Chapter 3
Lenses

Objectives
Information in this chapter will enable you to:
• List two simple rules of light and optics.
• Define transmitted light and tell why it is important to photography.
• Describe the types of lenses and how each transmits light.
• Explain focal length, aperture, and f-numbers.
• Describe different types of lens mounts.
• Describe the proper method of cleaning a lens.
• Describe how to change lenses while minimizing the amount of dust getting in the camera.

Technical Terms
aberrations
angle of view
bayonet lens mount
compound lens
correction lens
crop factor
divergent lens
element
fast lens
f-number
f-stop
focal length
focal plane
focus
image point
image size
incident light
lens
lens aperture
lens mount
magnification
negative lens
normal lens
optics
positive lens
refraction
screw mount lens
single-touch zoom lens
stopping down
two-touch zoom lens
zoom lens
A lens is a transparent material that has at least one curved surface. See Figure 3-1. When light enters the camera, it passes through a lens. The lens collects and bends light rays. The rays are bent so they form a sharp image on the film or digital sensor. See Figure 3-2. A lens can be made of special optical glass or plastic.

Simple Rules of Light and Optics

To understand how a lens works, some basic rules of optics, the physics of light, must be known. Light usually travels in straight lines, called rays. See Figure 3-3. If there is nothing in the path of a light ray, it will continue in the same direction. Light rays can be transmitted, absorbed, and reflected. The shape and properties of a material will determine what happens to the light ray after it contacts the material. See Figure 3-4.

In the study of camera lenses, we are mostly concerned with transmitted light. This is the light that passes through the lens.

Transmitted Light

Light rays can travel through a transparent or clear material such as water, glass, and plastic. The light rays, however, are bent as they pass through. The bending of light as it passes through an object is known as refraction. The principle of refraction makes it possible to design lenses that can make an object appear larger or smaller.

The Pinhole Camera

A simple pinhole camera can make photographs without a lens. See Figure 3-5. Light reflected from the subject enters through the pinhole. It travels through the empty space inside the camera to form an image on the film. The tiny pinhole allows light rays to travel in a straight line from the subject being photographed to the film. An inverted (upside-down) image strikes the film. See Figure 3-6.

If the pinhole is made larger it admits more light, but rays passing through the pinhole scatter. The resulting image is not very sharp. Figure 3-7 shows photographs taken with a pinhole camera.

Such cameras are not very practical for general photography. The results are poor,
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especially if there is any movement. Exposure times are long. But, the pinhole camera demonstrates how simple photography can be.

Web site
www.pinholeday.org
On the last Sunday of April each year photographers take pictures with a pinhole camera. You can post one of these photos to the website to share with visitors all over the world. Worldwide Pinhole Photography Day was created to promote and celebrate the art of pinhole photography.

Kinds of Lenses
The pinhole can be replaced with a simple lens. See Figure 3-8. Since more light can enter the camera, exposure time is reduced. However, a shutter is now needed to control the light.

Figure 3-8. A simple lens is more practical than a pinhole. The lens allows more light to strike the film.

The shutter is placed in or behind the lens, and can be opened for carefully measured lengths of time. Light falling on the film or digital sensor can be controlled to fractions of a second.

Light striking the surface of an object is called incident light. See Figure 3-4. A light ray passing through a sheet of glass changes its path as it enters the glass. However, the light ray will exit, traveling in the same direction as when it entered. See Figure 3-9.

This only happens when the glass surfaces are parallel. If the surfaces are not parallel, as in a prism, the rays will be refracted or bent at each surface. See Figure 3-10.

Most inexpensive cameras have simple lenses. The simple lens can be compared to two prisms placed base-to-base. See Figure 3-11. Notice how the light rays pass through the prisms. The rays do not converge (come together) at the same point.

However, by rounding the prisms, the rays passing through the lens are made to converge or focus at the same spot. This common spot is called the image point. The film or sensor in the camera is at this point. See Figure 3-12.

A simple lens is made of a single piece of glass or plastic. It may not meet all of the requirements for good photographs. Several lenses that refract light differently may be necessary to correct defects.

The Compound Lens
A compound lens is made up of two or more simple lenses, as shown in Figure 3-13. Each simple lens in a compound lens is called an element.

