of control may be exercised. If the intensification is to affect the entire image, the film is left in the bleach until the image appears completely white when examined through the back of the film. In the case of a very thin negative which is too contrasty (such as one which has been underexposed and overdeveloped), the process of bleaching is watched through the back of the film. The shadows will be whitened completely while the highlights continue to have a considerable amount of black deposit. If the bleaching is interrupted at this point and the negative placed in the wash, the subsequent blackening will have its full effect upon the shadows while the highlights will be proportionately less intensified.

After bleaching, the negative must be thoroughly washed. The washing should continue for at least 15 to 20 minutes. This washing will do much to eliminate later faults in the intensification. At this stage the negative must once more be blackened—that is, the light-sensitive chloride or bromide must be changed into a more stable and darker-colored material. The bleaching and subsequent blackening must both be carried out in a light which, although weakly actinic, is subdued sufficiently so as not to produce the reversal effect known as "solarization." In short, this submission to subdued light is in a sense an exposure, and must, within wide limits, be controlled. An excessive exposure would mean the risk of reversal of the image.

There are many methods used for blackening the image, the choice of which will be determined by the specific characteristics of each agent as described in the following paragraphs.

Ammonia

Ammonia (strong)	**2½ drams**
Water to make	**10 ounces**

This dilute solution of ammonia blackens the image almost instantly. The ammonia dissolves a considerable part of the chloride and a certain amount of the mercury, and the residue is extremely opaque but unfortunately it is not stable. For this reason ammonia is suitable for use only with negatives which do not have permanent value. Unlike many other forms of photographic fading, this image, after fading, cannot be restored by any known method. The solution must not be used for more than one negative which, of course, means one roll of film if the entire roll is to be treated.

Ammonia produces a considerable intensification of the heavier deposits, but has comparatively little action upon shadow detail. Its greatest value then lies in the intensification of line-copy negatives which are to be used for a specific limited time and then discarded. Because of the softening effect it is advisable to add about 2½ per cent potassium alum to the mercury bleach used. This means adding about ¼ ounce to the 10 ounces of solution.

Sodium Sulfite

Sodium sulfite, desiccated	**½ ounce**
Water to make	**10 ounces**

To the above solution sufficient sodium bisulfite or acetic acid is added to make the solution turn blue litmus paper pink. When sulfite is to be used for blackening, it is advisable to add potassium bromide to the bleach in an amount equal to that of the mercuric chloride. That is, 130 grains of mercuric chloride are dissolved in 5 ounces of water, an equal amount of potassium bromide is dissolved in another 5 ounces, and the two are mixed after the chemicals are thoroughly dissolved. This alteration of the bleach is applicable only to sulfite blackening. It is advisable because it not only increases the degree of intensification but also helps to avoid streaks and other irregularities.

Redevelopment. The bleached image may be darkened by redeveloping in any ordinary developer. Although amidol does not give quite as much intensification as some other developers, it is one of the best in point of retention of the proportionate densities of the original.

In all the foregoing methods of blackening it is necessary to expose the bleached image to a certain amount of white light because the blackening is a reduction in many ways analogous to development. There is one process, however, which does not require any exposure at all and which has two other very important characteristics. It is particularly adaptable to photometric and other precision work. This process is development in an iron developer and may be repeated a number of times with constantly increasing intensification, provided the emulsion has been hardened and is washed between the various steps. The proportionate density values are maintained with such accuracy that the intensified densities can be used as bases for photometric measurements.

A two-solution developer is used. Solution A is neutral potassium oxalate, 2½ ounces; hot water, 20 ounces. Allow this solution to cool to room temperature and carefully decant the clear supernatant liquid for use. Solution B is made up of ferrous sulfate, 2½ ounces, citric acid, 10 grains; water, 10 ounces. For use, one part of solution B is poured slowly into three parts of solution A with constant stirring (do not add A to B). This produces the reddish solution which is used to redevelop the bleached image.

One of the most energetic intensifiers for use following a mercury bleach is sodium thioantimoniate (or Schlippe's salt), which is made up by dissolving 100 grains of the salt in 10 ounces of water.

We have discussed intensification by redevelopment following the mercury bleach. There are several other intensifiers, one of which makes use of mercury in a single bath. This is a solution of mercuric iodide. The solution can be made in two ways, the first of which is ordinarily used when mercuric iodide as such is not available.

Mercuric Iodide Intensifier

Solution A.

Mercuric chloride	**17½ grains**
Water to make	**1 ounce**

Solution B.

Potassium iodide	**44 grains**
Water to make	**1 ounce**

Fig. 73. Print from negative which received 1/10 normal exposure and normal development. Scale could have been extended to make pure whites with gray blacks, or gray whites with full blacks.

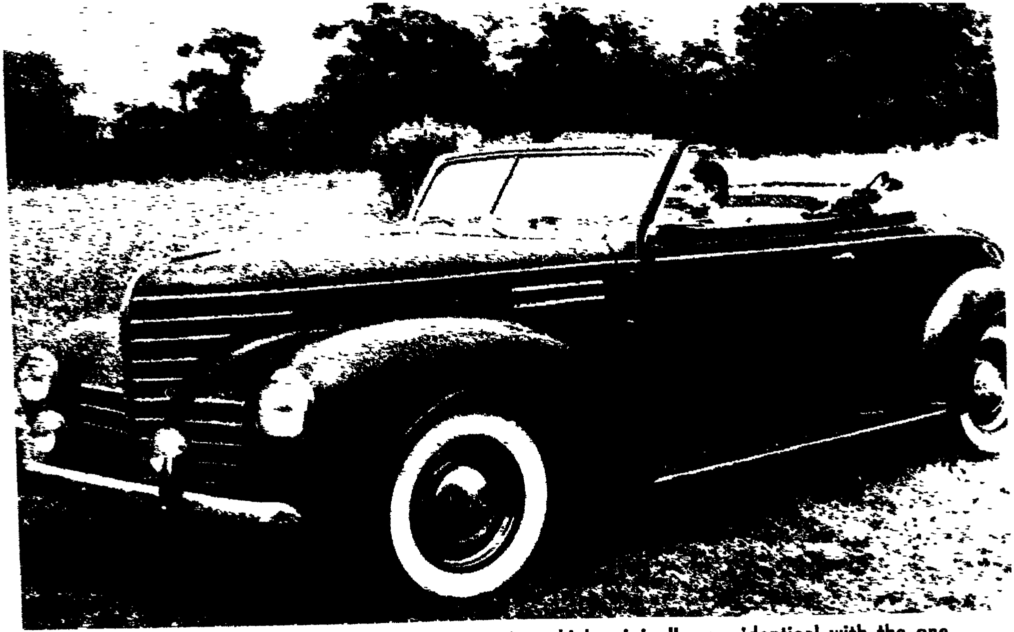


Fig. 74. This print was made from a negative which originally was identical with the one used for Fig. 73, but which was intensified with the mercuric iodide—sodium sulfite formula.

Make these solutions in any desired multiples of one ounce. When the solutions are made, pour about three quarters of Solution B into Solution A while stirring vigorously. Pour the remaining fourth of Solution B into A very slowly, using just enough to cause the solution to clear. Discard any remainder of the iodide.

If it is preferred to use mercuric iodide the following formula will be found satisfactory (Figs. 73, 74):

Sodium sulfite, desiccated	**1 ounce**
Mercuric iodide	**45 grains**
Water to make	**10 ounces**

The sulfite is added to the solution because the mercuric iodide, which is a very heavy red salt, is not readily soluble in water but it does dissolve quite easily in a solution of sulfite.

This intensifier is unusual in that slight traces of hypo remaining in the negative will not have any effect upon the intensified image. With most intensifiers a bare trace of hypo will produce spots and streaks. The negative, after washing or after soaking, is simply immersed in the above intensifier and allowed to remain until the desired degree of intensification has been reached. The negative takes on a warm tone and then turns to a distinct brown. When completely dry, the negative may take on a brilliant yellow-orange color. This is not objectionable and, in fact, adds to the printing density of the negative, although it can easily be prevented. Wash the negative for about 10 minutes in running water after intensification. Then place it in any ordinary developing solution for 10 to 12 minutes, and wash again.

This intensifier is extremely easy to use. It is one of the safest because it does not produce streaks and spots. As its action is proportionately greater on the shadow areas, it is valuable for improving thin, contrasty negatives which result from underexposure and overdevelopment.

Other intensifiers make use of chromium, copper, lead, uranium, and silver.

Chromium Intensifier

Solution A.	
Potassium bichromate	1 ounce
Water to make	10 ounces
Solution B.	
Hydrochloric acid C.P.	1 ounce
Water to make	10 ounces

For the greatest intensification take 10 parts of Solution A, 2 parts of Solution B, and 88 parts of water. For medium intensification use 20 parts of Solution A, 10 parts of Solution B, and 70 parts of water. For only a slight intensification use 20 parts of Solution A, 40 parts of Solution B, and 40 parts of water. The intensification must be done under a subdued light. This solution is a bleach in which the negative must remain until all traces of the original black image have disappeared. After bleaching it is essential that the negative be washed until all the yellowish color has been removed from the emulsion. As the bichromate color is quite obstinate, this washing can be hastened by giving the negative a minute or so rinse in a 5 per cent solution of ordinary sodium carbonate.

The image is redeveloped in any ordinary developer, although a metol type is one of the best. This development should be continued for at least 15 minutes as the intensification increases after the initial blackening, although there is no visual change in the density. Intensification can be repeated, although very little is gained after the second treatment. The intensified image is quite permanent, and because of the warm tone the solution may be used to intensify transparencies, lantern slides, and paper prints. In fact the dilution suggested for slight intensification is often used on prints simply to improve their color. This intensifier is not quite proportional to the original as the shadows tend to intensify proportionately more than the highlights.

Copper Intensifier. This extremely active intensifier is based upon a copper bleach followed by blackening in silver nitrate The original method was not entirely satisfactory with the modern type of emulsion, but an improved method was worked out in 1924 by Z. Zelger. The copper or bleaching bath which does not bleach but turns the image a distinct yellow color is in itself a two-part solution made by pouring Solution A into Solution B.

Copper Intensifier

Solution A.	
Copper sulfate	**11 grains**
Glacial acetic acid	**1 dram**
Water to make	**5 ounces**
Solution B.	
Potassium iodide	**11 grains**
Ammonia (strong)	**3½ drams**
Water to make	**2½ ounces**

When Solution A is poured into Solution B, a considerable amount of heat is generated and the bath is allowed to come to room temperature before using. The cool solution will be a clear blue color and should be tested for acidity with blue litmus paper. If the color of the litmus paper is not changed to a delicate pink, sufficient acetic acid must be added to accomplish this. Do not add so much acid that the litmus will turn to a distinct acid red.

The negative is bleached until the image becomes yellow throughout, which can best be ascertained by examining it through the back. After the negative is completely bleached it is immersed in the following blackening solution:

Silver nitrate	**10 grains**
Sodium acetate	**40 grains**
Water to make	**10 ounces**

When the image has become completely black the film is cleared for 2 minutes in a solution of 1 per cent ammonia. After rinsing for a minute it is placed in the following:

Sodium hydrosulfite	**¼ ounce**
Sodium bisulfite	**20 grains**
Water to make	**10 ounces**

Instead of this final bath one can use an ordinary amidol developer to which sufficient sodium carbonate is added to cause a strip of red litmus paper to turn blue. This intensifier increases the density of the negative about three times, and as a rule the process is limited to the intensification of line originals as it has a tendency to destroy delicacy of gradation.

Lead Intensifier. Lead is another intensifier which is extremely active but which, like the silver-copper method, is limited to line-copy or other negatives in which gradation is of little value. The bleaching solution is made up as follows:

Potassium ferricyanide	**180 grains**
Lead nitrate	**260 grains**
Glacial acetic acid	**90 minims**
Water to make	**10 ounces**

Bleach the negative in this solution and then place the negative in three successive baths of 3 per cent hydrochloric acid, allowing 5 minutes in each. The negative must be handled carefully at this stage because the acid tends to make the gelatin extremely delicate. Wash the negative thoroughly until all the yellow color is removed, and darken by placing it in a solution of ½ ounce sodium sulfide dissolved in 10 ounces of water. The two remaining intensifiers are of greater general value than the two preceding ones.

Silver Intensifier. Make up a solution of 1 part formalin in 10 parts of water. Place the negative in this bath for 5 minutes. Rinse for 2 minutes in running water. Then place in the following bath:

Potassium bichromate	**1 grain**
Potassium bromide	**20 grains**
Hydrochloric acid	**60 minims**
Water to make	**20 ounces**

The time of immersion in this bath should be exactly 1 minute at 68° F. If the time is prolonged the image will start to bleach, and if this occurs the original gradation will be lost. Rinse in running water for two minutes. Then place in the intensifying solution. If this solution is made in the two stock parts as given, and both preserved in dark amber bottles, they will remain in good condition for many months.

Solution A.

Silver nitrate	**400 grains**
Water (*distilled*) to make	**10 ounces**

Solution B.

Ammonium thiocyanate	**700 grains**
Sodium thiosulfate (hypo)	**700 grains**
Water to make	**10 ounces**

Add one part of Solution A to one part of Solution B while stirring the latter vigorously. When this mixture is completed add one-quarter of a part of pyro solution and one-half part of 10 per cent ammonia. The pyro solution is a 10 per cent solution of ordinary pyro with a sufficient amount of sodium sulfite added to prevent its discoloration by contact with the air.

As in all direct silver work, the trays and other utensils must be chemically clean. The negative is placed in such a tray and the mixed silver solution poured over it. Intensification will not start for about 1 to 2 minutes, and then proceeds gradually. The process may be stopped at any desired point by placing the negative in an acid fixing bath. When removed from the silver solution, the negative will have a slight brownish pyro stain. It should remain in the fixing bath until this stain has been removed. Following this the negative is washed thoroughly and at the conclusion of the washing the surface is rubbed lightly with a tuft of wet cotton to remove any deposit which has been formed by ordinary settling. This process is the most valuable method of intensification for miniature negatives, as they will retain the grain pattern even when the process is used with an ultra-finegrain negative. Silver intensification can be repeated to advantage if desired.

Uranium Intensifier. It has often been stated that the intensification of an image which was not recorded by the exposure is impossible. This of course is quite true. However, by the use of uranium it is possible to build up to printing density an image which is so weak that it is hardly visible. Therefore as it tends to increase contrast as well as build up an almost invisible image, it is an ideal intensifier for a negative which is so badly underexposed that it is quite unprintable (see Figs. 75, 76). The intensifying solution is made up as follows:

Fig. 75. Best possible print from a negative which was given 1/10 normal exposure and $\frac{1}{2}$ normal development. The companion negative from which print in Fig. 76 was made was too thin to produce a suitable print before intensification in uranium.

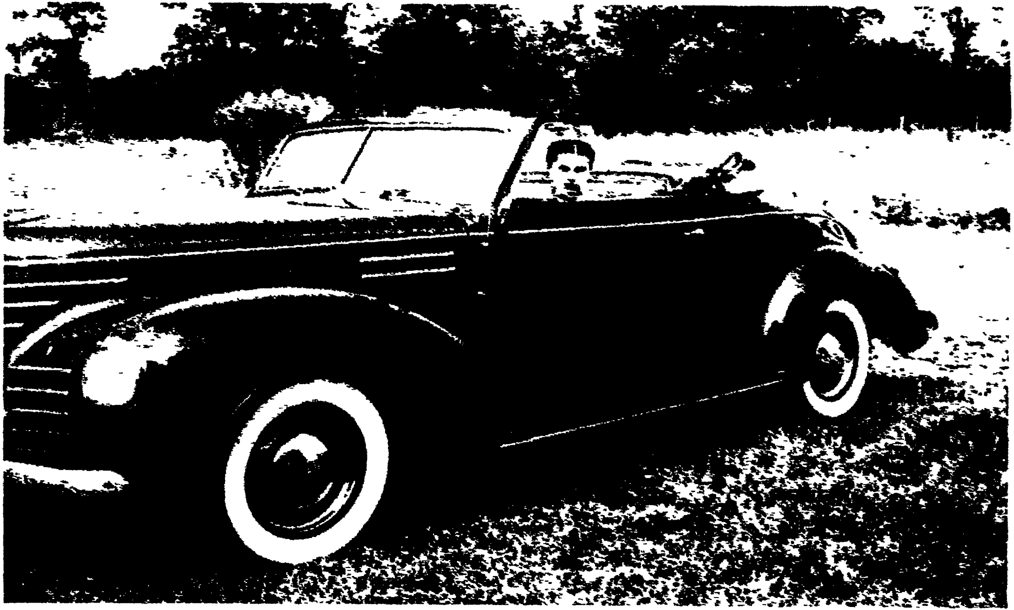


Fig. 76. Print from a negative which received 1/16 normal exposure, ½ normal development, and intensification by a single application of uranium as described. The grain is increased and gradation ruined, but the method serves in an emergency.

Solution A.

Uranium nitrate	**50 grains**
Water to make	**5 ounces**

Solution B.

Potassium ferricyanide	**50 grains**
Water to make	**5 ounces**

For use, mix 4 parts of Solution A, 4 parts of Solution B, and 1 part of glacial acetic acid. The negative must be absolutely free from hypo, or stains will be sure to result. When intensification has proceeded far enough, the negative is washed in soft or distilled water. The image has been converted to a mixture of silver ferrocyanide and uranyl ferrocyanide. As the uranyl ferrocyanide is soluble in alkalis, hard water cannot safely be used for washing.

If a yellow stain persists after about 15 minutes washing in running water, it may be removed by the following clearing solution:

Potassium citrate	**20 grains**
Sodium sulfate	**100 grains**
Water to make	**8 ounces**

If the intensification has been too great or for any reason it is desired to return the negative to its original condition, a weak solution (about 2 per cent) of ammonia or sodium carbonate will remove the intensification. Following this the negative should be placed for 2 minutes in a normal stop bath of 2½ per cent acetic acid and thoroughly washed. After washing, the intensification may be repeated if desired.

Thus far we have considered most of the types of intensification which are really of value (Fig. 72), and we may summarize the results as follows:

For ordinary work a mercuric chloride bleach followed by sodium sulfite will give a good degree of intensification and a stable image.

For a high degree of intensification, including repeated intensification with an exact preservation of the original density ratios, the mercury is used followed by the iron developer. For most general purposes the mercuric iodide intensifier is highly satisfactory because the results will not be spoiled if a trace of hypo is present; the amount of intensification is quite satisfactory, and the increase in grain size is not nearly as great as with the two-solution mercury intensifiers.

For finegrain intensification the silver method is best, although it does require extreme cleanliness and considerable care.

For extreme intensification of underexposed negatives, uranium will probably be found the most satisfactory.

For extreme intensification of line copy or any original where the fidelity of gradation may be sacrificed, the copper-silver or lead methods may be used.

So far as the effect upon contrast is concerned the following facts should be remembered: Mercury followed by ammonia intensifies the heavy densities without affecting the shadow areas. In fact, the method seems to have a tendency to reduce the shadows. Thus this intensifier tends to increase contrast.

Mercury followed by sodium sulfite is fairly proportional, although there is a tendency to increase contrast.

Mercury followed by iron developer is noted for the fidelity with which it retains the original density ratios.

Mercury followed by organic developers such as amidol maintains a fairly satisfactory proportionality. Mercuric iodide single-solution intensifier tends to reduce contrast by acting more energetically on the shadows than upon highlights. Chromium is another intensifier which tends to work more energetically on the shadow portions and thus reduce the contrast which so often is excessive in weak negatives.

Copper-silver and lead intensifiers, as we have seen, are not at all proportional and tend to exaggerate the heavy densities at the cost of the thin areas, thus making them most suitable for line copies.

Silver intensification preserves an almost exact proportional ratio among densities. This is to be expected, since its action is very closely allied to that of a physical developer, and physical development is noted for its fidelity to the tonal values of the original.

It can be seen from the foregoing that the choice of intensifiers is largely determined by the character of the original negative both as regards its contrast and its over-all density, as well as by the ultimate effect which is desired. Broadly speaking, the intensifiers using a mercury bleach are not wholly satisfactory. Neither are they economical, because whatever the blackening agent may be it must be discarded after having been used on a single film. The needs of the average advanced amateur will be fully met by the use of mercuric iodide, silver, uranium, and chromium.

It is suggested that the initial experiments with intensifiers be conducted with discarded negatives. Experienced amateurs proceed with intensification without hesitation, but for some reason it seems that the beginner almost invariably gets streaked and spotted negatives. This is largely due to the presence of hypo and to intensifying negatives which have been dried and not sufficiently resoaked. Once you have become accustomed to the process, however, you will not hesitate to intensify any negative which may need such treatment—with the possible exception of extremely valuable negatives which cannot be replaced.

Reduction.

Photographic reduction, not to be confused with the process of chemical reduction which forms the basis of development, is in a sense the opposite of intensification. Its purpose is to reduce the density of the image and, like intensification, this reduction may affect the contrast in different ways. It may be stated at the beginning that while intensification is a comparatively normal process to be attempted without any hesitation, the same thing cannot be said for reduction. Farmer's reducer, which will be discussed later, is a safe reducer; but other formulas which are used are apt to result in a lost negative unless the chemicals are positively known to be fresh and pure. Therefore the amateur should be warned to resort to reduction only

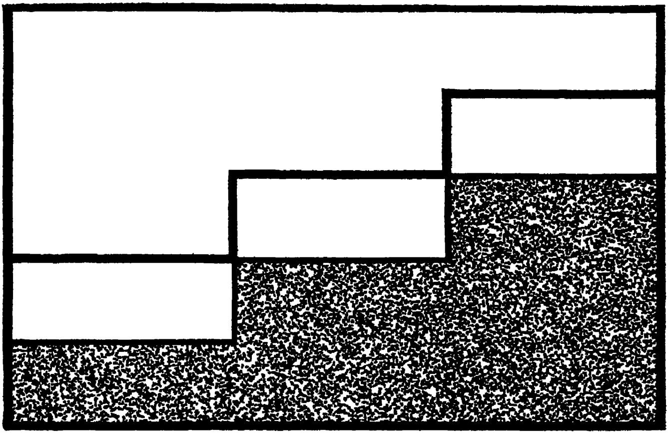


Fig. 77. Superficial reduction removes an equal amount of the silver from all densities. It increases contrast by destroying delicate tones without affecting greatly those of great density.

as a last measure—only when nothing else will serve.

On the contrary, it is certainly advisable for the amateur to try out the various types of reducer on waste negatives so that he can become accustomed to the process. Then when the necessity arises he will have confidence in his ability to do the best that might be expected under the circumstances.

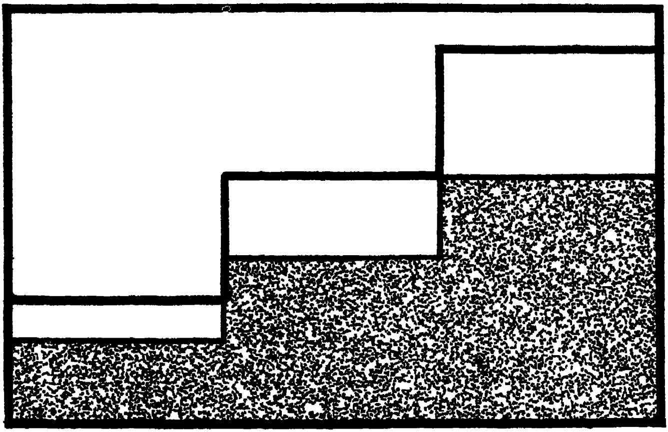


Fig. 78. Proportional reduction removes the same percentage of the silver from each of the different densities. The amount removed in any one area is determined by the actual density itself.

Reducers are generally classified according to their effect upon the resulting contrast of the negative. These three classes are superficial, proportional, and superproportional reducers (Figs. 77, 78, 79).

Superficial Reducers. This type reduces equally all densities of the silver image as it penetrates. That is, if the negative has twenty strata of silver particles and the reducer is allowed to act for two units of time, the densest highlights would still contain eighteen strata of silver while the thin shadow areas, which contain only one or two strata, would be entirely removed. Thus the effect of this reducer is to increase the contrast of the negative by destroying completely the most delicate tones while hardly making any perceptible change in those highlight areas of great density.

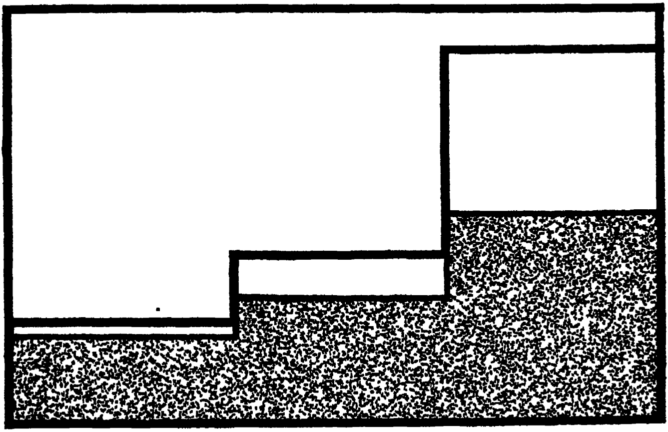


Fig. 79. Superproportional reduction removes a certain percentage of the deposit mass, the greater the original deposit the greater is the reduction of density. Contrast is also reduced.

The greatest value of this type of reducer is to remove fog from the surface of negatives, particularly those in which the image has sufficient body to permit such removal. The superficial reducer is also referred to in photographic literature as the subtractive, cutting, subproportional, or surface reducer.

Proportional Reducers. The proportional reducer takes away approximately the same percentage of silver from each density. Thus it tends to retain a normal degree of contrast. Although it is commonly said that this reducer does not alter the original contrast of the negative in terms of relative values, it does remove the printing difficulties encountered in the extreme contrast of overdeveloped negatives.

Superproportional Reducers. This type of reducer has a very slow solvent action upon the silver, but as silver is removed it is formed into silver sulfate. The presence of the silver sulfate accelerates the solvent action and appears to do so in proportion to the amount of sulfate present. Thus, the reducer will have a greater proportional action upon the dense deposits of the negative than upon the shadow areas and therefore it will produce a reduction of density and also a reduction in contrast at the same time.

Farmer's reducer is one of the oldest reducers known, having been originated by Howard Farmer in 1884. It is a **superficial** reducer, made up of equal parts of a 10 per cent solution of ordinary hypo and a 1 per cent solution of potassium ferricyanide. The ferricyanide tends to discolor the emulsion, so just enough sodium carbonate can be added to make the solution distinctly alkaline. This addition not only prevents discoloration, but extends the life of the solution and renders its action more regular.

The well-washed negative is placed in this solution, and the tray or tank agitated continuously throughout the entire process. The film is removed at intervals for examining by transmitted light, because it is impossible to judge the progress of the operation while the film remains in the tray. When the film is removed it must immediately be plunged into clear water and thoroughly washed before examination; otherwise streaks will be certain to form. The negative must be removed from the reducing solution before it has reached the desired density. The reason is that the reduction naturally continues for a short period after the washing is started. The allowance

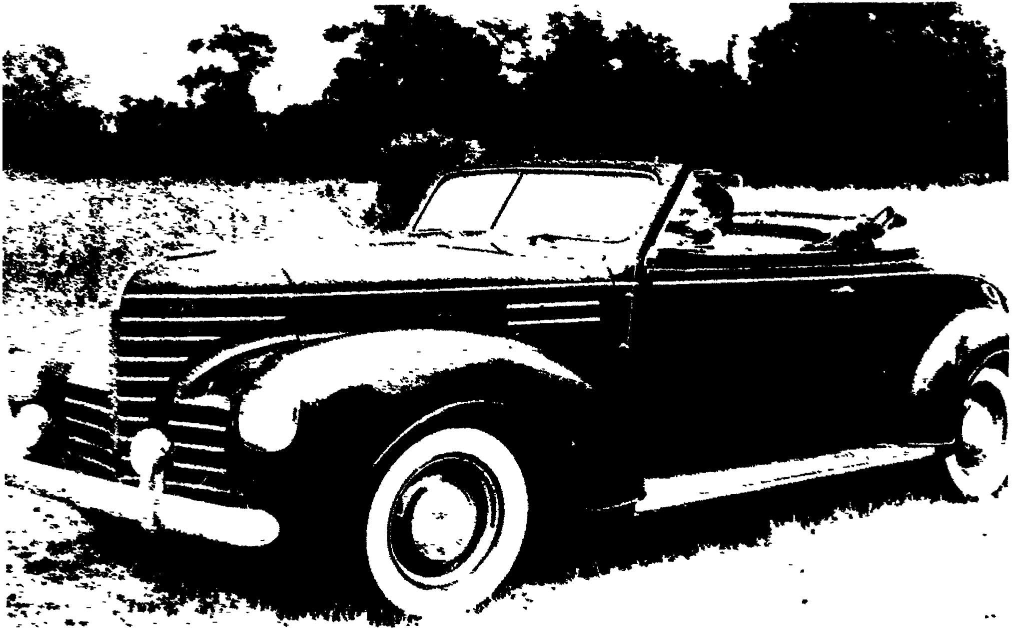


Fig. 80. Print from a negative which was exposed according to meter reading and then developed for the normal time in D-76.

