CHEMISTRY FOR THE AMATEUR PHOTOGRAPHER
II. EXPOSURE*

In order to get a satisfactory photograph of any scene it is necessary that the exposure be correct. The time of exposure required will, of course, depend upon the brightness of the image formed by the lens on the film, and this in turn will depend upon the aperture of the lens used and on the brightness of the scene photographed.

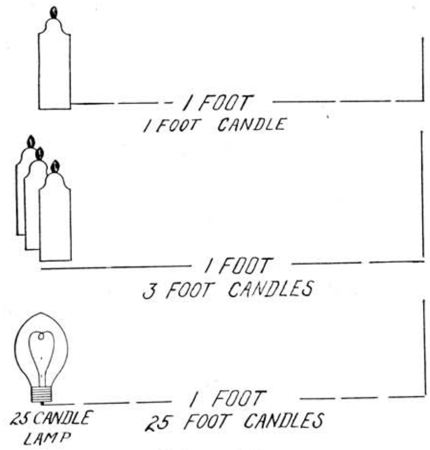

FIGURE 1

The brightness of a lamp is measured in terms of its candle-power; that is, a lamp is stated to be equivalent to 1, 5, 10, or 100 candles, the original unit being an actual candle, though nowadays the practical standards used are electric lamps which have been carefully measured and which are kept for use only as standards.

When the light of one candle falls upon an object at a distance of one foot, the brightness falling on the object is said to be one foot-candle. When we have 3 candles at a foot distance, the brightness would, of course, be 3 foot-candles, and if we use a 25 candle power lamp, the brightness will be 25 foot-candles (Figure 1). If we change the distance, the brightness will vary inversely as the square of the distance, because the cone of light which covers one square at a foot will embrace 4 squares of the same size at 2 feet, 9 squares at 3 feet, and so on; and since the same light that falls on one square at one foot is spread over 4 squares, at 2 feet distance, it is naturally $1/4$ of the strength, so that a 25 candle power lamp at one foot distance gives a brightness of 25 foot-candles, and at 5 feet distance it gives only one foot-candle brightness (Figure 2).

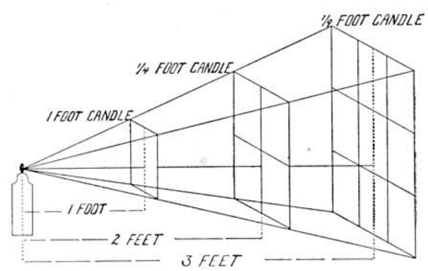

FIGURE 2

The brightness of natural objects can be measured by means of a pho-

* This series of articles is based upon selected chapters from "Elementary Photographic Chemistry" and "The Fundamentals of Photography," published by the Eastman Kodak Company, Rochester, New York. Cuts also are by courtesy of the Eastman Kodak Co.

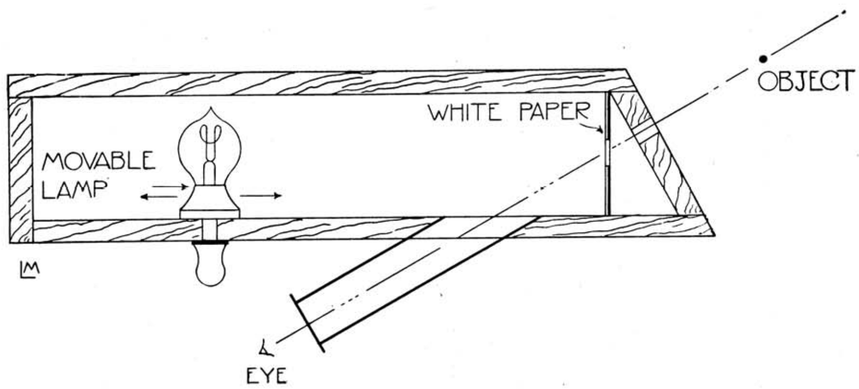

FIGURE 3

tometer, in which the brightness is matched with a lamp of known brightness. A convenient form of the instrument is shown in Figure 3. In this, the scene is viewed through a hole in a piece of white paper, and the white paper, which must be backed on metal so that it is opaque, is illuminated by a small movable lamp of which the distance from the paper can be varied. In order to use the instrument, it is held up to the eye so that