Individual lenses are classified into two major groups:
- A positive lens, also known as a convergent lens is thicker at the center and gathers light. See Figure 3-14. Convergent means it bends the light inward.
- A negative lens, also known as a divergent lens is thicker at the edges and spreads light. See Figure 3-15. It is called divergent because it bends light outward.

Lens Aberrations
Defects or flaws in a lens are called aberrations. These defects are not, in most cases, the result of a manufacturer’s carelessness. They are caused by the behavior of light. A lens maker can correct for most aberrations by using many elements.

Coated Lenses
Modern lenses are also coated to protect against stray light. A thin layer of a chemical substance, usually magnesium fluoride, may eliminate all but about one percent of these reflections. The amber, blue, or magenta tints seen on a lens indicates the presence of this coating.

Lens Quality
Lens quality depends upon the characteristics of the optical glass used and the lens design. Making one batch of glass often requires weeks. Even with rigid controls, most of the batch cannot be used to make quality lenses. The glass that can be used is remelted and cast in molds. The rough glass casting is ground and polished into the finished product.
Models of lenses are drawn on computers and evaluated before they are manufactured. In the past, the calculations were made by hand. It often took years to design a lens.

Finished lens elements are precisely fitted into the lens barrel. The lens barrel is carefully fitted to the camera body.

**Focal Length of a Lens**

All lenses have a focal length. The *focal length* of a lens is the distance between the lens and the focal plane when the lens is set to infinity. See Figure 3-16. The film or sensor surface is called the focal plane. Usually, focal length is described in millimeters (mm), but some lenses use centimeters (cm) and inches. See Figure 3-17 for a list of some common focal lengths. The focal length or range of focal lengths, of a zoom lens, is marked on the lens. You can find the markings on the front of the lens, side of the lens, or multiple places. See Figure 3-18.

<table>
<thead>
<tr>
<th>Wide angle</th>
<th>14 mm</th>
<th>20 mm</th>
<th>24 mm</th>
<th>28 mm</th>
<th>35 mm</th>
<th>50 mm</th>
<th>85 mm</th>
<th>100 mm</th>
<th>135 mm</th>
<th>200 mm</th>
<th>300 mm</th>
<th>400 mm</th>
<th>500 mm</th>
<th>600 mm</th>
<th>800 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telephoto</td>
<td>Infinity</td>
<td>50 mm</td>
<td></td>
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</tbody>
</table>

With modern technology, low-cost lenses can be molded from plastic. Plastic lenses are used mainly in inexpensive cameras.

**Lens Formulas**

A lens is made from a design or formula. The formula gives:
- The type of glass
- Curvature
- Placement and spacing of the elements

![Figure 3-12](image.png)

When a lens is properly designed, light rays passing through will converge, or focus, at the same spot. Film or a digital sensor is placed at this spot called the image point.

![Figure 3-13](image.png)

A compound lens consists of two or more simple lenses. Each simple lens is called an element.

![Figure 3-14](image.png)

A positive or convergent lens is thicker at the center and bends light inward.

![Figure 3-15](image.png)

A negative or divergent lens is thicker at the edges and spreads light.

![Figure 3-16](image.png)

Focal length is the distance between the lens and focal point, film, or sensor surface when the lens is set to infinity.

![Figure 3-17](image.png)

This is a list of common lenses, organized by focal lengths.

![Figure 3-18](image.png)

The area the camera lens sees when focused on 35 mm film. Film image size is 36 mm × 24 mm.
Focal length affected by digital sensor size
The focal length marked on the lens may not be the focal length exhibited by your digital camera. The size of the sensor affects the focal length, typically extending the focal length. The crop factor is the ratio of the diagonal length of a camera’s sensor to the diagonal length of a 35 mm frame. See Figure 3-19. To find the focal length of a lens that is attached to a camera, multiply the focal length printed on the camera by the crop factor. For example, a 50 mm lens mounted on a camera with a crop factor of 1.6 will extend the lens to 80 mm. See Figure 3-20.

Lens Angle of View
The focal length indicates the angle of view of the lens and the image size that will appear on the film or sensor. Angle of view is the largest angle of light rays that will pass through the lens and form an image of acceptable quality on the film or sensor. See Figure 3-21.

