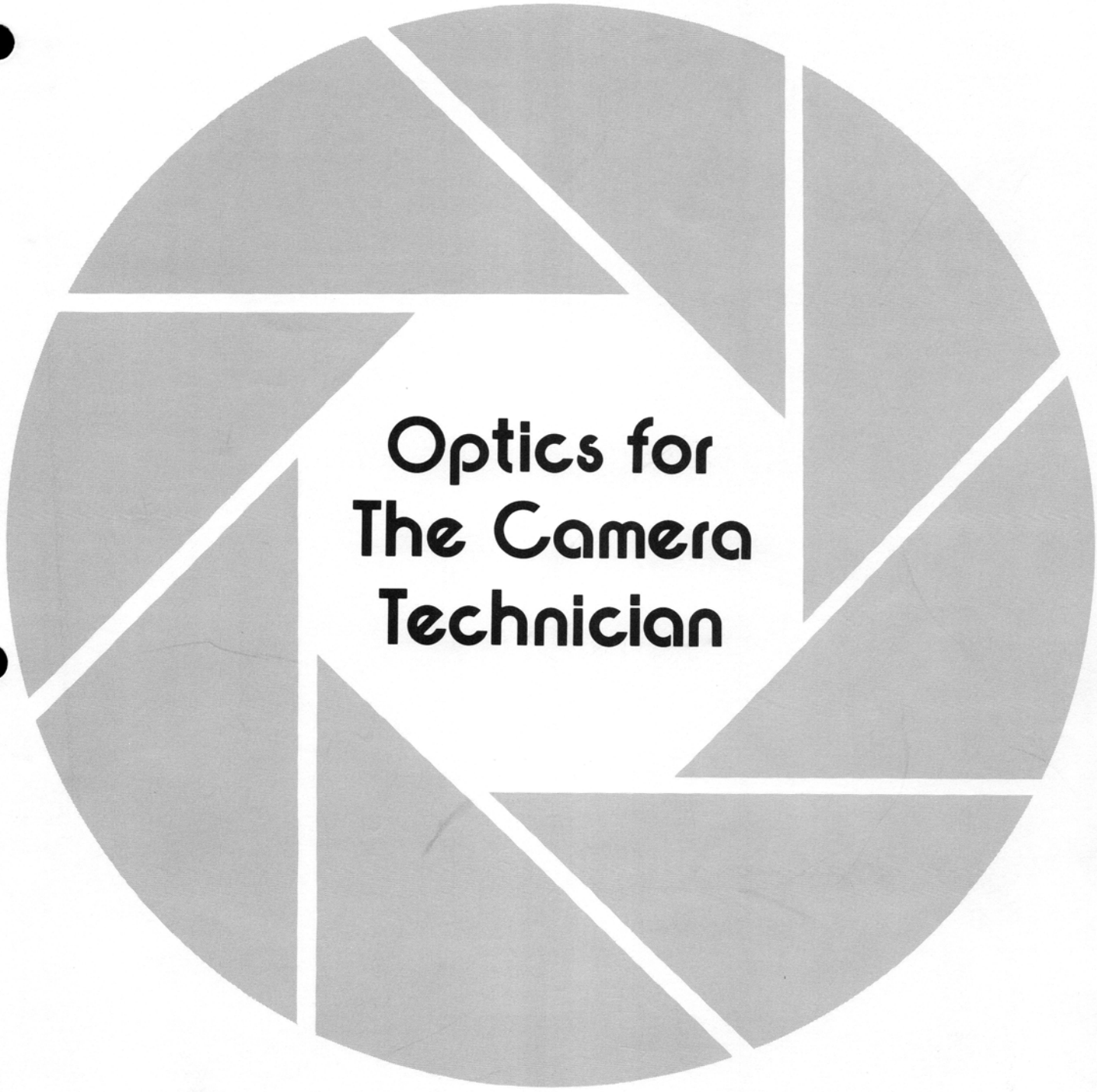
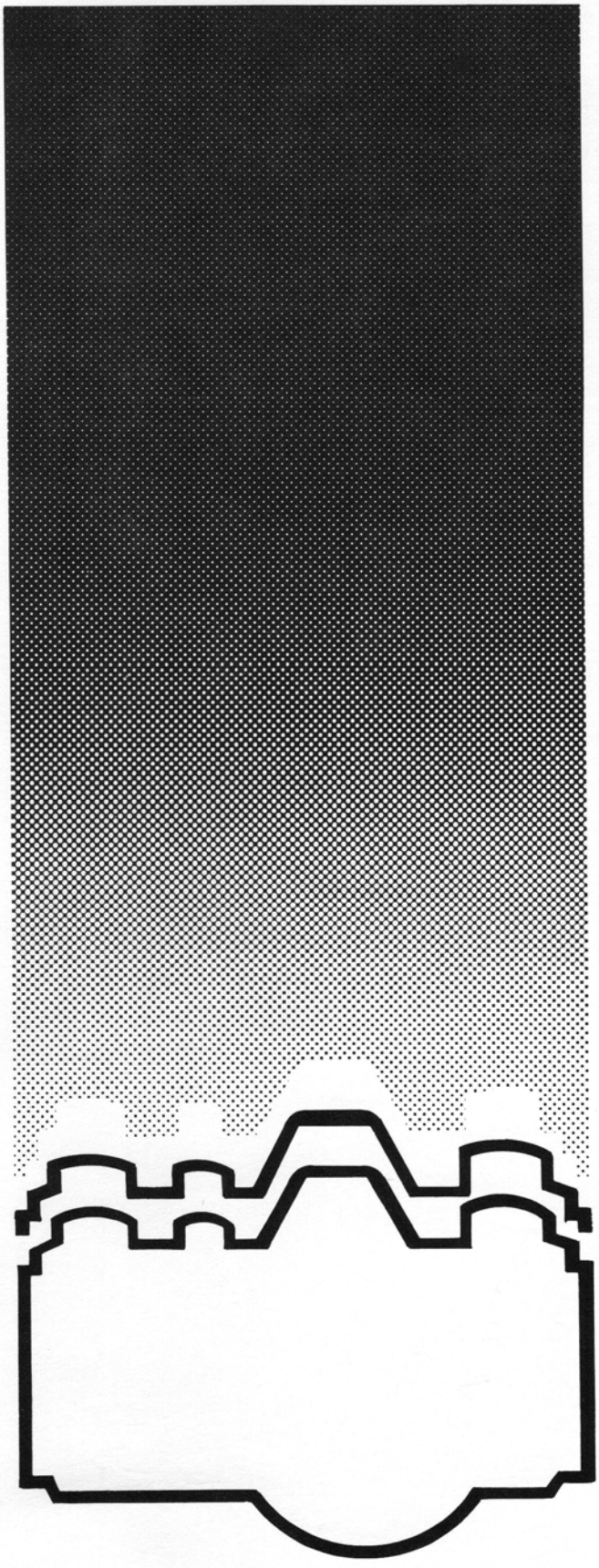

Optics for
The Camera
Technician



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Optics for The Camera Technician

contents

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Optics for The Camera Technician

WHY OPTICS?

As a camera-repair technician, you need a good background in basic optical principles. It's not necessary for you to become an optical engineer. Nor must you learn a lot of mathematical formulas. But you do need a working knowledge to service lenses and other optical systems.

You should also be able to recognize the faults in lens systems—the optical **aberrations**. In many situations, there's nothing you can do to correct the aberrations; they're inherent in the design. Yet it frequently happens that technicians unknowingly introduce or increase the effects of certain aberrations during a repair.

Let's consider a typical situation. A technician repairs a complex lens system for a customer. The customer, after shooting a roll of film, comes back with a complaint—the lens was sharper before the repair.

What has happened? Because the technician didn't understand optics, he introduced an aberration. Most likely the technician failed to realign the lenses within the system. Or perhaps he disassembled components which should never have been disturbed.

In lens-system repairs, it's important that you understand your own limitations. Some repairs of optical systems require elaborate equipment to perform the job properly. If your shop doesn't have the equipment, you must know how far you can go in the repair without disturbing critical alignment points.

Other lens repairs present no problems—you can perform the repairs without risking a loss of image quality. Since lenses are mechanically simple, they can then be fast repairs.

Your study of optics does involve new principles and terms. If you're new to the study of optics, you may find all those terms overwhelming. But don't try to memorize all the terms at once. For your reference, we've included a glossary of terms at the end of this lesson. So, if memory fails, just look up the term that seems hazy.

THE NATURE OF LIGHT

To understand optics, you must first understand light. After all, the whole purpose of optics is to control light behavior. What is light?

> Light is a form of electromagnetic energy that radiates through space in wavefronts.

"Electromagnetic" simply means that the energy has both electrical force and magnetic force. Other forms of electromagnetic energy also radiate in waves—for example, radio waves. But you can't see these forms. The difference between forms of electromagnetic energy you can see and those you can't see is the length of the wave, Fig. 1.

The human eye has limitations—it only responds to wavelengths within a certain range. Those wavelengths capable of stimulating the retina of the human eye comprise **visible light**.

Figure 1

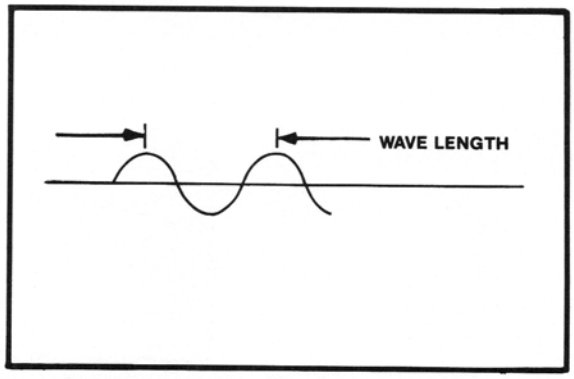


Fig. 2 shows a chart of the different types of electromagnetic energy—the electromagnetic spectrum. In some phases of camera repair, you'll be concerned with infrared light and ultraviolet light. Your eye can't see these forms of radiant energy. But some films and camera photosensors do respond to wavelengths just outside of the visible-light range.

However, in optics, you need only be concerned with visible light. Notice that the chart, Fig. 2, breaks down visible light into seven colors called the **color spectrum**.

The wavelength determines the color of visible light. Red has the longest wavelength; violet has the shortest. If you mix together the seven colors of the color spectrum, you get white light.

White light then consists of all seven colors. You can see the full color spectrum in a rainbow. Here, the moisture in the air breaks up the white light according to wavelength. The longest wavelength—red—appears at the top of the rainbow. Violet appears at the bottom.

Optical components can also break down white light into the color spectrum. Why? Because the different wavelengths behave differently. The effect is called **dispersion**—the separation of white light into the color spectrum.

You may be familiar with the use of a prism to disperse light, Fig. 3. A prism is a piece of optical glass that has the ability to bend light rays. As the different wavelengths pass through the prism, they bend different amounts. And the white light emerges from the prism in a rainbow pattern, Fig. 3.

