The Camera and Photography

CHAPTER 4

4.1
INTRODUCTION

Photography* resulted from the fortunate and ingenious union of the optics of the camera and the chemistry of light-sensitive materials made into film. For several centuries, people amused themselves with cameras of various kinds, from small portable models used as artists' aids, to large rooms you could enter and see realistic, moving, full-color projections of the scenery and life going on outside (Fig. 2.7). But the key step of recording such images permanently was not taken until about 150 years ago, when the precursors of our modern film were developed. Since then, a steady improvement in both cameras and film has resulted in a wealth of sophisticated photographic devices: from the instant camera that delivers a sharp, colorful photograph moments after a button is pushed, to specialized astronomical cameras for recording distant galaxies, to cameras capable of revealing the different stages of the explosion of a balloon as a rifle bullet pierces it. The veracity of the medium is summed up by the Japanese ideographs for "photography": *shashin*, literally "copy truth." The ubiquity of photography and its power to capture not only the ordinary, but the distant, the transient, the colorful, the otherwise unobservable, has greatly expanded our knowledge (not to mention our aesthetics). In 1925, when cameras were primitive by today's standards, the artist and photographer László Moholy-Nagy wrote: "We have—through a hundred years of photography and two decades of film—been enormously enriched. . . . WE MAY SAY THAT WE SEE THE WORLD WITH ENTIRELY DIFFERENT EYES."

Let's see how a camera manages to turn an eye on the world.

A. The essential parts of a camera

To produce a photograph, a ***camera*** must project on its film a good image of controlled intensity for a controlled amount of time. A somewhat old-fashioned camera (Fig. 4.1) is simple and large enough to illustrate all the essential parts clearly. The bulk of it is a *light-tight box*, which allows only the desired light to fall on the film. It has a ***lens***

*Greek *photo*, of light, plus *graphein*, recording.

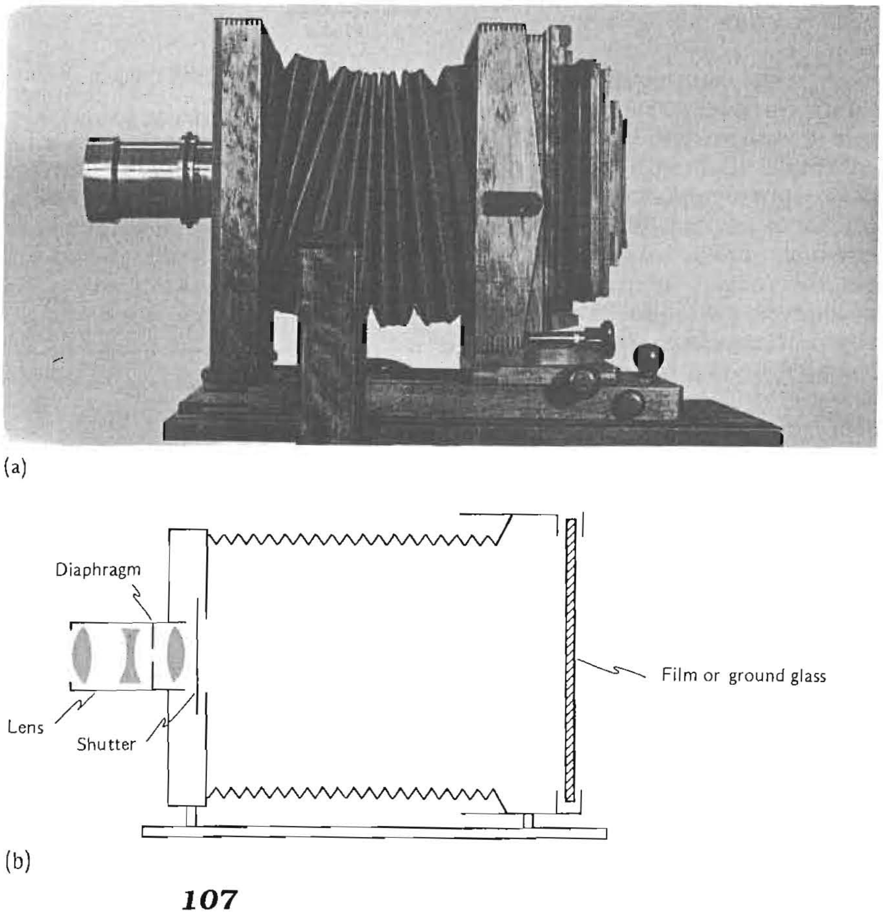


FIGURE 4.1

(a) Photograph of a large-format camera. The brass cylinder contains the lens. The back of this camera can carry either a ground glass screen for viewing or a film holder. (b) The essential parts of this camera.

in front to project a real image on the film, and a device to move this lens in order to focus the image on the film. The camera has an adjustable ***diaphragm*** to control the intensity, and a ***shutter*** to control the duration, of the light falling on the film. The back of the camera carries the ***film*** and devices to advance or change it between exposures. This fundamentally simple gadget allows us to do something fairly incredible: to preserve a permanent image of the world around us with almost no effort on our part.

The minimal effort required has always been one of the attractions of photography. In 1838, shortly after he perfected his process of making a permanent photograph, Daguerre commented on the ease of the process: "the little work it entails will greatly please the ladies . . . ." By 1889, George Eastman, the founder of Kodak, used a less sexist version of this statement to popularize his camera: "You push the button, we do the rest."

Many ingenious mechanical components have been invented to make picture-taking easy. For example, the bellows allows the lens to move while keeping the box light tight, cartridges let you put film into a camera without carrying a darkroom tent with you (as the early photographers did), and sprockets advance the film by precise amounts. You can easily figure out the purpose of many of these mechanical parts, so let's consider some of the less obvious optical components of a camera.