Selecting a Normal Lens
A normal lens produces an image about the same, as it would appear to the human eye. The angle of view is almost the same as is seen by the eye.

To determine which lens is a normal lens for a particular camera, find the diagonal distance of the film frame or the sensor. This is approximately equal to the focal length of the camera’s normal lens. See Figure 3-22. The frame size of a 35 mm camera is 24 mm × 36 mm. The diagonal of the frame is 43 mm. A lens with a focal length in the range of 40 mm to 55 mm is considered normal for a 35 mm camera. The 50 mm is a popular normal lens for a 35 mm camera, but there are a few manufacturers making a 43 mm lens. See Figure 3-23.

A 2¼ × 2¼” (6 cm × 6 cm) camera has a frame diagonal of 85 mm. Any lens in the range of 75 mm to 85 mm is considered the normal lens for this camera.

A digital camera with a 24 × 16 mm sensor has a sensor diagonal of about 34 mm. A 35 mm lens is the normal lens for this camera.

Image Size
Image size is the size of the subject produced on the film or digital sensor. The image size can be changed by moving either the camera or subject, or by using a lens of a different focal length. A longer focal length will increase the image size and narrow the angle of view. A shorter focal length will decrease the image size and expand the angle of view.

Figure 3-18. The focal length or range of focal lengths is marked on each lens body at least once.

Figure 3-19. If the digital camera you use has a sensor that is smaller than a 35 mm frame, then there is a crop factor for that camera.

Figure 3-20. Multiply the crop factor by the focal length of the lens to find the true focal length of your lens and camera combination.
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Figure 3-21. The angle of view is the largest angle of light rays that will form an image on the film or digital sensor.

Figure 3-22. The focal length of a normal lens for a particular camera is about the same as the length of the film’s or digital sensor’s diagonal distance.

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See Figure 3-24. A 100 mm lens will produce an image twice the size of a 50 mm lens.

Aperture Control

The lens aperture is a circular opening in a diaphragm that is usually located between the lens elements. See Figure 3-25. On a camera, the diaphragm is a cover made up of metal. Its openings control the amount of light that can pass through the lens to the film or sensor. A large aperture (opening) will admit more light than a small aperture.

Aperture size is specified by f-stops. The f-stops are shown as f-numbers on the lens barrel. See Figure 3-26. Some lenses made just for digital cameras may not have any external adjustable f-stop ring. See Figure 3-27. Internal motors control the adjustment of the aperture on these lenses.
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Pass through to the film or sensor. This permits satisfactory photographs to be taken in dim light.

Closing the lens aperture by one f-stop (f/2 to f/2.8, for example) reduces the light reaching the film or sensor by one-half, as shown in Figure 3-28. Reducing the size of the aperture is called stopping down. The same f-number on any lens of the same focal length will allow the same amount of light to reach the film.

Mounting Lenses on a Camera

The lens mount attaches the lens to the camera body. This feature permits the photographer to change lenses rapidly. There are two main types of mounts: screw mount and bayonet mount.

A screw mount lens uses threads to attach it to a camera body. See Figure 3-29. Several revolutions are needed to seat the lens in the camera body. These are found mainly in older cameras. Caution: Do not force a screw-mounted lens if it does not turn easily in the camera body. Forcing may damage both the lens and camera body, thus resulting in costly repairs.

The bayonet lens mount fits into a mounting flange on the camera body. A twist of 90° or less locks the lens into place. Nearly all major manufacturers of cameras with lenses that can be changed use this mount. See Figure 3-30.

Lens Scales

Adjustable lenses usually have three scales printed on them:

- Distance scale. This tells the operator how far away the subject is when the subject is in focus.
- Depth of field scale. It indicates the nearest and farthest distances the subjects in the picture are in sharp focus.

Figure 3-25. The aperture of a lens is changed with a diaphragm-like device between the lens elements. The amount of light passing through the lens to the film or sensor is controlled by making the aperture larger or smaller.

Figure 3-26. Aperture size is specified by f-stops. They appear as f-numbers on the lens barrel.

The "f" stands for fraction. A larger f-number has a smaller aperture opening. For example, an f/8 (1/8) aperture is smaller than an f/4 (1/4) aperture.

A lens with a maximum f-number aperture opening of f/2.8 is considered a fast lens. A fast lens allows a large amount of light to pass through to the film or sensor. This permits satisfactory photographs to be taken in dim light.