Figure 2

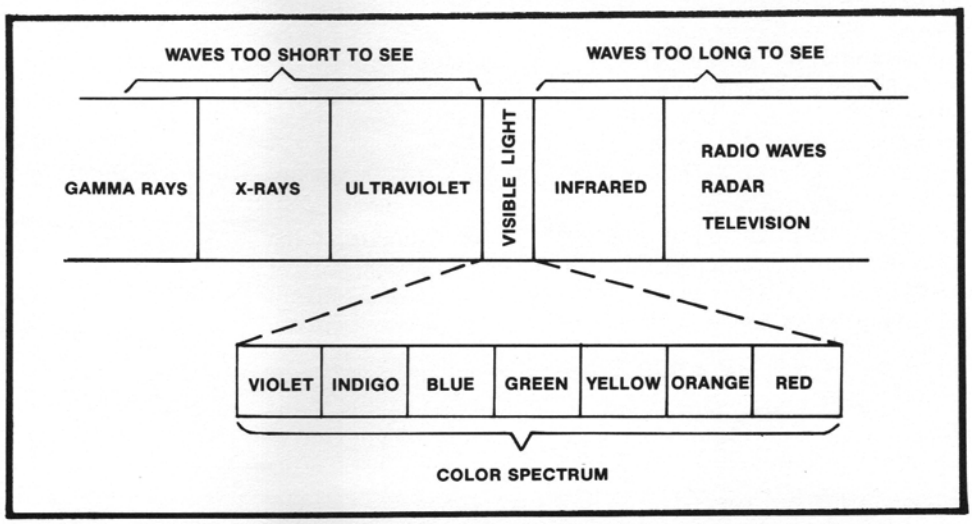
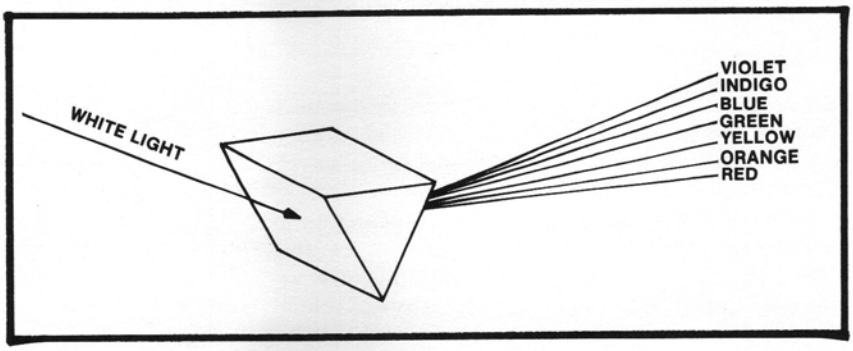


Figure 3



BEHAVIOR OF LIGHT

You've learned that light radiates from a light source in waves, Fig. 4A. The path upon which the light energy travels is called a **light ray**. In optics, it's most convenient to show light rays as straight lines, Fig. 4B.

Light does indeed travel in straight lines. It can't bend around corners without help. It also travels at a constant speed through a homogeneous medium (a medium of constant density)—over 186,000 miles per second through a vacuum. But, when light passes through a medium of different density, it changes speed.

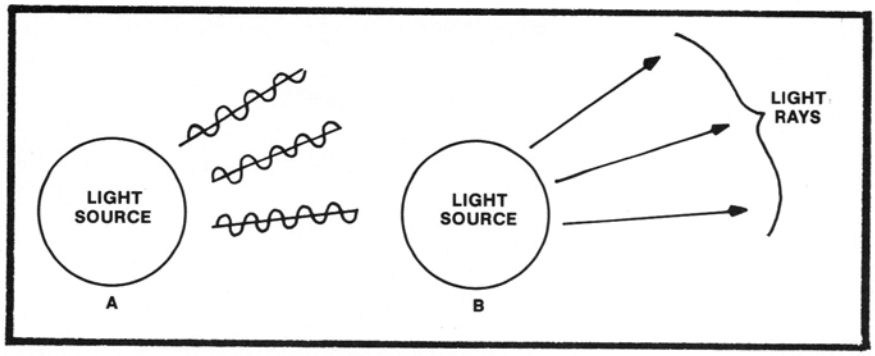


Figure 4

For example, consider that a light ray traveling through air strikes a piece of glass, Fig. 5. The glass has greater density than air. So, while traveling through the glass, the light slows down. The light then speeds up when it leaves the glass and re-enters the air.

Notice that each part of the light ray in Fig. 5 has a specific term. The portion of the light ray that strikes the glass is the **incident ray**—it's incident to the glass. The **transmitted ray** passes through the glass. And the **emergent ray** emerges from the other side of the glass.

The light ray in Fig. 5 doesn't change direction when passing through the glass. That's because the light ray strikes the glass at a right angle—the light ray is perpendicular to the surface of the glass.

As long as the glass in Fig. 5 remains constant in density, the light ray continues in a straight line. Optical engineers give this property of light a special name —**rectilinear propagation**. The term simply means that light travels (propagates) in a straight line (rectilinear) through a medium of constant density (a homogeneous medium).

However, not all of the light ray actually emerges from the glass. No medium can be a perfect transmitter—it can't transmit all of the light that's incident to its surface. Rather, the glass absorbs a certain amount of light.

This principle of light loss is **absorption**. Because of absorption, there's a certain amount of light loss in any optical system. Lens designers can reduce absorption. But they can't eliminate it entirely.

Along with absorption, there are two other principles of light which must be considered together—refraction and reflection. All three principles affect any optical system. Just as there are no perfect transmitters in optics (optics that transmit 100% of the light), there are no perfect reflectors.

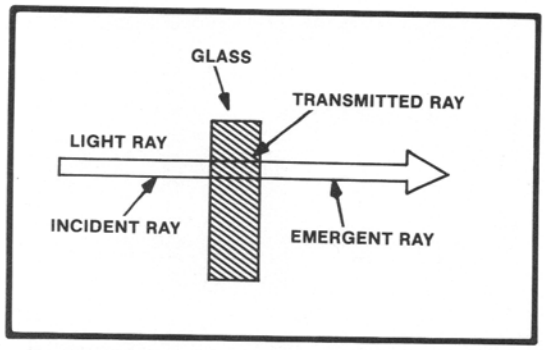


Figure 5

Refraction

What if the light ray in Fig. 5 strikes the glass surface at an angle? The light ray still slows down. But it also bends. This bending of the light ray is called refraction.

In principle, it's the same as if you were rolling a toy truck across the floor, Fig. 6. The truck moves pretty fast across the wood floor. But when the truck strikes the carpet, it slows down.

If the truck strikes the carpet at an angle, Fig. 7, it turns. In Fig. 7, the right front wheel reaches the carpet first. Since the right front wheel slows down before the other wheels, the truck turns to the right.

Now let's see how the same principle applies to the light ray. In Fig. 8, the light ray strikes the glass surface at an angle. The bottom portion of the light ray strikes the glass first—before the top portion of the light ray. So, while the top portion of the light ray continues to travel at its original speed, the bottom portion slows down. And the light ray refracts as shown in Fig. 8.

When the light ray leaves the glass, the top portion enters the air before the bottom portion. The top portion of the light ray then speeds up sooner. Notice in Fig. 8 that the emergent ray resumes the original direction of the incident ray.

A lens uses the same principle to refract the light rays. In Fig. 9, the lens has one convex surface (a convex surface curves out—a concave surface curves in). A light ray passing through the center of the lens—along the lens **axis**, Fig. 9—isn't refracted; it continues to travel along the axis. But a light ray striking a curved surface of the lens refracts toward the axis, Fig. 9.

The refracting capability allows the lens to gather light rays and bring them together at a point, Fig. 9—that's how the lens forms an image, as you'll see in a moment. The lens manufacturer must carefully design the curve of the lens surface to control the refracted ray. But there's one other consideration—the density of the glass. The denser the glass, the more it refracts the incident ray.

Figure 6

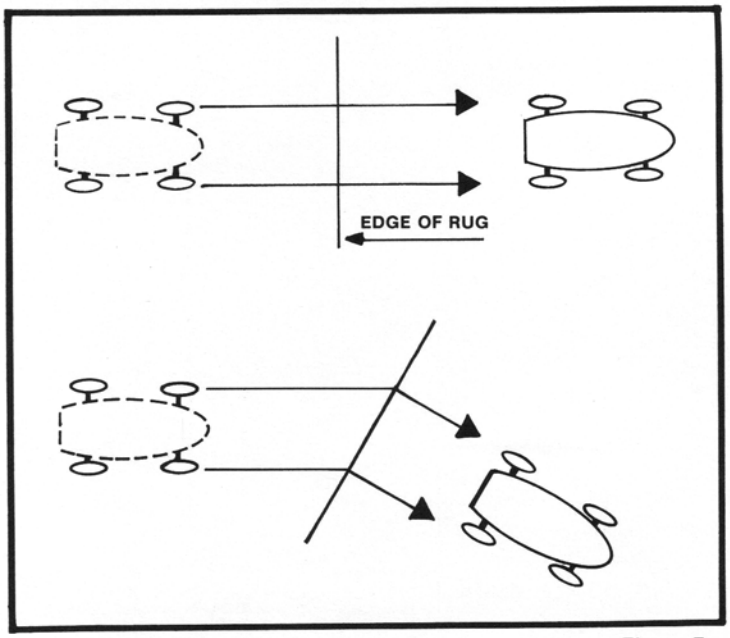


Figure 7

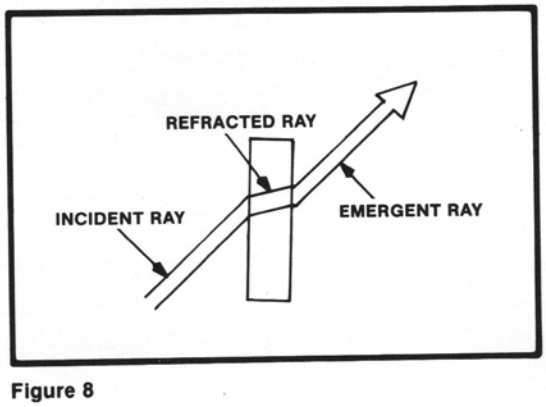


Figure 8

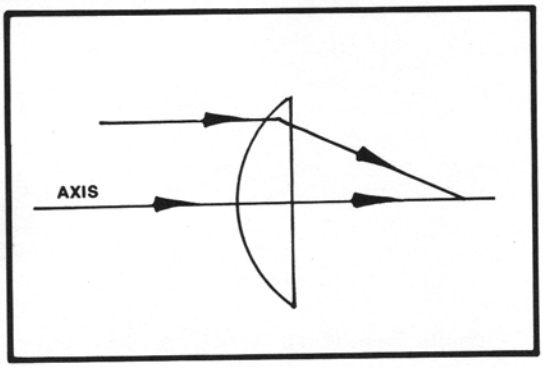


Figure 9

Different types of glass have different **refractive indexes**. The refractive index defines the capability of the glass to refract light; the higher the refractive index, the more the glass refracts the light ray.

The **law of refraction** defines the direction of the refracted ray as well as the amount of refraction. To apply the law, first draw the **normal**—a line perpendicular to the surface, Fig. 10. Notice that the normal touches the surface of the glass at the same point as does the incident ray.

If the light ray passes from a less-dense medium into a more-dense medium, it refracts toward the normal. In passing from a more-dense medium into a less-dense medium, the light ray refracts away from the normal.

Further, if the optical designer knows the angle of incidence (a in Fig. 10) and the refractive index, he can calculate the angle of refraction (b in Fig. 10). The law of refraction includes the formulas for such calculations.