4.2
FOCUSING THE IMAGE

In Section 3.4C, we saw how to locate the real image produced by a converging lens. To record this image, we put our film in the plane of the image. If the object were at a different distance from the lens, the image would be located on a different plane and we would have to relocate the film (or the lens)—the process of ***focusing.***

A. Depth of focus, depth of field

Suppose you are taking a photograph of a friend and you have focused her image onto the film. No matter how careful you are, her image generally will not lie exactly on the film and thus will be slightly blurred there. Luckily, you needn't have the image perfectly focused for the photograph to come out acceptably sharp. A little bit of blurring is not noticeable to your eyes, and in any event, all film has limitations that prevent it from recording absolutely sharp pictures, and there is always some blurring due to lens aberrations and motion of the object or camera. All of this means that if the image is not exactly on the plane of the film, the photograph may be only negligibly blurred. Thus there is a *range of film locations*, called the ***depth of focus,*** for which the photo of an *object at a given distance* comes out acceptably sharp (Fig. 4.2a).

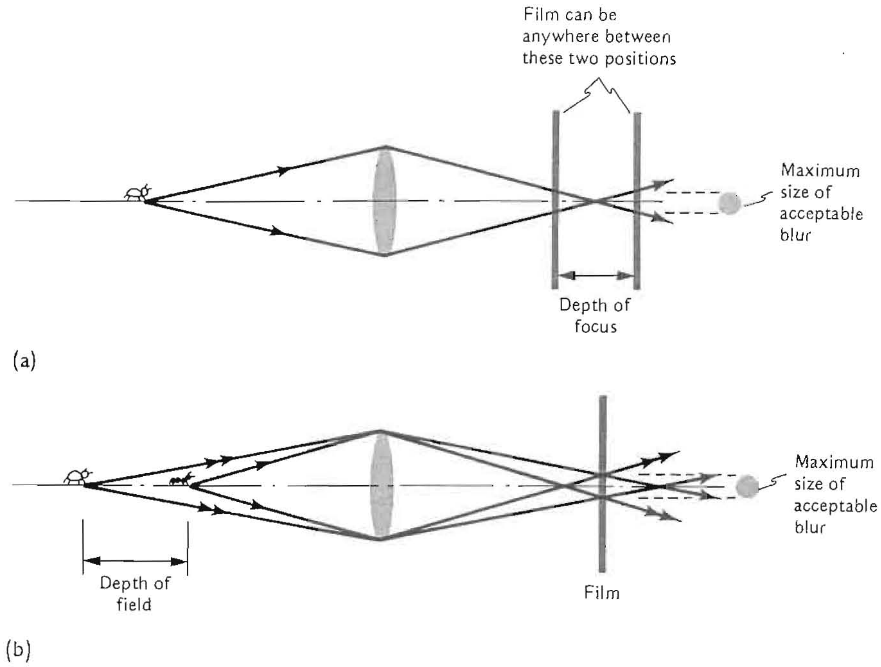
Suppose now that you wish to photograph *two* friends, each at a *different* distance. If you move your film to make one friend's image in focus, the other friend may be slightly *out* of focus. If your friends are at nearly the same distance, however, both images will be reasonably sharp. The *range of object distances* that result in an acceptable photograph, for a *given film location*, is called the ***depth of field*** (Fig. 4.2b). If one person is very close but the other is very far away, you cannot focus on both of them simultaneously—they both do not lie within the depth of field of your camera and hence at least one of their images will be significantly blurred. For this reason we needed two photographs for Figure 3.7. (Notice that the scratches on the plane mirror are visible only when the camera is focused on the image that is nearest to them.)

The depth of field depends on how far away you are focusing. For instance, no matter how far separated your friends are, if they are *both* very far away, their images will lie close to the focal plane of the lens and will be acceptably in focus—the depth of field is largest for distant subjects.

Adequate depth of field helps solve many focusing problems. Not only does it allow us to photograph

FIGURE 4.2

(a) Depth of focus. For the range of film positions shown, the image of the fixed object will be acceptably in focus.
(b) Depth of field. Objects within the range shown are acceptably in focus for the particular lens-film distance chosen.



three-dimensional (rather than only flat, planar) objects, it also lets us sometimes get away without having to focus at all ***(fixed-focus camera)***. Suppose a camera lens is mounted at some fixed distance from the film, such that the image of an object 3 m away is exactly on the film. Suppose further that the depth of field is from 1.5 m to infinity. Such a camera works fine, without the need to focus, for snapshots of people and landscapes (because the polite photographer does not approach people closer than 1.5 m). Many inexpensive cameras are made this way.

B. *The view camera*

To enable focusing on close as well as on distant objects, the lens (rather than the film) is usually made movable within the camera body. Moving the lens moves the image, so it can be manipulated to fall on the fixed film position.

One way to know when the camera lens is adjusted to its proper position is to replace the film by a ground glass screen and look at the image to see if it is sharp (Fig. 4.3). After focusing, the ground glass screen is replaced by a film holder, a slide that covers the film is removed, and then the film can be exposed. Although this somewhat lengthy procedure does not suit most people's fast-moving life style, such ***view cameras*** are still used for exacting work.

C. *The single-lens reflex*

A modern version of focusing by viewing the image directly is found in ***single-lens reflex (SLR) cameras*** (Fig. 4.4). Instead of exchanging ground glass and film, the image is first projected on the ground glass by a 45° mirror* that flips out of the way just before the picture is taken, allowing the film to be exposed. To view the horizontal ground glass ***focusing screen*** directly, the photographer would have to look down into the camera, and he would see a left-right reversed image. To avoid this image reversal, the viewfinder usually is provided with a ***pentaprism,*** a device that rotates the image for horizontal, nonreversed viewing.

The SLR's viewing system also may incorporate other interesting tricks to make the focusing easier: the ground glass, which scatters light in all directions, is sometimes replaced by a Fresnel ***field lens,*** which directs most of the light toward the eye, giving a more nearly uniform, bright image, especially around the edges (see Sec. 6.6A).