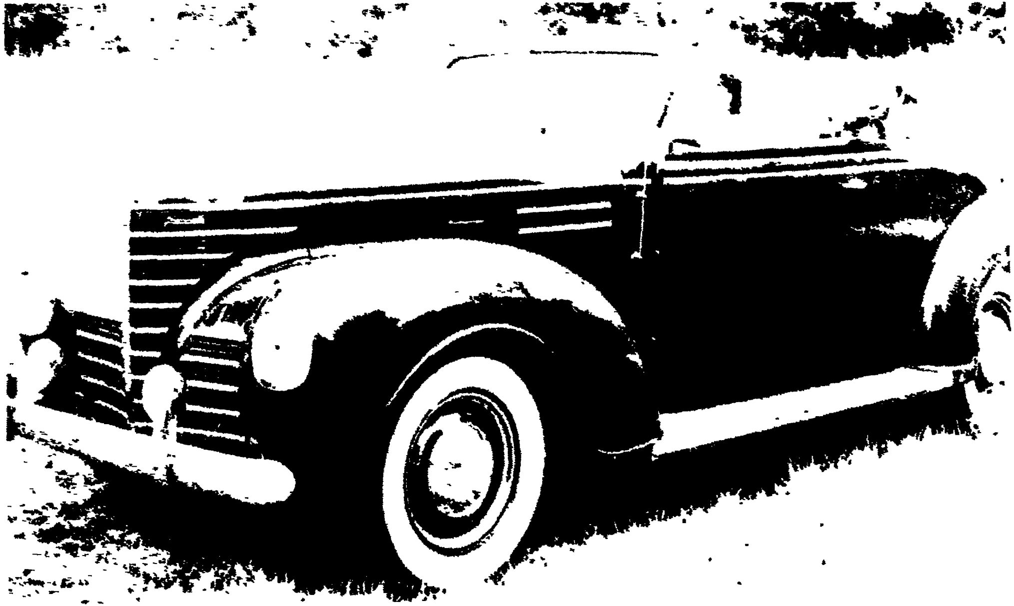


Fig. 81. This print was made from a negative which was exposed ten times normal, but which was developed for the normal time.

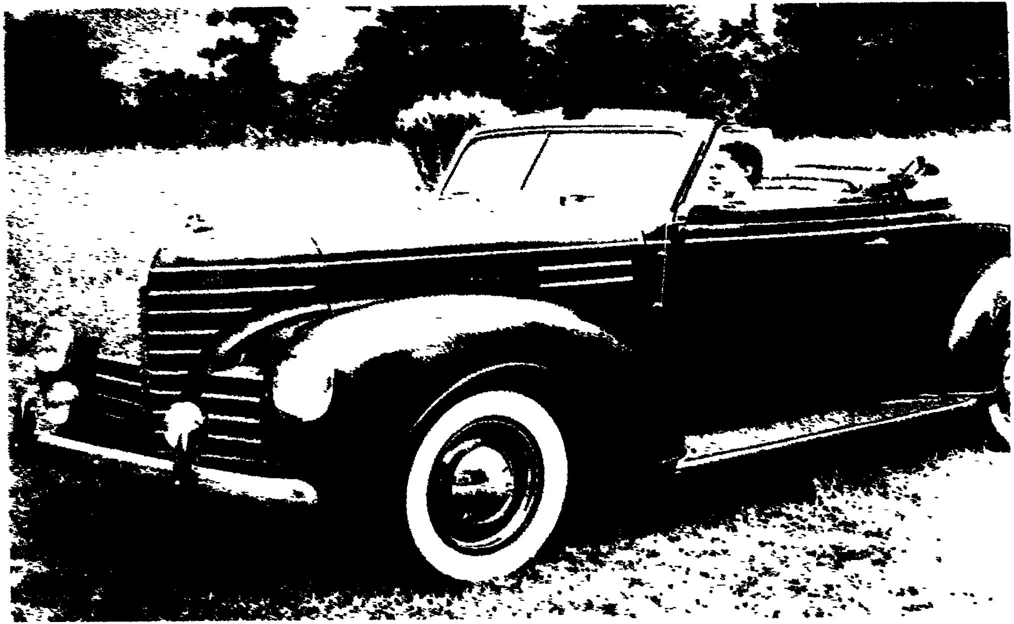


Fig. 82. Print from a negative which was exposed and developed exactly the same as that shown in Fig. 81, but which was first reduced in the hypo-ferricyanide reducer described in the text.

which must be made for this continued action can only be judged by experience (see Figs. 80, 81, 82).

Another superficial reducer is that of Belitzski. It contains potassium ferric oxalate and oxalic acid, and as it has very little if any advantage over Farmer's we will not discuss it at length. The formula is as follows:

Belitzski's Reducer

Potassium ferric oxalate	**150 grains**
Sodium sulfite, desiccated	**125 grains**
Water to make	**7 ounces**

When the solids are completely dissolved, add 40 grains of oxalic acid. Shake the solution until it turns to a distinct green. Allow solid particles to settle, and pour off the clear supernatant liquid. Add 1¾ ounces of hypo, and when this is dissolved the reducer is ready for use.

A very good **proportional** reducer which is not widely known is the ferric alum reducer. Ferric ammonium sulfate is made into a 2 per cent solution in rain water or distilled water. To this is added ½ per cent pure sulfuric acid. After the negative has been reduced, it is rinsed for 5 minutes in water containing 1/10 per cent sulfuric acid. Then it is washed thoroughly. Tap water may be used if it is definitely free from any trace of chlorine or chlorides.

The most common **proportional** reducer is one made by combining potassium permanganate and ammonium persulfate. This solution is mixed immediately before use, and should be prepared by dissolving each ingredient in about 5 ounces of water, after which they are mixed and water added to bring the total volume up to 20 ounces.

Potassium permanganate	**1 grain**
Sulfuric acid (1%)	**1¼ fl. oz.**
Ammonium persulfate	**90 grains**
Water to make	**20 ounces**

The negative is treated from 2 to 5 minutes, according to the amount of reduction desired. After reduction, it is rinsed and placed for 5 minutes in a 10 per cent solution of sodium bisulfite. It is then washed for about 20 minutes.

About the only satisfactory reducer of the **super-proportional** type is ammonium persulfate, which is obtained in the form of small colorless crystals. The salt absorbs moisture from the atmosphere and becomes unstable. If the odor of ozone is noticed when the bottle is opened, it is an indication that the salt has started to decompose. The persulfate is highly unstable in solution, and the reducing bath should be prepared immediately before use.

When using the reducer on a test negative pay particular attention to the heaviest deposits. If there is a slight white cloud formed, even one which is barely distinguishable, it indicates the presence of chlorine or chloride in the water. Such materials present even in extremely minute quantity alter the degree of proportionality in the reduction. When there is a considerable amount of chlorine in the water a persulfate made with this water will not reduce.

The most common proportional reducer is one is, the acidity of the bath in operation—will affect the velocity of reduction, so it is usual to make the bath acid before using it. The solution is made as follows:

Ammonium persulfate	**20—40 grains**
Sulfuric acid (1%))	**1½ drams**
Water to make	**2 ounces**

Reduction starts rather slowly and continues to gain in speed. Therefore the negative must be watched very carefully or the increasing velocity will carry the reduction beyond the desired degree. Because of this the negative must be removed before the desired degree of reduction is obtained. The process is terminated by immersing the negative for 2 minutes in a 10 per cent solution of sodium sulfite as a stop bath. The negative is not rinsed between the reducing bath and the stop bath. After removal from the sulfite bath it is washed for 15 to 20 minutes.

So far we have been concerned primarily with an alteration in the amount of silver in the emulsion. There are times, however, when the negative has highlights of too great density, and shadows which are not strong enough to permit any reduction. It is quite possible to modify such a negative by treating it first with an intensifier such as mercuric iodide and then with a superproportional reducer, so that the end result is a reduction of highlights with an intensification of shadows. A similar result may be obtained mechanically by making a very thin positive transparency and binding this in register with the negative. The total density is increased by this method, although contrast is reduced. As has been stated before, this combination of negative and positive is difficult to handle in the matter of registration, and is not at all suitable for negatives which have to be enlarged to any considerable extent.

Local After-Treatment.

There is one point where the old-time photographer was greatly superior to the modern one. This was in his manipulation of after-treatment. A part of his normal routine consisted of intensifying and reducing certain restricted areas of the negative. This is not difficult; the only real trouble is that it requires a tremendous amount of patience. Obviously when both a reducer and an intensifier are to be used on a single negative—and to be used only in certain parts of the negative—the process is limited to single-solution baths. The combination most ordinarily used is Farmer's reducer and mercuric iodide intensifier.

The negative to be worked upon should be attached to a sheet of glass by means of rubber cement. After the negative has been attached to the glass, a band of this cement is run around the edge of the film to form a seal. After attaching the negative to the glass, it is placed in a tray of water at about 65° or 70° F. and allowed to remain for an hour or so. It is then removed and the surface water wiped sufficiently with a tuft of absorbent cotton. Free surface moisture is then removed by blotting the negative with Textilex paper.

The reducer or the intensifier is picked up on a cotton swab wound on the end of a match or toothpick. The swab should be thoroughly wet but not dripping. The local area to be reduced is rubbed with this swab until a shallow pool of the solution is formed on the face of the negative. This is allowed to remain for about ten seconds. It is then picked up with a cotton swab which has been soaked and squeezed as dry as possible, and the negative lightly rubbed with cotton charged with fresh water. The negative is then blotted and the procedure repeated. The operation can be performed in much less time than is necessary to describe it, and the repetition is continued until the desired density is obtained. If the solution is applied and allowed to remain on the negative until the desired effect is obtained, the negative will show a sharp hard line around the edge of the area treated. However, by alternately treating and washing the area a blended edge which is rarely noticeable is obtained.

Local after-treatment, like all other forms of general retouching, is not practical for small negatives. When working with any negatives smaller than 5 x 7 inches—and this includes practically all modern amateur sizes—it is advisable to make a transparency upon glass 8 x 10 inches, or larger if a larger print is desired. A certain amount of work may be done upon this transparency, including the local intensification and reduction as well as actual handwork. An enlarged negative is made by printing this transparency by contact upon a second transparency plate. This negative is quite large enough for all ordinary after-treatment.

It is common practice to build up extremely weak shadows with a dye applied directly to the emulsion. The amateur is not encouraged to attempt this for several reasons. It is difficult to follow an outline with sufficient accuracy or to blend the dye so that no edge will be apparent in the final print. It is not applicable to miniature negatives, and if an enlarged negative is made it is extremely easy to reduce the shadows locally in the positive and, if necessary, to follow this by local intensification in the enlarged negative. This treatment preserves, in some degree at least, the proportionate densities of the shadow areas. The dye, on the contrary, simply makes the area more opaque to actinic light, and therefore does not carry through the tonal proportionality.

Handwork.

The negative often has a number of defects when it is dry. Aside from the general density problem which we have just discussed, there is almost always a certain amount of mechanical injury. This includes fine scratches, pinholes, dust spots, and similar imperfections. There are times when, due to extreme softening of the emulsion or carelessness, a considerable area of emulsion is totally removed. This often happens when the edge of a fingernail accidentally rubs the soft emulsion. All these difficulties may be remedied, but the degree of skill and the time involved are such that it is far better to make a new negative whenever possible.

The handwork involved in removing the imperfections described involves the same kind of remedial measures ordinarily used in portrait retouching—a process which involves a certain amount of alteration in the actual appearance of the image. Indeed, this is carried so far at times that features which are naturally unattractive are totally altered into a presumably more attractive form. As this involves a rather intimate knowledge of the esthetics of portraiture, we will not attempt to discuss retouching from that point of view. Instead, we will confine ourselves to the use of retouching media for the removal or alleviation of definite imperfections.

Building Up or Reducing Densities.

Retouching consists of several distinct operations. Densities are built up by the use of a pencil. They are reduced by superficial abrasion with a powder or by gentle scraping with an extremely sharp knife. Thin areas are built up by the use of charcoal or crayon on a groundglass support, and occasionally dyes are used in the manner which has already been described. The equipment needed includes drawing pencils, two or three fine sable brushes with sharp points, a pan of black water color, and a stick of India ink. Other items will be added from time to time as the necessity arises.

The use of abrasives or the knife for the reduction of density requires some training and constant practice. It was necessary for the photographer to acquire a considerable amount of skill when retouching was done on the large original camera negative. However, as the miniature size makes it necessary to produce an enlarged negative, and as the positive transparency is an intermediate step in the production of this negative, the use of any kind of mechanical abrasive is unnecessary. The use of the abrasive on the negative is always equivalent to the use of the pencil on the positive. Therefore we shall consider only the process of building up the image and of obtaining full control by working on both the enlarged positive and the enlarged negative.

Use of Glass Plates for Enlargements.

For reasons of convenience it is suggested that the enlarged reproductions be made on glass plates. Many professional photographers use films, but any one of them will agree that it is more difficult to perform hand operations on a film than on a plate. Any dealer can supply you with process plates in any size you may desire. When you buy your package of large plates it would be wise to get a dozen 2½ by 3¼ at the same time to use for testing purposes.

The process emulsion is not widely different from the emulsion on a conventional enlarging paper, although one of the small plates should be tested by allowing it to lie on the darkroom table for 10 minutes while the safelight is turned on. One-half of the plate is covered by three or four thicknesses of black paper. After this exposure, develop the plate in your regular developer. If the exposed half of the film shows any darkening it will be advisable for you to change your safelight to the next degree darker. Some process plates are slightly orthochromatic, and cannot be handled safely in the ordinary bromide paper workroom.

Process plates are ordinarily made for high contrast, and the formula recommended by the manufacturer is usually a rather hard-working one. That is, it tends to build up extreme contrast. As you are trying to duplicate a small negative you will want to avoid contrast and thus retain all the tones in the original. As a rule, a developer which is satisfactory for making bromide prints or enlargements will be quite satisfactory for developing the enlarged transparency and negative, if it is diluted with its own volume of water.

Retouching with a Brush.

Small scratches, dust spots, and similar imperfections in the original negative will be exaggerated in the enlarged negative in a degree exactly proportional to the degree of enlargement. If these defects are small and sharp they may be removed either by pencil or brush. The latter is preferable. Place two or three drops of water in a white saucer or other china vessel which has a smooth bottom. Place the end of the India ink stick in this drop of water and rub the end of the stick against the china, using firm pressure and a circular motion. The water will take up the ink, and the grinding should be continued until the water has acquired a strong black color. The color must be heavy enough so that when a brush is filled with it and drawn across a sheet of paper, the line will be dark gray.

The ink is then placed where it will not collect dust, and is permitted to dry upon the china. When it is desired to use the ink, a small brush is moistened in the mouth, touched to the dried ink, and worked up on the china. Success in this work will depend largely upon learning how to charge the brush. Wet color is never deposited upon the negative in the way that ink is placed upon paper. Instead, the brush is half dry and ink is deposited only where the point of the brush is placed with slight pressure. If the brush is touched to the edge of the negative there should be no appearance of a moist drop left behind. It is difficult to get the brush too dry, but very easy to get it too wet.

The negative to be worked on is placed upon a slanting support in which a hole has been cut so that light may pass through the negative. If it is necessary to rest the hand upon the negative a sheet of paper should be laid over that portion of the negative to prevent perspiration marks. Charge the brush as described, and very carefully touch one of the open spaces left by a speck of dust. The spot should take on a little color. Repeated touches with a rapid staccato dabbing movement will fill in the spot and gradually bring it up to the density of the surrounding image.

Start with a freshly charged brush on those spots in the heavier deposits, and as the brush gives up its color work toward the lighter spots. This same procedure may be applied to larger spots and scratches. It must be emphasized that only failure can be expected if the color is laid on as a uniform coating or wash. Scratches, for example, are filled by making a series of tiny dots along the scratch and bringing these dots up to the density of the surrounding area. When this is done the scratch will have taken on the appearance of a line of dots something like a string of periods. After this each open spot is treated just like any other spot in the negative (see Fig. 83).

Large areas will fill in by making strips of dots across the area to divide it into two smaller spots. Each of these is then divided into two still smaller ones, and this is continued until the area is entirely filled. When the spot has not been entirely removed, the process is repeated. The important thing to remember is that the tone is built up by a very large

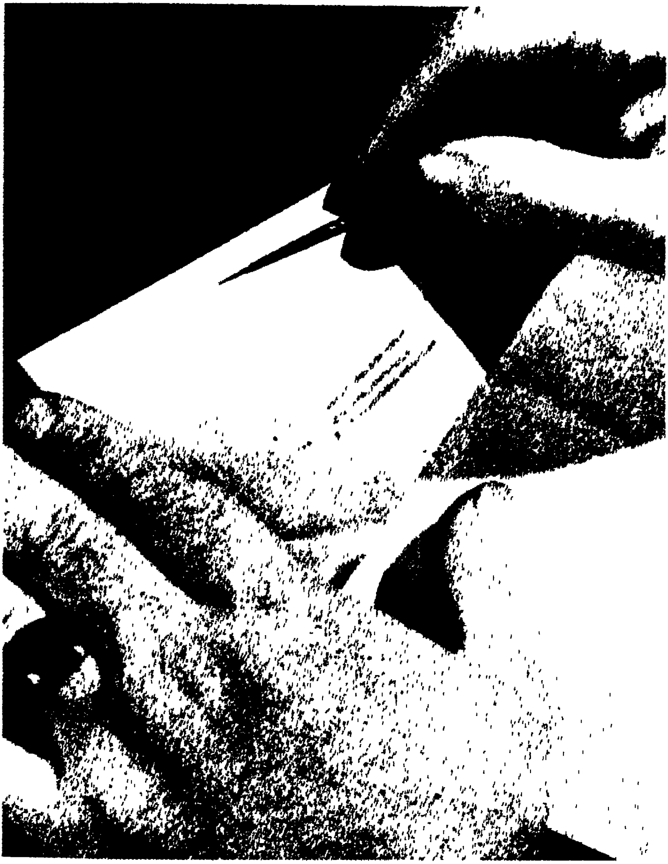


Fig. 83. Pinholes and other small imperfections can be corrected by spotting the negative, using a sharp-pointed sable brush.

number of minute dots of color and never by brush strokes. If too much color is put on a spot it is easily removed by light rubbing with a small tuft of moist cotton.

Beginners invariably object to moistening the brush in their mouths. There is an excellent reason for doing so. Saliva contains a ferment which attacks gelatin and makes it become liquid. This means that each stroke of the brush is in a sense burning the color into the gelatin. It will be found almost impossible to do a smooth job if the brush is moistened with water, and in some cases the color simply will not stick to the gelatin. About the only substitute which can be used —and it is far from satisfactory—is a solution of about 5 per cent ammonia in water.

There is a knack to spotting with the brush which must be gained by practice. I have seen successful teachers of retouching take students one after the other through a course in this subject, but have never seen a student learn spotting immediately. They see the entire process, but it is only after several hours' practice that the necessary touch is gained. Don't be discouraged if your first attempts at negative spotting are definitely crude.

Retouching with a Pencil.

Pencil work is even more difficult to master than brush work. The best pencil is the so-called artist's holder, which takes individual leads. It is advisable to use pencils in the grades of H, 2H, 4H, and 6H, although the 2H and 4H will meet most needs. A great deal of disappointment can be avoided by having the pencil sharpened correctly. The lead extends from the holder about an inch and a half—never less than one inch. The point is sharpened on fine emery paper by drawing the pencil across the paper with a rolling

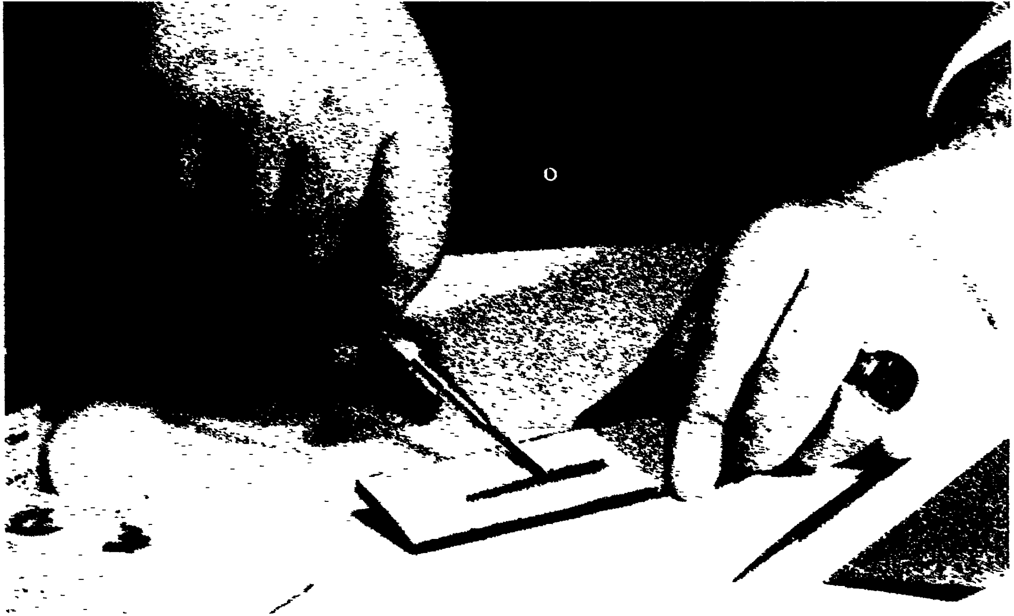


Fig. 84. The retouching lead is sharpened by drawing the point across fine sandpaper or emery cloth while rotating the pencil.

motion. The cone of the point is not less than one-half inch long and preferably about three-quarters of an inch. This gives a very long, slender point. It is difficult to sharpen a retouching pencil because this point must be absolutely needle-sharp and must be kept that way by repeated strokes across the emery paper while the retouching is progressing (see Fig. 84). The average so-called sharp pencil point is far too broad for photographic retouching.

The face of the negative must be prepared to take the pencil, and this is done by the application of retouching varnish, more popularly known as retouching "dope." This is a sticky, resinous varnish which can be made at home, but it is so inexpensive that it is certainly advisable to use the prepared product. It is not necessary to apply this varnish over all the negative —only to those parts where it is desirable to add penciling. However, because so many amateurs have difficulty in blending the edge of the varnished spot so it will not show in the print, it may be advisable for the beginner to cover the entire negative with varnish.

The amount of varnish to be used is determined by experience. About 6 drops should be sufficient to cover an 8 x 10 negative. The varnish is placed in the center of the negative and is spread by a tuft of cotton. Start spreading the dope from the center of the negative; use a circular motion and gradually enlarge this until the entire surface of the negative is covered. There must be enough varnish so that the entire surface is covered, and there must be enough so that by the time you reach the edges the center will be practically dry. It is essential that there be no ridges of varnish any place on the negative. In fact, the negative will look just like it did before except that it will have a slight sheen (see Figs. 85, 86).

Test the varnish with the pencil along the edge of the negative. If too little varnish has been used

Fig. 85. The retouching varnish or "dope" can be applied to the emulsion surface of the negative with the cork, as shown here.

Fig. 86. After the "dope" has been applied to the negative, it is spread with a tuft of cotton over the area to be retouched.

the pencil will slip over the gelatin without leaving a mark. If a little ball of varnish builds up on the pencil point, it shows that too much varnish has been used. When the negative is varnished correctly the pencil will leave a mark similar to but lighter than one it would leave on groundglass.

A support similar to that used for brush work is necessary, and you might as well start by getting a good professional retouching desk. They are inexpensive, and no substitute is ever completely satisfactory.

The negative should be illuminated by light which falls upon a sheet of white paper and is then reflected through the negative. A light which shines directly through the negative is so strong that you cannot see the delicate tones for careful matching. Sit well back from the negative, and do not try to see the spot too distinctly. Carefully touch the point of the pencil to the spot to be covered and then move it over a tiny area, using a wiggling motion (see Fig. 87). Work up to the edge of the spot—not across it. If you can see the pencil strokes they are too large. What you should see is simply a gradual darkening of the spot until it matches the surrounding tone. A similar treatment will eliminate scratches, although unlike brush work the scratch is penciled out with short, broken strokes running in the direction of the scratch.

The pencil is superior to the brush when it is desirable to build up the density of an area in which there is a graded tone. Thus, outlines of light objects against a dark background are sometimes too gray to be satisfactory. The pencil will serve to build up the edge and blend this tone imperceptibly into the original negative tone. This work requires practice, but once a method has been mastered it may be applied to building up any kind of graded tone.

Remember that when you use a pencil on the positive transparency you are darkening the image, and the result will be exactly as you see it before you. When you build up the negative it is exactly as though you are working on the positive with a white pencil. That is, each pencil stroke makes that particular area lighter in the finished print.

Good pencil retouching is rarely visible on a contact print. However, the pattern of the retouching is gross compared with the grain structure of the image, and only an expert can do work which is satisfactory for enlarging more than about three diameters. In working on an enlarged negative from which contact prints will be made this is no great obstacle. If you become deeply interested in this work it might be well to consult some of the texts devoted exclusively to retouching. However, by following the instructions given herein and practicing conscientiously you will have the basis of pencil retouching which can be extended to suit almost any demand.

Retouching to Get Cloud Effects.

There are times when it is desired to work in cloud effects—this simply means the addition of densities which have no definite edge. Groundglass is used for this purpose, and a sheet of it is attached to the enlarged negative or positive with the ground surface away from the transparency. It is possible to separate the two further by placing strips of cardboard between edges. The distance which separates the ground surface from the negative surface will determine the amount of diffusion. The negative with the groundglass attached is laid face down on the retouching desk or other illuminated surface, and the desired density is added by sketching it on the ground surface. A fine line is not very useful as it gives a broadened but very weak density. For this reason groundglass work is usually limited to comparatively broad masses which

Fig. 87. Pencil retouching is employed to build up the density of areas which print too dark. The work requires practice, but can easily be mastered after a reasonable amount of experience.

may be in the shape of definite directional strokes or made to cover any desired area. The charcoal outline is made somewhat smaller than the corresponding negative area and applied as evenly as possible. The powder is blown from the groundglass and then, using the ball of the little finger, the edge of the charcoal is smeared or blended so that no sharp line will be visible even on the groundglass. Full appreciation of the effect produced by two or three touches of charcoal here and there cannot be gained until some experiments are made.

The extent to which you indulge in handwork will be governed by your patience, your skill, and your personal preference in this matter. There is no reasonable objection to any amount of handwork which will improve the final print. It need hardly be added that where a great amount of handwork predominates over the photographic character the altered picture cannot sincerely be called an improvement over the original This is, of course, a matter for you to decide, but a comparatively small amount of sincere experimentation will demonstrate how easy it is to remedy many of the negatives which ordinarily would be considered useless.

VIII.

CHARACTERISTICS OF THE NEGATIVE

VIII.

Characteristics of the Negative

TOO often the amateur makes the mistake of thinking that all negatives are more or less identical. This misconception is one of the greatest obstacles in the path of successful negative making. The negative has a full range of individual characteristics, the recognition of which constitutes the somewhat unfamiliar art of "reading a negative."

Negative reading includes not only the identification of these characteristics, but also recognition of the specific causative factors. An analysis based upon these factors makes possible a complete critical analysis which will reveal the source of any existent errors, and be of material aid in the prevention of such errors in the future. It is not necessary for the experienced amateur to make prints from his negatives for the purpose of criticism. In fact, it is easier to criticize the negative than the print, because criticism of a print must take into consideration any technical errors involved in the printing process itself.

The photographic negative is primarily a "stencil" which, instead of being cut out of thin cardboard, is made up of a stratum of silver dust which has a constantly varying density. Physically speaking, this is the complete description of any photographic negative. However, the way in which the silver dust is distributed throughout the gelatin of the film gives rise to a variety of characteristics which have a definite effect upon the subsequent print. The terms used to describe these negatives are familiar to most amateurs, but there is some confusion concerning the exact meaning of the various terms. A negative may be thin, heavy, hard, soft, sharp, diffuse. It may exhibit a considerable amount of detail, or this may be almost entirely lacking. It may have good gradation or it may be very harsh. It has a definite color which may be gray, brown, yellow, orange, blue, or some other color. It also has characteristics not immediately apparent to the eye.

Certain of these negative characteristics are closely related, with the consequence that they fall naturally into subdivisions. This sub-classification will be apparent from the description which follows.