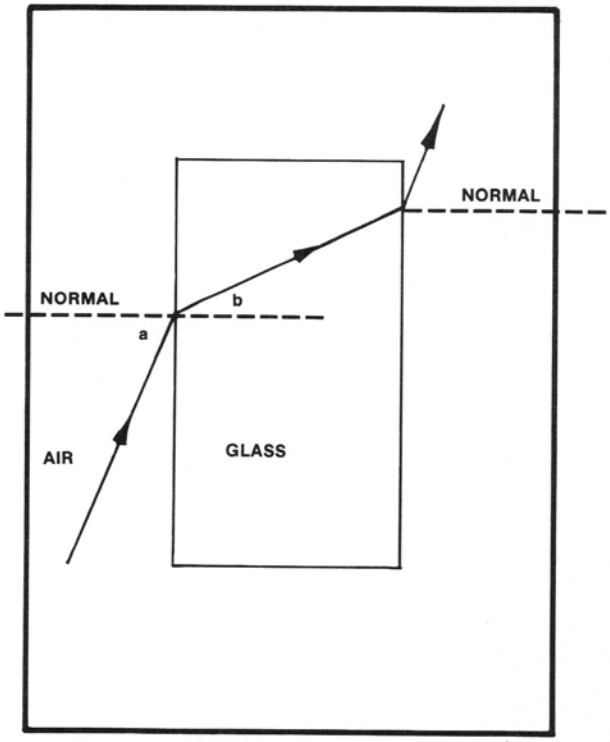


Figure 10

Reflection

In Fig. 9, we showed all of the light as being refracted by the lens. But, as you've learned, some of that light is actually absorbed. Also, a portion of the light ray is reflected, Fig. 11. Some of the light reflects from the front surface of the lens; some also reflects from the rear surface.

Reflection is the property of light that allows you to see objects. When light strikes an object, part of the ray reflects from the object to your eye. Your eye then focuses the reflected light to form an image. Similarly, a camera lens gathers and focuses the light that reflects from an object.

But no object can reflect all of the light that's incident to it—part of the light is absorbed. A perfectly black object would absorb all of the light and reflect none. Black is then the absence of light. How about a white object? As you've learned, white light contains all seven colors of the color spectrum. A perfectly white object would reflect all of the light and absorb none.

Since no perfect reflectors exist, however, even a white object absorbs a certain amount of light. An object may also absorb certain wavelengths and reflect others. The reflected wavelengths account for the color of the object. If the object appears green, for example, it reflects green light and absorbs the other colors. You might therefore say that the green object is really every color but green.

The reflections shown in Fig. 11 cause a drawback to the lens design—a loss of speed. Any light reflected from the glass-air surfaces is lost as far as the photograph is concerned. To minimize reflected-light losses, lens designers limit the number of glass-air surfaces in a lens system. Also, manufacturers coat the lenses with a thin deposit of magnesium flouride (a thickness of 1/4 the wavelength of green light). The coating increases the light transmission by reducing reflected-light losses.

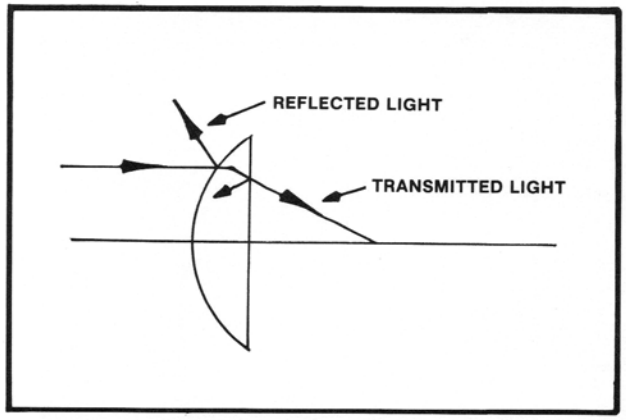


Figure 11

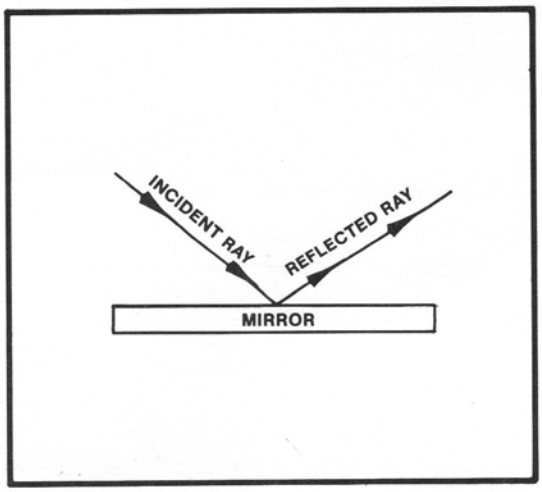


Figure 12

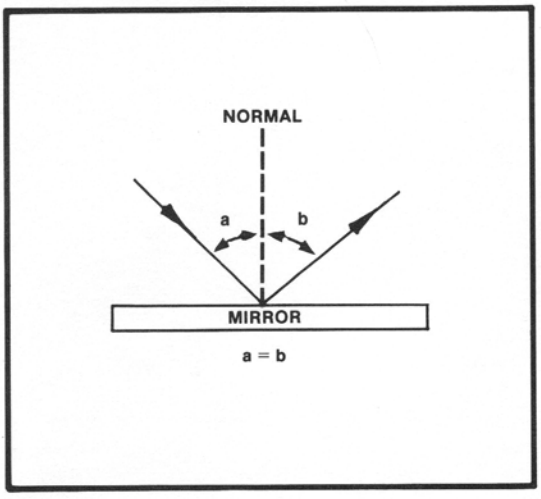


Figure 13

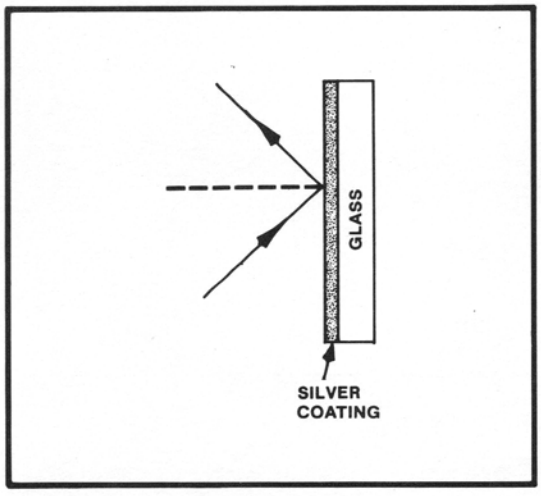


Figure 14 Front-silvered mirror

However, camera designs also take advantage of reflection. Mirrors and prisms are optical components designed specifically to reflect light. A mirror has a reflective surface coated with silver. The silver deposit reflects practically 100% of the light.

Light striking the silver coating perpendicular to the mirror surface reflects back upon itself. When the light strikes the surface at an angle, it reflects as shown in Fig. 12. You can always find the path of the reflected ray by applying the **law of reflection**.

> The law of reflection states that the angle of reflection (b in Fig. 13) always equals the angle of incidence (a in Fig. 13).

Notice in Fig. 13 that we've drawn the normal perpendicular to the mirror surface. The normal and the incident ray meet the mirror surface at the same point. It's now possible to measure the angle of incidence between the incident ray and the normal. Measure the angle of reflection between the reflected ray and the normal.

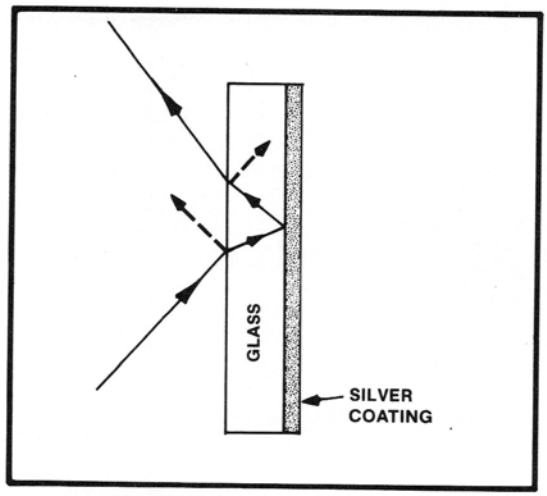
Fig. 14 shows the type of mirror used in photographic equipment. The silver deposit is on the front surface of the mirror. Ordinary mirrors, however, have the silver deposit on their back surfaces. The glass then protects the silver, Fig. 15.

Although the back-silvered mirror is more durable, it has some disadvantages. For one, it changes the normal path of the reflected light rays because of refraction. Changing the normal path of a light ray is called **displacement**. So the back-silvered mirror **displaces** the light.

Displacement causes an error in the mirror image (later in this lesson, we'll discuss how the mirror forms an image). Also, because the light ray must pass through the glass to reach the reflective surface, there's a light loss. Absorption accounts for part of the light loss with the back-silvered mirror. **Secondary reflections** account for the remaining losses.

In Fig. 15, the dashed arrows show the secondary reflections. When the light ray strikes the front surface of the glass, most of the light passes through the glass to the silver coating. But there's a secondary (weak) reflection from the front glass-air surface. Similarly, there's another secondary reflection as the light ray leaves the glass.

The mirror, like the lens, forms an image. But the image formed by a mirror is quite different from an image formed by a lens. Let's first look at how a lens forms an image. We'll then cover image formation with mirrors and prisms.



Back-silvered mirror Figure 15

TEST-YOURSELF QUIZ #1

1. A fault in a lens is called a/an ABBERATION .
2. Electromagnetic wavelengths capable of stimulating the retina of the human eye come under the classification of VISIBLE LIGHT .
3. The breaking down of white light into the color spectrum is called DISPERSION .
4. The path upon which light energy travels is called a/an LIGHT RAY .
5. When a light ray passes from air into glass it SLOWS DOWN (speeds up, slows down).
6. When the direction of a transmitted light ray changes, that ray has been REFRACTED .
7. Light that isn't transmitted or reflected is ABSORBED .
8. The law of reflection states that the angle of reflection must equal the ANGLE OF INCIDENCE .

IMAGE FORMATION BY A LENS

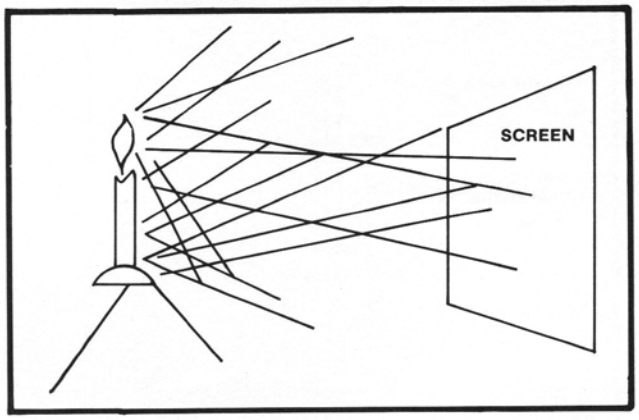


Figure 16

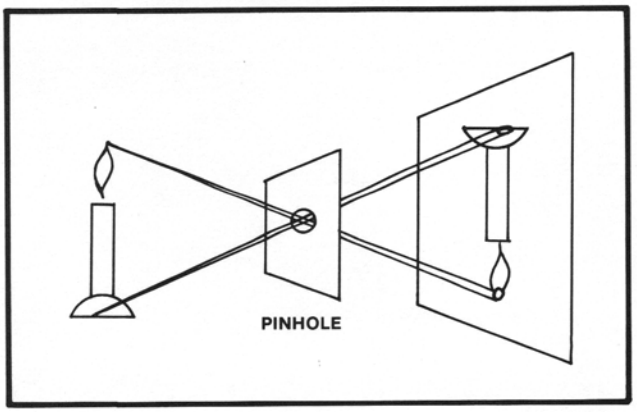


Figure 17

Earlier, we mentioned that you see an object by reflected light. But the light reflected from an object doesn't form an image. The reflected light scatters in all directions, Fig. 16. Those scattered light rays must be directed to form an image.

It's possible to form an image without a lens. A small hole in a piece of cardboard, Fig. 17, does the job of limiting and directing the light rays. Notice that the image formed in Fig. 17 is upside down.