Another trick relies on the fact that a prism displaces the apparent

*Which reflects, hence "reflex."

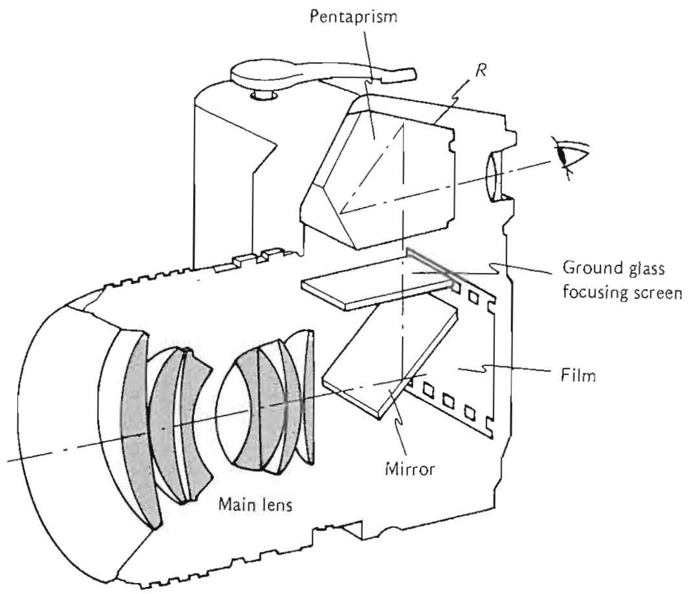


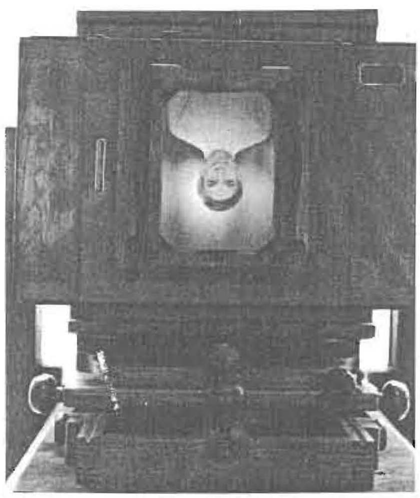
FIGURE 4.4

The main parts of a modern single-lens reflex camera. The distance of the light path from the lens to the film is the same as from the lens to the focusing screen by way of the mirror. The pentaprism inverts the image on the focusing screen before the photographer sees it. The roof *R* of the pentaprism consists of two faces that provide extra reflections perpendicular to the plane of the figure in order to reverse the image in that direction as well.

FIGURE 4.3

(a) The traditional view of a traditional photographer looking into the back of the camera, with a black cloth thrown over his head to exclude stray light so he can see the screen. **(b)** The actual view that the photographer may have as he looks into the back of his view camera.

(a)



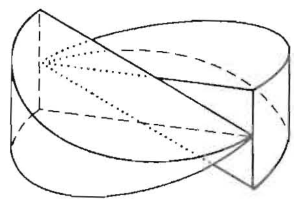
(b)

location of an object by an amount that depends on the distance of the object from the prism, and on the orientation of the prism. If you view this page through a prism, it will look displaced. Reversing the direction of the prism (so the base of the wedge is toward the left instead of the right) reverses the direction of displacement. As the prism gets closer to the paper, the amount of displacement gets smaller. When the prism rests on the paper, there is no displacement (for a thin prism). Therefore, if a pair of prisms that slant in opposite directions (a ***biprism***) is mounted on the focusing screen, the images seen through these prisms are displaced in opposite directions, *unless* the images lie exactly *on* the focusing screen. Unless the image is properly focused, then, you see a ***split image*** (Fig. 4.5). Since your eye can detect a break in a straight line with remarkable precision, this allows you to focus very accurately.

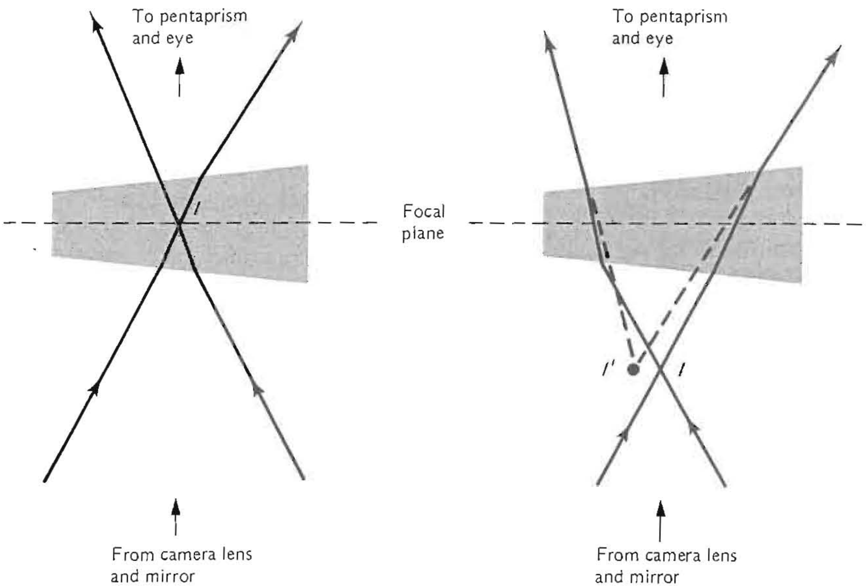
On some cameras, many small biprisms ***(microprisms)*** are distributed all over the viewfinder's field of view. The image is then broken up everywhere when it is not in focus, with the result that it appears to go out of focus much more quickly when the camera is defo-

FIGURE 4.5

(a) A biprism of the type often mounted in the center of the ground-glass screen of an SLR. **(b)** Effect of one of the prisms: When image *I* is on the focal plane, it is seen undisplaced (left). When it is below (or above) the focal plane, it is seen displaced, as *I'* (right).
(c) Photograph of the resulting split-image effect, when in focus (left) and out of focus (right). (Note the ring of microprisms around the central biprism.)