It is unfortunate that description must be used rather than illustration; but no illustration subject to reproduction has yet been made of a negative. The quality of transparency which characterizes the negative cannot be reproduced upon paper, so that the very points which are to be stressed are invisible. This makes reproductions of negatives so misleading that it is debatable whether or not such reproductions do not do more harm than good. The only method which I have found satisfactory in dealing with students has been actually to make the negative series. Obviously, this is too costly for general distribution. Even duplication loses some of the quality, so our student negatives are actual camera negatives. It would be an excellent plan to show all negative types, but it simply is not possible when reproduction is involved.

Most of the characteristics to be described have been mentioned in more or less detail in foregoing chapters, but such repetition as may be involved is justified by the opportunity of considering these various factors in a sequence which will reveal their relationship, one to another, and which permits a study in relation to their importance as negative characteristics.

Exposure and Density.

We have already seen that density refers to the amount of silver contained in a unit area. We know that the greater the amount of silver per unit area the darker the film will be. This means that when the negative is used for printing, a smaller amount of light will pass through a dense portion of the negative than through a light one. However, there is a fundamental density which must be understood before discussing the various densities found in a given negative. This fundamental density is explained most easily by an example which is rarely found outside the research laboratory. A negative is made by exposing a film to the light reflected from a uniform neutral gray surface. This neutral surface represents the average reflection from an average subject. The perfect monotone negative would contain exactly the same weight of silver as a negative of the same size, perfectly exposed and developed, which reproduces an average photographic subject. The difference is that the picture negative has the silver distributed in spots of various sizes and density, while the test negative has uniform distribution.

If a series of such test negatives is made, each negative receiving an exposure greater than the preceding one with the entire series advancing in geometric progression, and if these negatives are all given identical development, the result will be a series of negatives ranging from a very light, uniform deposit to a very heavy, uniform deposit. This rather detailed description is necessary to emphasize a fact which has been stated repeatedly by many photographic researchers and which, as a rule, is totally disregarded by the amateur. If you have visualized the series of experimental negatives just described, and remember that they all receive identical development, you will undoubtedly realize the importance of one of the fundamental principles of good photography—namely, **the density of a negative is determined by the exposure** (see Figs. 88, 89, 90).

One often hears arguments in camera clubs purported to demonstrate the fallacy of this statement. Such arguments usually refer to the fact that increasing the time of development will increase the density of the negative, particularly in the highlights. Now of course this is undoubtedly true. Not only is it true, but it demonstrates beyond all question that the individual advancing the argument has not the slightest acquaintance with any scientific or research procedure. Such arguments are on a par with any other half-statement which, while it may be true as far as it goes, gives a totally false impression.

The density—the all-over density, the fundamental density—of a negative is determined by the exposure and by the exposure alone. No matter what you do in the way of processing to alter this density, the same procedure applied to a negative which has received greater exposure would result in obtaining greater density. The one exception is the obvious one, namely, that any procedure which tends to exhaust a greater amount of silver than that in the emulsion will not be differentiated from other processes which do the same thing. The statement, however, does hold true for all

Fig. 88. Print from a thin negative given 1/4 normal exposure; note the lack of textural quality, as compared with Fig. 89. As will be seen, texture is limited to larger masses.

Fig. 89. This print is from a normally exposed negative. Here the texture of fine detail of the tree trunk is very satisfactory.

Fig. 90. A dense negative exposed 5 times normal produces a print which fails to give good rendition of detail and texture. As a result of this overexposure the texture has been "ironed out."

densities less than the maximum possible density of that particular film.

This is the reason for there being definite limits to the extremes of exposure which will result in an image. If a film is given a certain amount of extreme overexposure, reversal will take place, as we have seen. Short of this maximum it is usually possible to obtain an image of sorts from any overexposure. Considering the other extreme, if the exposure has been so brief that no image has been recorded, there is no agency whatsoever which will cause that image to develop. This is another of those very obvious facts which one feels should really not be mentioned; but in spite of its logic there is a widespread belief that a nonexistent latent image can be developed by prolonging or "forcing" development.

As is usual in such erroneous beliefs, there is a sound reason for this one. Sooner or later every amateur will realize that he has exposed a roll of film and that his exposures have been far under normal. From his reference books or a fellow club member he will obtain a formula for the development of underexposed negatives, and using this formula he will obtain fairly satisfactory negatives.

In too many cases the unsatisfactory consequence is that the amateur proceeds, by reason of his worship of speed, to assign to his film his own private speed rating which is four times greater than the facts warrant. Such an amateur belongs to that school of thought which considers an automobile in perfect condition as long as it can be operated. It is true that he uses the excessively high-sensitivity ratings and gets negatives from which prints and enlargements are made, and his answer to all arguments is the fact that he is doing it. The reason that he is permitted to win arguments in this way is that his fellow photographers are equally unfamiliar with the fundamental laws of the craft. Every experienced photographer knows that these processes and formulas can be used, and he also knows that they should be reserved for emergency uses only. This is not because of tradition or any other equally obscure motive, but simply because he knows that this procedure will not give the quality which every photographer has a right to expect when he produces a negative.

It is appropriate to mention in this connection that while the film manufacturer gives certain speed ratings for his products, he makes the statement that good usable negatives can be obtained by giving one-half the exposure indicated by this rating. And in an emergency, when the film is given the correct processing after exposure, it may be possible in some cases to obtain a usable negative with one-quarter the indicated exposure. Now in the case of a film which is rated at Weston 32, for example, this simply means that a photographer who knows what he is doing can use this film at an equivalent rating of 128 and still make a print. In such a case neither the photographer nor the manufacturer would dream of following the speed demon's example and use this fact as a reason for assigning Weston 128 to this emulsion as its normal rating. Such facts do not provide any proof—they do not even intimate that the density has been changed by processing.

Let us make use of another homely example. Suppose you bring home a quart of ice cream in a container. Suppose, moreover, that the only utensil available for removing the ice cream would reach only half way into the container. This would enable you to remove one pint. If you follow the reasoning of the usual amateur you will say that you did not get a quart but that you got a pint of ice cream. Of course there is only a pint that you can use, but that has nothing in particular to do with the actual amount available.

All you have to do is to get a longer spoon and dig the rest of the ice cream from the container.

The average amateur photographer uses a developer which will develop only a portion of the latent image, and if he is working with 35 millimeter film he probably uses a developer which will obtain only a small fraction of the available image. By using a high potential developer in fairly concentrated solution it is possible to develop all the image. It is also possible to develop almost all the image by a prolonged action of a diluted developer. It must be remembered, however, that there is no marked difference between the exposed and the unexposed emulsion. Before all the exposed silver grains are reduced, there will be a considerable degree of reduction among the unexposed grains. It has not been possible to develop **all** the latent image and **none** of the unexposed grains.

In normal photography we compromise by giving an exposure which really is somewhat longer than is theoretically necessary. Then we develop the film in such a way that we do get a satisfactorily large percentage of the exposed silver and a similarly satisfactorily small percentage of the unexposed grains. (This development of the unexposed grains is, of course, familiar to you as **chemical fog.**) This involves development which is less than that required to complete the chemical reaction. Speaking from a strictly chemical point of view, this is underdevelopment.

It should be obvious, therefore, that special and trick developing procedures based upon the use of extremely long periods of time, highly diluted developers, abnormally concentrated developers, and so on are merely procedures with which every experienced photographer is thoroughly familiar. But he would not dream of using them except in the specific emergency when each one becomes more valuable than the normal process.

Development and Contrast.

Like the relationship which exists between exposure and density, we have a similar relationship existing between development and contrast. While this is ordinarily said to be a factor of the length of the development period, it is actually a factor of the amount of development. Increasing the temperature or increasing the concentration of developer will have an effect upon contrast just as surely as will lengthening the period of time. Here again it is advisable to establish our limitations and state that **all other conditions being the same, the degree of contrast increases with the length of the time of development.**

Of course, any statement such as that in the preceding paragraph is subject to certain limitations and exceptions. We all know that if development is indefinitely prolonged there will be one period during which the contrast increases steadily, and that following this there will be another period in which the contrast decreases. There is a certain amount of actual loss of contrast in the image, but the greater part of the effect is caused by a steady growth of over-all fog which, added to any given degree of contrast, must necessarily reduce it.

Before becoming too deeply involved in a discussion of contrast it might be advisable to arrive at a definite understanding as to the exact meaning of the term. For the present we wish to do this without becoming involved in the intricacies of sensitometry. Contrast in photography means exactly what it means in any other connotation. That is, it means a difference—more specifically, a difference between two unlikes. Ordinarily you would hardly speak of the contrast between a pair of identical twins, but you might aptly refer to the contrast between a young man in his teens and his baby sister a couple of months old.

It is quite correct to speak of the contrast between two people of the same sex whose ages differ by about ten years, even though the contrast might be slight. Obviously, the contrast would be much greater between two persons of different sexes, one quite aged and the other extremely young. So we have not only the actual idea of difference expressed by contrast, but we must also recognize the existence of degrees of such difference.

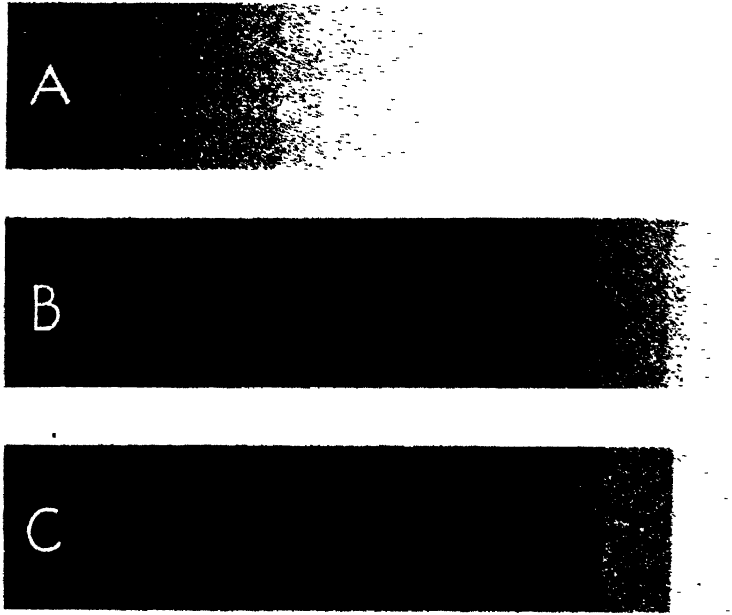
In the photographic negative we have certain areas which are more dense than other areas, and in any photographic negative we may locate and identify that specific area which has a greater density than any other area in the negative. Likewise we may identify that area which has less density than any other in the entire negative. That is, two areas are the keys to the contrast of that negative because the contrast of the negative is the difference between the densities of these two areas. This can be expressed numerically as the actual ratio existing between the measured densities. If the greater density is 3 times the lesser the negative has very low contrast, but if the denser area is 100 times as dense as the lighter then we have a negative of high contrast.

It is commonly thought that the numerical value of the contrast of a negative is that value indicated by **gamma**. This misconception is the basis of more misunderstanding than any other single factor in sensitometry. The contrast of the negative may be a result of photographing an original object in which the contrast was extremely high. For example, it was popular at one time to control such subjects by giving a tremendously long exposure—that is, the exposure required for the deepest shadow—and following this exposure with a proportionately short development. The result is a negative of rather high contrast but extremely low gamma. As we shall see later, gamma is the numerical value of the contrast in a negative which has been exposed to a carefully standardized original whose scale of contrast is known and definite. We shall go further into this in a later chapter, but for the present it is enough to state that a negative may not only be contrasty yet have a low gamma, but it may also have a very high gamma and still be definitely of low contrast.

Defining the Terms.

A number of the terms used in photography once had a logical meaning. Thus a negative was **contrasty** if it had an extreme range of contrast. If this condition were combined with a loss of gradation, blocking of the highlights, and empty shadows, the negative was said to be **harsh.** With older photographic materials it was of course difficult to obtain a negative of high contrast which did not have this harshness. Later the word "harsh" gradually grew into **hard.** The result is that today a hard negative simply means one of high contrast, and conversely a **soft** negative is one of low contrast. This is unfortunate, because the adjective "soft" is often understood to mean an absence of image definition; but this will be discussed later in this chapter. In like manner both "hard" and "soft" are very widely used to indicate the physical condition of the emulsion before drying. It is advisable for the amateur to stick to the older and perhaps less convenient terms of "harsh" or "contrasty" for that type of negative, and "flat" as descriptive of the opposite type.

Photography is peculiar in that it employs many terms which have two antonyms, and the two are rarely synonymous. For example, we may say that a certain negative is contrasty or has a high contrast. If the contrast is not excessive but still greater than ordinary


A
B
C

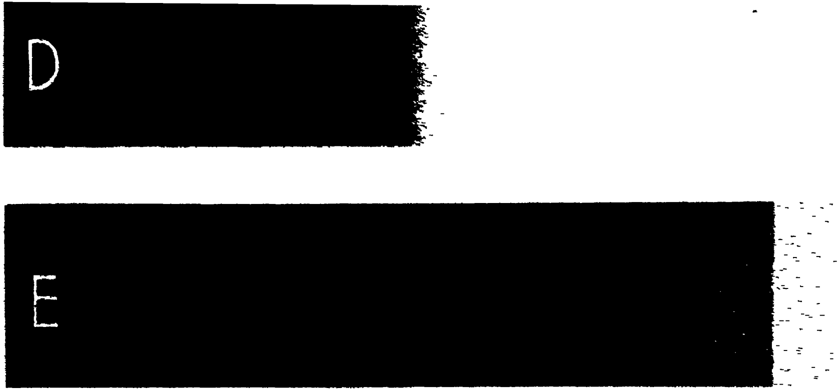


Fig. 91. Gradation or tone sequence shown by comparative strips.

A. Soft gradation; very little difference between any two steps. Tone range reaches only to mid gray instead of black.

B. A full-range, soft gradation, shown in a continuous tone.

C. Stepped gradation wedge corresponding to B. Although lost in reproduction, blacks are separated down to the last step.

D. An abrupt or "hard" gradation. The entire area of the strip is either white or black, except for narrow transitional band.

E. Hard step wedge shows only eight steps from white to black.

we may refer to the negative as **brilliant.** However, all these terms refer definitely to a high order of contrast. The condition which is described as "flat" or "soft" indicates an absence of contrast, and therefore these words must be antonyms of **contrasty.** A negative which does not have contrast usually presents a wealth of **detail.** It surprises a good many amateurs, some of them with a considerable amount of experience, to learn that "contrast" and "detail" are exactly opposite terms. To have detail it is necessary that the negative be soft or flat (but it is not to be assumed that the soft negative necessarily has detail, i.e., when the original had little detail).

There is another closely related factor—that of **gradation.** A negative which is contrasty to the point of harshness cannot have good gradation. A negative which is so soft that it presents the maximum amount of detail cannot have a full range of gradation. Considering all these factors together, we may say that "brilliant contrast" is at one end of the scale and "detail" at the other, while "gradation" occupies the middle ground.

To be sure that this matter is not misunderstood it is necessary for us to refer to the final print. A contrasty or even a brilliant negative cannot be printed on paper because there is no printing paper made which has a reproduction scale great enough to reproduce all the tones in the negative. A soft or detailed negative will produce a **gray** print. Now gray does not mean muddy—far from it. A gray print is simply one in which pure white or pure black or both are limited to extremely minute areas and serve only as accents. The body of the image is made up of a range of tones between light gray and dark gray. The prints of perfect gradation run the entire scale from the lightest to the darkest tones which the paper is capable of producing (see Figs. 91, 92).

Fig. 92. Gradation in nature. Any harshness and loss of tones in a subject like this would make clouds appear heavy and hard.

Having looked at these factors in their mutual relationship, we will consider each one individually.

The Soft Negative.

Because contrast already has been discussed individually, we will give our first attention to the negative of low contrast. The soft negative—using the common term—often has a maximum density range as low as 7 or 8 to 1. If it goes much lower than this it is rarely spoken of as anything but flat. This term arises from the fact that a photograph made by artificial light, and where the light is placed as close as possible to the lens, lacks any suggestion of plasticity. Unfortunately such a negative exhibits the lowest range of contrast ordinarily associated with extreme softness. It will be seen, then, that while "soft" and "flat" are not exactly synonymous, they are used to describe closely related degrees of the same condition.

Detail.

Detail, as its name signifies, is a faithful reproduction of minute characteristics of the original. Recently there was a considerable vogue in extremely sharp portraits. The success of the portrait was judged largely by the extent to which the skin textures were reproduced. Enemies of this type of photography usually referred to it as "pore" photography. Now it is obvious that any extremely harsh lighting of the face would obscure this skin texture by obliterating it in the highlights and obscuring it in the shadow. Such a result would leave the minute texture only in the few half-tone regions between the extremes. For the reason apparent in this example it is always considered impossible for contrast and detail to exist simultaneously in one negative.

Texture.

This has a very definite bearing upon the reproduction of texture. Texture is that quality in a photograph which reveals unmistakably the surface characteristics of the object photographed. The most elementary problems in texture are those concerned with differentiation between a polished metal surface and a surface such as a rug. This is the difference which one expects to obtain automatically. As far as the process of photography is concerned, it is just as easy to differentiate between satin and sateen or between linen and cotton as between metal and cloth. The difficulty lies in the usual absence of skill on the part of the photographer (see Figs. 93 to 98).

Texture is reproduced through accuracy of minute contrast and of minute tonal gradation. A skilled photographer has no difficulty in showing the difference between living flesh and a fine wax model, for example. Incidentally, this is done without a reproduction of the somewhat objectionable skin texture reproduction of "pore" photography. Because texture is so closely bound up with gradation—that is, subtlety of textural reproduction—we have to demonstrate the superiority of photography over any other graphic medium. Ordinarily it is assumed that this superiority lies in the extreme fidelity of tonal reproduction. This, of course, is the most obvious superiority over other graphic media which photography possesses. A well-made photograph can and will faithfully reproduce differences of tone which the eye cannot perceive and which are determined only by measurement. It may be argued with some justification that a subtlety of tone which cannot be appreciated by the eye is of little practical value. If the tone itself were the only point of interest this would be perfectly true, but these same nuances of tone are the very things which lend reality

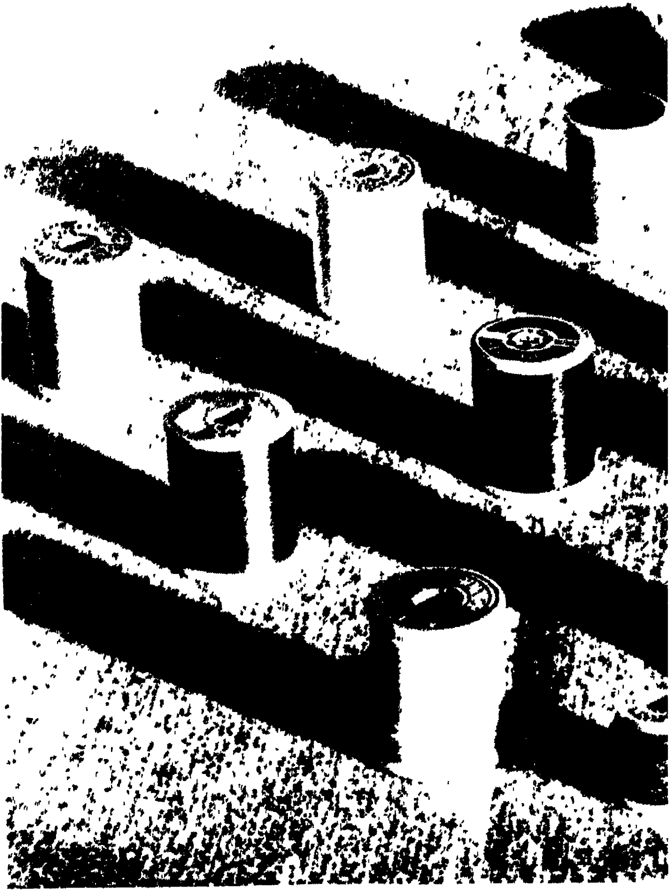
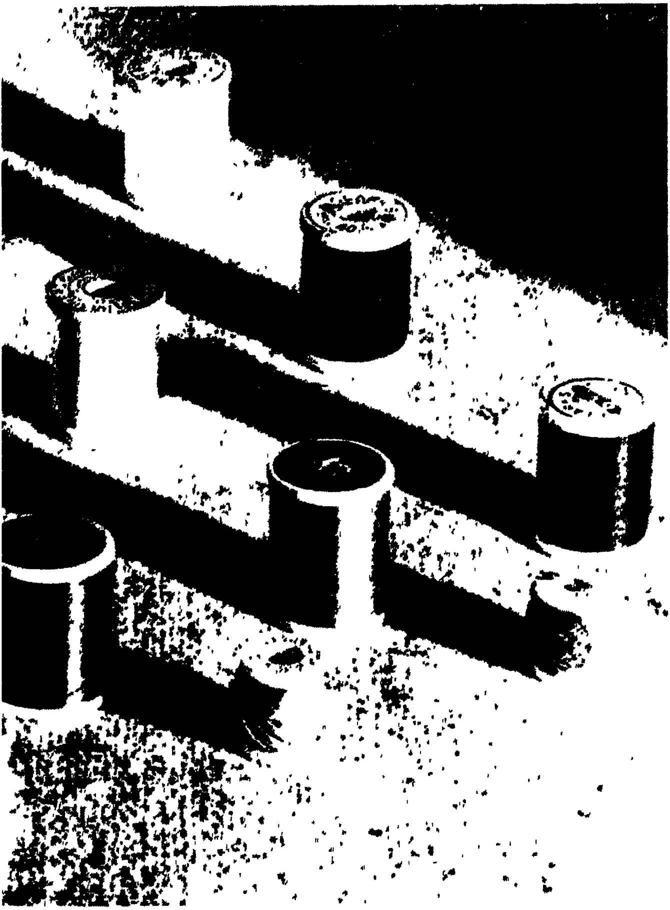


Fig. 93. By crosslighting this setup with two spotlights,



both texture and pattern were obtained in the photograph.

to texture. If photographic differences of tone were limited to those which are visible as such, it would be impossible to have the extremely faithful textural reproduction for which photography is famed.

This ability to reproduce texture is inherently bound up with the "continuous tone" photographic quality. It is obvious that the more subtle textures cannot be reproduced by any half-tone or other reproduction process, as the physical nature of the process removes a certain amount of the delicate differences. Gelatin printing perhaps most closely reproduces the fine photographic quality, but it is costly and limited in the number of reproductions possible from a given plate. Therefore in practically all reference texts, the illustrations fail to show what the context would seem to indicate.

The ability to appreciate texture in a negative is gained only after long experience. We are not familiar with the actual elements of textural appearance, so that when they are seen in negative form they are more or less meaningless. However, the print will tell the story provided the photographer has the ability to make a good print. It may be added parenthetically that the finest negative in the world is useless unless the photographer who has made it is capable of making a print worthy of the negative.

Color.

We have stated that there is a wide difference in the color of the negative. Negatives fresh from processing may be black or neutral gray; they may have a blue-black tone, a warm black, or even deep chocolate color. They also may be almost any shade of yellow, brown, orange, or tan-gray, while intensified negatives are often a very definite yellow or orange. Negatives which have been dyed to produce a finer grain structure will of course have the color of the dye used, and that may be anything within the choice of the photographer. Negatives which are blue-black or blue-gray have different printing characteristics from those which are yellow-orange or reddish in tone. The red and yellow colors give a negative with a longer printing time than its density would indicate, and have an apparently greater contrast. Thus a hard negative dye-toned violet and a soft negative dye-toned red will both tend more toward normal than in their original condition.

Among negatives of similar absolute density range a blue or blue-black negative will not give as much contrast as a brown or reddish-brown one. In actual practice those negatives developed in a staining developer such as pyro have both greater density and greater contrast than their appearance would indicate. For this reason it is advisable to try to keep your negatives as nearly uniform as possible in the matter of color. This is not directly under your control, of course, but any specific developer will usually produce negatives of uniform color. If you continue to use one type of developer, you will not have to worry about this problem. If you use three or four different types of developer and obtain negatives of corresponding color variation, you will find it difficult to control printing exposure unless you make systematic exposure tests

Resolving Power and Grain.

There is another factor of considerable importance in negative quality, and that is resolving power. Resolving power is the ability of a negative to reproduce extremely fine lines which are very close together. In any photograph a sharp line is always represented by a blended edge. Instead of being all black on one side of a geometric line and all white on the other, there

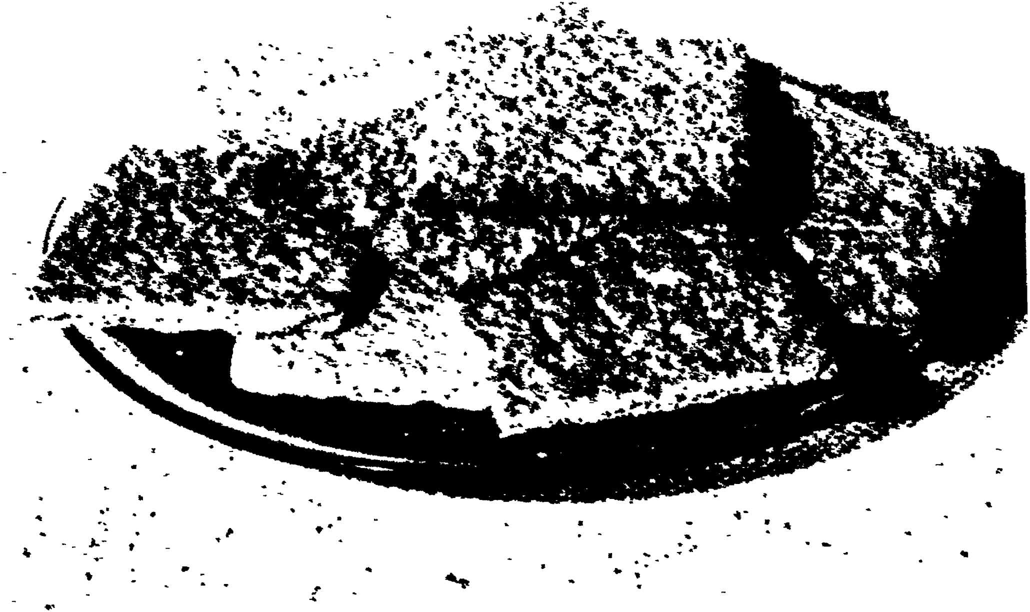


Fig. 94. Because of improper lighting the true texture of the graham crackers is not shown; actually they appear to be damp.

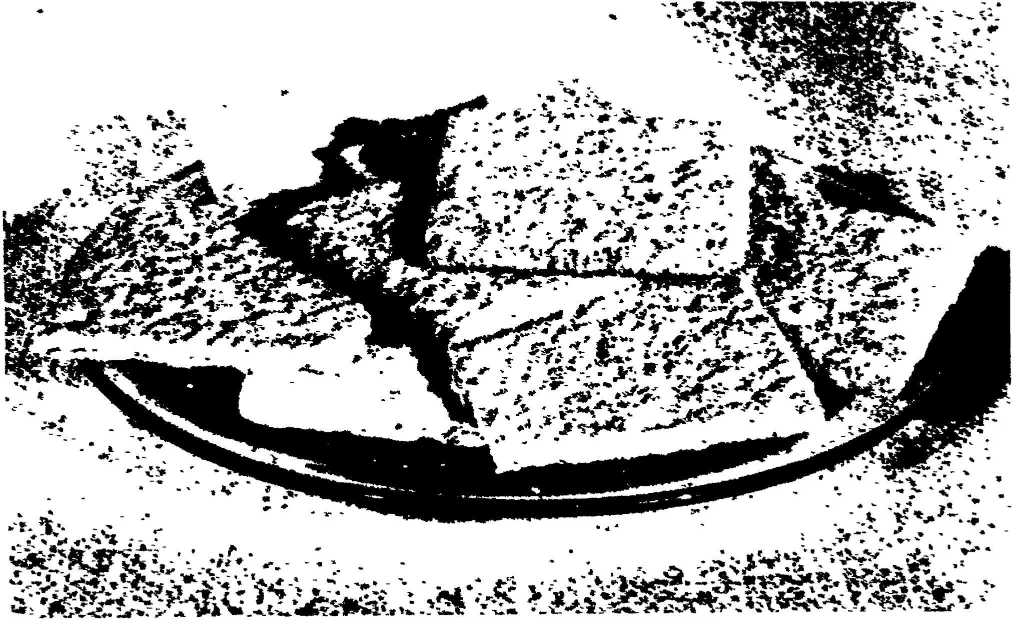


Fig. 95. Corrected lighting produces a definite shadow pattern, and the crackers now take on added crispness and true texture.

is a certain intermediate boundary between the two in which the deposit of silver grows steadily lighter. This area may be comparatively narrow or it may be extremely wide. For example, if you pour wet sand on a board in parallel lines the sand will pile up in the center of the ridge and the sides will flow only a small amount. This leaves a number of high ridges with deep valleys between them. If you do the same thing with dry sand the sand will run, and the ridges will be low and wide instead of high and narrow. This is exactly the condition which exists in films of high resolving power and low resolving power respectively.