Closing the lens aperture by one f-stop (f/2 to f/2.8, for example) reduces the light reaching the film or sensor by one-half, as shown in Figure 3-28. Reducing the size of the aperture is called stopping down. The same f-number on any lens of the same focal length will allow the same amount of light to reach the film.

Figure 3-27. Many lenses made for digital cameras lack a mechanical aperture ring. The aperture is controlled by internal motors. (Sigma)

A screw-type lens mount was once very popular.

Figure 3-30. A large f-number indicates a small aperture. Stopping down means reducing the size of the aperture.

Figure 3-28. A large f-number indicates a small aperture. Stopping down means reducing the size of the aperture.

Figure 3-29. Screw type lens mounts were once very popular.

Figure 3-30. Bayonet type lens mount. Modern SLR cameras use this type.
Aperture scale. This indicates the f-stop at which the aperture is set. Proper use of the scales is explained in greater detail in the chapter Using a Camera. A typical lens scale system is displayed on the lens barrel shown in Figure 3-31.

Lens Selection

A 50 mm lens is standard or normal for most 35 mm film cameras. This lens usually has a large aperture for low light conditions or fast shutter speeds. The "nifty fifty," as it is sometimes called, is an all-purpose lens when only one lens is available. See Figure 3-32.

As discussed earlier, the 50 mm lens on a 35 mm camera creates pictures with an angle of view close to the human eye.

Wide-Angle Lens

A wide-angle lens has a shorter focal length than a normal lens. See Figure 3-33. At any distance it will take in a larger area than a normal lens. A short focal length gives a greater angle of view. Depth of field also increases with a shorter focal length. Wide-angle lenses are used to photograph landscapes, buildings, and groups of people. See Figure 3-34.

Telephoto Lens

A telephoto lens acts like a telescope and makes distant objects appear closer. See Figure 3-35. A larger focal length gives a larger magnification. Magnification is making things appear bigger than they really are as seen by the eye. Telephoto lenses are useful for nature photography, sports photography, and for taking candid photographs. Figure 3-36 compares wide-angle, normal, and telephoto lenses.

A large focal length lens can be quite large and heavy. A compact telephoto lens is a mirror lens. See Figure 3-37. The light path is folded by a mirror in the lens, making the overall physical length much shorter.

Zoom Lens

A zoom lens is like many different lenses in one, because the focal length is adjustable. See Figure 3-39. Such lenses are found in many different focal length ranges. There are wide-angle zooms, telephoto zooms, and wide angle to telephoto zooms. Most zoom lenses have smaller maximum apertures than fixed focal length lenses. This means that a slower shutter speed is needed. Focusing may also be more difficult without autofocus.
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28 mm wide-angle lens
300 mm telephoto lens
100 mm telephoto lens
50 mm normal lens

Figure 3-36. This set of photos compares wide-angle, normal, and telephoto lenses. (Jack Klasey)

Figure 3-37. A mirror lens is lighter and more compact than a long lens because the mirror folds the light path. (Sigma)

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Manual-focusing zoom lenses are either single-touch or two-touch. With a single-touch zoom lens, focusing is accomplished by twisting a ring to focus and pushing or pulling the ring to change focal length, or zoom. A two-touch zoom lens has two rings, one for adjusting focus and the second for changing the focal length.

Care of Lenses

Never clean a lens with facial or toilet tissue, silicon eyeglass cleaning tissues, handkerchiefs, fingers, or water. For best results, use the following procedure to clean a camera lens thoroughly and safely.

Figure 3-38. A teleconverter can increase the focal length of a lens by a factor usually of 1.4X or 2X. (Sigma)

Figure 3-39. A zoom lens can take the place of a number of fixed angle lenses. A. This autofocus lens covers the wide angle range of 12–24 mm. (Sigma) B. This autofocus lens covers a wide angle to telephoto range of 18–200 mm. (Nikon) C. This large telephoto lens covers the telephotos ranges of 200–400 mm. (Nikon). When used with a digital camera having an equivalency factor of 1.5X, what are the actual ranges compared to a 35 mm camera?
Cleaning a Lens

1. Avoid having to clean the lens by permanently installing a UV filter. Only the filter will need to be cleaned.

2. Use a bulb blower to blow off the dirt and dust.

3. Put one or two drops of lens cleaning fluid on a tissue made for cleaning lenses.

4. Wipe the lens by pulling the tissue from the outside toward the center of the lens. Pull the tissue away from the lens during the wiping motion.