(a)



(b)

(c)

cused than without the microprisms. This of course also permits precise focusing.

D. The rangefinder

Cameras other than SLR's employ a different means of focusing. It is easy enough once and for all to calibrate the device that moves the lens. Often the lens moves in and out on a screw fitting, and the object distance corresponding to the various settings is marked on the rotating focusing ring (Fig. 4.6a). To focus by this scale we only need to measure the object distance, for example by pacing it off. One cannot pace to all subjects, though (e.g., down a steep cliff, or across an alligator-infested swamp).

Where no great accuracy is necessary, the *apparent size of a standard length,* such as a typical person, can be used: if the person's head just fills the viewfinder, she is quite close; if the frame shows her from head to toe, she is at some intermediate distance; and if she is much less than a frame's size, she must be pretty far away, effectively at infinity. On simple cameras the focusing scale is often marked only according to these three situations (Fig. 4.6b), with satisfactory results.

For more critical work one uses a ***rangefinder*** based on the principles of surveying ***(triangulation),*** as shown in Figure 4.7a, where P measures the angle between his line of sight (PS) and B's line of sight (BS) as well as the (alligator-free) distance from P to B. With the help of a little mathematics, he then deduces the desired distance $\overline{PS}$.

A rangefinder follows the same principle (Fig. 4.7b) but replaces B by a rotatable mirror M_B, P by a half-silvered mirror M_P, and P's mathematics by a built-in scale that converts the angle of M_B into the distance $\overline{PS}$. You fool around with M_B until the image seen reflected in M_P and M_B coincides exactly with that seen directly through M_P. In fact, M_B can be directly coupled to the camera's lens position so that the camera is always focused on the place where the two rays seen through the rangefinder intersect.

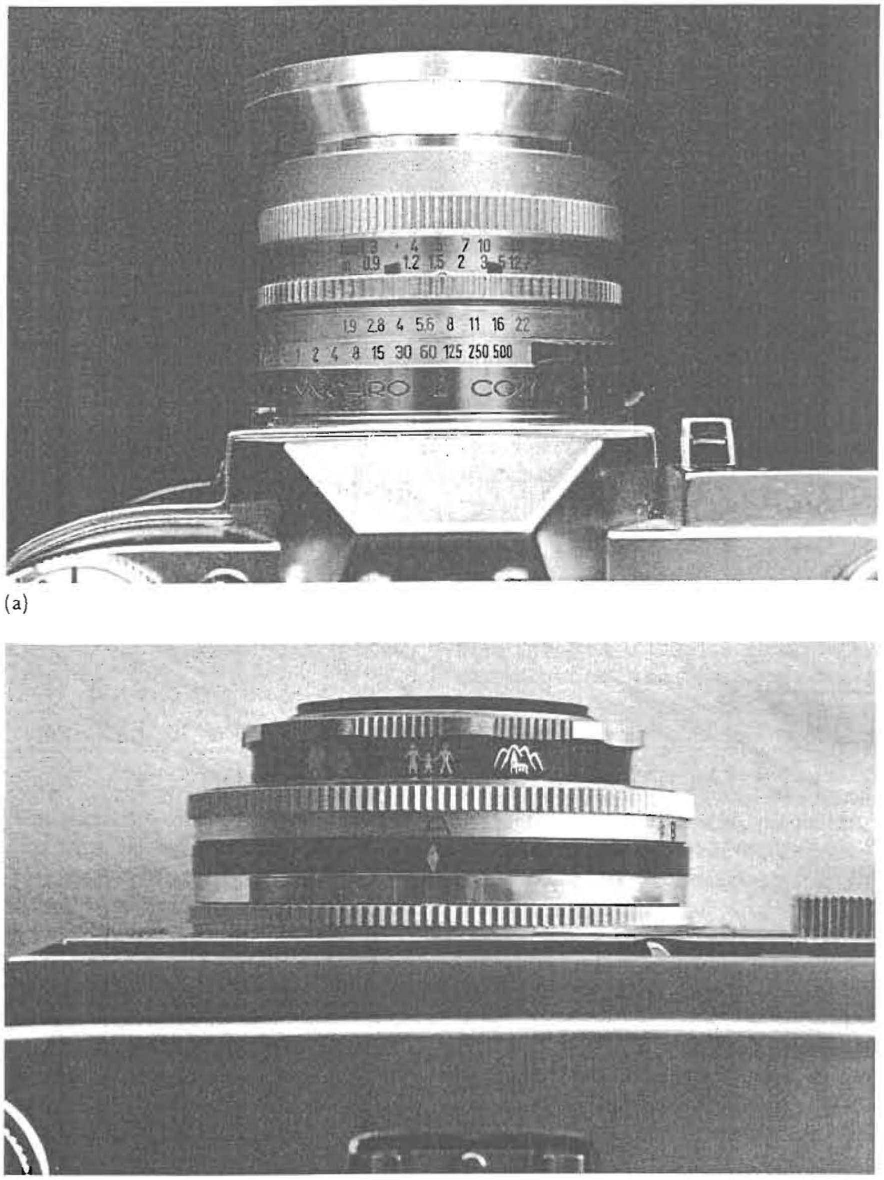
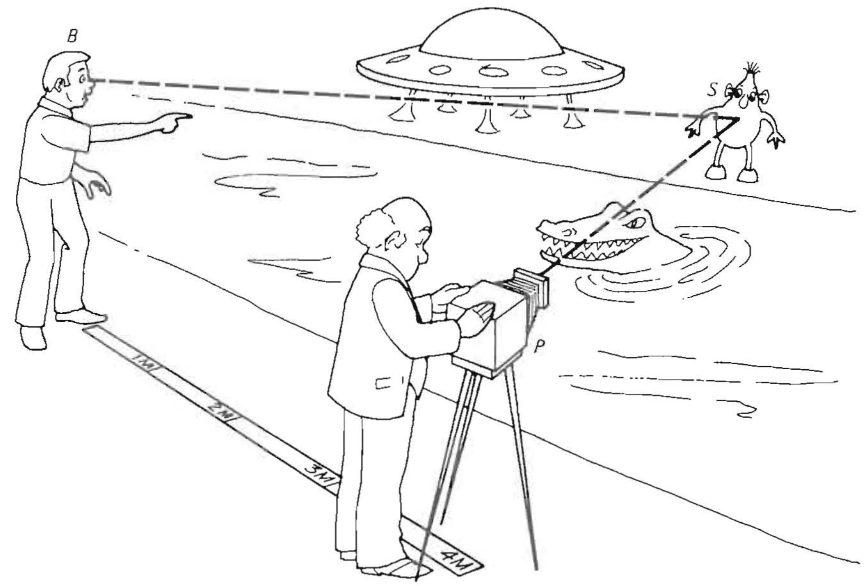