When a film has a low resolving power the fine lines will tend to spread out until they join the spread from the next line, and so the original which consists of many fine lines will be reproduced as a uniform gray area. An emulsion with a high resolving power does not have this great spreading at the edges, and the break between highlight and shadow is sufficiently abrupt. Therefore, a much larger number of lines may be photographed in the same negative area without losing their identity. Stated in more practical terms, a negative of high resolving power can be enlarged satisfactorily to a much greater degree than one of low resolving power. If you wish to consider the conditions which actually exist rather than the visual ones, the negative of high resolving power is actually sharper —that is, it has better definition than one of low resolving power.

As a rule, among negatives of a large general class the finegrain negatives have a greater resolving power than have the coarser-grained ones. It is also true that negatives of high resolving power are of a finegrain nature. These facts, however, must not lead you to the assumption that fine grain and resolving power are identical. The resolving power is a characteristic of a negative which has a fine grain, but other characteristics are also necessary. Generally speaking, the emulsion which has a high resolving power is slow, and it is almost always true that the slower this type of emulsion is made the higher its resolving power will be. We know, of course, that extremely fast emulsions usually have coarse grain and low resolving power. Also, the emulsion which has a high resolving power is inherently a contrasty emulsion We know that very fast emulsions usually have an inherent lack of contrast. From the foregoing we would assume, and quite correctly so, that the very fast emulsions suffer quite definitely when measured on a basis of resolving power.

Practically it may be stated that there are emulsions which can be used at much greater degrees of enlargement than any of the popularly used films, and these emulsions are deliberately made to possess high resolving power, contrast, and fine grain. Of course they could be used for ordinary work, but they are very slow. It is indeed difficult to hold the contrast with such film to within those limits which are considered desirable for pictorial reproduction. A few comparative tests made between films such as Micro-File, Microcopy, and Minipan, on the one hand, and the super-highspeed films ordinarily used for amateur photography on the other, give you a vivid example of the extreme to which fine grain and definition can be carried if you are only willing to sacrifice speed.

Of course a negative with a large-grain pattern could not produce a highly resolved image. The grain structure itself would produce the blending at the edge of an area, which would preclude high resolving power. To this extent there is an identity between fine grain and high resolving power. Yet there are negatives which have extremely finegrain structure yet which form images whose boundaries are so diffusely blended that the image shows considerably less resolution than might be obtained from an emulsion of much larger inherent grain pattern. This is the most striking dif-

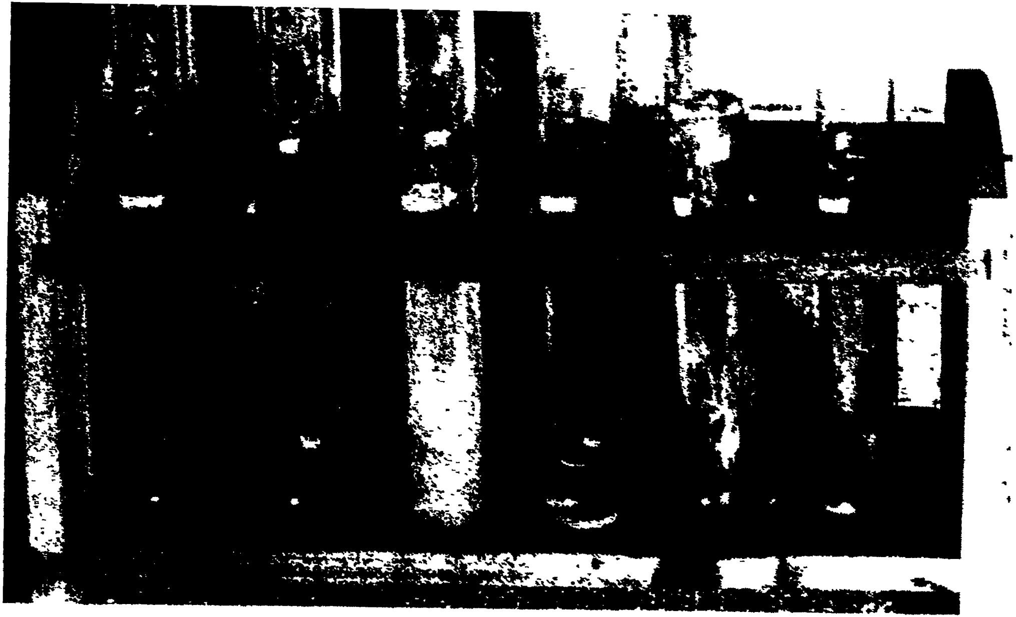


Fig. 96. Photographed with conventional broad lighting, these test tubes filled with liquid appear flat and without texture.

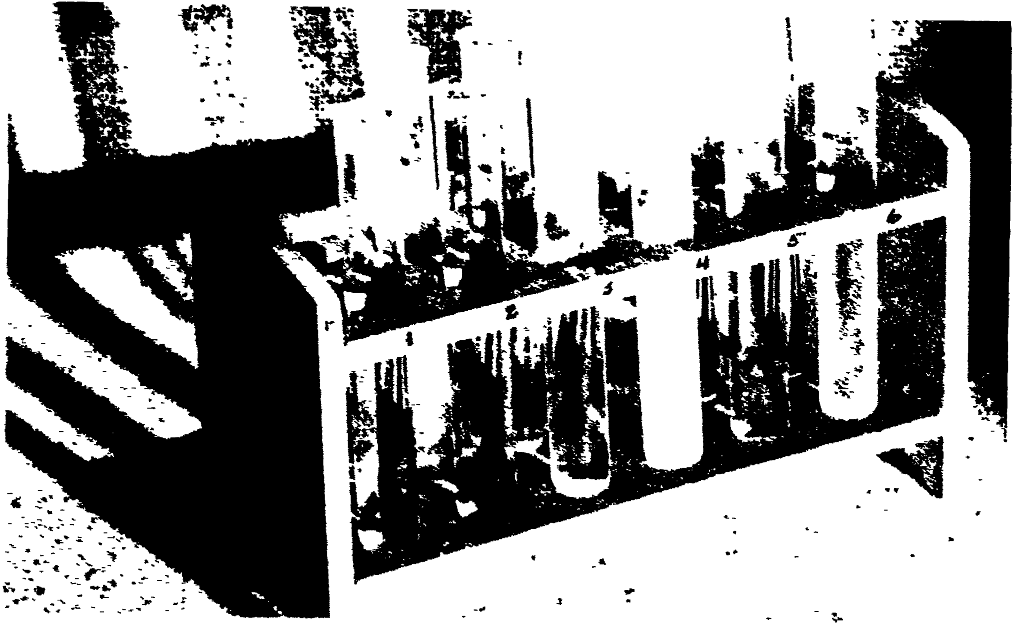


Fig. 97. Change of angle and the addition of a spotlight make the glass tubes and liquids appear to be what they really are.

ference between fine grain and resolving power. A practical aspect of these facts is encountered in using miniature negatives which will break down in definition before the grain pattern becomes objectionable, while other emulsions which do show an objectionable grain pattern in the same degree of enlargement show no indication whatsoever of breakdown.

Thin emulsions usually have greater resolving power than heavy ones because irradiation in the thick emulsion will break down the fine line. The thinner the emulsion, the less will be this effect. Also, single emulsions will usually display greater resolving power than double-coated ones. In short, high resolving power is related to any factors, positive or negative, which tend to prevent the "spreading" of a sharp edge.

It is perfectly reasonable to say that an emulsion of high resolving power will probably have high contrast and fine grain, but neither of these subordinate factors will necessarily give an emulsion high resolving power. It is obvious, therefore, that the subject of grain must be considered from many points of view. We have just considered its intimate relation with the problems of resolving power. In an earlier part of the discussion we saw that grain had no real physical existence as such, but is an appearance produced by a physical formation which is exactly opposite to it. In short, if we take care of the holes in the negative, the "grain" of the positive will take care of itself. We have also seen that the condition which we must try to prevent is the clinging together of actual grains into clumps of such shape that the grain-producing apertures in the pattern will be prevented, or when present they will be so uniformly distributed that the result is an apparently uniform tone.

It is necessary, then, that we consider grain as a characteristic of a negative which will have a certain influence upon printing. Of course, we do not have to consider grain or resolving power in a negative which is to be used for contact printing. When the negative is to be projected to a considerable size, then the grain pattern is important (see Figs. 99, 100, 101).

It has long been popular to illustrate the grain distribution resulting from some specific developer by making photomicrographs of an emulsion developed in it. There are two objections to the use of the photomicrograph for this purpose. Every photographer is familiar with the restriction imposed upon him by the limitations of the **depth of focus.** When a photographer works very close to his subject this limitation causes the background to become diffused and out of focus. This same thing applies to photomicrography, except that in the case of the photomicrograph the planes of the subject, both in front of and behind the plane of principal focus, simply disappear. This effect, of course, is variable and depends upon the technique used Speaking generally, the photomicrograph does not give the entire picture but is limited more or less to a single plane. Therefore a photomicrograph will show the true nature of the negative only when that negative has an extremely thin deposit confined to its surface. This effect, known as **optical sectioning,** is deliberately used to make photographs of a single plane within a comparatively thick material.

The other objection to the use of the photomicrograph for this purpose is the fact that the negative of the photomicrograph presents a far more truthful picture of the actual conditions than does the positive print. This is simply because the photomicrographic negative has been made from a negative, and so in relation to the problem we are investigating it is actually in the positive phase. If we want to know the effect of a grain pattern we want to see the holes between the negative grains represented as dark with the

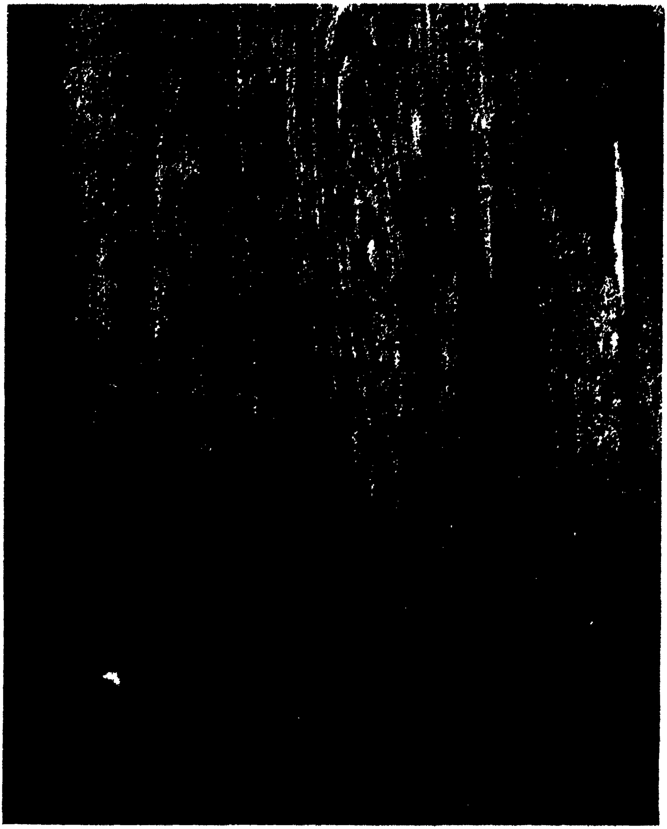


Fig. 98. Good lighting, proper exposure, and correct development combine to bring out texture of unpainted cypress plank.

actual grain area light. The illustrations accompanying Chapter V show direct projections from photomicrographs of a physically developed negative and a chemically developed one, both in the same scale. The significant point of this is that the only reliable test for graininess of a negative is actual projection and in microscopic examination. In the reproductions of the projections, both of which were made at 40 diameters enlargement, the physically developed negative will be seen to have the greatest apparent freedom from grain, while one would be inclined to choose the chemically developed negative from the original photomicrographs alone.

Negatives to Fit Your Needs.

You will want to know what kind of negative is most suitable for your particular purposes. This, of course, is something which cannot be stated without knowing what your particular requirements may be. In short, each experienced photographer has his own standard from which he can obtain the best prints, and for the establishment of most of these standards there is no apparent reason. Once you have decided what you prefer in the way of a negative, then it becomes comparatively easy to make your negatives to this standard.

As a rule, an enlarger which uses diffused light works best with a negative of fairly thin density and not too great contrast. An enlarger fitted with a condensing system will give satisfactory results from negatives of moderate density and moderate to low contrast, while for contact printing, negatives which are definitely contrasty are often used. All these terms are extremely vague; they are offered for use only in comparing negative qualities. Many photographers using diffusion enlargers work with much more contrasty negatives than others who use condenser enlargers. It is true, however, that there are negatives entirely too soft for satisfactory contact printing which will give good enlargements. Likewise there are negatives entirely too hard for any projection which will give quite satisfactory contact prints.

The ultimate print must be kept in mind at all times. A white object which is to appear as such in the final print must have its image in the negative sufficiently transparent for the light to pass through in quantity great enough to produce the detail which prevents the object from appearing as a pure white silhouette. This imposes a very stringent limitation upon the maximum density of the negative. Maximum exposure is that which will barely suffice to produce a completely black area when passed through the clear film base. This is the exposure which will give the rich shadows essential in a good print. The strongest highlight must therefore be limited to a density which, in this same period of exposure, will permit the paper to be exposed sufficiently to produce the delicate shading which makes the highlight detail.

If the exposure is greater than this, shadow detail will be burned out. If the exposure is less than this, highlight detail will not be visible. We have a leeway or latitude from only two sources. If the lighting of the original subject has been sufficiently low in contrast so that the practical scale of the negative has not been used entirely, we will have a slight leeway in exposure without detriment. The other latitude is obtained by the various grades of contrast provided by the paper used. However, it must always be remembered that the necessity for using hard or soft paper is in a measure a confession of insufficient scale to produce a perfect negative.

It is the dream of every photographer, amateur and professional, to master photography to such an extent that all his negatives will be printed on the same grade of paper using the same time of exposure It must be understood that this is a goal to be achieved and not a condition which could become practical for anything other than straight record and laboratory photography. It is practical to work toward the time when this procedure will reproduce effectively the true appearance of the original. This still leaves us full freedom for the exercise of our personal judgment and choice in determining the pictorial value of any photograph which we make.

Most of the discussion up to the present point has been concerned with the method of obtaining the various specific characteristics which have been described. Therefore, when by personal experiment you have determined the quality of negative which you prefer, the production of this negative will be easy by simply following the instructions already presented.

For example, if you find that your negatives are so contrasty that you cannot print them, not even by using the softest paper and a special soft positive developer, you have the solution immediately at hand; but first check the results. Under the conditions just mentioned, your print will show highlights of pure white without any detail when the shadows are printed to their fullest depth. When detail is printed into the highlights all the shadows, even those of intermediate depth, become massed into a more or less uniform black splotch. If you attempt to compromise, your shadows will be too dark and your highlights too white. If one of these three conditions does not exist in your print, you have mistaken the diagnosis. For example, if your highlights not only print out in full detail but begin to get a little gray, and your shadows are a light gray instead of being a rich black, you are working in the wrong direction. Such a print indicates an absence of, rather than too much, contrast. However, to return to the first assumption that the negative has too much contrast, you will recognize this as a signal for you to reduce the time of negative development.

If your negative is so dark and heavy that an exposure of 20 seconds or more is required to produce even a light deposit in the shadows, then you will recognize overexposure. In this case you can arbitrarily assign a sensitivity rating to that particular emulsion higher than the one generally accepted. If you like an extremely thin negative but somewhat full scale, you will find it advisable to increase the speed rating still further. This, of course, is the same as giving a shorter exposure.

It is possible to use two or three exposures without greatly affecting the resulting print, provided each exposure is followed by its complementary development technique. For example, if you decrease development following a normal exposure to get a very thin negative, the negative will not have the desirable amount of contrast. It is sometimes possible to decrease the exposure as much as 50 per cent without seriously affecting the printing result. The reason is not difficult to understand. If you have a full-strength negative, the shadows must be heavy enough to prevent clogging during the comparatively long exposure necessary with good rich highlight deposits. If the exposure is cut in half, the negative image will be considerably thinner in the shadows—so thin that they would not hold detail if the accompanying highlights were extremely black. However, with a thin and delicate highlight the over-all density is so slight that a comparatively brief exposure will cut through the highlight sufficiently, and this brief exposure will permit the retention of shadow detail where the shadow deposit is of extreme delicacy. This adjustment of exposure to produce a given contrast with a given development does not indicate contrast control by exposure. The apparent paradox is explained when one considers the

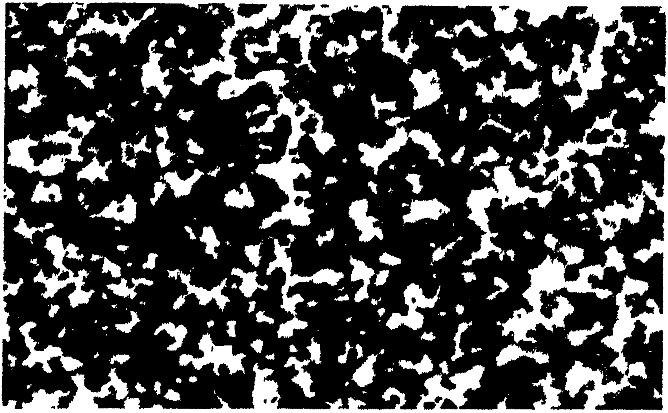


Fig. 99. Above, photomicrograph of medium, uniform tone area from a negative which had been developed in p-diamine-glycin. The original negative was then placed in the enlarger and a 175x positive projection made from the same tone area (below).

proportionate amounts of light which pass simultaneously through various areas of the negative.

This fact is not to be confused with **film latitude.** Film latitude is a quality which must be limited to a given processing. It may be defined as that characteristic of an emulsion which will result in satisfactory negatives from a certain variation of exposure both greater and less than normal when the film is developed by a specified procedure.

This basis for individual ratings of sensitivity has received little attention, but some consideration will show that the man who demands a rich, heavy negative must of necessity use greater exposure than one who uses a negative so delicate that the image is hardly visible.

Thin vs. Heavy Negatives.

There is very little choice between the thin negative and the heavy one as long as the proportionate differences in tones are maintained throughout. It is much easier to preserve delicate gradation in a heavy negative than in a light one. On the contrary, it is more difficult to produce a good print from a heavy negative than from a light one. These apparent contradictory statements can be reconciled by any photographer who will do a little experimenting in his own darkroom. He will find the difficulties are those of maintaining infinitesimal variations in the thin image and in keeping the extreme densities of his heavy negative within the reproduction scale of the paper used. For this reason most amateurs of today pursue an intermediate course and make use of negatives which twenty years ago would have been considered extremely soft as well as thin, but which today are simply average.

There are undeniable advantages to be gained by using a very thin negative. The advantages which lie with the heavy negative are just as undeniable. As we have had occasion to observe before, photography is essentially a craft of compromise in which wise amateurs carefully balance advantages and disadvantages and seek to maintain that average balance which gives them the greatest general advantage. At the same time they never hesitate to make use of the extreme advantages of any technical factor when circumstances warrant their paying the price of other advantages lost. Much of the failure which discourages even amateurs of considerable experience when trying out a new technique arises from the fact that the attendant technique is a highly specialized one—usually imitating some individual who, after long experience, has mastered the use of an unusual negative type.

Experimenting with New Techniques.

I remember a specific example of this kind. A certain young man—an ardent experimenter with an educational background which warranted him in making extensive experiments—had developed a technique whereby he produced prints of beautiful quality from negatives so thin that they could only be studied in detail by laying them upon a piece of white paper. His prints were so good that many neighborhood amateurs tried to imitate his technique. Among all the aspiring imitators only one achieved success. He was the only one in the group who paid sufficient attention to the process to note several contributing factors. First, exposure was followed by complementary development. Second, the enlarger used had been converted to a very low-intensity indirect lighting type. Probably most significant of all was the fact that this particular young man limited himself to subjects of extremely delicate tone and ordinarily high key. The

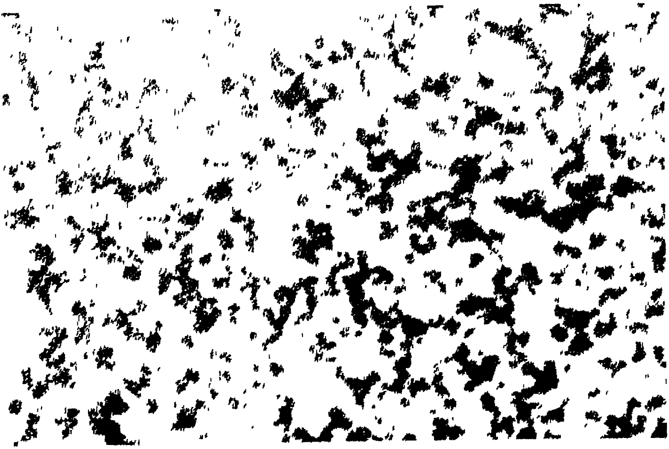


Fig. 100. Above, photomicrograph of uniform tone area developed in D-76. Below, 175x enlargement from same area. Note fine grain.

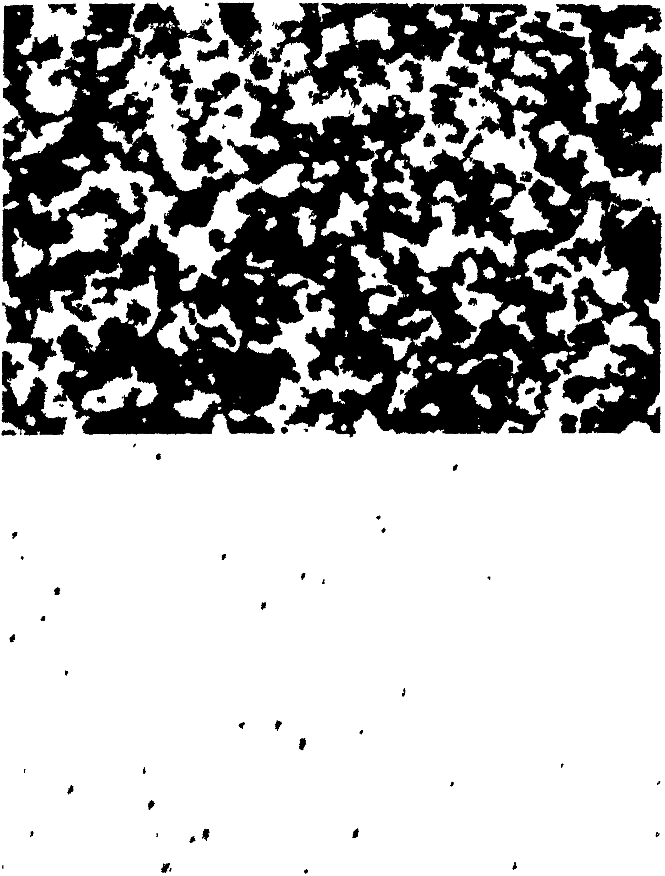


Fig. 101. Above, photomicrograph of area overdeveloped in D-76. Below, 175x blow-up of same area. Compare grain with Fig. 100.

tonal range of his prints, although they never looked flat or muddy, rarely exceeded one-half the scale between pure black and pure white.

When you are introduced to some unknown technique it would be well for you to investigate every factor in the technique very carefully if you wish to imitate it successfully. Never be guilty of asking someone what average exposure he gives when enlarging. This, by the very nature of photography, must be governed by many factors, all of which you would have to know before you could make intelligent use of the information requested. For example, you would have to know both the color and the intensity of the light used. This is governed by, but is not necessarily identical with, or even directly proportional to, the intensity and color of the lamp itself. The influential factor is the intensity and color of the light which falls upon the paper. Many enlargers have condensing lenses which are so green that the color temperature of the light at the paper is effectively higher than at the source.

You must also know the degree of enlargement, the lens aperture used, the particular type and grade of paper, and the negative density involved. Assuming all the working conditions to be identical, some amateurs prefer a negative so heavy that the exposure may run from 1 to 5 minutes, while another prefers negatives so light that exposures in the same enlarger and under the same conditions would be from 5 to 10 seconds. Yet both of these photographers, if sufficiently skilled, would turn out prints of highly satisfactory quality and conceivably would produce prints which were indistinguishable when exhibited.

The problem of negative quality—or more strictly speaking, of negative individuality—is a serious one. This is not because any one type is so much to be preferred over another, but more often because the average amateur habitually produces negatives of such an extreme variety of types that he has no opportunity to master any one of them. Consequently he fails to produce a high-quality print from any one of them.

You have undoubtedly surmised the conclusion toward which these remarks have been directed. If you wish to achieve the highest possible success in photography as considered from a purely technical point of view, experiment with the various types of negatives, limiting yourself to those which are capable of producing a satisfactory print. From these you can determine by actual printing experiment that type with which your personal technique appears to be most compatible. When you have determined which type gives you the best results, devote your attention to producing this type of negative exclusively. Of course you cannot make all your negatives alike, as the different subjects which you photograph will demand a certain variation within limits. You can, however, so establish these limits that they will not form any impediment in your work and yet will be sufficiently close to throw all your negatives into a specific type class. Then learn how to get the best possible print from this particular type of negative, and don't worry if you cannot produce a superb print from negatives with other general characteristics. The successful salon exhibitor, the successful commercial or portrait photographer, and the successful amateur are specialists. Primarily they are specialists in subject matter. Rarely, indeed, do you find one photographer who excels in still life, landscape, figure, and portraiture. It is quite logical that the choice of subject matter will in a measure influence the choice of a negative type. This interrelationship is not stringent; in fact there is no relationship involved which is absolute. But ordinarily speaking, the type of subject chosen for specialization will at least indicate a possible preference in the negative type.

More About the Emulsion.

A photographic emulsion is necessarily very unstable and is affected to a considerable degree by many agencies other than light. Pressure upon a sensitive emulsion—particularly pressure along a narrow line such as might be caused by drawing a highly polished point across the film—will result in as definite a deposit of silver as will exposure to light. There are many chemical fumes which will produce a general reduction of the silver in the form of fog. As film is usually packed either in sheets piled closely together or in strips tightly rolled up, fog of this nature is usually considerably heavier along the edges than in the center. In fact, one way in which this fog may be detected is by its high degree of uniformity along the edge and its gradual decrease in density toward the center of the film. Fog which is caused by light striking the edge of the film is usually much heavier in some spots than in others.

When the film is exposed to dampness as well as to chemical fumes, the dampness penetrates more easily by reason of the absorption of the packing paper. It must be realized that in speaking of chemical fumes we are not limited to heavy or noticeable fumes; the term must cover any constituent of the atmosphere which has a harmful effect upon the emulsion. Film stored in a room where illuminating gas is used will become fogged in a comparatively short time. Any kind of sulfur gas in the air is dangerous. Vapors including very slight amounts of mercury, oil of mustard, or chlorine will react with the film. The best way to preserve film before use is to keep it in some storage place which is relatively dry and if possible where the temperature does not at any time exceed 65° F. The warmer and damper the atmosphere surrounding the film, the shorter will be its useful life.

Under ordinary conditions the standard package which contains the film is proof against deterioration for a period of a year or more. There are certain regions, however, particularly in the tropics and subtropics, where there is a combination of high temperature and high humidity which makes it difficult to keep film in good condition for any extended period of time. In the Gulf States, where for a considerable part of the year temperatures above 90° F. and humidity greater than 85 are almost the normal condition, the standard packing has proven entirely satisfactory. I have used film two years old which has been stored under these conditions, and have found that except for a slight loss of sensitivity the films were fairly satisfactory. The increase in general fog was noticeable, but so uniform that the result was limited to a loss of contrast and the other losses incident to a heavier-than-normal fog level.

Where conditions are so extreme that film is seriously damaged in a comparatively short time, or where film has to be carried under variable conditions for a considerable period of time (such as is the case in exploring parties), a special packing commonly known as **tropical packing** can be obtained. This packing provides an outer shield of tin, lead, or similar soft metal in which the film is hermetically sealed. It must be remembered that when a film is removed from this packing the protection of the packing is completely destroyed. As a matter of fact, it is often advisable to remove the film from the packing a few hours before it is to be used. Otherwise, if the dry film is placed directly in the camera, there may be a condensation of moisture upon the dry surface. Films removed from such a package should be exposed and processed as soon as is reasonably practical.