5. Check the lens for any streaking or missed dirt. Repeat steps 2 to 4 if needed.

Changing Lenses

1. Place the new lens on a table or securely in a camera bag with the back of the lens pointing up.

2. Loosen the rear lens cap, but do not remove it.

3. Hold the camera so the old lens is pointing down. Keep the camera in this position throughout the lens change to prevent dust from falling in the camera.

4. Remove the old lens and place it next to the new lens.

5. Move the cap that you loosened earlier to the old lens.
6. Install the new lens.

7. Secure the cap on the old lens and move the lens to a safe area.

Protect the camera and lens from temperature extremes. Avoid salt spray and moisture at the beach. If a lens and camera has been accidentally dropped in water do not try to disassemble the camera and lens to dry them out. Immediately take the battery out of the camera. Bring the equipment immediately to an approved camera and lens repair shop. The shop should be able to dry them out with a minimum of damage. The camera repair person will also be able to check camera and lens operation to ensure that they operate as designed.

When not in use, both ends of the lens should be protected with lens caps. See Figure 3-40. The lens should then be stored in a lens case.

Figure 3-40. When a lens is not mounted on the camera, lens caps should be used on each end for protection. A body cap should be used on the camera, as shown.

Test Your Knowledge

Write your answers on a separate sheet of paper. Please do not write in this book.

1. List two basic principles of light related to how a lens works.
2. A _____ camera does not need a lens to make a photo.
3. A lens composed of two or more simple lenses is known as a _____ lens. Each of these simple lenses is called a(n) _____.
4. The angle of view of a lens is determined by the _____.
5. True or False? A dimly lit subject would be photographed with a fast lens.
6. Check the f-stop best suited to take the picture in No. 5. _____ f/2 or _____ f/16
7. Depth of field is controlled by _____.
   A. focal length of lens
   B. f-stop of lens
   C. type of lens mount used
   D. All of the above.
   E. None of the above.
8. List three uses for a wide angle lens.
9. When should a telephoto lens be used?
10. How does a zoom lens differ from other types of lenses?
11. Which of the following items are recommended to safely clean a lens?
   A. Soft brush
   B. Silicon eyeglass tissue
   C. Clean handkerchief
   D. All of the above.
   E. None of the above.

For Questions 12–31, match each of the terms with the definition on the right.

12. Lens
13. Pinhole camera
14. Transmitted light
15. Refracted light
16. Simple lens
17. Convergent lens
18. Divergent lens
19. Aberrations
20. Stopping down
21. Image size

a. Does not need a lens to take a picture
b. Made of a single piece of glass or plastic
c. Made from transparent material with at least one curved surface
d. Light rays that are bent
e. Light that passes through transparent material
f. Size of subject produced on the negative
g. Flaws or defects in the lens
h. Lens that bends light rays inward
i. Lens that bends light rays outward
j. Reducing size of lens aperture
Things to Do

1. Make a pinhole camera with the back removed. Cover the back with thin tissue. In a darkened room, point the camera toward a lighted bulb or candle. Observe the image formed on the tissue.


3. Collect 10 photographs from magazines. (Do not remove them from library copies.) Pass them around during a group discussion. Discuss the possible aperture setting and lens focal length used for each photo.

4. Collect lens advertisements. (They can be secured from local camera dealers, lens manufacturers, and from discarded photo magazines.) Secure a cutaway illustration of a lens. Count the elements. List the number of convergent and divergent lens elements in the cutaway. Discuss the differences among the various types of lenses.

5. Most photo magazines evaluate lenses. Study several of these evaluations and explain to the class how the lenses are tested.

6. Secure a camera with an adjustable lens. Take a series of photos at different aperture settings and note how the depth of field changes. Prepare a table showing the depth of field at different aperture settings.

7. Secure a simple camera with a fixed aperture but adjustable focus. Photograph a subject at various distances while changing the focus. Note how the depth of field changes. How do pictures made with this camera and lens compare with photos made with the camera in Activity No. 6?