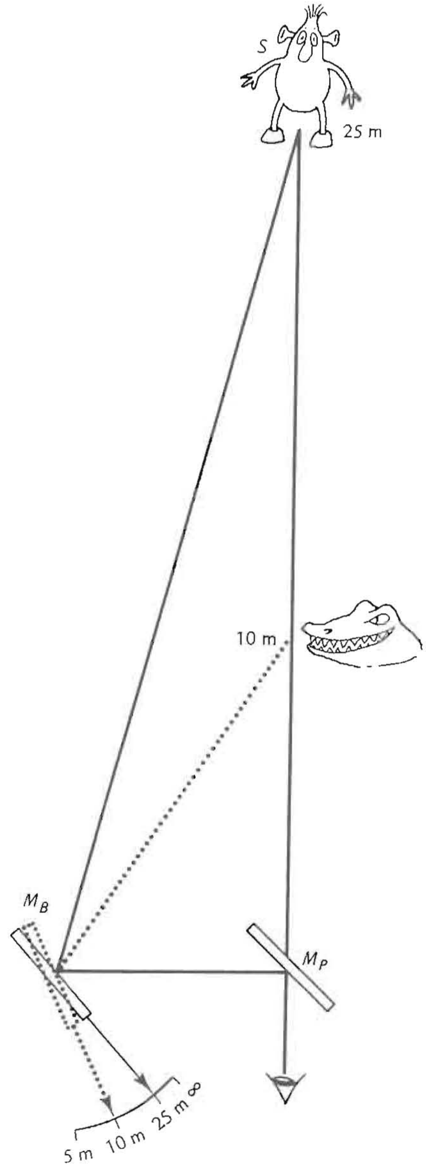
FIGURE 4.6

Photograph of distance scales on photographic lenses. **(a)** Distance scales in meters and feet. Pointers not only indicate the distance of best focus, but also bracket the depth of field. Note how the close distances are spread out, and the far distances are crowded together on this scale, corresponding to the way the lens crowds together the images of distant objects. **(b)** Size of common objects as seen in viewfinder may serve as distance indicator.

The rangefinder can do double duty if it is also coupled to the viewfinder window (the window through which you frame your picture) to correct for ***parallax.*** Suppose the viewfinder is 5 cm above the camera lens. Then the field seen by the viewfinder is 5 cm higher than what the camera photographs. These 5 cm make no difference in a picture of a distant landscape, covering many meters or kilometers; but a closer object might miss its top 5 cm in the finished photo. Tilting the viewfinder by an amount determined by the rangefinder setting can eliminate this parallax discrepancy.



(a)



(b)

FIGURE 4.7

(a) The rangefinder problem: Our photographer *P* wants to measure the distance $\overline{PS}$ to a subject *S*. A bystander *B*, a little distance away, is also staring at *S*. (b) Solution to the rangefinder problem.

Rangefinders have been automated for cases where speed (or laziness) is of the essence. Some cameras send out an infrared beam and hunt for its reflection from the object by a displaced rotating mirror, similar to M_B of Figure 4.7b. Others use the echo technique discussed in Section 1.1B, not with light but with a slower sound pulse (sonar).

PONDER

Which of these automatic rangefinders would work on the moon (where there is no air)?

4.3 EFFECTS OF FOCAL LENGTH

High-quality cameras can not only move their lenses for focusing, they can remove them entirely and replace them with lenses of different focal lengths; or they have a zoom feature, which smoothly changes the focal length of a lens. The point is to be able to change the *size* of the image without having to change the camera's position.

A. Telephoto and wide-angle lenses

Consider an object sufficiently distant that the image is at the lens' focal plane, to a good approximation. Since the central rays (ray 2) are undeviated by any lens, the size of the image must be proportional to the lens' focal length (Fig. 4.8). So a lens of larger focal length gives a larger image, as if you were photographing through a telescope. A long focal length lens is a **telephoto lens,** and is what the photographer of Figure 4.7a should use (rather than trying to get closer to *S*). A telephoto lens makes a big image of a small portion of the scene, so it

TABLE 4.1 Focal length and angle of view for 35-mm cameras

Focal length of camera lens	Wide angle			Normal	Telephoto		
	17 mm	28 mm	35 mm	50 mm	85 mm	135 mm	300 mm
Diagonal angle	104°	75°	63°	47°	29°	18°	8.2°
Horizontal angle	93°	65°	54°	40°	24°	15°	6.9°
Vertical angle	70°	46°	38°	27°	16°	10°	4.6°