The set-up shown in Fig. 17 forms the basis of the pinhole camera. All you need to make a pinhole camera is a shoebox. Place a small hole—the pinhole—at one end; mount the film to the other end inside the shoebox. The pinhole directs the light rays onto the film, forming the image.

How large should you make the pinhole? The smaller you make the pinhole, the sharper the image will be. A small pinhole does a better job of directing light rays than does a large pinhole. But the small pinhole also admits less light. So, with a small pinhole, you need a long exposure time—or a lot of light on the subject. A larger pinhole increases the speed of the system; you don't need as long an exposure time. However, the quality of the image suffers.

A pinhole camera then has two major drawbacks—slow speed and poor image quality. When you improve one, the other suffers. Replacing the pinhole with a lens takes care of both problems. The lens uses its refracting ability to efficiently gather the light and direct the rays to the film. The result? A sharp image in a relatively short time period.

First consider how a lens forms an image of a point source of light. A point source has no dimension; it's infinitely small. Light radiates from the point source in all directions, Fig. 18.

The light rays in Fig. 18 diverge from one another. However, the further those rays travel, the closer they come to being parallel. So, if you could extend the light rays in Fig. 18 an infinite distance, they would be virtually parallel to one another. The following principle is basic to optical systems:

> Light from an infinitely distant source travels in parallel rays.

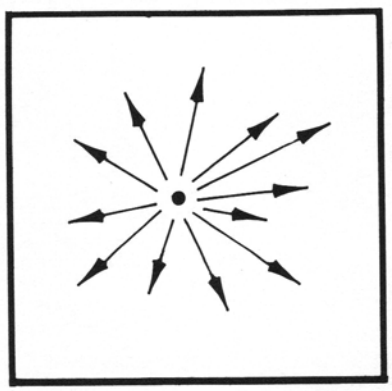


Figure 18

Fig. 19 shows the parallel light rays from an infinity source striking the lens. The lens now refracts the light rays and brings them together at point F, Fig. 19. Point F—the point at which the light rays converge—is the **focal point**. And the distance from the focal point to the center of the lens is the **focal length**—f in Fig. 19.

What happens if the parallel light rays strike the opposite side of the lens? The lens then brings the light rays together at point F', Fig. 19. Any lens thus has two focal points, one on each side. Here's the definition of the focal point:

> The focal point is a point on the lens axis located so that any light approaching or leaving it will travel in a path parallel to the axis after refraction.

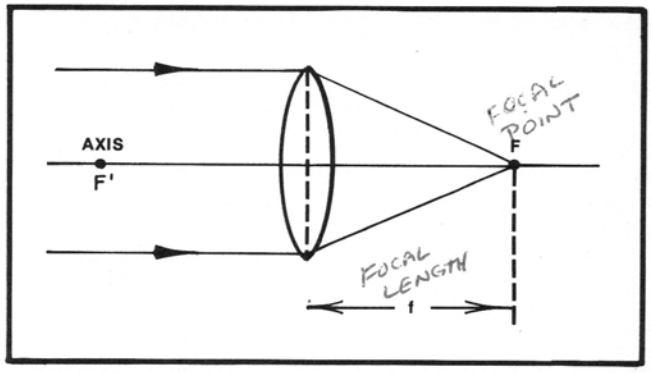


Figure 19

To apply the definition to Fig. 19, let's reverse the position of the light source. Suppose that a point source of light sits at point F. The light rays still travel along the paths indicated in Fig. 19. But now they diverge from point F until they strike the lens. After refraction, the light rays travel parallel to the lens axis.

In the camera, the focal point corresponds to the position of the film. The film sits in a plane—the **focal plane**—which passes through the focal point. Light rays from an infinite distance then converge at the focal plane.

Next consider a point source that's closer than infinity. The light rays are no longer parallel. Rather, the light rays diverge from the point source, Fig. 20. And the lens brings the rays together behind the focal point.

The image formed at the focal plane is then out of focus. Rather than being a point, the image has dimension as indicated by the arrows on the dashed line, Fig. 20.

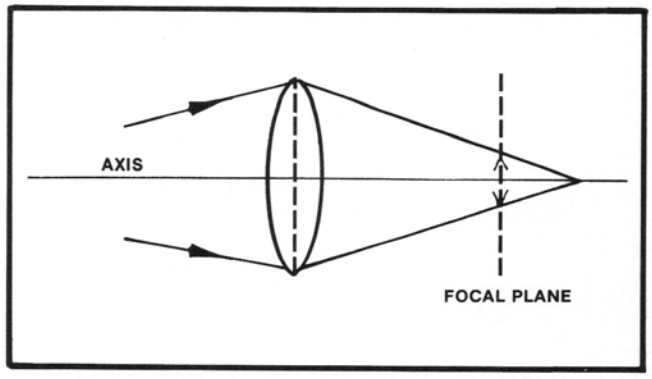


Figure 20

To focus the lens, you must bring the point at which the light rays converge back to the focal plane. You could move the focal plane backward. But most focusing systems take a different route—they move the entire lens forward. The lens moves forward until the light rays once again converge at the focal plane, Fig. 21.

If the light source moves closer yet, the light rays diverge even more. So, once again, you move forward the lens. Eventually, though, you reach the minimum focusing distance of the lens—the lens can't move forward any further.

The mechanical limitations of the focusing system may determine the minimum focusing distance. Or the light source may be so close that it's within the focal length of the lens—between the lens and point F', Fig. 19. In that case, the lens can't bring the light rays together.

You've seen that the image of a point source should also be a point—a point imaged at the focal plane. But what if the object has dimension? The image must also have dimension. Rather than consisting of a point, the image consists of many points. Each point in the image has a corresponding point on the object.

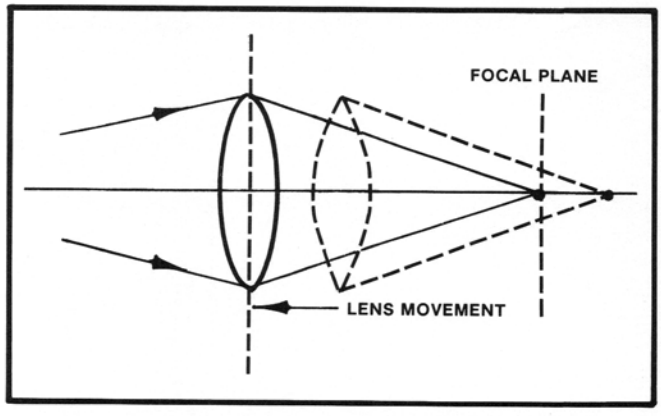


Figure 21

Fig. 22 shows an example of an object with dimension (the arrow). The object sits outside the focal length of the lens (further from the lens than point F′ in Fig. 19). By plotting only two of the image points, Fig. 22, it's possible to locate and define the image.

The solid light-ray lines indicate one point—the tip of the arrowhead. Notice that we've drawn one line from the tip of the arrowhead through the center of the lens; this light ray isn't refracted. We've drawn the other line parallel to the lens axis. The second ray, refracted by the lens, intersects the first ray behind the lens as shown in Fig. 22.

Since the solid lines converge, they image a point. The point corresponds to the tip of the arrowhead. We've followed a similar procedure to plot the image point corresponding to the bottom of the arrow.

However, in Fig. 22 we've located the bottom of the arrow on the lens axis. The light rays then diverge toward the lens as shown by the dashed lines. After refraction, the dashed lines intersect on the axis behind the lens.

Having located two points, it's now possible to draw in the image, Fig. 22. Since we positioned the bottom of the arrow on the lens axis, though, it wasn't really necessary to plot the second image point. Simply locating the image point of the tip of the arrowhead provided all the information we needed. Notice in Fig. 22 that the image is upside down. Also, the image is smaller than the object.

Further, the image in Fig. 22 is a **real image**. A real image actually exists at the position where it appears. Consequently, it's possible to project the real image onto a screen.

By contrast, a **virtual image** can't be projected. A virtual image doesn't acutally exist at the point where it appears to exist.

The lens shown in Fig. 22 can also produce a virtual image. But the object must lie within the focal length of the lens. In Fig. 23, we've moved the object so close to the lens that it's within the focal length. Now the lens can't bring the refracted rays together to form a real image. Instead, the lens forms a virtual image.

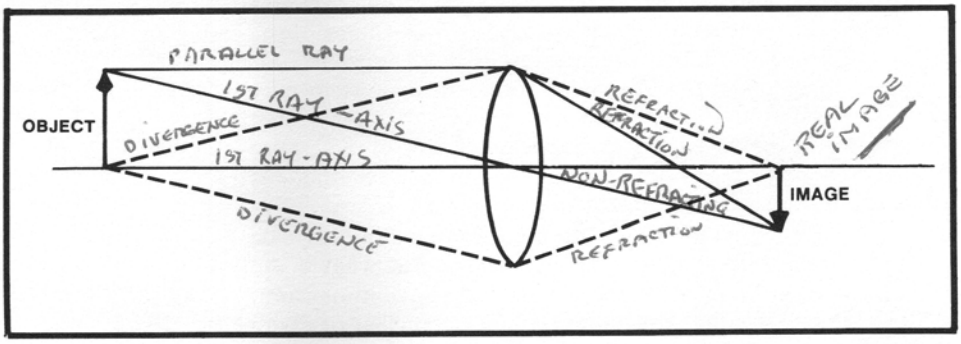


Figure 22

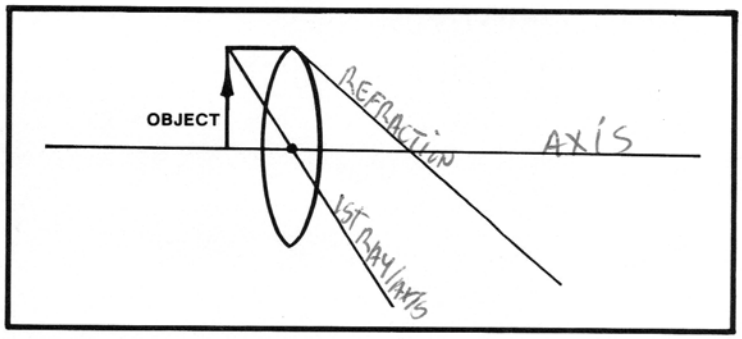


Figure 23

To locate the virtual image, we've extended the two light rays in Fig. 24. Now the lines converge. But they converge on the same side of the lens as the object. The result? A virtual image.

Notice that the virtual image is right side up. Also, it's larger than the object. If you look through the lens from position F, Fig. 24, you see the virtual image as an enlarged representation of the subject.

You've seen a virtual image if you've ever used a magnifying glass. The magnifying glass is simply a lens like the one shown in the drawings. When you position the magnifying glass so that the object is within the focal length, you see the magnified virtual image. The eyelens in a camera works the same way to give you a magnified view of the subject.

In effect, your eye has been tricked. The eye assumes that all rays entering it follow a straight line. So the image appears at the position shown in Fig. 24—even though no image actually exists at that point.

All of our illustrations so far have shown the same type of lens—a **convergent** or **positive** lens. A positive lens forms a real image of an object located outside its focal length. The taking lens of a camera is therefore a positive-lens system.