There are certain locations in which the climatic conditions are such that the latent image will fade slightly and in time disappear completely. It has been reported that in the Congo valley film may be exposed, left untouched for a week, and then re-exposed. Immediate developing after the second exposure reveals the second image without a trace of the first. Conditions like this are extreme, but it is only reasonable to suppose that a degree of protection which is efficient under such extreme conditions would be proportionately even more efficient under less abnormal conditions. Of course there is no particular reason for obtaining tropical packing for any normal purpose within the limits of the continental United States.

There is another factor which we have not considered concerning the interval between exposure and development. E. R. Bullock has contributed some valuable information on this subject in communication No. 425 from the Kodak Research Laboratories (Volume XV, 1931-32). The fact that there is a growth of the latent image to a certain extent corresponding to an actual increase in exposure has been established beyond question. However, the fact has been made the basis of many rather bizarre statements, including one to the effect that simply permitting exposed film to remain undeveloped would be equivalent to a two- or threefold increase in exposure.

As a matter of fact, we might compare the impact of the light upon the emulsion to the fall of an acrobat into a net. The original impact carries the net down and this in turn causes an extension of springs or ropes which support the net, and so the force is felt for an appreciable interval after the original impact. Under actual laboratory test conditions it has been found that the maximum effect is observed after an interval as short as five minutes following exposure, and that after an interval of five or six hours further increase becomes almost negligible. Influencing factors are the type of emulsion used, the intensity of the exposure, and the temperature and humidity of the air.

The color of the light seems to have little or no effect, nor does prefogging or any of the other solarization effects sometimes resorted to for the purpose of influencing the subsequent exposure. The increase in density under such conditions is on the order of 5 to 7 per cent. This is great enough to be extremely interesting to the laboratory researcher; but when practical photography demands an increase in density of at least 25 per cent to make an appreciable change, the slight density gained is certainly of greater theoretical than practical interest.

Color Sensitivity.

There is another attribute of the original emulsion which has a very great effect upon the finished negative. This is the range of color sensitivity of the emulsion itself. As we have already stated, we do not have definite information regarding the specific action of color sensitization. S. E. Sheppard, in the *Journal of the Franklin Institute,* 1930, published a most interesting paper on the optical sensitizing of silver alloys by colloidal silver. The basis for the experimental work in this direction is the discovery of Becquerel, who found that a preliminary exposure of a silver chloride emulsion to blue-violet (or white) light followed by a fresh exposure of yellow or green light resulted in an image of greater density than the preliminary exposure alone would produce. Lüppo-Cramer demonstrated in 1909 that this increased sensitivity was due to optical sensitizing by colloidal silver. He combined colloidal silver in gelatin, and after careful preparation obtained an emulsion which was sensitive to ultraviolet, to the entire visible spectrum, and even into the infrared. It is interesting to note that here an effect is obtained which might logically be produced by the change in the size of the penetrating particle, and one which is in many ways similar to the effect obtained with dye.

It is hardly within our province to go deeply into the subject matter of this particular report, as it is largely concerned with more recent developments in atomic physics. But it is interesting to note that one authority attributes the sensitizing action to the presence of "a bromide ion surrounded on all sides by silver ions in the lattice. This will be strongly deformed, since the field of the silver ion is not screened by neighboring bromide ions."

Among the various theories presented, perhaps the most interesting is the one based upon the known photoelectric activity of silver and other materials. If this is indeed the case, the sensitization by colloidal silver is roughly analogous to the use of intensifying screens in radiography. In other words, the original light induces fluorescence by the particles themselves—that is, the particles of colloidal silver—and this in turn reacts with the silver halide in a manner similar to that of the shorter wavelengths of light. Whether this is a true fluorescence—a re-emanation of a radiation within the visible band—or whether, as is most likely, the disassociating effect is directly electronic is not important. The mere fact that the colloidal silver acted upon by a long wavelength such as visible red or infrared is stimulated to reradiate energy of any form which will produce the desired effect is significant in forming our conception of color sensitizing.

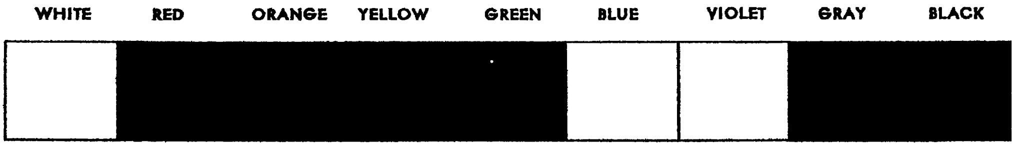
We should be perfectly willing to accept the fact that the reaction of the emulsion to specific colors is only incidentally achieved by the use of dyes which are themselves coloring agents. There is definitely a coincidence here, because the evidence shows that the color of the dye as such has little if any direct relation to the color-sensitizing of the emulsion. All the evidence points toward a rather complex ionic reaction which conceivably could be produced by a colorless material, namely, colloidal silver.

This discussion, however, leads us again into the fascinating field of conjecture where theory is not always identical with fact, and where certainly neither theory nor fact has any great influence upon the practical application of the material in question to the work of the photographer. Of course we must realize that the problems of the research laboratory and of the manufacturer of sensitive materials, while having no direct and practical bearing upon our own work, are doubly interesting to the inquiring amateur. The material which he uses today is a direct result of the research of yesterday, and the insight which a superficial acquaintance with these processes brings to the amateur gives him a certain familiarity with his sensitive materials. This, in turn, is often of value not only in interpreting the results obtained but in indicating probable procedures to be followed for the most satisfactory results.

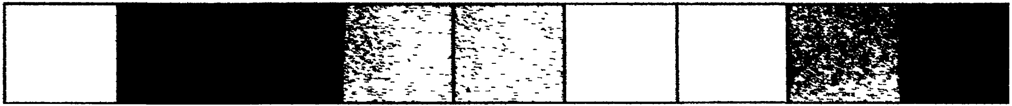
The color-sensitizing of photographic emulsions has long since passed out of the experimental stage, although research in this direction is never abandoned or even allowed to slow up. The one significant factor concerning color-sensitization is that the film manufacturers have never yet produced an emulsion with characteristics satisfactory for commercial manufacture yet which was definitely blind to the blue end of the spectrum. Almost any combination in sensitivity in the other two-thirds of the spectrum can be produced at will in a commercially satisfactory emulsion.

It must be remembered, of course, that sensitivity or lack of sensitivity is always based upon practical application. Suppose an emulsion has a sensitivity of such nature that it will be fully exposed by the red, and during that same interval of time the green will not

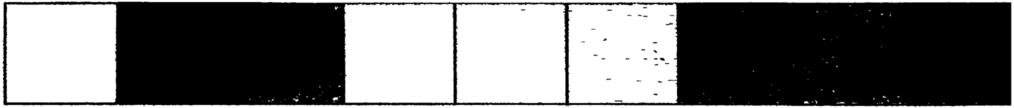
Fig. 102. How Films "See" the Different Colors.



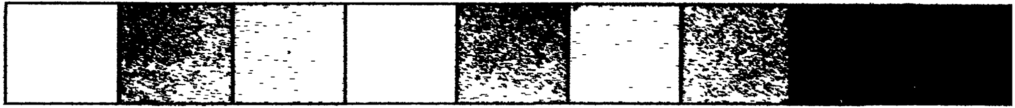
Regular or color-blind film.



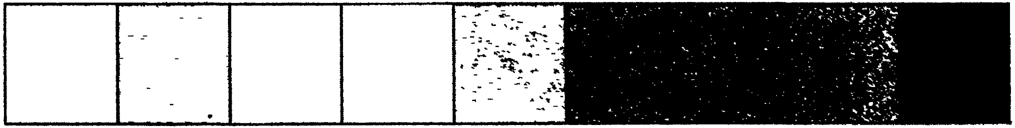
Orthochromatic film, no filter.



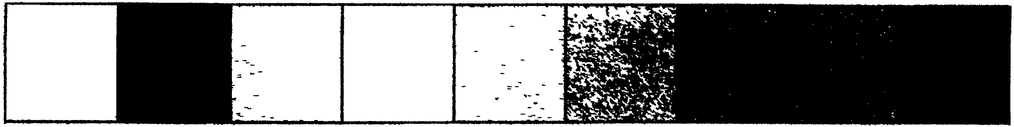
Orthochromatic film, with yellow filter.



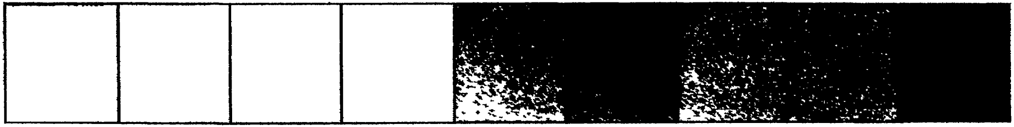
Panchromatic film, no filter.



Panchromatic film, with yellow filter.



Panchromatic film, with light green filter.



Panchromatic film, with red filter.

A color band was prepared by cutting squares from six spectral colors in addition to white, gray, and black. It was then photographed on the three types of films indicated above to show their sensitivity to the various colors. Note effect produced by the different filters.

produce an exposure sufficient to result in a developable image. That emulsion may truthfully be said to be green-blind, even though a prolonged exposure to green alone would produce a developable image. So when we speak of such a green-blind emulsion it must be remembered that "green-blind" is only a relative term, and that all other similar designations are likewise relative.

It is assumed that orthochromatic film is sensitive to blue and green but not to red. However, it is a known fact that some of our fast orthochromatic films can be used with a red-orange filter and a satisfactory negative obtained in a reasonably short time. Under the same conditions of aperture and light, the exposure necessary for the red would be sufficient to burn the image out completely if an unfiltered exposure were given. The foregoing statement, of course, takes into consideration the influence of the filter factor. Even when this is taken into consideration the stated result will be obtained.

We have already seen the extreme vagueness of the nomenclature of sensitivity. With an infinite variety of sensitivity types possible, and some dozen or more distinct types actually available, the accepted tripart film subdivision is only one step better than no classification at all. It is true that the advanced amateur has been taught to think in terms of six classifications. These are color-blind, ortho, high green ortho, and panchromatic types A, B, and C. Perhaps these six subdivisions are sufficient for practical purposes, but every darkroom worker knows that his color-blind enlarging paper is quite distinct in its color sensitivity from the "process" or "commercial" negative emulsions which are placed in the same sensitivity group. Inasmuch as no specific names have been given beyond the six mentioned, we will as a matter of convenience guide our discussion by these six definitions (see Fig. 102).

Basic Nature of the Spectrum.

At the risk of some repetition the basic nature of the spectrum should be reviewed. Visible light can easily be broken up into its constituent elements. These elements consecutively placed and visually examined are revealed as a band of color starting with pale violet, running through blue, green, orange, and ending with deep red. This arrangement of color, seen in the rainbow, is commonly called the visible spectrum. Its length is not given definitely because it cannot bc; it differs for each individual.

The spectrum can be divided arbitrarily into any number of subdivisions as it is a continuous band of color. Because of the mystic significance of the number "seven," the spectrum was considered for a long time to consist of seven colors. Scientifically as applied to three-color vision, photography, and reproduction the spectrum is divided into three approximately equal divisions. When the spectrum has been subdivided, each division can be recombined to provide a uniform mean color. The result is a blue of a somewhat soft and rich quality, a clear green, and a red which is on the order of a rich vermilion. The names given to the three bands on the basis of their composition rather than a too literal interpretation of their actual apparent color are blue-violet, green, and red-orange.

It is significant that while yellow is a color of the greatest importance in photography, it is not a part of the spectrum. There is a very narrow spectral band to which the name "yellow" has been assigned, but it is not a yellow in the sense that it would be recognized as such visually. When light reflected from an open summer sky is broken up by a spectroscope and all the spectrum obscured except this so-called yellow line, and a number of individuals are requested to identify this color, the term "yellow" is always modified. One of the most striking results of this experiment is that some people will call the color a greenish or pale lemon-yellow, while others will state that the same color is a slightly reddish or orange-yellow.

All this is interesting to us because the yellow with which we are concerned in photography is actually a mixture of red and green. That is, two-thirds of the spectrum taken together produces the yellow with which we are familiar. It is obvious, therefore, that any emulsion which is sensitive to green must also be sensitive to yellow. It is a curious fact that orthochromatic film was originally advocated as a yellow-sensitive emulsion rather than what it really was—a green-sensitive one.

Our three general types of emulsions, as we have stated previously, correspond to the three arbitrary divisions of the spectrum which have been mentioned. If the spectrum were divided into four by subdividing the red into two equal portions, we would find that type A and type C panchromatic represent, respectively, the corresponding sensitivity groups. It is not true, as so often stated, that this existing fact (three groups of sensitivity corresponding to three arbitrary subdivisions of the spectrum) proves that the tri-part subdivision is a natural one. It only proves that the ingenuity of the researcher has gradually extended the sensitivity of the film by what were really imperceptible degrees.

Types of Color-Blind Emulsions.

Among the color-blind emulsions the ones commonly used for negative making include that group which is commercially designed for positive reproduction. These are the positive motion-picture films, diapositive and transparency films and plates, and lantern-slide plates. Most of these emulsions are strictly blue-sensitive, but so limited in their reaction that they might with a little stretching of the truth be called violet-sensitive. These emulsions are most often used for the reproduction of black-and-white copy. In this sense "black-and-white" means copy without half-tones, or as it is perhaps more commonly known, "line copy." The most common form is letterpress—that is, printed pages of books, newspapers, etc. It also includes mechanical drawings, uncolored maps, plates, and similar material. This choice is dictated by the fact that these emulsions are not only color-blind—a characteristic which is of extremely slight importance—but because they are ordinarily slow, fine-grained and capable of reproducing extreme contrast.

The fallacy of believing that the color sensitivity has anything to do with the line-copy reproduction is proven, even to the unthinking photographer, by the fact that recently a new type of panchromatic material has been introduced expressly for photographing fine detail. It actually surpasses the color-blind material in making small-scale copies of large black-and-white originals. This emulsion, used on the narrow-width films (usually 35 mm) for copying books and manuscripts, is marketed under such names as Micropan, Micro-File, and Microcopy. It is made as a panchromatic emulsion so that any filter combination may be used which the color or condition of the original may dictate. This will be discussed later.

Another type of color-blind material is the ordinary "commercial" emulsion. This is used for routine commercial work such as real-estate publicity, catalogue illustrations, and so forth. It is not used as widely now as it once was because the public has become accustomed to panchromatic rendition, and the false color values obtained with color-blind material are not acceptable. Strangely enough, color-blind material is sometimes used to obtain pictorial effects through the exaggeration of haze and smoke effects incident to photography by a blue-violet light.

The conception of color sensitivity, particularly as complicated by the use of filters, remains a mystery to many amateurs. It is basically a specific application of colored light. If you could use a gigantic filter placed between your subject and the sun, or placed over your artificial lights so that the light itself is colored, the effect would to all intents and purposes be identical with that which you obtain by placing a comparatively small filter over the lens. As a matter of fact, in photomicrography it is standard practice to place a filter between the light and the object rather than between the object and the camera. The use of a color-blind film, therefore, is equivalent to illuminating your subject with a pure blue light; and by extension the same thing applies to the other conditions of specific sensitivity and the use of filters.

The average amateur, however, will ordinarily restrict his use of color-blind materials to the reproduction of line copy insofar as negative making is concerned.

Types of Orthochromatic Emulsions.

In the orthochromatic class we have two subdivisions, the normal orthochromatic which has a sensitivity to the green ordinarily somewhat less than its sensitivity to blue, and the orthochromatic in which the green sensitivity is as great as that of the blue, or even slightly higher. Naturally there are intermediate grades, so that we have almost a continuous scale of emulsion sensitivity. The ordinary or original type of orthochromatic emulsion is now regarded by many people as a sort of glorified color-blind emulsion. The most widely used form of this emulsion is the popular "chrome" type of roll film, while the definitely high-green-sensitive film is widely used in commercial and portrait photography.

For the casual amateur, for the individual whose camera is a source of souvenir photographs, for the specialist in outdoor and landscape photography, and for the portrait photographer, the orthochromatic emulsion offers many attractions. The advantage in landscape photography should be obvious inasmuch as the role of the emulsion is to reproduce an infinite number of tonal gradations, all of which may be generically labeled "green." The orthochromatic film tends to give a more brilliant negative, particularly with outdoor subjects, than does the panchromatic type. We are, of course, now speaking about the use of the film without a filter.

In portrait work the orthochromatic emulsion gives a greater degree of contrast. This, in turn, exaggerates the tonal differences of the face and produces a result which, while less faithful to the original than a panchromatic reproduction, is more attractive because of the same exaggeration of features produced by skillfully applied makeup. Without going into any debate upon the question of morality or taste involved in the use of makeup, it cannot be denied that skillfully applied makeup does give an accentuation to the features which makes the feminine face more attractive than it is without. It is well known among photographers that when working without filters it is necessary to use a heavier makeup on a model photographed with panchromatic than when an orthochromatic emulsion is used. It is suggested that the beginner whose work is largely restricted to outdoor subjects, particularly landscapes or other scenes where foliage is predominant, make orthochromatic film his routine material.

This is not in contradiction of the fact that panchromatic film is the most versatile and most valuable sensitive material we have, but because its capabilities cannot be used to advantage until the user has thoroughly mastered the proper application of filters. If you are willing to take the time to learn the truth about filters, to learn how to arrive at a choice of filters through an analysis of the subject rather than by the rule of thumb, then you should make a type B panchromatic film your routine medium.

Types of Panchromatic Emulsions.

The panchromatic emulsions are designated as types A, B, and C. Type A is typical of the earlier panchromatic emulsions in which green sensitivity is sacrificed for red. The region of least sensitivity is usually about wavelength 500 or between 500 and 520 millimicrons. The deficiency continues to about 560, which is in the region of the distinct yellow or lemon-green. The peak sensitivity is usually at about wavelength 600, which is practically the location of the so-called yellow line which is specifically denoted as the **sodium line.** It must be understood that these characteristics are not the definite characteristics of any existing, specific emulsion, but simply serve to indicate the general characteristics which all films of this type approximate.

This is a good emulsion for technical purposes, and may be obtained in very low sensitivity factors including some emulsions which are rather contrasty and extremely finegrained. This original panchromatic type is primarily an emulsion to be used with contrast filters—that is, filters which are chosen for some specific effect usually quite different from the so-called natural correction. When a high degree of green sensitivity is necessary in work of this kind it is usual to employ an ortho rather than pan emulsion.

Photo by Franklin H. Avers

Orthochromatic film offers many attractions for outdoor work. This fine picture was made on one of the "chrome" type films.

For the time being we will pass over type B to consider type C. Type C panchromatic is made for one specific purpose, and that purpose is making photographs at high speed by artificial illumination. Because of the inherent low intensity of blue in any incandescent light, films of type C show a red reaction as much as ten times as great in the deep red as in the blue. By daylight the conditions are almost reversed, although not to quite the same degree. There are certain extreme speed films (such as Tri-X and Superpan Press) which have emulsions of this type. It is interesting to note that the equivalent tungsten speed is usually about four-fifths of the daylight speed, whereas the type B is more often in the neighborhood of five-eighths to three-quarters. Therefore type C is fundamentally a film to be used with artificial light when short exposures are necessary.

Type B is the nearest practical approach to the ideal sensitivity range. The sensitivity of this type of emulsion, which is represented to a greater or lesser degree by most popular modern panchromatic emulsions, approaches the average visual sensitivity about as closely as we can expect. The exact visual correction cannot be reproduced because the visual curve is not a fixed characteristic. Through mental compensation we have learned to transpose the curve from daylight to artificial light conditions with very little apparent change.

The type B panchromatic emulsion shows its maximum sensitivity in the blue range under daylight conditions and in the red range under artificial light conditions, while the eye maintains its maximum sensitivity in the yellow-green region under both types of light. It is interesting to note, however, that most of these type B emulsions have an almost uniform response to the average green under both light conditions. Incidentally, this green sensitivity is almost as great as in an ordinary type of orthochromatic film, thus overcoming the gravest objection to the use of a panchromatic emulsion.

This type of emulsion, which has quite properly been called the **orthopanchromatic** type, is the nearest approach we have to a genuinely universal emulsion. It can be obtained in a sufficient variety of speeds and grain structures to meet most demands, and through the use of color filters it can be made to yield a truly astonishing variety of tonal balances and degrees of contrast.

The statement has often been made that a panchromatic emulsion is the only emulsion needed by any photographer because it can be made to reproduce the effect of any conventional emulsion. This statement is absolutely true, but as stated it is highly deceptive. No single panchromatic emulsion will do this because certain types of work require a different inherent contrast than others. If the photographer is permitted every kind of panchromatic emulsion, he can imitate with satisfactory accuracy the results obtained from an ortho or a color-blind emulsion. However, if he is going to have such a selection of emulsions available, there is no logical reason why the orthochromatic should not be added.

To leave the realm of theory and return to the practical aspects of applied color sensitivity, it is suggested that the more serious amateur make panchromatic his basic emulsion. In pursuance of this idea it is further suggested that experimental work be done with filters to provide a competent knowledge of their application. If for any reason this cannot be done, it is best to make an orthochromatic emulsion the basic one.

The choice of panchromatic type will depend upon the individual conditions, although ordinarily a type B film will be used. If picture taking is to be done largely by artificial light or under other poor light conditions, one of the extremely fast films, which are usually type C, should be used.

For cameras using 2¼ inch rollfilm and smaller, a finegrain emulsion should be chosen, but for sizes larger than this there is no particular need for it. For the best all-around results, therefore, a type B panchromatic film of moderate speed and fine grain will serve practically every purpose.

IX

SENSITOMETRY

IX.

Sensitometry

SENSITOMETRY is a study of the mathematical relationship which exists between exposure and the density of the developed image. It can be, and is, applied to the study of both negative and positive images on transparent and opaque materials.

The entire process of photography depends upon obtaining a physical image as the result of exposure. The image can be silver, as in the ordinary photograph; but it can also be produced by a differential hardening of the gelatin. In the latter case, plain gelatin will provide a matrix for dye printing. Gelatin impregnated with pigment will produce a visible image (dependent upon the density of the pigment layer), as in carbon and carbro processes. An image can be produced as the result of a differentiation in the water content of an emulsion; this is the basis of the oil and bromoil processes.

The exposure, too, may vary widely both in degree and in kind. The **degree** of exposure depends upon the quality of the radiation used. Thus, the radiation used for the exposure may be X-ray, ultraviolet, visible light, or infrared. The variation in **kind** may be explained by the following comparison: Exposure used with ordinary photography is an exposure to radiation (light), while in processes such as carbro the exposure is a chemical one in which light or other radiation plays no part.

Yet, no matter what the exposure, no matter what the character of the resulting image, some variation of sensitometry may be applied to its study. The significant point to be remembered is that the sensitometric procedure used should, insofar as may be practical, duplicate that used in the routine processes which the sensitometric study shall control. For example, sensitometric study of exposure to ultraviolet would provide little information of value regarding exposure to visible light.

Sensitometry is as nearly subjective as any physical process can be. The original object photographed is intangible, being simply reflected light. The images are two-dimensional with no definite characteristics other than density. Here we do not deal with images of rocks, trees, houses, and human beings; here we have no simulation of solidity and three dimensions. Therefore, it will be necessary for us to reshape our present conception of some familiar photographic factors.

It might be argued that if sensitometry is so far removed from practical photography its value is questionable. That assumption is both right and wrong. It is right because there are hundreds of competent photographers (in the sense of being successful in making pictures with a camera) who know nothing beyond the bare essentials of photometry. It is wrong in that all modern research into photographic practice—research in the field of emulsions, in the field of exposure, in short, most photographic research—is based upon sensitometry. Moreover, those branches of photography which are more scientific than aesthetic—such as sound recording for motion pictures, the practice of color photography, the photographic photometry of astronomy—can hardly be carried on successfully without the aid of sensitometry.

Some Definitions.

In order to understand more fully the factors involved in the study, let's first give our attention to a few definitions. These will cover the processes, factors, and instruments which are to be discussed in this chapter.

Exposure. The exposure is of the utmost importance in sensitometry. In gauging exposure we must know the intensity of the light, the time during which it is permitted to act, and its spectral characteristics. We can gauge intensity with a reliable foot-candle meter; the time of exposure is under mechanical control; the spectral characteristics or "color value" of the light may be assumed to be constant for any reliable, standardized light source. The light should have the characteristics of normal daylight, average normal incandescent light, or some region between the two. This, of course, is not true when the sensitometric investigation concerns the action of light of some specific color. The same thing holds true if the investigation concerns any of the photographically active "invisible radiations." Therefore, in this as in other factors, general statements must be recognized as being subject to exception, and the general statement recognized as applicable only to the typical case.

The duration of the exposure must be considered in two parts. First we have the exposure of a given time duration. This means that the exposure is started, allowed to continue and when the time period has elapsed, the exposure is stopped. The second case is when the exposure has a value equivalent to a given time duration. In this case the unit of exposure may be very brief, and this brief exposure repeated many times until the sum of the short exposures equals the stated total period. It is a recognized fact that a **continuous exposure** and a similar **intermittent exposure** will produce different results even though their total lumen-second factor is identical.

Exposure also varies with the type of control used. The intensity of the exposing light may be maintained at a uniform level, and variations in exposure obtained by variation in the **time** of exposure. This is the **time-base exposure** which is ordinarily used in the more exacting type of research; control sensitometry in commercial application usually is based upon exposure controlled by means of intensity differences. In practical application the first method is similar to the use of the shutter to control the time of exposure, an operation familiar to every amateur. The other is just as familiar because it employs a series of screens which resemble somewhat an ordinary negative. Thus, printing through a screen which has a number of areas of different density will produce a shaded print just as a negative produces a print made up of various tones.

Sensitometer. Exposure usually is not made in a camera, but in an instrument or device known as a sensitometer. This is often a long box, not unlike a camera, with a holder for film or plate at one end. In front of the box a disk containing cutout sectors revolves to make the exposures in a series of circular, concentric stripes or segments of such stripes. A variation is a flat panel in front of which a sliding panel, also containing cutout stripes, is slowly raised or lowered. Still another variation

Fig. 103. Home-made sensitometer. Left, ready for operation; A indicates film sheath. Right, with bottom removed to show disk.

is a cutout cylinder with the light near its center and the film exposed in a corresponding curved position. All these variations of time-base sensitometers have their corresponding types in which the cutout mask is motionless and the plate or film is moved past these openings. It will be seen that any uniform system of exposure must follow one or the other basic patterns of straight motion in a plane, revolving motion in a plane, or rotating motion in a cylindrical path.

The intensity type sensitometer also has three variations, although two of them are rarely used. In the first the exposures are all uniform in time, but the intensity of the light is altered between exposures. This necessitates making the exposures successively instead of simultaneously, which is a disadvantage. The light may be dimmed by moving it farther from the film and utilizing the inverse square law of intensity; or it may be dimmed by a rheostat in the circuit. The rheostat control is impractical because with each change of intensity there is also a change of color, so that the net result is one of intensity plus color instead of change in intensity alone.

An intermediate type is one in which successive exposures are made to the same light, but a difference is produced by the introduction of neutral density screens between the light and the sensitive material. This is hardly a practical instrument.

The third type is one in which the various neutral density screens are all combined into one artificial "negative." That is, a sheet of transparent material such as glass or celluloid bears a series of increasing densities. This type of sensitometer is commonly used by amateurs; it is placed between the picture negative and printing paper to indicate the best exposure for printing. Development will reveal a series of tones which are not unlike those obtained with the time-base sensitometer (see Figs. 103, 108, 109).

The time-base sensitometer, so constructed that the slotted disk turns once to make the exposure, is the best type for experimental use. It is not difficult to construct. Using an electric clock motor, such a device an be made at home, and will be quite accurate enough even for advanced work. Using black cardboard, several disks can be made to give a series of exposures based upon any system of progression desired. For example, one disk can have sectors advancing in geometric progression—that is, 1, 2, 4, 8, 16, etc.; another can produce advances on the basis of the square root of two; another can be divided into five-second intervals; and so forth. The density type of sensitometer is not as accurate, and it is almost impossible for the amateur to make one which will be at all satisfactory. Remember that **sensitometry cannot be practiced unless the exact value of each exposure step is definitely known!**

No, you can't make sentitometric measurements on your pictorial and portrait negatives. You can measure the densities of these negatives, but you can't use this information in sensitometric work unless you also know the value of the exposure which resulted in these densities.

Development. There has been a great deal of discussion concerning standard developers for sensitometry. This is a problem which needs only the application of common sense for its solution. The developer to be used is the developer you normally use! There are standard developers for sensitometry, but these are used when the sensitometric control is exerted over the manufacture of emulsions. Here again we have a division of interest. Sensitometry will show what happens in making the negative. We know quite well that the negative image is a product of exposure plus emulsion plus developer. The alteration of any one will seriously affect the other two.