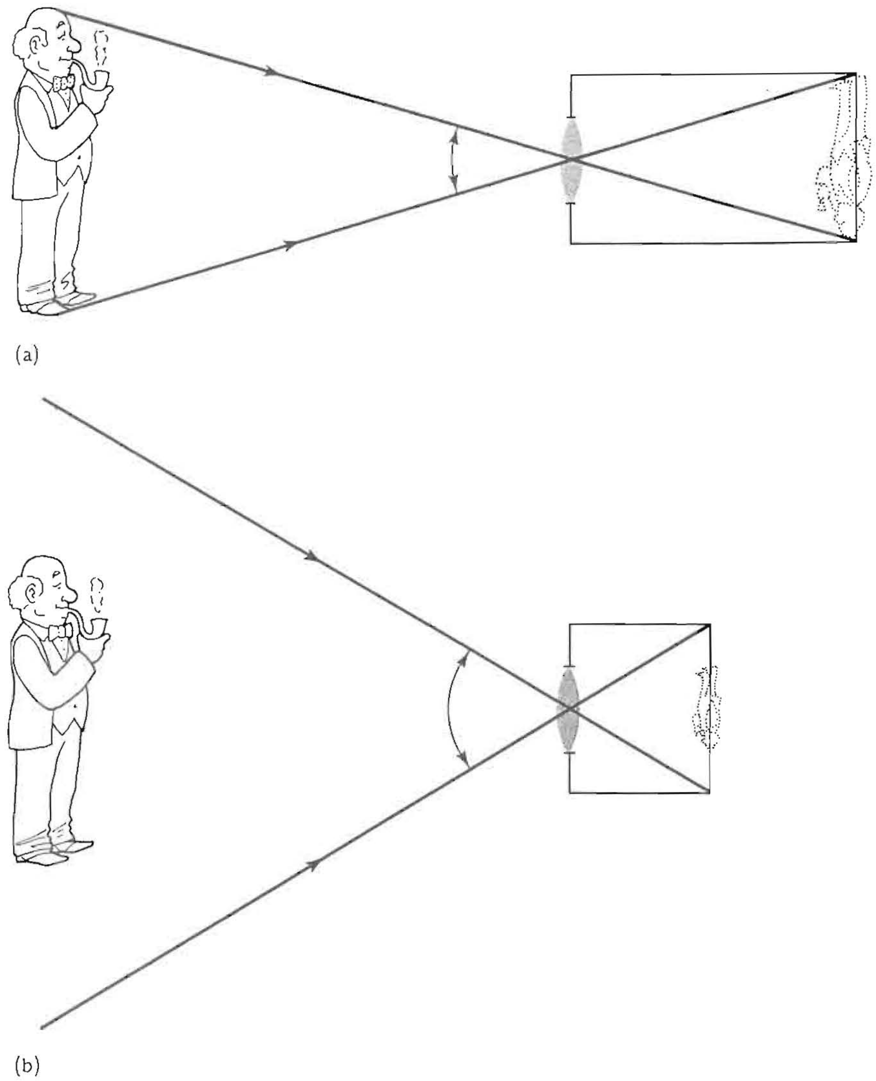


FIGURE 4.8

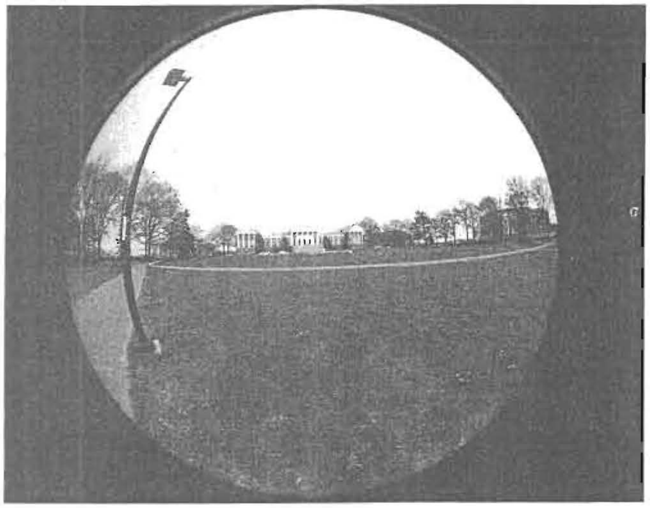
Image size and angle of view depend on lens-film distance. The two lenses have different focal lengths and must be at different distances from the film to produce a sharp image of a given object. **(a)** The long focal-length lens produces a large image of the object and has a small angle of view. **(b)** The short focal-length lens produces a small image of each object and has a large angle of view.

corresponds to a small ***angle of view*** (Fig. 4.8a). Angle of view is specified in degrees—the angle subtended at the camera by the entire scene recorded, customarily measured along the diagonal. Table 4.1 gives this angle for various lenses on a 35-mm camera.

The opposite effect is achieved by a lens of *short* focal length. Here the image of any object is smaller, hence more objects will appear in the same film frame; the picture will take in a larger angle of view. Such a short focal length lens is called a ***wide-angle lens.*** It makes an image of a larger portion of a scene (Fig. 4.8b), and, therefore, is useful when you cannot step back to encompass all of a large object in your picture, for example, to snap a large building from across a narrow street. Lenses of an intermediate focal length, neither telephoto nor wide angle, are called ***normal*** (Fig. 4.9). Experience shows that pictures appear normal when the focal length of the lens roughly equals the diagonal of the film frame. For example, as 35-mm frame has dimensions 24 × 36 mm, and a diagonal of 43 mm. So 40 to 50 mm is a normal lens for a 35-mm camera. Whereas a $3\frac{1}{2} \times 4\frac{1}{2}$ inch Polaroid picture has a 12-cm diagonal, which is close to the focal length of the normal lens on a Polaroid camera.