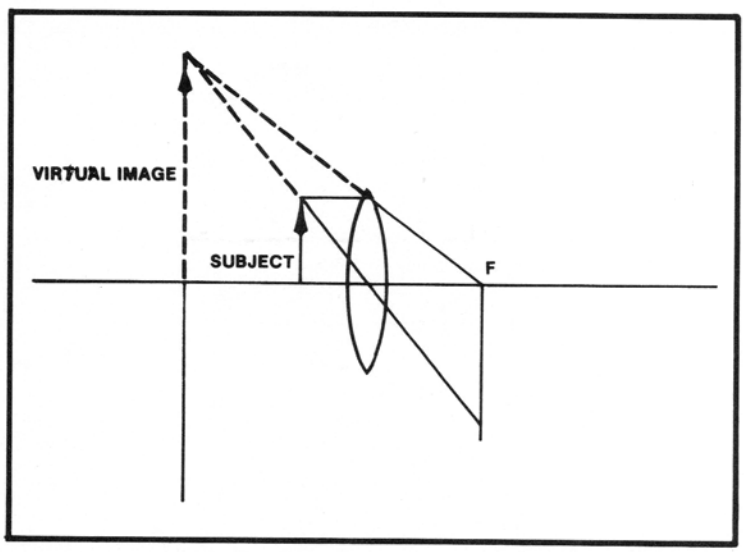


Figure 24

TYPES OF POSITIVE LENSES

You can identify a positive lens by its shape—it's thicker in the center than it is at the edges. The lens shown in Fig. 24 has two convex sides. So it's called a bi-convex lens. Further, since the two sides are symmetrical, the lens is a symmetrical convex (or equiconvex) lens.

But a positive lens may have one flat side (plano) and one convex side, Fig. 25A. This lens is a plano-convex lens. Another type of positive lens has one concave side and one convex side, Fig. 25B. Such a design is called a **meniscus lens**.

You could substitute either of the shapes shown in Fig. 25 for the lens shown in Fig. 24. Later, you'll see why designers use different types of positive lenses according to the application. But let's first look at the second basic type of lens—one that can't form a real image. That's the **divergent** or **negative** lens.

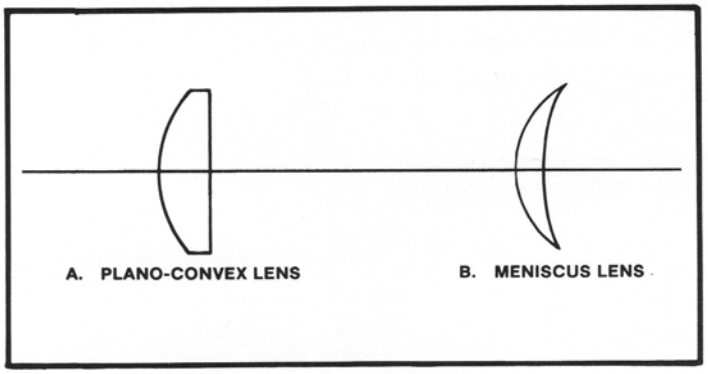


Figure 25

THE NEGATIVE LENS

Fig. 26 shows one type of negative lens. Since the lens has concave sides, it can't bring light rays together. Rather, its refracting power spreads the rays apart. Parallel light rays passing through the negative lens diverge as shown in Fig. 27.

To locate the two focal points of a negative lens, just extend the diverging lines as shown in Fig. 27. In Fig. 27A, we've located focal point F′ on the same side of the lens as the parallel light rays. To locate focal point F, Fig. 27B, we've first caused the incident rays to converge until they leave the lens as parallel rays.

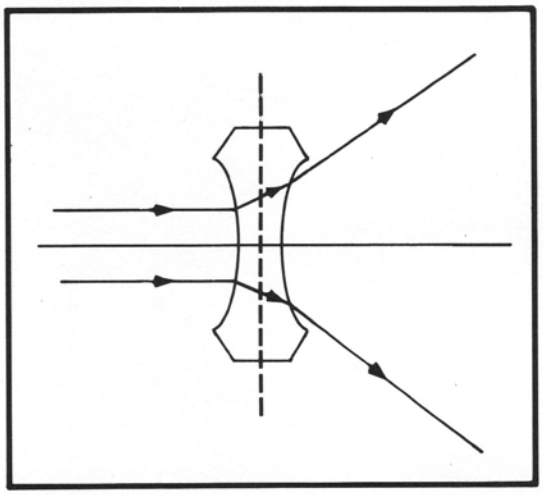


Figure 26

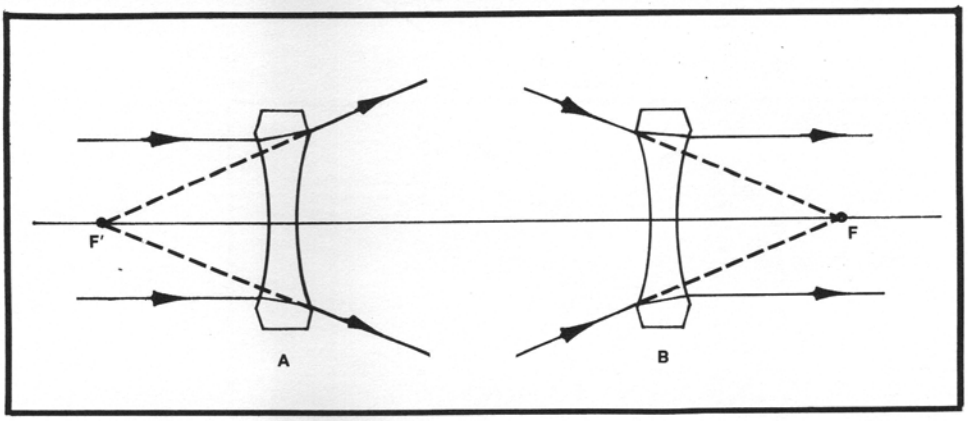


Figure 27

The negative lens can't form a real image. But it does form a virtual image. Fig. 28 shows how. As before, we've drawn one line from the tip of the arrowhead through the center of the lens. We've drawn the second line from the tip of the arrowhead parallel to the lens axis. Notice that the two lines will never intersect behind the lens.

To locate the image, it's necessary to extend the refracted ray to the front of the lens. The dashed line in Fig. 28 indicates the extended ray. The image point corresponding to the tip of the arrowhead is where the extended ray intersects the nonrefracted ray.

Notice that the virtual image is right side up. And it appears to be on the same side of the lens as the object.

In camera optics, you'll see the negative lens used as part of the complete system. The designer combines the negative lens with the positive lens to correct aberrations. Besides the double-concave lens, Fig. 28, you'll encounter plano-concave and negative meniscus lenses. But all negative lenses are thicker at the edges than at the center. And they all cause the light rays to diverge.

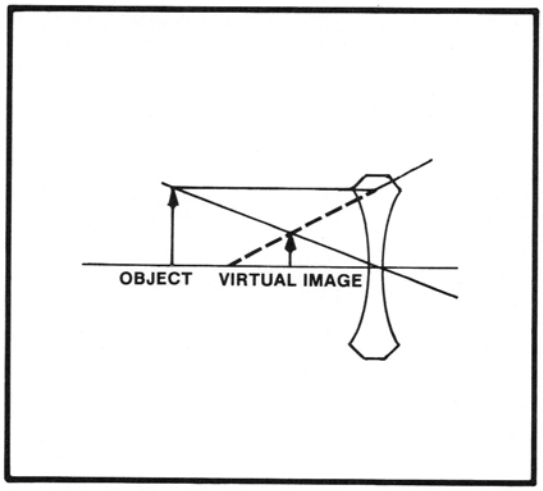


Figure 28

TEST-YOURSELF QUIZ #2

1. You get better image definition with a SMALL (large, small) pinhole.
2. Parallel light rays come from a/an INFINITY / INFINATE light source.
3. The point at which a lens brings together parallel light rays is the FOCAL point.
4. The image formed by a positive lens of an object outside the focal length is a REAL (real, virtual) image.
5. If the object is inside the focal length of a positive lens, the lens forms a VIRTUAL (real, virtual) image that's LARGER (larger, smaller) than the object.
6. The negative lens forms a VIRTUAL (real, virtual) image.

EXPERIMENTS WITH REAL IMAGES

If you have a shoebox and a magnifying glass, you can verify the principles we've discussed. The magnifying glass provides a simple positive lens. And with the shoebox (or any similar box), you can make a pinhole viewing system.

The length of the shoebox should be approximately the same as the focal length of the magnifying-glass lens. How can you determine the focal length? If you've ever used a magnifying glass to burn a hole, you know the procedure. The sun then serves as an infinity source.

Just focus the sun's rays on a piece of paper. Adjust the distance between the magnifying glass and the paper until the rays come into sharp focus—a small, clearly defined point of light. The distance between the magnifying glass and the paper tells you the focal length of the lens.

You can also use the magnifying glass to image a subject. Sit by a window inside a darkened room. Direct the magnifying glass to a subject outside the window. Now hold a piece of paper behind the magnifying glass. By adjusting the distance between the paper and the magnifying glass, you should be able to form a sharp image of the subject. The distance between the magnifying glass and the paper will be close to the focal-length measurement you made earlier.

Notice that the image is upside down. And it's smaller than the subject. Since the subject sits outside of the focal length, you've used the magnifying glass to form a real image.

As you've already learned, it's also possible to form a real image without a lens. You can make a good comparison of a pinhole image to a lens image by using the shoebox. To make the pinhole viewing system, cut out a rectangular section at each end of the shoebox. Mount a piece of white paper (such as onion-skin paper) over the cutout at one end—that's your viewing screen.

Next make a couple of rectangular masks out of black paper to cover the cutout at the other end. Cut a hole in the center of each mask. But make the two holes different in size—one might be around 5mm in diameter and the other around 2mm in diameter.

Tape the mask with the larger hole to the front of the shoebox. The pinhole now allows you to form images of brightly lit subjects on the paper, Fig. 29. You might use a television screen in a darkened room to verify the principles we've discussed.

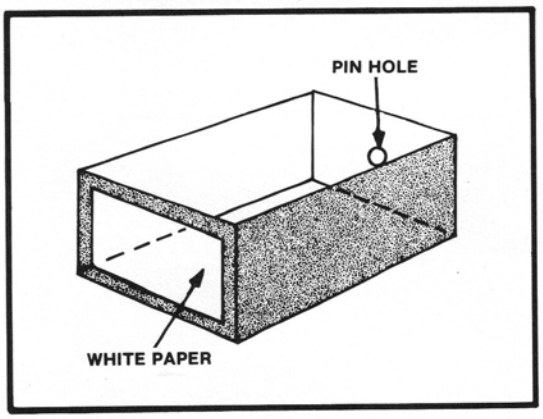


Figure 29

Aim your pinhole viewing system at the TV screen. With the TV set turned on, you get good contrast between light and dark. And you should be able to make out an image of the TV program on the pinhole viewing screen. Note that the image is upside down. Also, because of the relatively large pinhole, the image should be very fuzzy.

Repeat the experiment using the smaller pinhole. You should see a significant improvement in the image quality. But the image now becomes quite dim. If the image is too dim to see, try making the comparison with a lamp (rather than the TV screen) as the subject.

You can also make a quick comparison of the pinhole-formed image to a lens-formed image. Again examine the image using the larger pinhole. Now, while watching the pinhole viewing screen, hold the magnifying glass in front of the pinhole. You should see an improvement in the image—both in sharpness and in brightness.

However, the image now formed by the lens may not be in sharp focus (depending on the length of the shoebox and the focal length of the lens). To focus the image, you'll probably have to move the magnifying glass closer to the pinhole viewing screen. The focal length of a magnifying-glass lens is normally less than the length of a shoebox.

Remove the lid of the shoebox. Then turn the shoebox upside down so that the open side faces the darkened floor. And hold the magnifying glass behind the pinhole. While watching the pinhole viewing screen, move the magnifying glass away from the pinhole (toward the screen) until you get a sharp image.