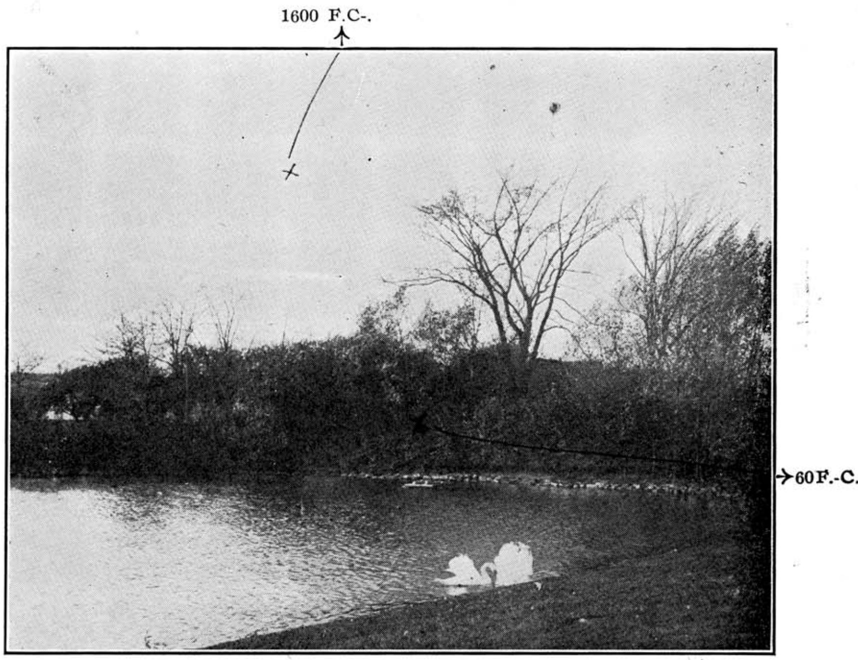

FIGURE 4

the brightness to be measured can be seen through the hole in the paper, and then the lamp is moved until the brightness on the paper is the same as that seen through the hole. Now, the brightness which the lamp throws on the paper can be calculated from the distance of the lamp, and consequently we can read on the instrument the brightness of the object to be measured. In Figures 4 and 5 are shown two landscapes which were photographed and at the same time were measured with the photometer, and it will be seen that the sky in these has a brightness of about 1600 foot-candles, while the deepest shadows in the foreground have a brightness of about 60 foot-candles.