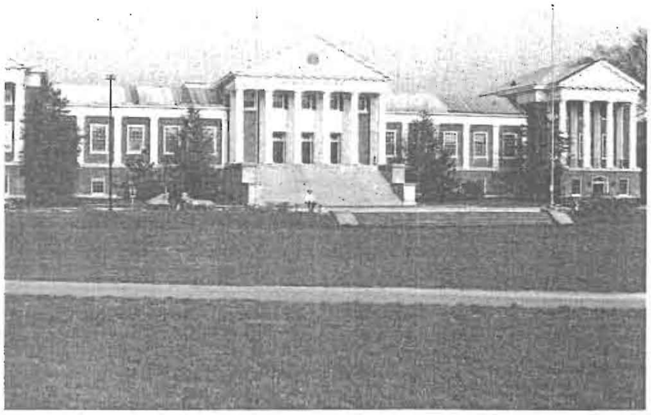
Another type of special lens is called for when you want to photograph small objects. One way to get a large picture is to approach the object closely. However, the closer the object is to the lens, the farther the image is. For close-up work, the lens-film distance needs to be considerably greater than the focal length (e.g., for 1:1 reproduction it should be $2f$, see Fig. 3.26), and the usual focusing range of the lens does not extend that far. Hence, you can either put the lens on a special ***extension tube*** or ***bellows*** (to increase the lens-film distance), or you can use a close-up lens (Sec. 4.4D). Another problem associated with close-up work is that you must get uncomfortably close to the subject, for example when trying to photograph the pistil and stamen deep in a flower. You could use a lens with long focal length (as long as that of a telephoto lens) whose aberrations have been corrected for close-up work. Such a ***macro lens*** demands a large film-lens distance, but allows you to move back comfortably from the subject.

If you want an image that is really large, larger than the object, you can get a reversal ring, which allows you to reverse your telephoto lens, so that the end usually facing the film faces the object. This is done because the lens aberrations are corrected assuming a distant object and a nearby image. The lens is equally well corrected if you run the light rays backward, as long as the "front" is always facing whichever is more distant, object or image. If the object is at about the focal length, the image must be considerably farther from the lens than its normal distance. In this way you can get considerable magnification, but, as we'll see in Section 4.5B, you also sacrifice some light.



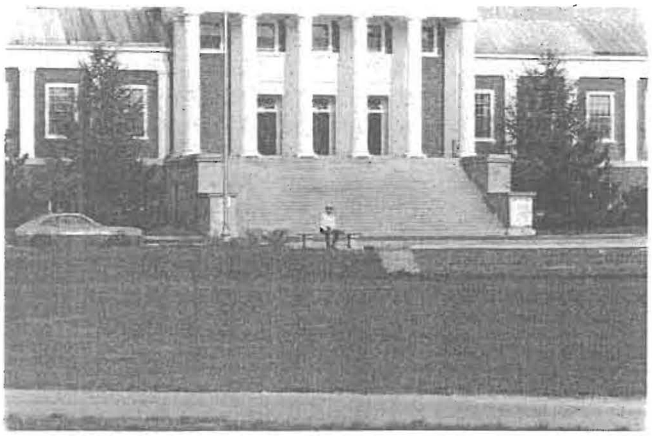
f = 8 mm

f = 28 mm

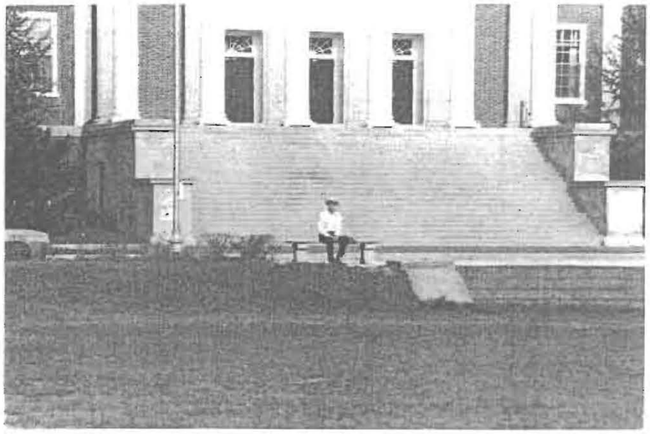


f = 50 mm

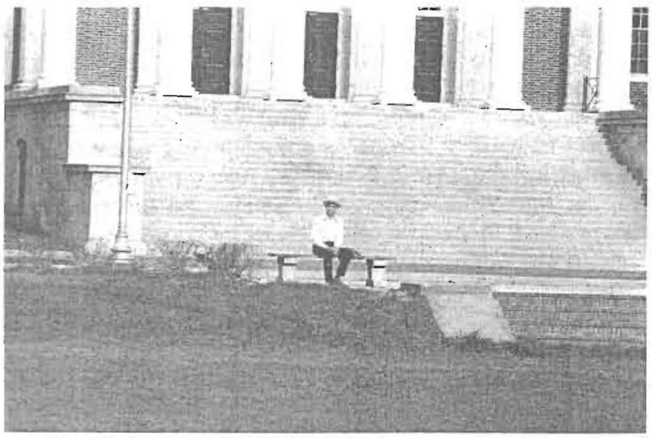
f = 75 mm



f = 100 mm



f = 150 mm



f = 200 mm

f = 400 mm

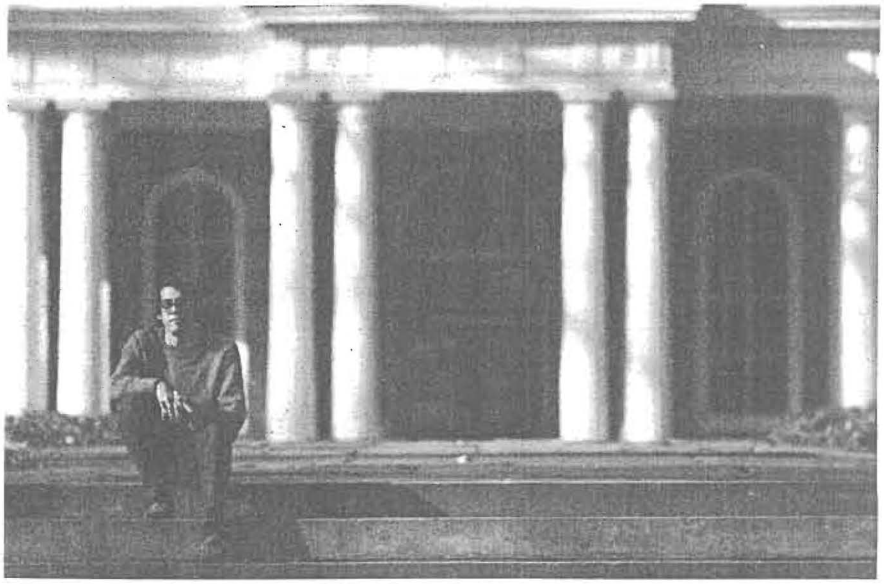
FIGURE 4.9

Photographs taken by a 35-mm camera with lenses of different focal lengths, as given below the pictures. Notice that the telephoto pictures are the same as smaller regions of the f = 50-mm picture.