The focal length of your viewing system now depends on the magnifying glass. What's the focal length without the lens? When only the pinhole forms the image, the focal length depends on the length of the shoebox. A longer shoebox gives you a larger image and therefore a longer focal length.

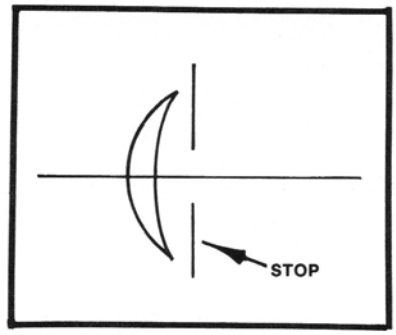


Figure 30

LENS ABERRATIONS

A lens surface may be ground from optical glass or molded from plastic. We refer to a single-piece lens as an **element**. The top-quality, fully corrected lenses use several elements in the design.

But an inexpensive box camera often uses a single meniscus lens, Fig. 30. The stop (opening) placed behind the lens provides a small aperture—typically around f/16. Since the simple lens has no corrections for aberrations, it provides satisfactory results only at small apertures. You'll learn in this section why stopping down a lens reduces aberrations.

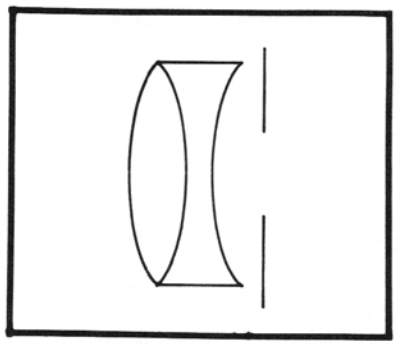


Figure 31

It's possible to correct certain aberrations by combining two elements, Fig. 31. Fig. 31 shows the type of lens used in the better box cameras. The two elements are cemented together, forming a **compound lens**. By cementing the elements together, the manufacturer eliminates two glass-air surfaces.

Notice that the compound lens in Fig. 31 has both a positive element and a negative element. In combination, the two elements serve as a positive lens—they form a real image.

More sophisticated lenses consist of several elements. The Tessar shown in Fig. 32 has four elements—one compound lens, one positive and one negative element. Although the lens contains two negative elements, the combination again serves as a positive lens.

The lens designer uses multiple elements to correct aberrations and to control the focal length. You've already learned the definition of focal length—the distance between the optical center of the lens and the focal point. In a complex lens such as that shown in Fig. 32, the optical center is located between lens groups—the position of the diaphragm.

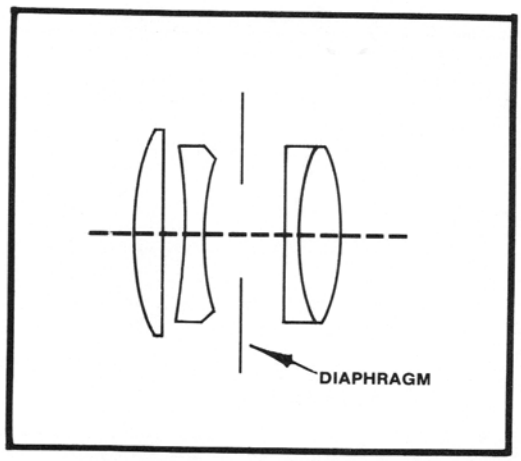


Figure 32

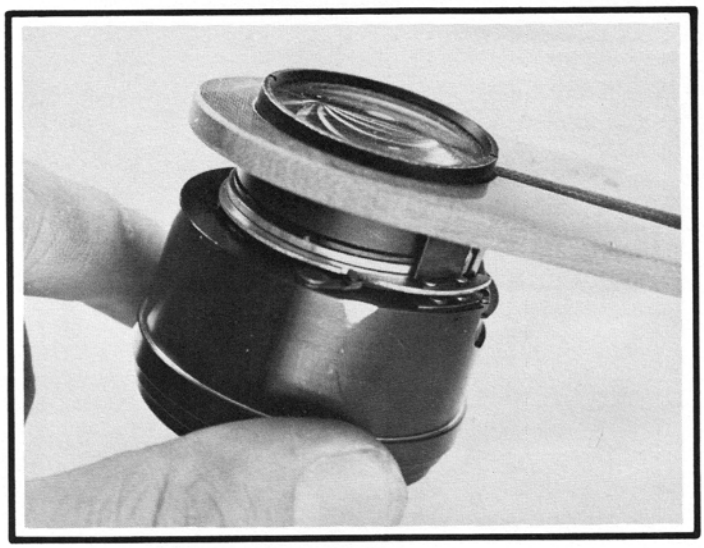


Figure 33

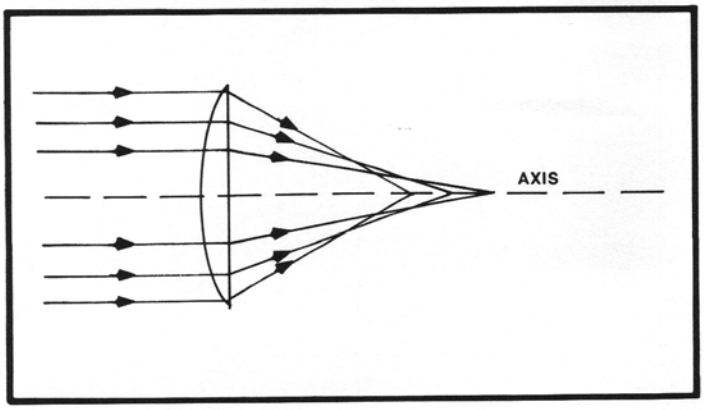


Figure 34

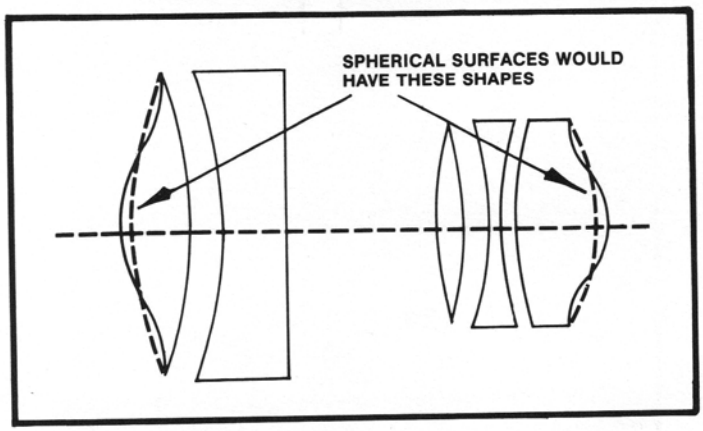


Figure 35

Let's now more clearly define a lens aberration. An aberration is a fault in the lens performance—something that causes the rays of light to not converge exactly at the focal point. No lens can be completely free from aberrations. Yet lens designers can reduce the effects of aberrations to the point where they're virtually undetectable.

Correcting aberrations is the job of the lens designer, not of the camera-repair technician. Yet you might introduce aberrations by errors in lens reassembly. The more complex the lens design, the greater the risk of introducing aberrations during the repair. Why? Because the more complex lens has more optical elements. And the optical centers of all the elements must precisely align with the optical axis.

In general, you should disassemble a lens no further than necessary to make the repair—especially with complex systems. Typically, groups of elements mount in tubes called **lens cells**; the lens cell normally screws into another portion of the lens. It's generally safe to unscrew the lens cell to reach the inner portions of the lens unit, Fig. 33. But try to avoid removing the lens elements from the lens cell.

Yet there will be times you'll have to remove individual elements. You should therefore be able to recognize the effects of the different aberrations. Later in this lesson, we'll describe the test techniques. But first let's look at the common causes and effects of aberrations.

Spherical aberration

A perfect lens brings all the light rays to focus at the same point. But no lens is perfect. The light rays behavé more as shown in Fig. 34. With spherical aberration, the rays striking the edges of the lens come to a point of focus nearer to the lens than do the central rays.

Because of the misdirected light, spherical aberration can cause the entire image to lose both sharpness and contrast. Also, an image of a point source of light appears to have a halo around it. That's because the light rays in the outer zones cross the axis at other points. Halos from all the points of light in the image then blend together, causing an overall fog.

A compound lens, such as the one shown in Fig. 31, can provide correction for spherical aberration. The manufacturer uses one type of glass—crown glass—for the positive element and another type of glass—flint glass—for the negative element. Crown glass and flint glass have different refractive indexes. In combination, the two types of glass tend to bring the marginal rays to focus at the same point as the central rays.

Another way to correct for spherical aberration is to use a lens surface that isn't a portion of a sphere—an **aspherical** surface, Fig. 35. An aspherical surface can be designed to bring the marginal rays to the same point of focus as the central rays. But using an aspherical surface increases the difficulty of the design. Modern computers have greatly reduced the time required to design an aspherical surface. The designer can now perform all the experiments electronically rather than having to grind experimental surfaces.

Chromatic aberration

Earlier, you saw how white light can be dispersed into the seven colors. The dispersion effect occurs in a lens because the different wavelengths refract different amounts, Fig. 36.

Chromatic aberration causes images produced by different colors to be in different focus. If the subject is made up of white light, part of the image will be sharp and other parts won't be sharp. Even a picture of a two-color object can't be sharp for both colors.

The compound lens shown in Fig. 31 also provides correction for chromatic aberration. Here, the crown-glass element tends to bring the blue wavelengths to focus closer to the lens than the red wavelengths. And the flint-glass element tends to bring the red wavelengths to focus closer to the lens. Used in combination, the two types of glass then bring red and blue to the same point of focus. A lens designed to bring together two colors to the same focus point is called an **achromat**.

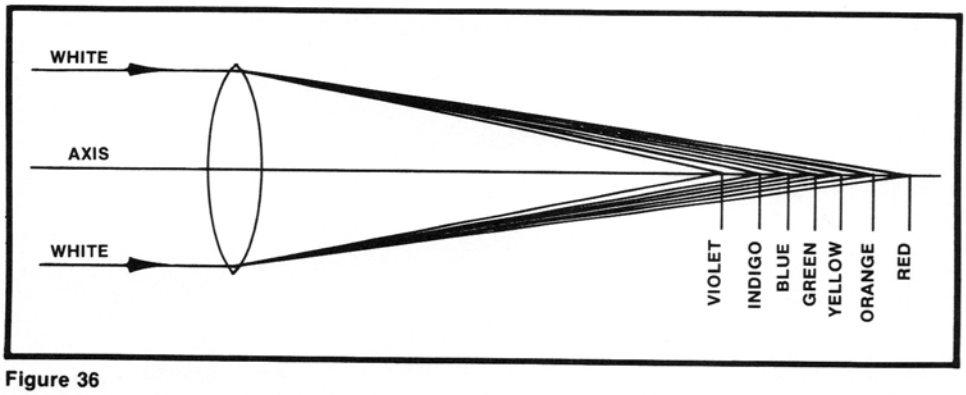


Figure 36

Distortion

Distortion occurs when a lens system does not have uniform lateral magnification over its entire field. A straight line then appears curved in the image. There are two types of distortion, named according to the effect—**barrel distortion** and **pincushion distortion**, Fig. 37.

Barrel distortion results when the magnification decreases toward the edges of the field. And pincushion distortion results when the magnification increases toward the edges of the field.

A single lens element may be virtually free from distortion. But, when the manufacturer makes corrections for other aberrations, distortion may result. Placing the diaphragm or shutter blades in front of the lens or behind the lens may also cause distortion. That's why you'll normally find diaphragm leaves and shutter blades near the optical center of the lens.