As we use a differential exposure as a measuring stick it is obvious that we have two possible combinations:

1. Standard emulsion and unknown developer, the developer being the factor under investigation.
2. Standard developer and unknown emulsion, the emulsion being the factor under investigation.

As few of us are concerned with experimental emulsions, we may disregard the standard developer. On the other hand, as we have a most fertile field open in the investigation of both exposure and development, we do need a standard emulsion. This would offer a serious problem if we were engaged in exacting research. But for our purposes, for the control of practical photographic processes, we may assume that any film from a reputable maker is a "standard" emulsion, providing that films for both the test and the practical application be taken from the same original package or from packages bearing the same emulsion number. Sensitometric control using films of different emulsion batches can, and often does, do more harm than good.

Developer Control. Carefully prepared sensitometric control indicates the time and temperature of development which will give the result desired from an exposure, and also the concentration of the developer to be used. As a secondary factor, relatively unimportant, it will indicate the printing exposure which will give the most faithful reproduction of the original tones.

We often hear or read the expression "develop to a gamma of 0.7," or something like that. We know that contrast does increase with development, so with a control it is of course entirely practical to continue development to some exact degree wanted and to stop there. That is the essence of sensitometric control in the photographic workshop. A practical application is that of keeping the three separation negatives of a color set within the contrast limits necessary for good reproduction. Nor is this process limited to negative making. A good densitometer is arranged for reading print densities as well as negative densities.

Densitometer. The densitometer is an instrument used to measure the density of the developed image. It may have any of several different forms, many of them based upon entirely different principles. Some of them are visual, some electric; some are comparison instruments, some are inverse-square-law instruments, some make use of polarized light for dimming, and some are straight photometers. The inverse-square type is the simplest instrument for home construction.

Photometers are instruments used to measure light. In the broader sense all exposure meters are photometers. However, there is one instrument which, to use its full name, is known as the Pulfrich Gradation Photometer. This instrument resembles a comparison microscope having two tubes and lenses, but with a single eyepiece. The field seen is divided by a hairline, and one half of the field comes from each objective lens. If a constant light (which need have no standard value) is used to illuminate both lenses and a negative is placed before one lens, the corresponding half field will be darkened. When this occurs, the diaphragm of the other tube is slowly closed until the field is again uniform. The reading of the control wheel now indicates the relative transmission of the negative as compared with open light. Reference to a graph gives the density which corresponds to this percentage of transmission. If the instrument mirror be replaced by a special holder and a print placed on one side with a standard white reflector on the other, the same comparison of **reflected** intensity is obtained.

Although the gradation photometer is an instrument of wide laboratory value, it has some shortcomings as a densitometer. These are primarily in the translation of the readings and in the comparatively small size of stages for both negative and positive types. However, density calibration may be obtained on special order. One advantage is that by the use of an auxiliary ocular the negative image may be seen and any desired area selected. Then upon return to the usual optical system the diffuse field reading is observed. Any desired area may be selected by the use of auxiliary stage stops.

This instrument is in one sense the prototype of the densitometer, and represents the basic principle of density measurement. It is a far more elaborate and costly instrument than the densitometer, and as its additional uses will probably not appeal to the photographer we shall discuss those instruments made for the specific purpose of measuring photographic density. However, before doing this we must leave the discussion long enough to consider the factors involved in density measurements.

Transmission. This is the factor which represents the amount of light that passes through a more or less transparent substance. It is given a numerical value corresponding to percentage. Thus if 90% of the light passes through the substance, the transmission value is 90; if only one per cent passes, the value is 1; if only 1/1000 (1/10 of 1%) of the light gets through the film, the transmission is 0.1; and so forth.

This practice has not been standardized. Many workers hold the opinion that the transmission factor should be represented by the normal decimal value, a contention which is certainly sound. This means that the 90% factor would be 0.90, the one per cent as 0.01, and the 1/1000 would be 0.001. Because this is a logical procedure, it is the one we shall use in this discussion. Another reason for using the decimal values is that this is the only system which will give the correct opacity values by a normal computation.

Opacity. Opacity is the opposite of transmission. When light falls upon a partially transparent substance the amount which passes through represents the transmission, and the part which does not pass through represents the opacity. Both together must equal the whole, and if opacity were valued in percentage, it would always equal 100 minus the transmission. However, instead of negative percentages, we give to opacity a value which is **the reciprocal of the transmission value.**

As the reciprocal of a number is **that sum by which the number must be multiplied to equal one**, and as the transmission is always less than one itself, it follows that the opacity must always be **greater than one.** (In the first mentioned system, the reciprocal is taken as that sum by which the number must be multiplied to equal 100, thus involving an indirect computation.) Using our previous transmission values of 0.90, 0.01, and 0.001, the opacity values corresponding would be expressed as 1.1111+, 100, and 1000 respectively.

Density. Transparency is a quality which results from the negative deposit which **is not there,** so it is a **negative** quantity. Opacity is a measure of the effect of the negative deposit which **is there,** so it is a **positive** factor, more desirable to work with than the transparency. However, we do not use the opacity value in photography. Instead we make use of another factor, **density.** Density is the **logarithm of the opacity.** This has the advantage of advancing at a rate of progression more nearly approaching the rate of building of the photographic image.

Before leaving the discussion of these three factors, there is one conception of opacity which is interesting. Opacity may be said to be a direct measure of the number of units of light which must fall upon a given surface in order that one unit may pass through. While the three-factors are distinctly different in their

SENSITOMETRIC FACTORS

Density	Trans-mission	Opacity	Density	Trans-mission	Opacity	Density	Trans-mission	Opacity
.02	.955	1.05	1.02	.096	10.5	2.02	.0096	105
.04	.912	1.10	1.04	.091	11.0	2.04	.0091	110
.06	.871	1.15	1.06	.087	11.5	2.06	.0087	115
.08	.832	1.20	1.08	.083	12.0	2.08	.0083	120
.10	.794	1.25	1.10	.079	12.5	2.10	.0079	125
.12	.759	1.31	1.12	.076	13.1	2.12	.0076	131
.14	.725	1.38	1.14	.072	13.8	2.14	.0072	138
.16	.692	1.45	1.16	.069	14.5	2.16	.0069	145
.18	.661	1.51	1.18	.066	15.1	2.18	.0066	151
.20	.631	1.58	1.20	.063	15.8	2.20	.0063	158
.22	.602	1.66	1.22	.060	16.6	2.22	.0060	166
.24	.575	1.74	1.24	.058	17.4	2.24	.0058	174
.26	.549	1.82	1.26	.055	18.2	2.26	.0055	182
.28	.525	1.91	1.28	.053	19.1	2.28	.0053	191
.30	.501	2.00	1.30	.050	20.0	2.30	.0050	200
.32	.478	2.09	1.32	.048	20.9	2.32	.0048	209
.34	.457	2.18	1.34	.046	21.8	2.34	.0046	218
.36	.436	2.29	1.36	.044	22.9	2.36	.0044	229
.38	.417	2.40	1.38	.042	24.0	2.38	.0042	240
.40	.398	2.51	1.40	.040	25.1	2.40	.0040	251
.42	.380	2.63	1.42	.038	26.3	2.42	.0038	263
.44	.363	2.75	1.44	.036	27.5	2.44	.0036	275
.46	.347	2.88	1.46	.035	28.8	2.46	.0035	288
.48	.331	3.02	1.48	.033	30.2	2.48	.0033	302
.50	.316	3.16	1.50	.032	31.6	2.50	.0032	316
.52	.302	3.31	1.52	.0302	33.1	2.52	.0030	331

.54	.288	3.47	1.54	.0288	34.7	2.54	.0029	347
.56	.275	3.63	1.56	.0275	36.3	2.56	.0028	363
.58	.263	3.80	1.58	.0263	38.0	2.58	.0026	380
.60	.251	3.98	1.60	.0251	39.8	2.60	.0025	398
.62	.240	4.17	1.62	.0240	41.7	2.62	.0024	417
.64	.229	4.37	1.64	.0229	43.7	2.64	.0023	437
.66	.219	4.57	1.66	.0219	45.7	2.66	.0022	457
.68	.209	4.79	1.68	.0209	47.9	2.68	.0021	479
.70	.200	5.01	1.70	.0200	50.1	2.70	.0020	501
.72	.191	5.25	1.72	.0191	52.5	2.72	.0019	525
.74	.182	5.50	1.74	.0182	55.0	2.74	.0018	550
.76	.174	5.76	1.76	.0174	57.6	2.76	.0017	576
.78	.166	6.03	1.78	.0166	60.3	2.78	.0017	603
.80	.158	6.31	1.80	.0158	63.1	2.80	.0016	631
.82	.151	6.61	1.82	.0151	66.1	2.82	.0015	661
.84	.144	6.92	1.84	.0144	69.2	2.84	.0014	692
.86	.138	7.25	1.86	.0138	72.5	2.86	.0014	725
.88	.132	7.59	1.88	.0132	75.9	2.88	.0013	759
.90	.126	7.94	1.90	.0126	79.4	2.90	0013	794
.92	.120	8.32	1.92	.0120	83.2	2.92	0012	832
.94	.115	8.71	1.94	.0115	87.1	2.94	.0012	871
.96	.110	9.12	1.96	.0110	91.2	2.96	.0011	912
.98	.105	9.55	1.98	.0105	95.5	2.98	.0010	955
1.00	.100	10.00	2.00	.0100	100.0	3.00	0.010	1000

Fig. 104. Table showing relationship of sensitometric factors. Transmission is the percentage of incident light passing through the film, expressed in decimals to permit extending values beyond two places. Opacity is the reciprocal of the transmission, and density is the logarithm (to the base 10) of the opacity.

real characteristics, it will be seen that there is a definite value for any two of these factors which must always correspond to a definite value for the third. Thus, transmission 0.144 and opacity 6.92 must always correspond to each other, and both must correspond to density 0.84. A list of such related values is given in Fig. 104 on the preceding pages.

The Densitometer.

From the foregoing it is obvious that the densitometer may be calibrated in any one of the three factors and still be a thoroughly practical instrument. Moreover, it is equally obvious that an instrument scale can be changed from one set of factors to another without altering any part of the instrument other than the scales themselves. However, it is common practice for all photographic instruments to be calibrated directly in terms of density.

Most of the densitometers in use are of the visual type. A divided field is observed and brought to a condition where the two parts of the field are made equally bright, the position of balance being determined by visual examination of the divided field. This type is subdivided into several models, depending upon the mechanism used to dim the open light to make it conform to the negative transmission.

There are many types of electric densitometers, the principal difference being that some make use of true photoelectric cells while others utilize the self-generating barrier layer cell ordinarily used in exposure meters. The true photoelectric cell must have a current applied to it from a battery or electric outlet. The amount of electricity which flows through the cell depends on the amount of light which falls upon it. This type of cell is extremely sensitive to minute changes in light intensity, and so is adapted to making density measurements with a low-power light which cannot injure the negative. However, it requires an auxiliary circuit, and also requires some skill on the part of the operator to obtain accurate results.

Densitometers using the barrier layer cell, which actually generates electricity when light falls upon it, are now being developed. Originally this type of cell was too low in sensitivity for accurate response. Certainly those devices which are made for use with exposure meters as the sensitive element are not satisfactory for the most accurate work. One manufacturer is said to be making such an instrument of the highest accuracy which, in a perfected form, will be ideal for general use. It will avoid the natural human error—all eyes grow tired and some people can never learn to match fields accurately. At the same time it will not have the delicacy and instability of the photoelectric valve cell.

It might be thought that extreme delicacy is desirable, but those who have had experience with a radio set which howls every time a control is touched know this is not always true. The photoelectric valve cell instrument is often so delicate that stimuli which have nothing to do with the exciting light will change the reading. Moreover, the operator must know its vagaries and how to set it to zero point and how to keep it in adjustment; otherwise the readings will wander all over the map. The photronic instrument, with its familiar stability and constant reading, would indeed be a boon to advanced amateur photographers.

The visual densitometer is a photometer adapted for photographic density measurements. We have already described the laboratory photometer as the basic type. Now we shall give our attention to other visual instruments.

As the earliest photometers were of the inverse square type, so was this type of construction evolved early in the development of the densitometer. The

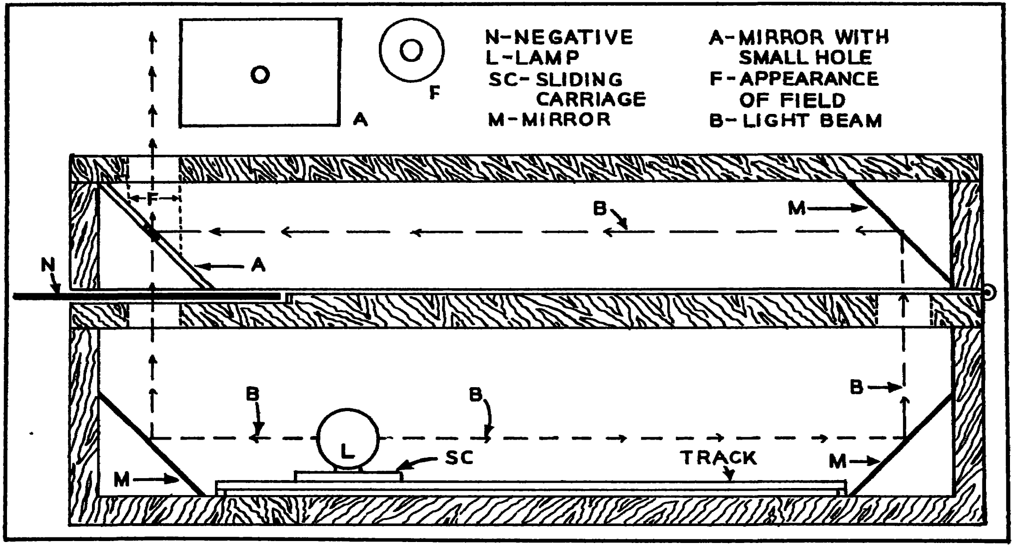


Fig. 105. Box type densitometer. Light travels in both directions; right beam circles box, strikes mirror A; left beam passes up through negative and the small aperture in A. F shows appearance of field in which central spot is lighter or darker than surrounding ring; when balanced, both areas are identical.

inverse square law states that the intensity of light changes in inverse proportion to the square of the distance of the light source. Thus if a light at one inch has an intensity of 100 candles, at 10 inches it has an intensity of only one candle. As it is possible to work to dimensions such as these, it will be seen that a full-range densitometer with calibration from 0.00 to 3.0 would require an intensity change of 1 to 1000. ' The square root of 1000 is only 31.62+, and a design which allows the nearest position of the light to be 1/32 of its farthest will permit density readings up to 3.0. However, this type of densitometer is usually the "box" type in which mirrors are arranged to reflect the light so that it goes around the "box" and finally emerges. The light moves between the two base mirrors, above one of which the negative is placed. It is evident that if the light is so arranged that the field is balanced when the light is most distant from the negative mirror, any movement of the light toward that mirror will **increase** the intensity of the light upon the negative according to the inverse square law, and that the intensity of the other part of the field will be **diminished** (see Fig. 105).

For example, suppose the "box" is laid out in a straight line and the light is placed midway between two measuring instruments.' We shall assume that the light is 10 inches away from each meter, and that each meter registers one unit of light—that is, $A = 1$ and $B = 1$. Now if we move the light to a position five inches from A, we shall have the condition $A = 4$, and $B = 0.44$, or a ratio of approximately 9:1. Now if the light is moved to within 1 inch of A, we have $A = 100$ and $B = .25$ (approximately), or a ratio of 400:1. This would include a range of somewhat more than density 0 to 2.6, so that if the "box" has 10-inch sides a perfectly practical instrument can be made. It must be remembered that the short end arms of the box are also included in the measurement.

The next type of densitometer also makes use of the reflection box—that is, the four-directional travel of the light beam—but the light does not move except to balance the field to the zero point. A prepared gray wedge moves through the open field beam and thus serves to bring the intensity down to that of the negative area. The Eastman densitometer (Fig. 106), a standard laboratory instrument, is of this type, the wedge being circular in shape and bearing a circular scale of densities both for reflection and transmission.

A similar densitometer is made in England, perhaps the only thoroughly satisfactory instrument ever to be sold at a low price. This instrument is simply a box containing two small mirrors, and with two holes cut in the top. A slot at one end takes a linear gray scale, and within its limitations of density it has proven a thoroughly efficient and reliable instrument. It was originally marketed at about ten dollars, but is probably not available now (see Fig. 116).

Another type of visual instrument uses a polarization photometer as the eyepiece of the "box." In this case the light from the negative passes unimpeded to the eye, while the open light is dimmed by rotation of a polarizer. As this instrument alone sells for more than the usual densitometer, it was never popular except in large commercial laboratories. The polarizing elements used in these instruments are the conventional, costly prisms chosen for their perfect optical quality and high light transmission.

The Eastman densitometer using the circular wedge has a disk almost 9 inches in diameter and bearing density calibration in almost uniform divisions, while the polarization disk is usually 3 inches or less in diameter, with the full range limited to a quarter rotation and with the effective dimming of the field

Fig. 106. The Eastman transmission and reflection densitometer;

limited to about 30 degrees of arc or less. This is due to the non-uniform extinction of the polarizer. For this reason the wedge type instrument has proven more popular.

Accessories. In order to work out problems in sensitometry the student should supply himself with a table of logarithms (obtainable at any bookstore which handles high school and college textbooks), some sheets of graph paper (either regular or semi-log divisions), a drawing board, triangle, straight edge, metric scale, protractor, and pencils. It is true that sensitometry can be handled purely as a mathematical problem, but it has been found that more usable information is obtained if the characteristic curve is drawn and the desired information derived from that. Moreover, it has also been found that while the mathematical computation of gamma gets many students hopelessly mired, the graphic method can be used with just as much accuracy, much greater ease, and far more rapidity. The student whose mathematics is limited to arithmetic can, if he has log tables, do all of the necessary computation of sensitometry by the graphic method and arrive at conclusions just as accurate as those of the mathematical wizard. For that reason we shall stress the graphic method of computation.

The Characteristic Curve.

The result of a sensitometric analysis is computed as a curve, referred to as the characteristic curve, or often as the **H&D curve** after its originators, Ferdinand Hurter and Charles Driffield. You will remember from school days that a "curve" in graphic work may be a straight line, but it happens that the photographic curve takes on the shape of a more or less flattened letter "S" (see Figs. 10 to 12, Ch. II). The paper used is divided into spaces by lines running both vertically and horizontally. The horizontal lines indicate the values of the **abscissas,** while vertical lines indicate the values of the **ordinates.** Usually the abscissas are given density values and the ordinates are given exposure values.

If the paper is divided into regular squares, the ascending values along the left-hand vertical edge are the density values. Remember that density is a logarithmic value. The lower, horizontal edge may be evenly divided, or the divisions may be crowded together at the left. If the former is the case, the exposures are listed along the bottom in regular logarithmic sequence. In the latter case the paper is divided into uneven spaces of logarithmic value, so that entering the normal exposure values in sequence will automatically space them on a logarithmic base. It is always simpler to use the table of logs and convert the exposure values to logarithms, and then use ordinary cross-section paper. In fact such paper may be made by drawing horizontal and vertical lines at regular intervals, say ¼, ½, or 1 inch apart. Suppose our exposures were 1, 2, 4, 8, 16, 32, and 64 seconds. If we refer to the log tables we shall find the following values:

Number	Logarithm
1	0.000
2	0.301
4	0.602
8	0.903
16	1.204
32	1.505
64	1.806

Now suppose that your divisions are spaced one inch apart. If you used the natural system of measurement, and if your last exposure resulted in a density of 3.0, your graph paper would be 3 inches high and 64 inches long. By using logs, the same graph can be made on a sheet measuring 1.8 x 3 inches or any multiple thereof. In the first case the curve would rise too gradually to show anything, while in the second the curve is sufficiently abrupt to reveal the characteristics of the negative. Thus the reason for using log exposures.

As a rule, the space occupied by exposure 1 on the horizontal scale is made equal to density 1 on the vertical scale, but this is not at all necessary. It is only important that you establish a definite system for yourself and then stick to that system so that the curves will all bear a definite relationship to each other. If you vary the values of your abscissas and ordinates you will end with confusion much worse than no result at all.

If you expose the sensitive material with a disk sensitometer, the disk can be cut from a piece of cardboard according to the following instructions (see Fig. 107). Read this and the next paragraph carefully before starting to work. First cut a 10-inch disk from the cardboard. Then, starting with a center circle 4 inches in diameter, draw 10 additional concentric circles at ¼-inch intervals. This makes a band 2½ inches wide and composed of 10 circular stripes, and leaves an outside supporting band of ½ inch. Now draw 6 radii spaced 60 degrees apart, just as you would cut a pie into 6 equal pieces, and construct "spokes" along these radii making each 10 degrees wide. These spokes use up 60 degrees of your disk. Using the protractor, mark a radial slit ½ degree wide on the first or outer ¼-inch circular stripe and adjacent to one of the spokes. The outer band is used for the ½-degree slit because it is the smallest used, and will be considerably wider on the outer circle than it would be on the small inner circle. Cut out the slit, and extend the cut next to the spoke toward the center of the disk until it crosses all ten of the circular ¼-inch bands or

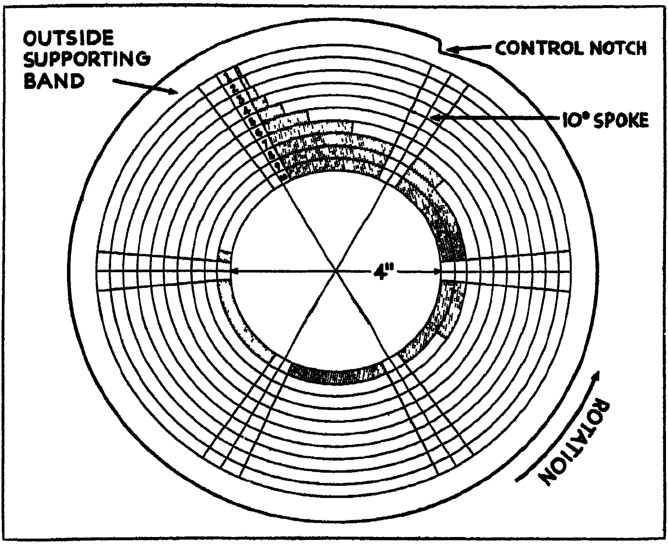


Fig. 107. Exposure disk for sensitometer. Arrangement of sectors is preferable to that shown in Fig. 103; the ½° slit will be wider on outer band and therefore easier to cut accurately. Control notch can be cut where desired (see Figs. 108 and 109).

stripes. Now in the second ¼-inch circle (second from the outside) mark off one full degree, then continue marking off sectors from the same starting point (the cut along the edge of the spoke) according to the following table:

Circle	1	2	3	4	5	6	7	8	9	10
Degrees	½	1	2	4	8	16	32	64	128	256

Since the first or ½-degree slit will represent an arbitrary exposure value of "one," each of the following slits has a value equal to just twice the number

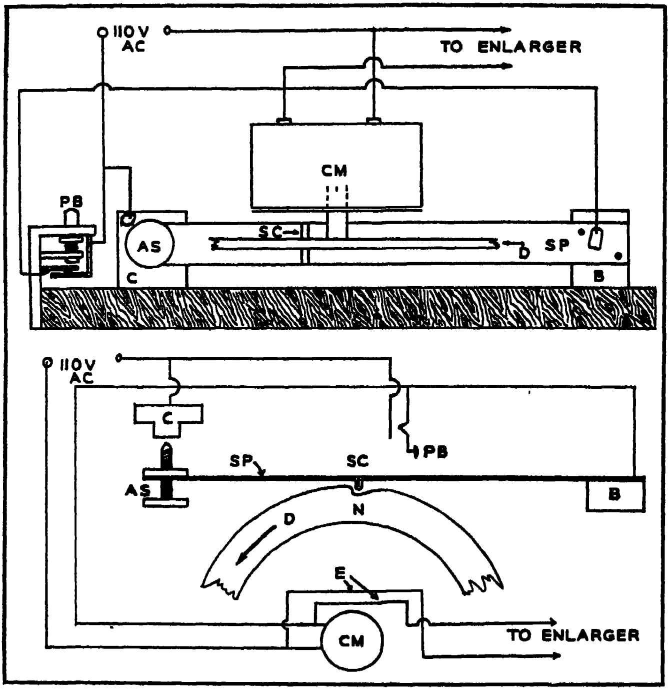


Fig. 108. Wiring diagram of disk sensitometer shown in Figs. 103 and 109. The device is designed to operate on 110-v. 60-cycle AC current. Self-starting clock motor CM is actuated by pushbutton PB; as disk D turns, the contact ridge SC on timing spring SP leaves timing notch N, closing contact between adjusting screw AS and the contact block C. This keeps disk turning after the button is released. B is an insulating block, and EE are leads to the enlarger which is used simply as a light source. After disk makes one complete revolution, SC drops into N, breaking the contact. This stops the motor and turns off the enlarger.

of degrees. Therefore exposure values for the disk range from 1 to 512.

As the length of the slits increases they will include the "spokes," which are not to be cut out. So for each spoke included you must add ten degrees to the total length of the slit. Thus, when the sectors are cut out, the cutout portion of any band represents the total number of degrees called for, and the finished disk will correspond to Fig. 107. If this disk is now laid over a sheet of sensitive film or paper and rotated it will in a single revolution give 10 exposures ranging from 1 to 512, or a log range of 0.00 to 2.70. It must be remembered that these are only relative exposures. In practice the light intensity is so low that exposure 1 is barely sufficient to make a perceptible deposit upon the film. Thus emulsions as slow as contact paper or as fast as the most ultra-rapid modern film can be exposed correctly for later study.

While it is out of place here to give details for the construction of instruments, Figs. 108 and 109 show a fairly simple disk sensitometer which was put together in a few hours and functions quite satisfactorily. Assuming that the sensitometer disk is driven by a clock motor and makes one revolution in one minute, this is equivalent to 360 degrees in 60 seconds or 6 degrees per second. As the unit slot is ½ degree wide, the film beneath it receives an exposure of 1/12 second per revolution. The other exposures are:

Circle	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Exposure	**1/12**	**1/6**	**1/3**	**2/3**	**1.33**	**2.66**	**5.32**	**10.6**	**21.2**	**42.4**

Expose a piece of film with the light at any desired distance. For films use a 10-watt bulb or less at 3 or more feet. If the innermost circle is as black as the outermost, you have at least 512 times too much exposure. Interpose a sheet or two of paper to dim it and try again.

Assume that this time circles 5 to 10 are solid black, but there is some differentiation among the others. This indicates that circle 5 received the maximum exposure, so the light must once more be reduced, this time to 1/16 its previous value. However, assume that the first test shows nothing in circles 1 to 4, but that 5 shows a slight tint. Then that is the exposure for circle 1, and the light must be increased 16 times. Once you become familiar with the instrument you will find it possible to judge the light closely enough so that a single test will give you the information necessary to make a good exposure.

The film is developed in your standard working developer and when dry, the density of each stripe is read on the densitometer. It is better to buy your densitometer than to try to make it, because it is almost impossible to calibrate the instrument without a reference wedge. As the wedge is the most costly part of a densitometer, it actually would be cheaper to buy a commercial densitometer of the non-wedge type than to buy a conventional calibrated wedge. The densities of the various stripes are read, and each reading is entered on the graph paper. This is simple for those who have done graph work, but if you haven't, a word of explanation will be given. Suppose we have made our readings and that they are as follows:

Circle	Exposure	Log Exposure	Density
1	1	0.00	0.1
2	2	0.30	0.12
3	4	0.60	0.24
4	8	0.90	0.50
5	16	1.20	0.80
6	32	1.50	1.12
7	64	1.80	1.45
8	128	2.10	1.77
9	256	2.40	2.00
10	512	2.70	2.10

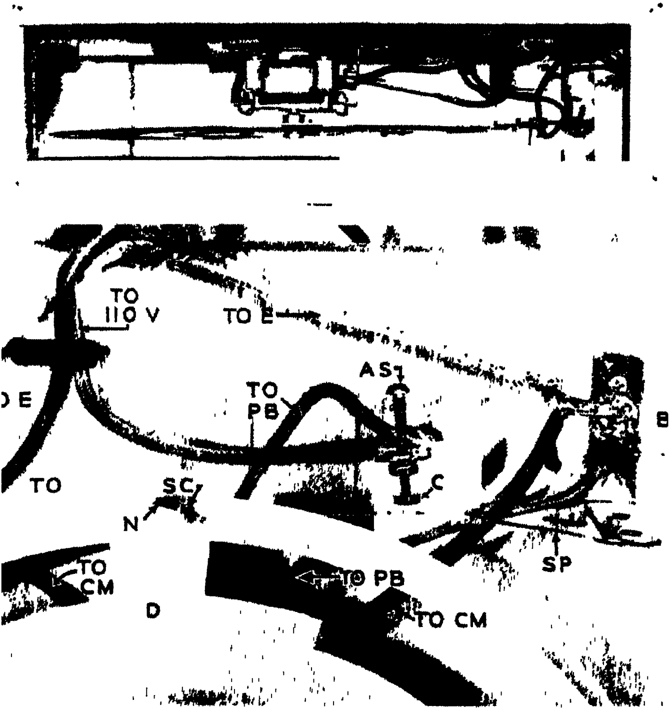


Fig. 109. Above, side view of sensitometer. Below, closeup of wiring, lettered the same as Fig. 108. Here the adjusting screw AS is a part of the contact C instead of working against it, and the sliding contact SC is at the end of the arm instead of the middle. The construction shown in the diagram allows a greater opening between contact and spring, and facilitates adjustment.