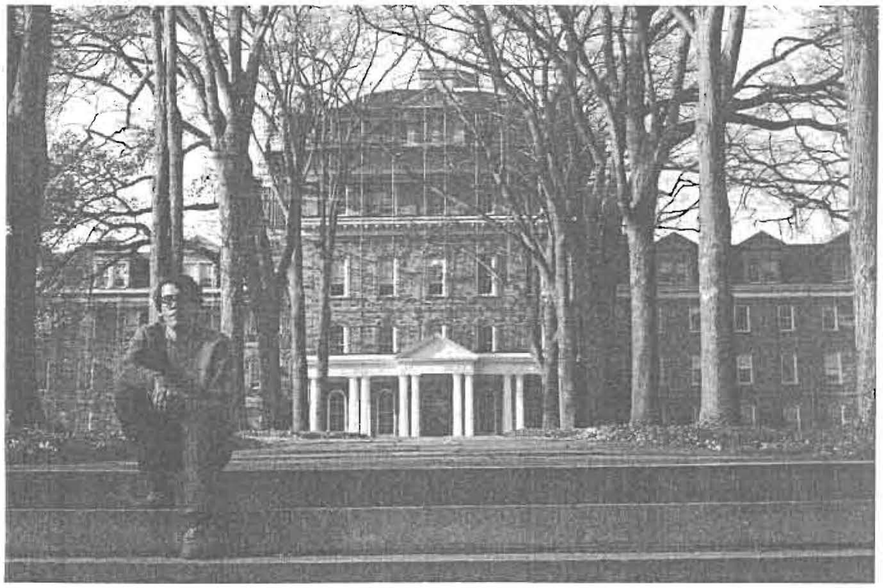
B. Perspective

It is sometimes said that wide angle and telephoto lenses distort ***perspective.*** This is not strictly true; a telephoto picture is the same as a small portion of a normal picture taken from the same place (see Fig. 4.9). You could make the two pictures identical by enlarging the central portion of the normal picture. But enlarging the normal picture only increases the sideward dimensions, not the apparent depth. So it is as if in the original scene everything kept its *distance* from you but grew in the *lateral* directions by the enlargement factor. Judged by your normal conditioning of space perception, objects along the line of sight look crowded in such photos. That is, under normal viewing conditions, a *telephoto lens* gives a *larger image* (side to side), as if you were closer, but the *same perspective* (depth relations) that you had from the point at which you took the picture (see the TRY IT and Appendix G).

Conversely, in a *wide-angle picture* it is as if everything in the picture had *shrunk* in the *lateral directions* only, but kept its distance along the line of sight. A person's nose then seems to bulge out far too much toward the camera, and looks too large compared with the size of the head. If you place your eye sufficiently close to a wide-angle picture so that the picture subtends the *same* large angle at your eye as the original scene did at the camera, everything looks normal again (Fig. 4.10).



(a)



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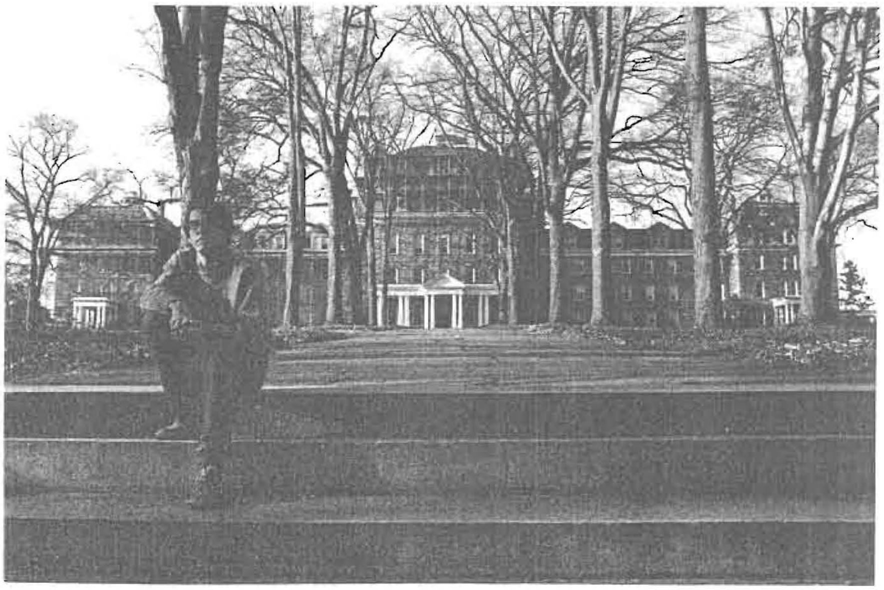

(c)

FIGURE 4.10

Object distance and focal length were changed simultaneously in these photographs so as to keep the size of the main subject constant. The size of objects at other distances varies, changing the perspective: **(a)** telephoto perspective, **(b)** normal perspective, **(c)** wide-angle perspective. If you hold your eye about 5 cm from **(c)**, the perspective should look normal again. (You probably cannot focus clearly on such a short distance, unless you use a magnifying glass.)