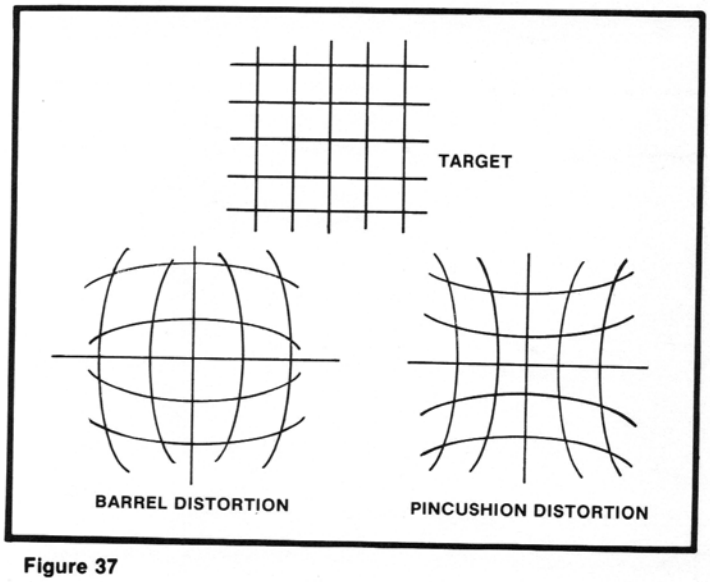


Figure 37

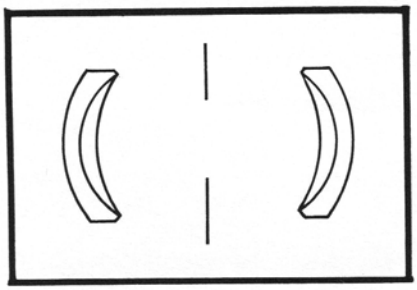


Figure 38

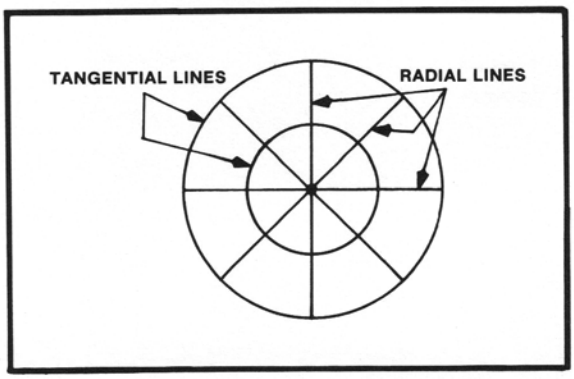


Figure 39

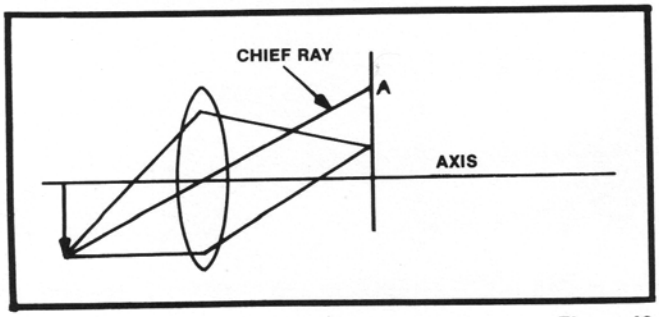


Figure 40

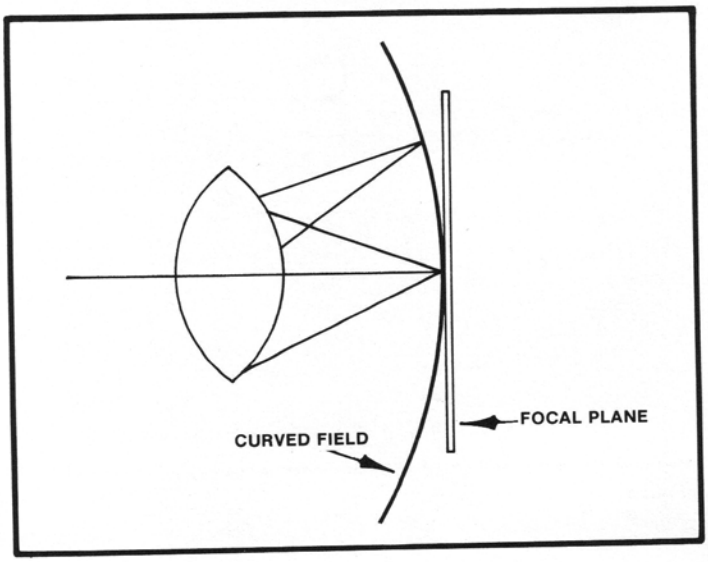


Figure 41

The rectilinear lens, Fig. 38, provides excellent correction for distortion. Notice that the rectilinear lens consists of two nearly symmetrical lens groups. The diaphragm leaves are between the two lens groups at the optical center of the system.

Astigmatism

Astigmatism causes lines running in different directions (with respect to the lens axis) to be brought into focus at different points. Consider the pattern shown in Fig. 39. Here, there are two types of lines—**radial** (or sagittal) **lines** and **tangential** (or transverse) **lines**.

The radial lines, when extended, pass through the center of the image. But the tangential lines remain an equal distance from the image center. Even when extended, the tangential lines never pass through the center of the image.

A lens with astigmatism can bring either the radial lines or the tangential lines into focus. However, it can't bring both types of lines into focus at the same time. To correct for astigmatism, the designer uses several elements with different shapes and proper spacing.

The astigmatism effect is most evident in the outer edges of the lens. Stopping down the lens—using a smaller f/stop—then minimizes the effect. A smaller f/stop also reduces the effect of spherical aberration. As you'll recall, spherical aberration occurs because of a focus difference between the central portion of a lens and the edges. So, by using only the central portion of the lens, you can minimize aberrations.

Coma

Coma is yet another aberration you can minimize by stopping down the lens. Coma affects only those portions of the image which lie off the optical axis—toward the edges of the picture. The aberration results because a lens produces slightly different images from its various areas.

Fig. 40 illustrates the cause of coma. The chief ray from the object point comes to focus at point A on the focal plane. But the marginal rays from the same object point come to focus elsewhere. Coma can cause a point source of light to appear as some shape other than a point, such as a teardrop shape.

Curvature of field

Curvature of field causes the focused image of a lens to lie in a curved—rather than perfectly flat—plane, Fig. 41. An image toward the center of the focal plane may be in sharp focus. But the sharpness falls off for images away from the center. At the edges of the field, the image sharpness may improve.

It's possible to design a lens that exhibits practically no curvature of field—for example, the lenses used with enlargers normally have a high degree of correction. However, correcting for field curvature may introduce other aberrations.

In most situations, the effects of field curvature aren't objectionable. However, a technician might increase the effects by improper alignment during reassembly of a lens. You'll later see how you can detect the effects of field curvature with lens tests.

DIFFRACTION AND VIGNETTING

The aberrations we've discussed result from failures of the optical components. But the mechanical systems in a lens can also cause limitations. One such limitation is due to another property of light—diffraction.

We've stated that light travels in a straight line. It can't turn corners without help. When light strikes an opaque object, then, one might expect it to form a well-defined shadow with a sharp edge.

However, since light actually travels in wavefronts, it has a tendency to curl around an opaque object. The resulting shadow feathers out as indicated in Fig. 42. In a lens system, the diaphragm leaves may cause the diffraction effect.

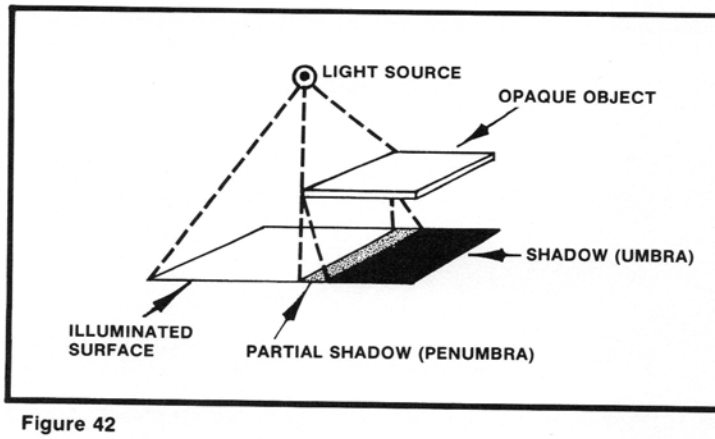


Figure 42

You've seen that stopping down the lens minimizes most aberrations. However, as you stop down the lens, you're increasing the effects of diffraction. Diffraction becomes the limiting quality as far as the image is concerned at the small apertures.

Most lenses provide their best results at the middle apertures—usually f/5.6 or f/8. Here, you've stopped down the lens far enough to minimize aberrations. And diffraction hasn't yet caused a noticeable effect on the image quality. At smaller apertures, diffraction can cause a loss of definition in the image.

Vignetting results from a different type of interference. The actual tube which holds the lenses can cause a decrease in image brightness toward the edges, Fig. 43. Vignetting is one of the factors that limits the size of the picture that the lens can produce.

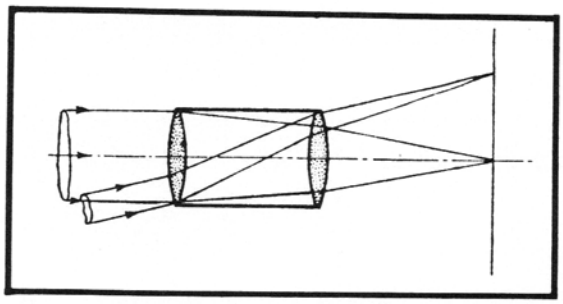


Figure 43

You'll frequently see the vignetting effect resulting from operator error. If the camera owner uses an improperly fitting lens hood, for example, he might bring you a picture like the one shown in Fig. 44. Notice that the lens hood has cut off the corners.

In Fig. 44, the lens tried to cover a wider field than the lens hood would allow. Too small a filter or other lens accessory would cause the same problem. A particular accessory may work fine with one focal length of lens. But, when the owner tries to use a shorter focal length with the same accessory, he gets the vignetting effect.

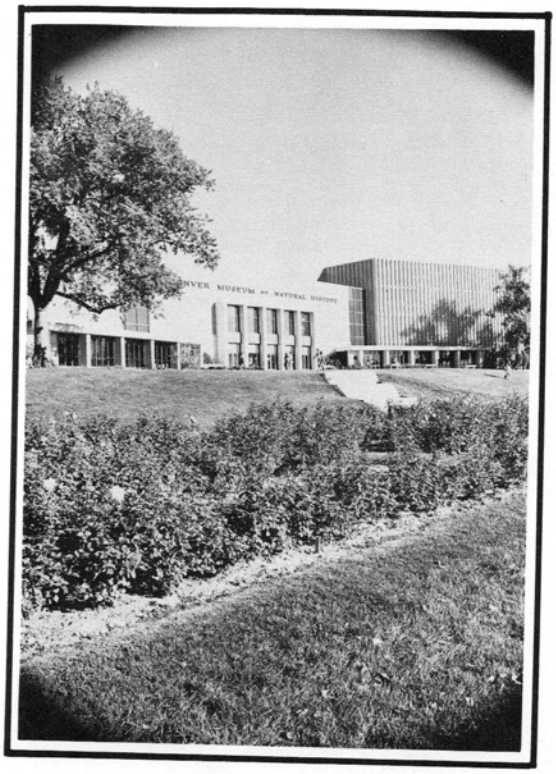


Figure 44

TEST-YOURSELF QUIZ #3

1. The aberration caused because the lens shape is part of a sphere is SPHERICAL aberration.
2. A lens surface that is not a part of a sphere is a/an ASPHERICAL lens surface.
3. If a lens forms a sharp image of one color but not of another color, it exhibits CHROMATIC aberration.
4. When the magnification of the lens decreases toward the center, the lens has PINCUSHION distortion.
5. Lines which, when extended, pass through the center of the image are RADIAL lines.
6. The tendency of light to curl around an opaque object is called DIFFRACTION .
7. When a lens accessory or part of the lens barrel cuts off the corners of an image, the effect is called VIGNETTING .