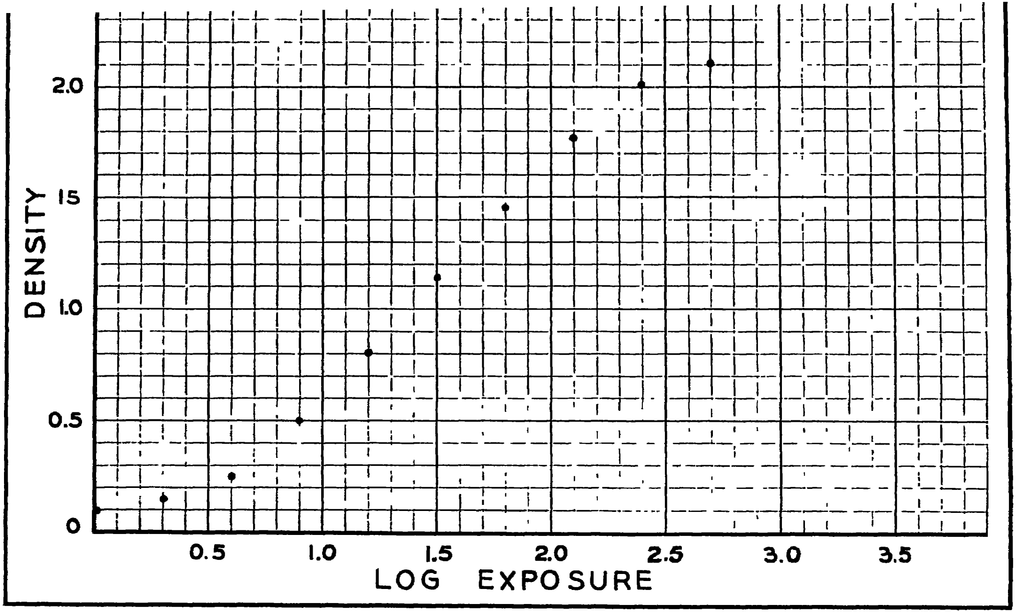


Fig. 110. Film exposed in sensitometer is developed; density readings made of each stripe are plotted on graph, as shown.

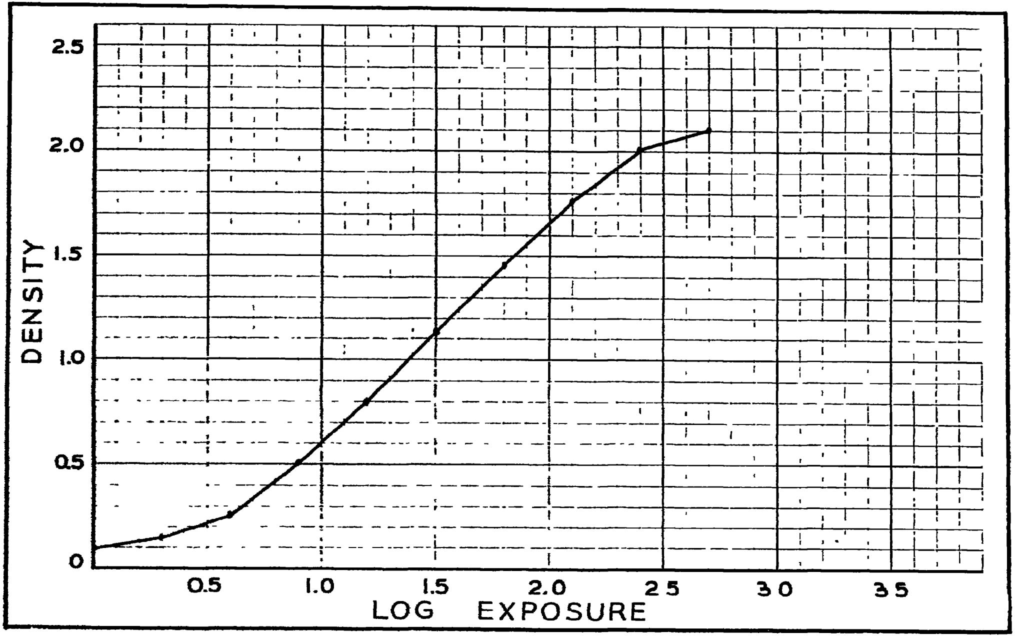


Fig. 111. After survey points are plotted, draw straight, fine

Starting with the first log exposure and the first density proceed as follows: Run up the extreme left-hand vertical edge of the graph which represents log exposure 0.00, until you reach the first 1/10 subdivision of the first major division. This represents density 0.1. Make a dot here. Now move to the vertical line which represents log exposure 0.30 and on it make a dot just above the 0.1 line. On the vertical line representing log exposure 0.60 make a dot about midway between the 0.2 and 0.3 density lines. On the log 0.90 vertical line make a dot at the 0.5 density line, and so forth, until on the log 2.70 vertical line you make a dot on the 0.7 line above the major horizontal division line numbered 2.5. Reference to Fig. 110 will make this clear.

When this is done, draw straight lines connecting each adjacent pair of dots. Then lightly sketch in a line which will convert the series of short lines into a continuous curve (Figs. 111, 112). After the dots have been connected by short lines, the straight-line portion may have a more or less zig-zag appearance, representing small errors which may be disregarded when the continuous curve is drawn. It is astonishing how the dots will fall into an almost perfect "curve"—with toe, straight-line section, and shoulder—after a little experience in reading the densitometer. While small errors can be disregarded, gross errors (where a dot may fall way out of line) call for a re-reading of the film. If an error is consistent, examine the exposure disk. You may find that one of the sectors is off 2 or 3 degrees. Remember that the disk must be cut accurately, or errors are bound to appear in your work.

There are several sources of minor errors which tend to throw the survey points off slightly, but they may be ignored unless the displacement of the dots is considerable.

1. Errors in reading the densitometer. This may

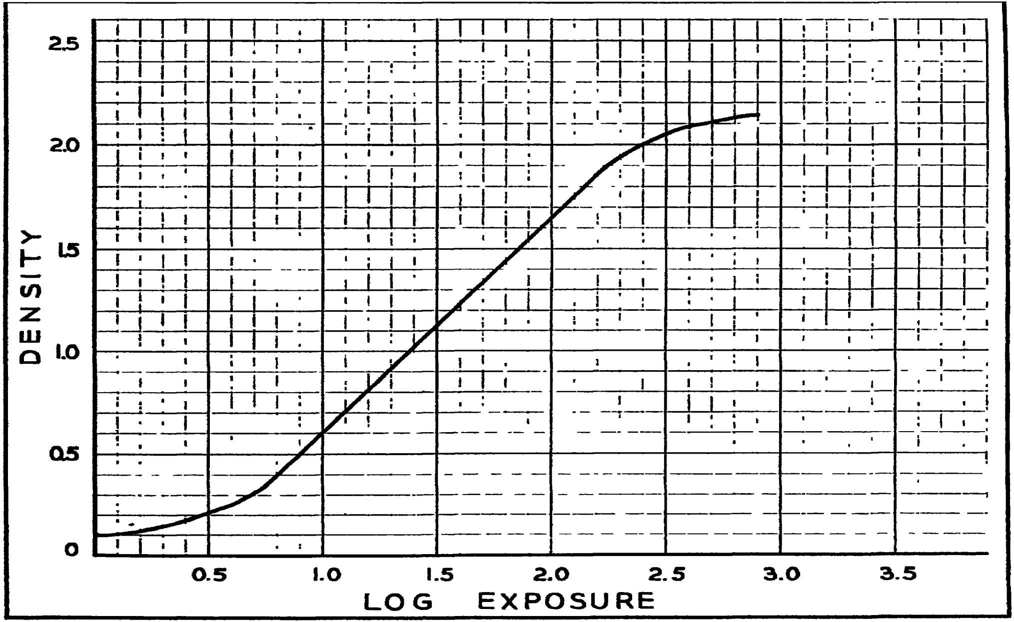


Fig. 112. Using the zig-zag line as a guide, draw in smooth curve, disregarding small errors on the straight line portion.

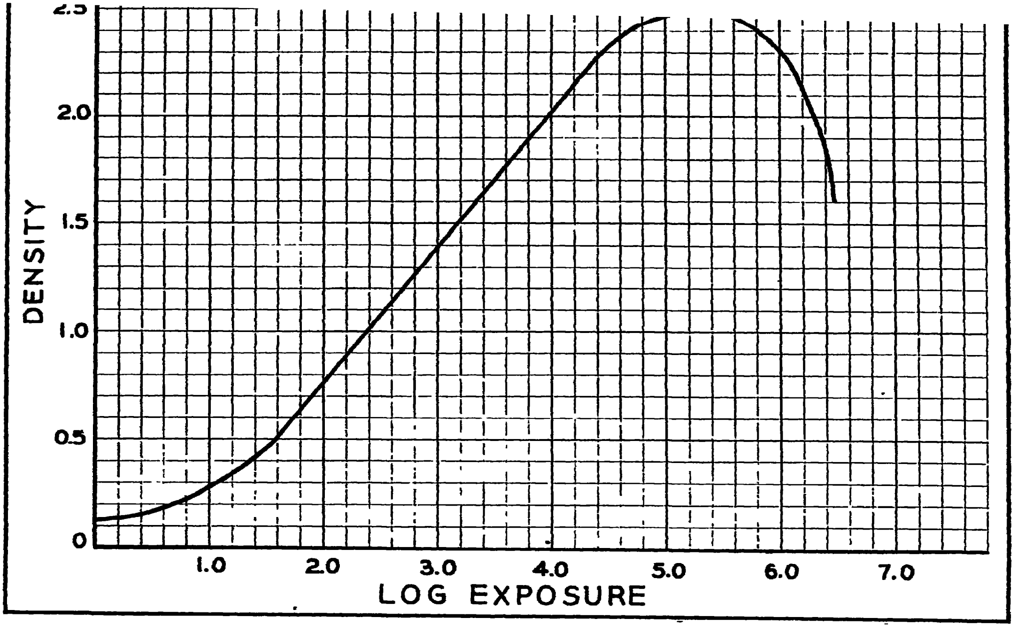


Fig. 113. Extreme overexposure results in decreasing densities and image of reversed values, shown by descending shoulder curve.

be caused by an instrument which is inaccurate or out of adjustment. A dust spot on the negative can affect the over-all reading. In every case a slight error in observation is expected, so that density readings are made by taking the average of three or more readings for each exposure.

2. Emulsions are not always uniform in their silver distribution, nor is the effect of development constant. These errors are too slight to affect picture taking, but the densitometer reveals them.

3. Variable drying and dust particles on the negative will affect the reading somewhat. It must be remembered that while the densitometer aperture is small, it integrates all densities within that area.

Reading the Curve.

You will find that your curve is made up of a central portion which is a straight line. At the left (lower) end of this line there is an upward curve, the **toe**; at the right (upper) end there is a downward curve, the **shoulder.** If the exposure is carried to extremes, this shoulder will continue its relative downward direction, and the densities will actually grow **less** with increasing exposure; but this requires an excessive amount of exposure (see Fig. 113).

The toe is curved because equal increases in exposure produce relatively small increases in density, although the amount of increase is greater for each exposure step. **This is the region of underexposure.** Likewise at the shoulder the increase in density is small as compared with increase in exposure, and the amount of increase grows smaller with each succeeding exposure. This is just the reverse in procedure of the toe, but the ultimate result is strikingly similar. **This is the region of overexposure.**

In the center lies the straight line, and along this line any increase in exposure will result in a uniform increase in density. Thus, if the exposure is doubled, the density will be doubled, and so forth. It must be remembered that this has nothing to do with the actual density. The increases in log exposure may be in the progression 1, 2, 3, etc., and the density increase may be 0.25, 0.50, 0.75; or it may be 1.25, 2.50, and 3.75. However, when the curve is such that log exposure 1 gives density 1, log exposure 2 gives density 2, and log exposure 3 gives density 3, we have a condition in which uniform increases in exposure give uniform and **proportional** increases in density. In this condition the relative intensities of the original light will be reproduced as a series of negative densities bearing the same relationship. In short, we have a faithful tonal reproduction. In the uniformly divided graph paper this straight line rises at an angle of 45 degrees.

The negative in which this proportional increase occurs is one which has a gamma of unity. This brings us to a discussion of a much-talked-of and, for practical purposes, a superlatively unimportant factor in sensitometry, namely, gamma.

Gamma.

Gamma is a number which represents the relationship existing between the range of sensitometric exposure and the extreme range of the negative density. Thus if you have an extremely contrasty subject and condense the tonal values by overexposure and underdevelopment, you have a gamma **less** than unity because each degree of exposure is representd by a degree of density correspondingly smaller. If you have a flat subject and build up contrast by overdevelopment, you will have a gamma of **more** than unity because comparatively small degrees of exposure are represented by comparatively large degrees of density.

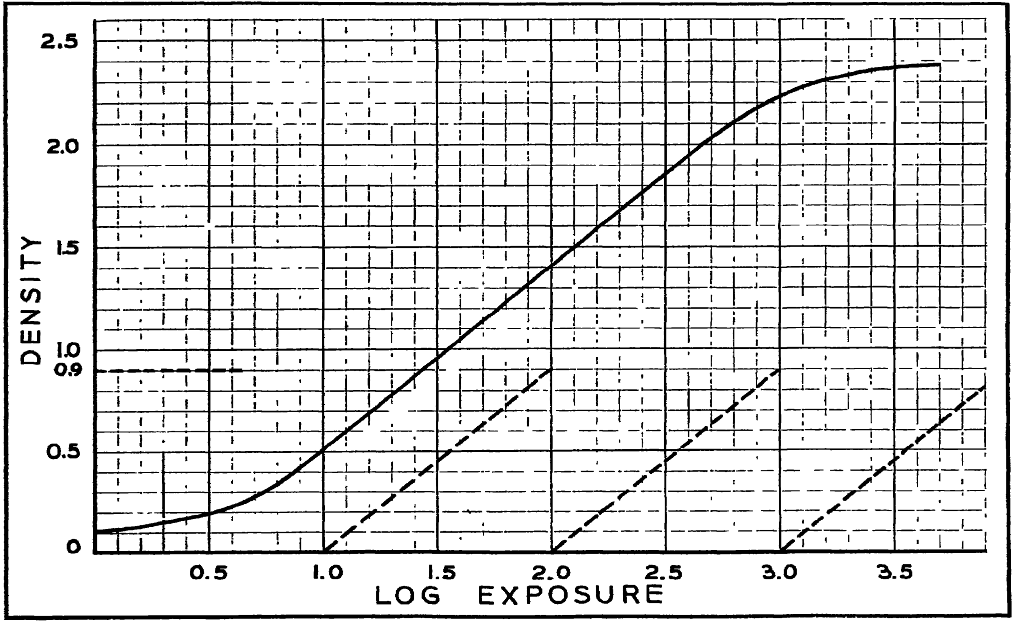


Fig. 114. Non-mathematical method of determining gamma, as explained in text. Graph indicates gamma of curve shown to be 0.9.

This is true even though the first photograph may be contrasty and the latter one flat.

For those who like the figures in the case, let us represent density by D. Then D1 will be the least density in a **sensitometrically exposed** negative, and D2 will be the greatest density. You cannot make gamma readings on ordinary negatives for you must know the log exposure for each tonal area. Now then D2 minus D1 gives the difference or **density range.** If we let lE equal **log exposure,** then we shall have **lE2** minus lE1 equals the exposure range. Having these factors from controlled exposure and from densitometer readings we also have:

$$\text{Gamma} = \frac{D2 - D1}{lE2 - lE1}$$

However, there is a much simpler way to do it, and this is the graphic method in which gamma is determined by utilizing an otherwise wasted corner of your graph sheet (see Fig. 114). On the base line of the graph, which includes log E 1.0, 2.0, 3.0, make a dot where any one of these four vertical lines intersects the base line. Now using a parallel ruler (or a triangle if care is taken) draw a line from this dot and continue it until it intersects the next major vertical line; **and make it parallel to the straight line portion of the curve.** Where this line intersects the next major division read the density value of the intersection, and this reading will be the gamma of the negative. Thus, if you start at 1.0 read at the intersection of 2.0; or if you started at 2.0 read at the intersection of 3.0, etc.

Gamma simply tells you whether the density differences are relatively smaller or greater than the corresponding light intensity differences of the original, and how much smaller or greater they are. True, gamma is of the utmost value in certain work, such as color printing, or in motion-picture work where automatic and semi-automatic methods must be held to a standard. But it is open to serious question whether or not the ability to determine gamma, or to work to a certain gamma, has ever made or will ever make a renowned pictorialist from a mediocre snap-shooter! Personally I have never known of any amateur who has been aided in his printing and enlarging by working under sensitometric control. The results simply are not worth the investment of time and money unless you are working in some special methods where differences too slight for the eye to appreciate will affect the result in some unwanted manner. However, it's good to have an understanding of the real meaning of gamma.

Gamma Infinity.

This is the greatest gamma which can be obtained. While gamma is largely a function of development liberally affected by the inherent emulsion quality, gamma infinity is largely a matter of emulsion characteristic, although decidedly affected by the developer used. It is known that the longer development continues the greater will be the contrast. It is also known that forced development invites fog. Therefore, when that point is reached where fog is growing so rapildy that the contrast actually decreases with further development, then that turning point marks gamma infinity.

Because this end point is difficult to determine, because the high densities involved are difficult to read, and because the presence of the fog makes reading difficult, gamma infinity is usually determined by computation. Two strips are exposed exactly alike in the sensitometer (it is better to expose a single strip and cut it in half if the sensitometric design permits). These two strips are developed so that one is developed for exactly twice the time of the other. These are known as **t1** and **t2.** Then the formula is:

$$\text{Gamma Infinity} = \frac{(\text{gamma t1})^2}{(2\text{x gamma t1}) - \text{gamma t2}}$$

Gamma in Practice.

As we have said, gamma is highly important to the research worker, to the controller of mechanized processing, to the developer of sound tracks, to the color worker; but the photographic picture maker will make just as good pictures if he has never heard of gamma. A remark similar to that once brought out this question at a lecture: "Then you mean that we should pay no attention to negative contrast—just go ahead and print everything on any old grade of paper?" No, that is exactly what is **not** meant. If you are going to base printing on **gamma,** then be sure you understand what it means; do not confuse it with **negative contrast,** for it is not the same thing at all!

For example, you can have a negative which is so flat that it is hardly more than a monotone and it may still have a gamma in excess of one. On the contrary, you may have a negative so hard that no paper is soft enough to print it, and yet that hard negative may have a gamma of 0.5 or 0.6. Do not make this mistake! No one can look at a negative and even guess at its gamma unless he is familiar with the original!

With any given emulsion, gamma is a function of development. If you have a developer which will develop a negative to gamma 1 in 12 minutes at 65°, then any emulsion identical with the test emulsion will also be developed to a gamma of one in that developer in 12 minutes at 65°. This is in accord with photographic law. Now if you run tests and find that this developer will develop to gamma 0.5 in 5 minutes, to gamma 1.0 in 12 minutes, and to gamma 1.3 in 20 minutes, you are ready for the final test.

Expose two negatives. For one, stretch a gray woolen blanket where even light will fall upon it, and make a photograph which will include nothing but the cloth. Then make a square tube of cardboard or wood about a foot square and 2 feet long. Line it with black velvet except for the extreme front edges; paint these edges white. Now make a head-on photograph using the exposure shown to be correct for a pearl gray card held 3 inches back in the mouth of the tube. Of course the card is used only for the meter reading and is not included in the picture.

Develop the blanket photograph 20 minutes and the tube negative for 5 minutes. The blanket negative will be a gray monotone with no contrast range whatsoever, although its gamma is 1.3. The tube will present the extreme range of white and black as a white too opaque to print and a black with no vestige of silver deposit. Here you have contrast far too extreme to be printed correctly, although you know the negative gamma is only 0.5!

No, the relationship between gamma and negative contrast range is a vague one at best. As a governing factor it might just as well not exist at all. True, these examples are extreme, but they show the danger of accepting as fact a principle which works out approximately under normal circumstances. It is true that with normal light and normal exposure and normal subject, the relationship between gamma and negative contrast range become apparently closer. But the fact that extreme examples—such as the one just described—will shatter any evidence of normal relationship is conclusive proof that lesser differences are only changes of degree and not of kind.

Exposure Range.

Now, either factor of gamma is vitally important to every photographer, but he learns their importance a long, long time before he starts to worry about gamma. We refer to the exposure range **E2 — E1** and the density range **D2 — D1.** Exposure range is not often thought of in those terms, but instead we speak of "brightness range," although no one knows why. The brightness is not the point, but the exposure is. So that brings up another point which the student of sensitometry knows full well but which other photographers seem to ignore, and that is that in most normal photographs the exposure ranges from extreme underexposure to extreme overexposure all in the same negative. Shadows must be underexposed or they will not look like shadows; highlights must be overexposed or they will be gray! So our so-called "brightness range" is known to student photographers by its true name, **exposure range**—the exposure caused by the brightness is all we are concerned with.

Exposure range is important because subsequent development must be controlled to correspond. If the exposure range is extreme, development must be curtailed; but if it is low, then development must be extended. Now I expect this will raise some questions. Are we not controlling gamma by this manipulation of development? Certainly we are, and this brings us to the critical point of this whole discussion of gamma.

Automatic time-and-temperature development will result in negatives which are all of approximately the same gamma. This is the supposed ideal condition—but is it? It is if you are after fidelity of tonal reproduction, but is that to be desired? We think not. This means that dull subjects will be flat, and brilliant subjects will be too hard to print. It may be acknowledged that if the photographic process could reproduce faithfully the full range of the average, normal, outdoor scene then such a condition would be desirable, and a constant gamma would be advantageous. However, photography is crude; its limitations are closely set, and only the abnormally dull object can be faithfully reproduced.

In view of the severe limitations of photography it is usually (but not always by any means) desirable to utilize the fullest possible tonal range in reproduction, regardless of the character of the original subject. Therefore, the careful amateur will endeavor so to handle his material that **D2 — D1** will always be a constant—and that means gamma will be varied in each negative.

It is comparatively easy to maintain a relatively stable gamma. Just use a developer kept up to standard, and use a rigid time-and-temperature system. In short, the average, normal technique does just this; and the result is that the amateur learns to avoid many subjects which would give him exquisite pictures, just because experience has taught him that such subjects are outside the limits of his gamma fixation (yes, he learns to evaluate his subjects in this way even though he never thinks of gamma).

However, when density range (D2 — D1) is made the standard, and the amateur learns how to vary the time of development so as to approximate this standard, then there are few things indeed which the eye can see which cannot be photographed and photographed well. Yes, gamma is like fire. It is an indispensable servant when kept in its place, but a terrible master when it breaks its bonds. It has already proven a veritable "Old Man of the Sea," and has made a good start toward ruining the success of many promising amateurs who have elected to dabble in the laboratory end instead of putting cameras to their destined purpose—that of making pictures.

H & D Value.

If you expose a half-dozen films identically in the sensitometer, give them increasing times of development, then draw all the curves upon the same paper, you will see that each increase in development makes the straight-line portion become more nearly perpendicular. However, if you disregard the toe and extend these straight-line portions, you will find that all these extensions eventually meet at a common point (see Fig. 115). This may or may not lie on the base line. (This is not always strictly true, but in simple emulsions was true often enough to be recognized as significant in determining H & D value.) If there is any free bromide in the developer, either added or dissolved from the emulsion, then there is a shift of the intersection toward the right. It might also be mentioned that in some of the newer super-speed emulsions, continued development seems to shift the whole curve to the left, creating the photographic paradox of **increasing the sensitivity of the emulsion by over-development.**

However, ordinary emulsions do work quite regularly according to the law. This point of intersection is known as the **inertia point.** The value indicated by this point of intersection is used as a divisor for a factor (H & D factor 34) which gives the H & D number of that emulsion. For example, if the inertia is 0.02 we have the H & D number:

$$\frac{34}{0.02} = \text{H\&D } 1700.$$

It will be noticed from this equation that high-speed emulsions have low inertia values while slow emulsions

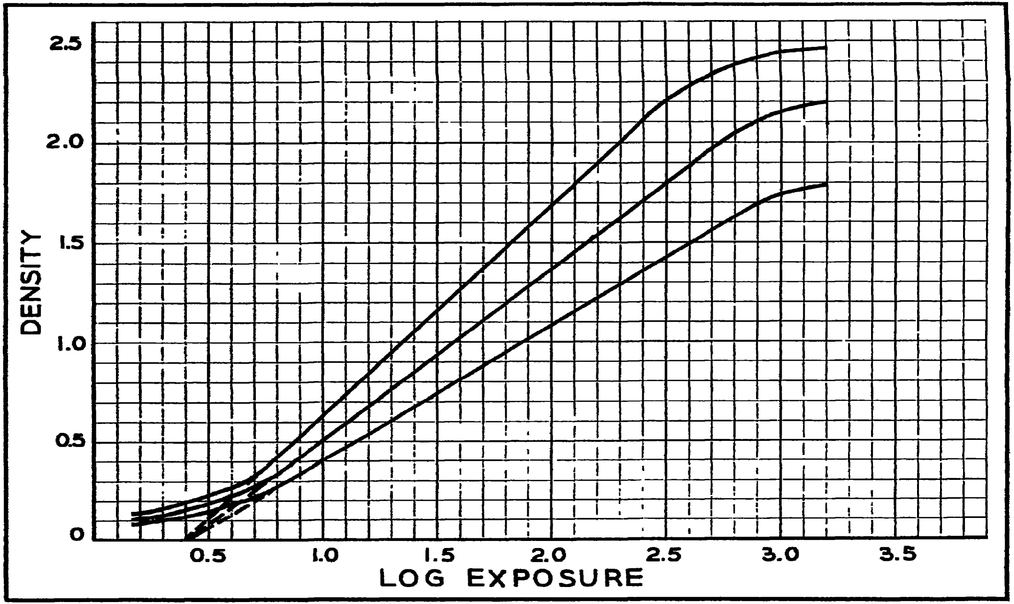


Fig. 115. The longer the development, the more nearly vertical the straight-line portion, and the higher the gamma. Various developing times with a given emulsion produce curves as shown. Extensions of the straight line portions meet at "inertia point."

have high inertia values. For years the H & D number was used as a speed rating, and as originally developed it was a good one as it indicated an exposure between the **threshold** and full exposures. (The minimum exposure that will yield a perceptible darkening of the emulsion is known as the threshold exposure.) However, the manipulation to which the H & D system has been subjected may be recognized by the fact that emulsions of similar sensitivity but made by different manufacturers may be rated as far apart as four to one! Today, the H & D value has no value as a measure of sensitivity.

Some Further Considerations of Sensitometry.

So far we have covered the headlines of this fascinating subject; now suppose we explore a few of the byways. There is always something new in sensitometry, but there are some almost fundamental facts to which attention should be given after the basic principles have been grasped. These things are by way of elaboration of the basic discussion.

As sensitometry is concerned with the physical characteristics of the photographic image, that is, the physical properties of the silver embedded in the gelatin, and as the principal property of the image is that of obstructing light, we should give some attention to the formation and structure of that image. This applies not only to the normal image, but to one which is formed under what may be termed abnormal conditions, such as with the use of a filter.

The photographic image is a very real thing; it has length, breadth, and also thickness. It may properly be considered to consist of a great many layers of silver grains laid one upon the other, so that density is not so much a matter of a closer grouping of the particles, as a matter of the depth to which additional layers are deposited. This is true of both the negative and positive images. In fact there is, sensitometrically speaking, no differentiation of negative and positive. Both are photographic images.