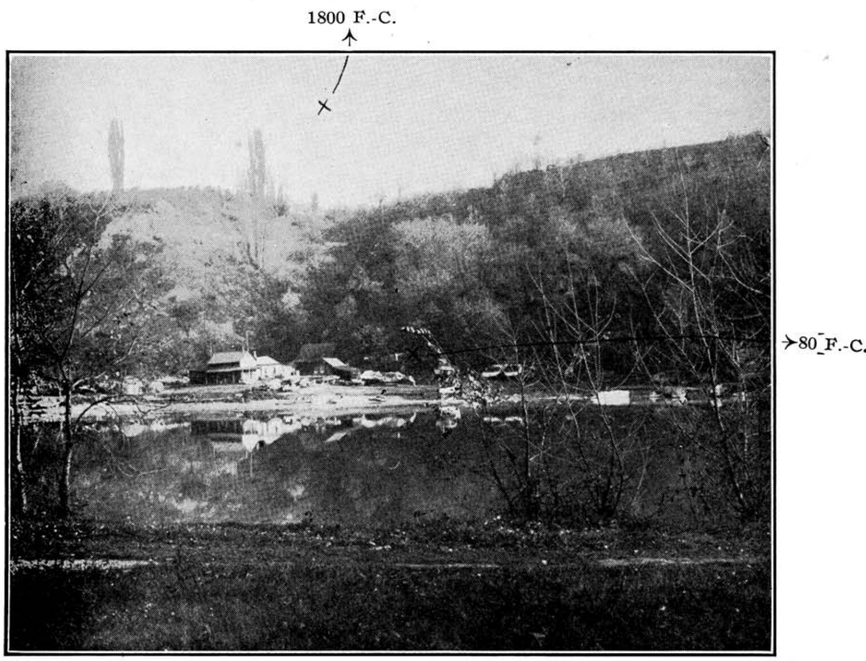

FIGURE 5

It is often believed by photographers that the range of light intensities occurring in natural objects is very great, and that in an ordinary landscape, for instance, the sky will be enormously brighter than the shadows, but this idea is quite incorrect. In a bright landscape with heavy shadows, the sky is only about 30 times as bright as the deepest shadows, while in the case of open landscapes in which there are no close objects in the foreground, the range of intensities will be much less than this, the sky often being only 5 or 6 times as bright as the shadows. The range of light intensities, therefore, with which it is necessary to deal in ordinary photography will vary from, perhaps, 1 to 4 at the least up to 1 to 50 as a maximum, and the brightest part of a landscape—the sky—will have a brightness of from 1000 to 3000 foot-candles. This is the photometric brightness of the sky itself; but when we take a photograph, we are concerned not with the brightness outside but with that inside the camera; that is, with the brightness of the image which falls upon the film. This brightness depends upon the aperture of the lens, and we can calculate it from the fact that at an aperture of *f*.8 the photometric brightness of the image is about $^1/_{100}$ of the brightness of the object outside, so that the light from the sky falling upon the film will have a brightness of, at most, 30 foot-candles, and the shadows will be represented by a brightness of about one foot-candle in a photograph of a landscape having a brightness range of 30 to 1.

Now, let us consider how much time of exposure will be required for the film to reproduce the shadows, of which we see that the image formed on the film has a brightness of one foot-candle. In order to do this, we must know how much exposure is required by a film to make it developable. We can find this by exposing the film to a candle at a fixed distance and giving it a series of different times of exposures. It is convenient to have each of these exposures double the next one, so that one part is exposed for one second, the next for 2 seconds, the next for 4, and so on. If, now, we develop and fix the film, and then after it is dry find out how much silver per square inch we have produced in each exposed part we shall find that each time the exposure was doubled we added almost the same amount of silver (Figure 6).

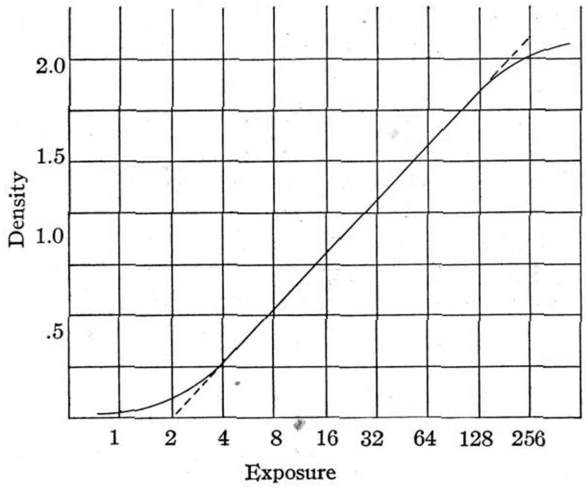

FIGURE 6

It is rather hard to measure the amount of silver by actual analysis, but it can easily be done optically by measuring the blackness of the deposit, and this measurement of the blackness, which is proportional to the amount of silver per square inch, is called the "density." A density of unity is taken as the standard and represents the blackness of a deposit which lets through only $^1/_{10}$ of the light; it corresponds to a very small amount of silver—only about $^1/_{100}$ of a grain weight per square inch.

The relation between the density and the time of exposure of a film can easily be represented as a curve, and for most of this curve the density is increased proportionally as the exposure is doubled (see Figure 6). This condition is that which produces a correct rendering of the original in the print, and for that reason the part of the curve for which it is true is known as the region of *correct* exposure. But at the beginning and the end, the curve is not straight; at the beginning, the slope of the curve increases; this is known as the region of *under-exposure,* and at the top of the curve the increase of density falls off and finally it fails to increase at all when the exposure is increased; this is the region of *over-exposure.* We may note that in the example taken the under-exposure region persists while the exposure increases from unity to three and one-half units; then we have correct exposure until the exposure becomes about one hundred and twenty-eight units, and then the over-exposure region appears, differences in exposure failing to show an increase in density after about five hundred units of exposure. For a rapid film, the point marked unity on this curve represents an exposure of about $^1/_{50}$ of a candle-foot-second; that is, this film requires an exposure of $^1/_{50}$ of a second to a candle at one foot distance in order to give the first visible trace of deposit.

When photographing a landscape, we want to obtain in our negative just a trace of deposit for the shadows, and we have already seen that the image of the shadows on the film will have a brightness of one foot-candle, so that the correct exposure time to give for such a landscape will be $^1/_{50}$ of a second with the lens working at an aperture of *f*.8. The exposure given for such a landscape will therefore vary from $^1/_{50}$ candle-foot-second in the shadows to $^{30}/_{50}$ or $^3/_5$ of a candle-foot-second for the sky.

This reasoning applies to an ordinary film, but photographic materials are of various speeds, and we can clearly define the speed according to the exposure required to give an impression upon it. The shorter the exposure required, the "faster" the film; and from the exposure which we find to be required, we may calculate a number which will represent the "speed" of the film.

A film might be said to have a speed of unity which requires the exposure of $^1/_{50}$ of a second to give a deposit equal to that given by the light of an intensity of 1 foot-candle, such as is produced in the camera with a lens working at an aperture of *f*.8 by the light, reflected from the darkest shadows of a landscape. But it would be inconvenient to choose unity as the speed of our film, because the speeds of all slower materials would have to be expressed in fractions, and in practice such a film is said to have a speed of 250 in the units generally used by photographic workers.

We see, therefore, that for a film of speed 250 at *f*.8 we shall require an exposure of $^1/_{50}$ of a second if the light reflected from the darkest portion is about 100 foot-candles. If the light reflected from the darkest shadow of the object is one foot-candle, we shall require an exposure of one second on a film of speed 500, or 500 seconds with a film of speed one. Or, generally, if L is the light intensity from the darkest part of the subject, P is the speed of the film or plate, and E is the exposure at $f.8$, then

$$E = \frac{500}{L \times P}$$

E being exposure in seconds, L in foot-candles, and P in the usual speed units.

It will be seen that this method of calculating exposures assumes that the exposure is made for the shadows, and in practical photography this is almost always true; one exposes to get shadow detail and trusts to the latitude of the emulsion being sufficient to render the whole scale of gradation of the subject.

If, instead of a landscape with foreground, we photograph a quite open landscape with sea or open country in the distance, then the darkest part of the picture will reflect perhaps $^1/_5$ of the sky light or about 500 foot-candles. Using a film of speed 250, we should have to give an exposure of only $^1/_{250}$ second at $f.8$ or about $^1/_{60}$ of a second at $f.16$.

Using this line of reasoning, let us consider what the shortest exposures practicable for figures in rapid motion are likely to be. The range of contrast when taking a photograph of an athlete jumping, for instance, will be much smaller than in our typical landscape, and probably 1 to 10 would be a fair approximation; if the scene is in sunlight, the shadow detail may be represented by 250 foot-candles. Using the rapid lenses available for such work, we may reckon on having 3 times as much light as a lens at $f.8$ will give, and we can use a plate of speed 500; the exposure required will therefore be $500/(250 \times 3 \times 500)$ or $^1/_{750}$ of a second. We see, therefore, that unless the light conditions are of the very best, the use of such high shutter speeds will involve some degree of under-exposure, and this fact illustrates the advantage, well-known in practice, of taking very rapidly moving objects as silhouettes against the sky.

When photographing in the streets of cities, a considerably greater exposure is permissible than in landscape work, because there are always deep shadows outside the main range of contrast, in which an increase of exposure will give detail at the expense of the highlights, and an increase of exposure therefore means a shifting of the center of the scale of gradation from the highlights to the shadows. In practice topographical views are usually made at the shorter exposures, while the pictorial photographer prefers the longer exposures which concentrate interest on the lower-toned portions of the picture.

When using color filters, their factors must be allowed for in considering exposure; thus, taking the speed of film as 250, the use of the color filter requires an increase of five times in the exposure, so that for our typical landscape when using a color filter at *f*.8 we shall need an exposure of $^1/_{10}$ of a second.

Positive Printing

When printing positives either on paper or on plates for lantern slides, working conditions are somewhat different, no camera being used and the object reproduced being a negative instead of the original subject. The range of contrast in negatives is frequently much greater than in natural objects, but the exposure is governed by the same conditions as those which apply in the negative making. Such an exposure must be given that the greatest opacity which it is desired to print through at all just produces a visible deposit. Usually the highest light of all should be printed free from any deposit, and the next tone to this should be taken as the one to be printed through.

Turning to the curve shown in Figure 6 and considering a bromide paper, this will have a speed of about 5 on the speed scale, so that it is 50 times slower than the film which we considered first and the point marked 1 on the exposure axis corresponds to an exposure of a candle-foot-second. Now the highlight which we shall want to print through in an average negative will let through only about $^1/_{20}$ of the light, so that we shall have to give such a bromide paper an exposure of 20 candle-foot-seconds behind such a negative, and for a paper or plate of any speed we may write:

$$E = \frac{5 \times O}{P}$$

where P is the speed of the paper and O is the opacity of the highlight in the negative which it is desired to print through. If the highlight in a negative lets through $^1/_{20}$ of the light, then the opacity of that negative is said to be 20. If it lets through $^1/_{100}$, it is 100, and so on.