The instruments used in large research laboratories are elaborate and costly. Those used in smaller laboratories are also costly if they are of high accuracy. It is true that inexpensive densitometers are said to be in process of development and soon to be offered to the public; but at present a high-grade densitometer runs above one hundred dollars and any instrument worth using will cost at least a few dollars less than fifty. Therefore, let us first turn our attention to home-made devices which, although in no way substitutes for conventional instruments, will prove of value and permit a certain type of sensitometric control to be exerted. By giving up actual numerical valuations and working on a comparison basis, such devices may be made at home.

The Comparison Scale.

Obtain a **section liner** from a dealer in artists' and draughtsmens' supplies. This is a device which moves a straightedge over a sheet of paper at regular intervals so that uniform shading may be drawn. Set this device so that each movement of the straightedge will advance it about ¼ inch or more. Make tests with your enlarger, so that a 1-second exposure will produce a barely perceptible tint upon a sensitized film (use process film or similar slow material). You will probably have to close the lens diaphragm to its smallest aperture and insert one or two pieces of white paper in the negative carrier. If paper is used, throw the lens out of focus to overcome the grain pattern of the paper.

Lay out a piece of film. This need not be more than 2 inches wide and 10 inches long. Set the section liner so that the straightedge will move down along this strip. Now with masking tape attach a sheet of black paper to the leading edge of the straightedge, and bring it down to cover the film with about ½ inch of the paper extending beyond the end of the film.

Turn on the light, and using either a sweep clock or audible timer, move the arm once each second. The paper will be drawn back ¼ inch each second and you will then expose the film in single-second intervals for 32 seconds. As soon as the black paper gets to within ½ inch of the end of the film, extinguish the light and develop the film. If the contrast range is not sufficient, you can make another strip using 2-second intervals. If you want to make a log exposure strip, with the exposures running 1, 2, 4, 8, 16, 32, 64, 128, 256, and 512, start with an exposure of 256 seconds; then move the paper and expose for 128 seconds, and so on down the line until you get to the end of the series. Then when you have exposed for one second, you move the mask and again make a 1-second exposure. Leave one unexposed section on the end. This gives you the desired series as can be seen:

No.	Single Exposure	Total Exposure	Total Exposure per Strip
1	256	256	512
2	128	256 + 128 = 384	256
3	64	384 + 64 = 448	128
4	32	448 + 32 = 480	64
5	16	480 + 16 = 496	32
6	8	496 + 8 = 504	16
7	4	504 + 4 = 508	8
8	2	508 + 2 = 510	4
9	1	510 + 1 = 511	2
10	1	511 + 1 = 512	1
11	0	0	0

Fig. 116. An amateur densitometer, wherein step wedge is pulled through by hand. Negative lies on top of box under white window; comparison field is seen within by looking into an aperture at the end. Object in the foreground is a simple reflection scale.

With care and a few trials, a strip can be obtained which has these definite relationships. When the light intensity required to produce a fully graded strip under such conditions has been obtained, it is suggested that a full 8 x 10 inch film be exposed. After it is dry it can be cut into 6 or 8 identical strips. This strip forms the basis of your comparison densitometer. Of course the disk sensitometer is more convenient than the section liner for making this density wedge, but it is also more difficult to construct. In their most elementary form the tone wedge and the section liner with which it was exposed constitute your "densitometer" and "sensitometer." We shall refer to the density wedge as a "comparison scale."

If you have access to a densitometer you can read the values of your scale steps, but this isn't necessary for working upon the comparison basis. Such a comparison instrument has been used quite successfully in color control, and while it lacks a great deal of the advantage of a good densitometer, it is actually to be preferred to the cheap but inaccurate meter.

The Gray Scale.

For the best results it is advisable to make use of a gray scale in making your exposures, just as is done in color photography. These may be purchased for a few cents, but as the commercial scales have tints in regular squares, it is used only as a standard.

Expose several sheets of matte paper to varying light and try to obtain uniform tones over the entire sheet. Try to make not less than 30 degrees of gray between black and white. Fix out an undeveloped sheet for the white, and expose a sheet to a 100-watt lamp for 2 or 3 seconds to produce the black step. When these are dry, compare them with the commercial scale and try to select matching tints. Number these on the back of the sheet and make your own scales from them. Make the individual tints about 3 x 8 in one scale, 2 x 6 in another, 1 x 3 and ½ x 1½ in two more. The idea of the various sizes is to obtain a readable size tint along the edge of your negative regardless of the size of the original object. Include this scale when making exposures, and place it so that the ends of the individual tints extend slightly outside the picture area. Now when the negative is developed, the safe edge may be trimmed off the side where the gray scale appears, leaving the tint running right off the edge of the film.

Assume that the tints are ⅛ inch wide in the negative. Cut a length of black cardboard slightly larger than your comparison scale, and cut square notches into one edge, ⅛ inch deep and ⅛ inch wide, spaced so that one notch is centered upon each single step in your scale. A preferred construction is a similar but wider cardboard with rectangular openings ⅛ x ¼ inch. The comparison scale is attached permanently or temporarily to this mask, and the black border prevents visual confusion. The negatives are held against the edge of the comparison film, and the scale steps in the negative can be matched with those of the comparison scale, or they can be assigned intermediate values. You can interpolate intermediate values in making the original scale to get 21 steps instead of 11.

It may be said in passing that a series of paper tints each with a small hole punched in it provides an excellent comparison gauge for reading the reflection values of paper prints. Such a gauge can also be calibrated by comparison with a reflection densitometer, but in such case it is advisable to convert the reflection densities to reflection percentages.

And now that we are so familiar with sensitometry that we make our own instruments and set our own standards, what is it all about?

The Photographic Image.

Let us assume that we have a series of neutral density screens which transmit just half of the incident light. While these could be stacked up without seriously impairing the experiment, let us place them one upon the other with a space of an inch or so between each adjacent pair. Then let us see what happens to 100% of incident light.

Screen	**1**	**2**	**3**	**4**	**5**
Incident	**100%**	**50%**	**25%**	**12.5%**	**6.25%**
Transmitted	**50%**	**25%**	**12.5%**	**6.25%**	**3.125%**
Opacity	**2.0**	**4.0**	**8.0**	**16.0**	**32.0**
Density	**0.30**	**0.60**	**0.90**	**1.20**	**1.50**

The negative is formed by the deposition of silver in the gelatin, deposited in a certain ratio to the amount of light to which it is exposed. If we ignore the toe and shoulder curves for the time being we may assume that if one unit of light will produce a unit deposit of silver, 2 units will deposit 2 units, and so on. Now if we consider 5 successive exposures, each of which results in a silver film of 50% transmission quality, these 5 exposures may be substituted for the 5 neutral density screens, and the screen numbers at the top of the table may be now referred to units of light in the exposure. This reveals some interesting facts.

If 5 units of exposure gave a deposit 5 times as dark as that following a single unit exposure, then exposure 5 would produce a 10% transmission, an opacity of 10, and a density of 1.0. However, the light-obstructing power grows by steps of density 0.30, and as density has a logarithmic progression, we see that the normal growth of photographic density is also a logarithmic progression. This is the fundamental reason for using logarithms instead of ordinary values—simply because it reflects the natural progression of photographic image growth.

Film-Speed Ratings.

One of the most widely used applications of sensitometry is that of determining the specific sensitivity or "speed" of an emulsion. We have already shown how the H & D values are obtained. Other systems also are based upon sensitometry, but their origins and methods of development are widely different. There are some systems which take the least amount of light which will produce a visible density as the fundamental index. This is hardly advisable. Two emulsions might have the same threshold exposure—that is, required the same amount of light for the first visible density to be produced. Yet if the first emulsion has a long, sloping toe and the other a short one rising abruptly, the second emulsion would have the greater sensitivity.

Other systems base their indexes upon the exposure which is necessary to produce a negative density of 1.0. This is a much better system, for density 1.0 lies more or less midway in the tonal range of a good average negative, and so avoids the possible error of starting with the tip of the toe. As we have seen, the H & D system uses neither of these but instead an extension of the straight-line portion of the curve.

All systems have their advantages and disadvantages; but those systems which aim at half-tones rather than either extreme are likely to be more satisfactory. Incidentally, it should be noted that although the inertia value is found at the base of the graph, it is a midway system because it is governed by the central portion of the curve.

The Eder-Hecht Sensitometer.

At one time it was popular for amateurs to make their own determinations of relative sensitivity, and among the simpler sensitometers for this purpose was the **Eder-Hecht** type. This is nothing more than a printing frame with spring covers over both faces. Enclosed is an artificial step negative in which each tenth step is numbered. Along the sides are strips of gelatin colored blue, green, yellow, and red, with the graded steps running beneath them. The film to be tested is exposed behind this negative and developed (see Figs. 117, 118).

Naturally such a device is useless unless there is some predetermined exposure control, because with fixed and numbered steps, a correspondingly fixed exposure is necessary. To meet this demand the outfit includes a needle set in a wooden handle, and a box containing several small pieces of magnesium ribbon. The exposure is made by picking up a piece of magnesium, supporting it at a distance of one meter from the frame, and igniting the magnesium.

This system is very simple, almost crude, but the results obtained with it are strikingly uniform, and for certain purposes this sensitometer finds use even today in the laboratory. For example, the tricolor filters give the whole story of sensitivity to the three separation colors on a single film. This information may be translated directly into filter factors. The only correction is that of differences between filters. To overcome this, the original filters are removed from the negative and replaced by the ones in actual use. Or one side may contain the A-B-C set of tricolor filters and the other side the filters used for making separations from Kodachrome. For this purpose alone the sensitometer is worth more than its modest cost. The Sanger-Sheppard sensitometer is similar except

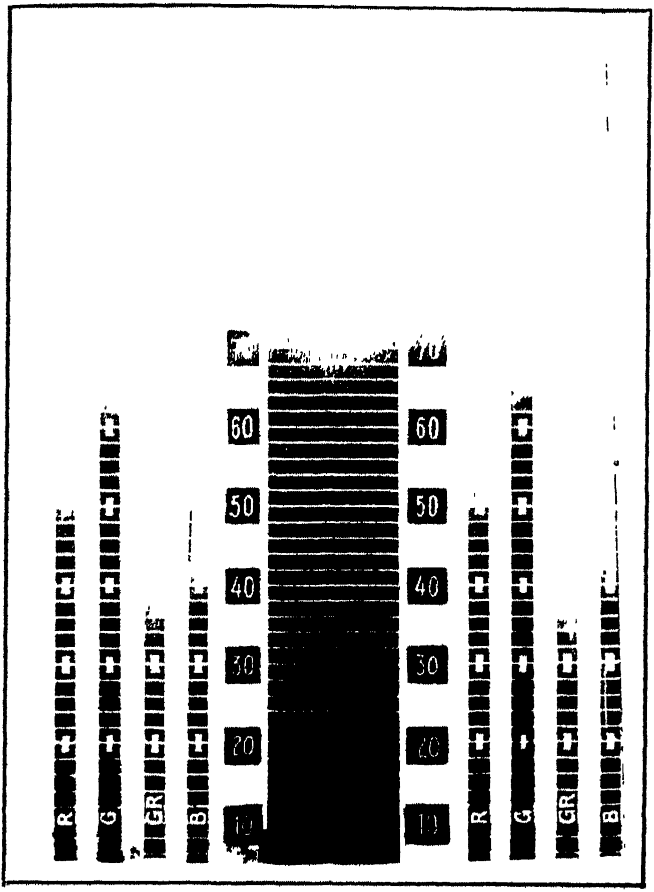


Fig. 117. Film exposed under the Eder-Hecht tablet. Note color stripes R, red; G, yellow; GR, green; B, blue. Film tests E-H 90.

that the densities, instead of being arranged in ladder formation, occupy rectangular spaces. It is not quite as convenient as the Eder-Hecht type, but is highly satisfactory.

This description of the Eder-Hecht sensitometer has been given because it is typical of those measurements of sensitivity which base the film-speed rating upon the exposure producing the least perceptible deposit. In the discussion of H & D values, the problem of sensitivity rating was mentioned; but as the H & D characteristics have more importance than mere sensitivity rating, the subject was not elaborated there.

The Eder-Hecht sensitometric tablet already described is the actual basis for speed rating according to the Eder-Hecht rating system, the last visible number being the speed number of the film. It can be understood that wedges turned out in quantity will probably vary, and this is true; so we encounter the first source of possible error. However, this is minor when we consider the low possibility of determining the "least perceptible deposit," and the great likelihood of its being obscured by fog. We have already pointed out that the threshold exposure does not take into account the shape of the curve, and threshold ratings are to be regarded with deep suspicion.

Scheiner Film-Speed Ratings.

It may surprise many amateurs to know that the **Scheiner** film-speed ratings are also threshold ratings. They differ from Eder-Hecht ratings only in the method of primary determination and the values of the numbers used. In both cases a series of numbers in arithmetic progression indicates logarithmic increases. Thus, every three degrees Scheiner represent a doubling in sensitivity. This same thing is true of

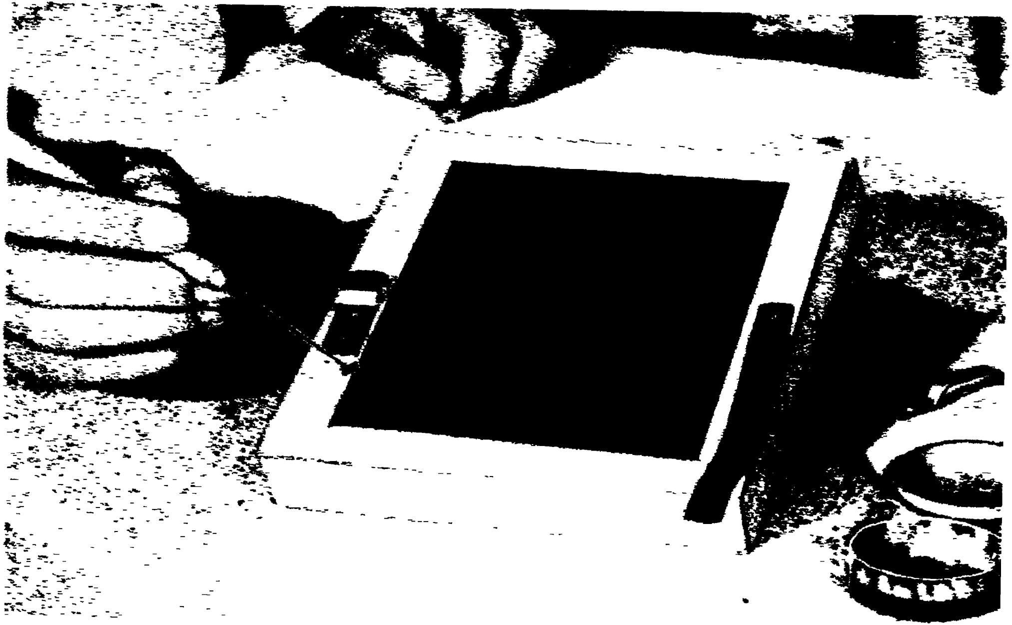


Fig. 118. Eder-Hecht sensitometer, showing frame containing step negative and needle with magnesium ready for ignition.

DIN as well as of Eder-Hecht. The Scheiner exposure is made on a logarithmic base with the ratios of exposure extending from 1 to 100. The resulting increasing exposure is read by means of an arbitrary scale. Thus we have the series:

Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
Relative Exposure	**1**			**2**			**4**			**8**			**16**			**32**			**64**			**128**			**256**

and so forth. The Scheiner is better than the Eder-Hecht only in that the determinative exposure is made through a time-base sector wheel, and to that extent has less liklihood of error. All of the fundamental objections to the threshold system still hold.

Other Systems of Sensitivity Rating.

Some years ago the **DIN** system was given to the world as the ultimate in sensitivity rating. It was foolproof; it was unalterable; it was the universal standard. Now what is the DIN system? Why, nothing whatsoever but our old friend Scheiner—except that the exposure required to produce density 0.1 is taken rather than the vague threshold exposure. Density 0.1 is still so far down the toe that the objections to the threshold index still hold insofar as the curve shape is concerned; it is still hard to determine and it is easily masked by fog, but it offers the advantage of a firm basis, a known, definable, and measurable point of departure. In actual practice DIN offers no real advantages over Scheiner, and it is subject to the same manipulation as is the Scheiner system. In recent years the Scheiner rating has had to be identified as being European, German, or American, because a film rated at Scheiner 23 in America was rated 26 in Germany and 29 in other parts of Europe. The German film of equal rating was one-half the American speed, and other European films of equal rating were only one-fourth the American speed. Naturally this resulted in great confusion, particularly when Americans went to Europe and suddenly found themselves losing pictures through gross underexposure.

The Watkins and Wynne systems of rating were based upon the inertia point and differed from H & D largely in their numerical values. They have been little used in this country and are now obsolete, so we will not discuss them.

We now encounter two modern systems, one the **minimum useful gradient,** the other the **D-log-E base.** The minimum useful gradient is based upon that exposure which falls upon the part of the curve where the density increase per unit of exposure is a definite fraction of what it is on the straight-line part of the curve. In short, it lies at a definite point in the upper part of the toe curve, where the chosen fraction is great enough for good results. In practice it is that exposure which will produce a print satisfactory to the average amateur. This sounds rather vague, and it is a vague system until the important fraction has been assigned a definite value. The system is being used by Eastman, who have determined the value of the fraction as suited to their needs.

An exposure which is based upon the characteristic of the relationship of density and log exposure for a definite gamma is probably the most sensible approach to the problem. The point is located in the straight-line portion of the curve, and permits the inclusion factor for gamma, so that the speed rating for a process film recognizes the fact that it will be developed to a high gamma, while the factor for a portrait film recognizes the fact that the gamma will be low. Such a system is the **Weston** method of rating. The fact that this system gives good results in all parts of the world and that even beginners are usually successful when using it suggests that, if not the ideal speed rating, it is at least a substantial approach to the ideal.

A truly ideal rating cannot be reached, because there is no "correct" exposure, no absolute sensitivity rating. The sensitivity of a film depends upon the nature of the light, the color, texture, and general form of the object, and above all upon the aesthetic effect desired. Therefore, if we have a system which will indicate for us the exposure which would be satisfactory in a sensitometric test, we can let experience guide us in the degree of departure necessary to cope with the details of the individual picture to be made. It must always be remembered that strict sensitometry and aesthetics mix about as well as oil and water. You can emulsify them, but it is a difficult task.

Curves and Their Interpretation.

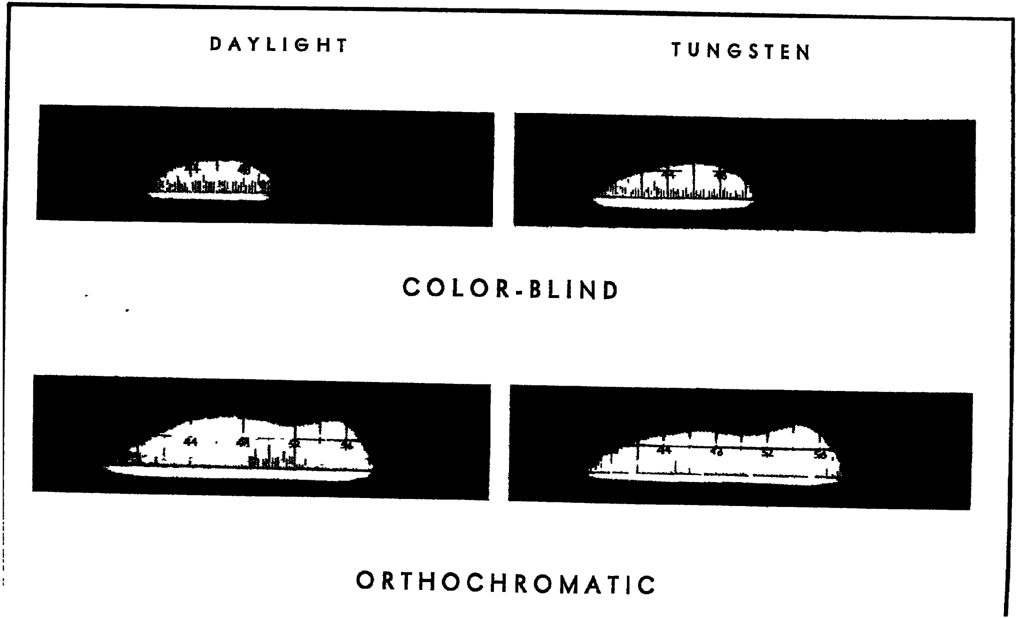
The characteristic curve as drawn from sensitometric data provides a wealth of information regarding the developed image, as well as the inherent characteristics of the emulsion and the developer. But there are other curves just as valuable as the H & D curve, and as these also provide information which may be included within the scope of sensitometry, we should give some attention to them. Those relating to specific spectral sensitivity are perhaps the most important, because they reveal the exact color response of the emulsion. Quite similar curves show the characteristics of filters, and by combining an emulsion curve and a filter curve you see graphically the actual effect of using a combination of specific filter and specific emulsion.

Visible color is made up of a series of wave forms whose lengths vary from about 380 millimicrons in the violet to about 750 millimicrons in the red (see Fig. 3, Ch. I). We say "about" because the exact limit varies with different individuals. The radiation immediately adjoining the violet that is shorter than the shortest visible violet marks the beginning of the ultraviolet, while that adjoining the deepest visible red marks the infrared. The only separation is in the vision of the beholder, because the wave train goes right along in unbroken sequence. It is common knowledge that some people cannot hear a shrill sound while others are able to hear it. It is the same with light; but whenever the boundary is passed, for that individual, either ultraviolet or infrared starts. For that reason the laboratory curve usually includes considerable of both without any demarcation. This is logical because the emulsion is not subjected to the same limitation as is the human eye, and as long as we have emulsions sensitive to wavelengths in the ultraviolet (in the neighborhood of 250 to 300 millimicrons) and in the infrared (in the neighborhood of 1000 millimicrons), our curves should be based upon that scale.

However, as a rough guide keep in mind the divisions 400, 500, 600, and 750. For approximations you can regard these as marking: 400, beginning of visible violet; 500, boundary between blue and green; 600, boundary between green and red; and 750, the lower limit of visible red.

Therefore the base line of your graph is divided into sections representing wavelength—250 to 1000 for the total spectrum, or 380 to 750 for the visible spectrum. A convenient division is one space for every 25 units; start at 375 and let consecutive divisions equal 400, 425, 450, 475, 500, and so on. For the benefit of those familiar with the non-uniform spectrum of a prism, it may be said that the spectrum produced by the diffraction grating is of uniform linear value, so that the location of any two points provides a standard

WEDGE SPECTROGRAMS



PANCHROMATIC

INFRARED

Fig. 119. Typical wedge spectrograms showing sensitivity of color-blind, ortho, pan, and infrared films to the wavelengths (colors) which make up the light source. They are made by exposing emulsion to a spectrum produced by a diffraction grating or prism in conjunction with a uniformly divided scale. This scale is calibrated in two figures; thus 48 indicates 480 millimicrons or 4800 Angstrom units. The height of the white area shows film's sensitivity to the wavelength indicated by scale.

for the accurate determination of wavelength value. Of course in a graphic outline, the spacing is uniform by reason of construction.

As a rule the vertical scale is logarithmic, the first line representing density 1, the second 2, the third 3, and so on. Thus, in actual light intensity the first line has a value of 10, the second of 100, the third of 1000, and so on. This is the reason spectral photographs published by film manufacturers have such slight differences from point to point.

Wedge Spectrograms.

If light is passed through a prism, or preferably through a fine grating, it will be spread out into a colored band in which the wavelengths are side by side instead of superimposed. If this band is projected upon an emulsion surface, an automatic record of the color sensitivity is obtained. However, as the reaction is recorded simply as varying densities, special instruments are required to convert this record into a graph. A gray wedge which varies in density from 0.0 to 4.0 is placed in the path of the beam. Under such restraint, the brighter parts of the band pass through heavier portions of the wedge, while weaker colors can pass only through the thinner portions of the band. But if the light is of uniform strength its intensity grades from bottom to top, and the colors to which the film is more sensitive will be recorded as higher peaks than others. Thus automatically a record is made which indicates the sensitivity of the emulsion to that color by the height of the line (see Fig. 119).

These **wedge spectrograms** are supplied by most film manufacturers, and may be converted directly into curves by direct copying, as the spectrogram is a true graphic curve in itself. Thus by taking the wavelength divisions and the density divisions from the spectro-

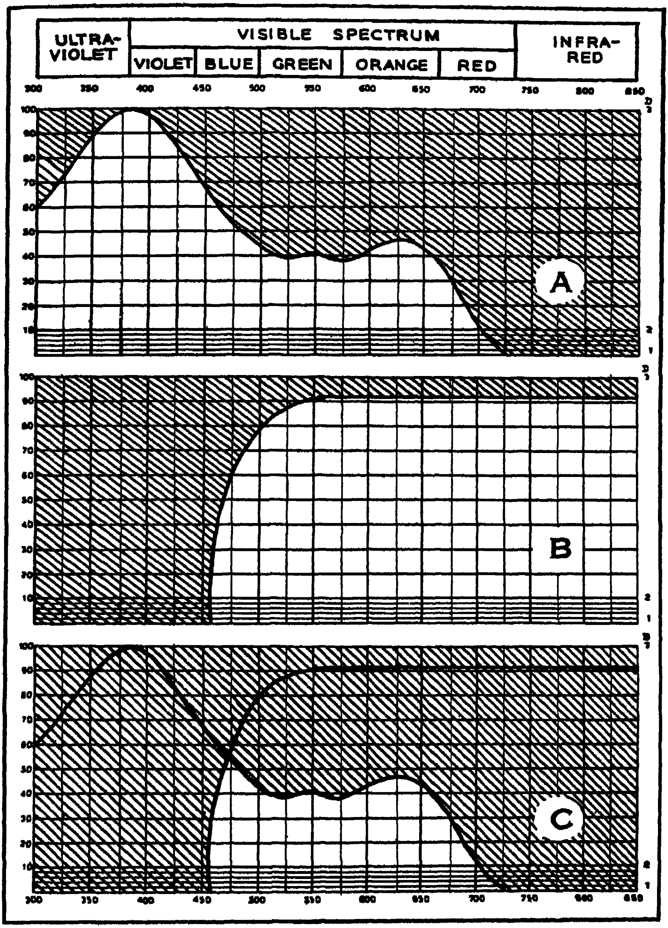


Fig. 120. A, color curve showing response of panchromatic film to daylight. B, the transmission curve of a deep yellow filter. C, curves superimposed show net result of the combination. The reason for large filter factors with deep filters is obvious.

gram and transferring them to your graph paper, you will have a true graph of the color sensitivity of the film.

The Filter Curve.

The filter curve presents greater difficulty. If it is made photographically, the resultant curve is necessarily one which gives the net result of emulsion color sensitivity plus filter curve. For example, if it is a red filter and the emulsion used is ortho, there will be no result. This means the filter is opaque, as it is to an ortho emulsion; but that is far from the true characteristic of the filter. Commercial testing laboratories will make spectrophotometric records of a filter, or you can make a good guess with an ordinary spectroscope; but generally you will find it easier to depend upon the curves supplied by the manufacturer.

If you redraw the filter curve upon the same type of graph blank used for the emulsion curve, but drawn upon transparent paper, you can superimpose the filter curve upon that of the emulsion, then that portion of the curve which is common to both curves is the net usable light. To make such readings easier, it is suggested that instead of a single line curve, the portion of the graph outside the line be blackened. This is done on both curves, then the usable light for any combination is represented by the amount of white paper visible. This white area may then be identified as to wavelength (color) and intensity (density), so that you will have a very good idea of the actual photographic result. The accompanying diagram (Fig. 120) will make this more clear.

Most other graphs used in photography are of the usual type; that is, they represent time against temperature, concentration against vigor of action, or other common factors, and are read exactly like the stock-market and production graphs which are found in the daily press. The curves already discussed, i. e., those which involve logarithmic values, are more significant, and are the ones most commonly used.

Thus far we have skimmed the highlights of sensitometry as applied to the negative. No consideration has been given to the subject of the control of the positive through sensitometric analysis, nor have we space for such a discussion. However, this is a method of control which, like the exposure meter, gives us the technically correct exposure from which we may depart in any direction and to any degree desired for the production of some specific effect.

We have purposely avoided the more advanced mathematics of sensitometry and have limited theoretical discussion as far as possible. Sensitometry is a complex subject, one which has not been thoroughly explored. To treat of it fully would not only require far more space than we have available, but such a discussion would undoubtedly prove unendurably boring. However, it is hoped that the treatment of the subject as presented will enable you to utilize the fundamentals of this branch of photographic science, and that it has presented clearly the fundamentals of the measurement of negative characteristics. There are two facts so vital to sensitometry that we venture to close this chapter by repeating them.

Sensitometry is based upon these two fundamentals:

1. A series of graded exposures of **known** value.
2. The accurate measurement of the densities resulting from this series of **known** exposures.