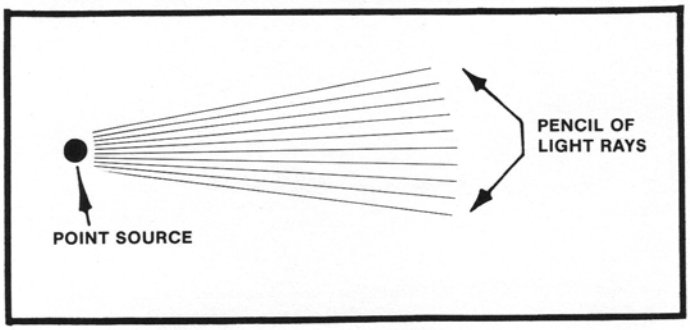


Figure 45

LIGHT INTENSITY AND LENS SPEED

The speed of a lens refers to how fast the lens can burn an image onto the film. We mentioned earlier that the lens is much faster than the pinhole (a principle you may have already proved to yourself with the pinhole viewing system). The lens can burn the image onto the film in much less time—or with far less light on the subject.

In the pinhole experiments, you could also increase the brightness of the image by moving closer to the light source. The light intensity changes according to distance. As you move closer to the light source, the intensity of the light increases. Fig. 45 shows why.

Consider that the light rays in Fig. 45 come from a point source. Notice again how the light rays diverge. If you had a three-dimensional drawing in Fig. 45, you'd be able to see that those light rays form a **cone** of light. The tip of the cone joins the point source. And the base of the cone gets larger the further the light rays travel.

Such a light cone is called a **pencil** of rays. If there are several point sources, each emits its own light pencil. You then have an accumulation of pencils called a **beam** of light.

Since the light rays within a pencil diverge, they continue to spread apart. The further the light rays travel, the greater the distance between the rays. Thus the pencil of light becomes less intense the further you move from the source.

The light intensity is then inversely proportional to distance. But more than that—the light intensity is inversely proportional to the square of the distance to the light source. This principle is the **inverse square law**. Expressed as a formula:

$$\text{Intensity of light} = \frac{\text{intensity of light source}}{d^2}$$

where d is the distance between the light source and the subject.

There are several units used to measure the intensity of the light. For example, the intensity of the light source might be

measured in candlepower (cp). And the light on a subject illuminated by the light source might be measured in foot-candles. A foot-candle represents the amount of light falling on a surface placed one foot away from a standard candle.

Using these units of measurement, let's see how the formula works. Suppose that the intensity of the light source in Fig. 45 is 5000 cp. What's the illumination on a subject placed 10 feet from the light source?

First find the square of the distance—10 x 10 = 100. Dividing 5000 by 100 gives you 50 foot-candles, the illumination on the subject.

At this time in your training, it's not necessary for you to cover all the different units of light measurement; you'll learn about these units during your study of exposure-control systems. And, in camera repair, you'll normally be working only with the two units covered in the next section of this text. All you need at the moment is an understanding of how the light falls off as the distance to the light source increases. Fig. 46 should clarify the inverse square law.

Consider that surface A, located one foot from the light source, is one square foot in area. And the light on surface A is one foot-candle.

If you now move aside surface A, the same amount of light must cover surface B. The light that formerly had to cover only one square foot must cover four square feet. By applying the inverse square law, you can find the light on surface B—1/4 the light on surface A, or 1/4 foot-candle.

Surface C has an intensity of 1/9 foot-candle. Here, the same light source must cover a surface area of nine square feet. And surface D, with sixteen square feet, receives only 1/16 foot-candle. Since surface D is 16 times greater in area than surface A, it receives only 1/16 the illumination.

You can see why the size of a pinhole affects the brilliance of the image. If you place a small pinhole at surface D, Fig. 46, only a small proportion of the light gets through. A larger proportion of the light passes through a pinhole placed at surface C.

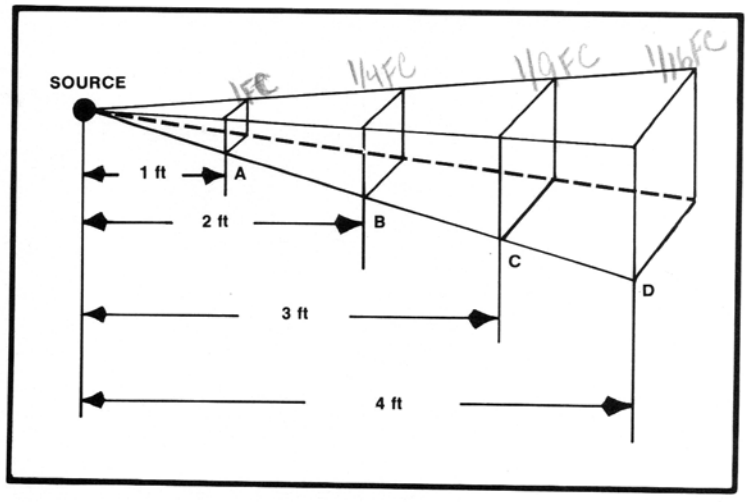


Figure 46

Similarly, a lens with a larger opening size transmits a larger proportion of the light. The lens speed is normally expressed as the size of the largest aperture. A "fast" lens might have a maximum aperture of f/1.4 compared with a "slow" lens having a maximum aperture of perhaps f/4.

Two factors actually determine the speed of a lens—the diameter of the opening and the distance between the lens and the film (the focal length). The f/stop then refers to a ratio called the **speed ratio** of the lens. To find the speed ratio, use the following formula:

$$\text{Speed ratio} = \frac{\text{focal length}}{\text{diameter of lens opening}}$$

Let's take an example. Suppose that you have a 50mm focal-length lens. And the diameter of the lens opening at the largest f/stop setting is 35mm. What's the speed of the lens?

Just divide 50mm by 35mm—1.43. The largest f/stop calibration could then be considered f/1.4.

Similarly, you can use the formula to find the diameter of each aperture. Perhaps you have a 50mm lens, and you want to know the opening diameter at f/8. Transpose the formula as follows:

$$\text{Diameter of lens opening} = \frac{\text{focal length}}{\text{speed ratio}}$$

Or, 50mm divided by 8 = 6.25mm diameter.

For a longer focal length, you need a larger diameter opening to have the same lens speed. Consider in our first example that we change the lens focal length to 100mm. The lens speed now becomes 100mm divided by 35mm = 2.86. So, even though we didn't change the size of the opening, we have a slower lens.

The intensity of the light reaching the film also decreases as you focus to closer distances. Remember, as the object moves closer to the camera, you must move the lens away from the film. Since you're increasing the distance the light must travel, the intensity at the film decreases.

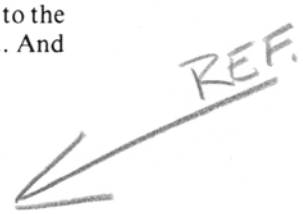
Over the normal focusing range the light loss isn't significant. But some close-up lenses (macro lenses) have extended-range focusing mounts that allow you to move the lens even further from the film. An extension tube or a bellows attachment for close-up photography also allows moving the lens beyond its normal minimum-focusing distance. The light loss then becomes a factor. In the close-up range, you must use a longer exposure or a larger f/stop to compensate for the light loss.

THE APEX ADDITIVE EXPOSURE SYSTEM

We mentioned that there are many different units used to indicate light intensity. However, you'll be working mainly with two units—**brightness value (BV)** and **exposure value (EV)**. Factory service manuals refer frequently to the BV when discussing light intensity. And most camera-test instruments have EV calibrations.

The brightness value is the unit of light intensity in the APEX system. Each of the variables that affects the exposure to the film has an APEX value. **SV—speed value**—refers to the film speed. **TV—time value**—indicates the shutter speed. And **AV—aperture value**—means the diaphragm opening.

BV (brightness value)	=	light intensity
AV (aperture value)	=	diaphragm opening
SV (speed value)	=	film speed
TV (time value)	=	shutter speed



All the variables have parts in determining the EV. So, rather than being a unit of light, the EV is a unit of exposure. Yet manufacturers use the EV to indicate light level, both in service manuals and with test instruments. A light-meter tester, for example, normally has several light levels calibrated in exposure values. EV 15 may be the high light level. EV 9 may then be the low light level.

However, a light level of EV 9 only provides proper exposure to the film at a certain combination of shutter speed, film speed, and diaphragm opening. By contrast, the BV considers only the intensity of the light; none of the other variables has any effect. The APEX system makes it possible to determine the EV by adding the values of other variables.

To see how the APEX system works, refer first to chart #1 which shows the APEX values corresponding to shutter speeds and f/stops.

Notice in the chart that TV 5 refers to a shutter speed of 1/30 second. And AV 5 refers to a diaphragm opening of f/5.6. By using chart #1, you can quickly figure any combination of shutter speed and diaphragm opening that will result in the same exposure.

Let's say that you're using a diaphragm opening of f/8—AV 6. And you're using a shutter speed of 1/125—TV 7. By adding 6 and 7, you get a sum of 13. Any other combination of AV and TV that totals 13 gives the same exposure to the film—the same EV. For example, a shutter speed of 1/500 (TV 9) and a diaphragm opening of f/4 (AV 4) also total 13. 1/500 at f/4 then provides the same exposure to the film as 1/125 at f/8. Now you can see why we use the term, "additive system."

In order for the exposure to be the same, however, the BV and SV must not change. Chart #2 shows the additive values for different film-speed settings (SV).

CHART #1

TV, AV	Shutter Speed	Diaphragm Opening
0	1	f/1
1	1/2	f/1.4
2	1/4	f/2
3	1/8	f/2.8
4	1/15	f/4
5	1/30	f/5.6
6	1/60	f/8
7	1/125	f/11
8	1/250	f/16
9	1/500	f/22
10	1/1000	f/32

CHART #2

SV	ASA Film Speed
0	3
1	6
2	12
3	25
4	50
5	100
6	200
7	400
8	800
9	1600
10	3200

A factory service manual doesn't always tell you what SV it's using when it refers to the exposure value. But most factories use a standard SV—SV 5 (ASA 100). So, unless the manual specifies some other film speed, you can assume ASA 100.

Suppose now that the service manual refers to a specific light level in the exposure value—perhaps EV 15. The light level is EV 15 only at ASA 100; if you change the film speed, you also change the exposure value. To get EV 15, the manufacturer has added the brightness value (BV) to the speed value. Or,

$$BV + SV = EV$$

Any combination of shutter speed and diaphragm opening that totals 15 should then provide proper exposure. For example, 1/500 second (TV 9) at f/8 (AV 6) provides proper exposure to the film at EV 15. Or,

$$TV + AV = EV$$

From the formula BV + SV = EV and the formula TV + AV = EV, we can get one more formula:

$$BV + SV = TV + AV$$

These formulas provide the basis of the APEX additive system. You'll work again with exposure values in your lessons on exposure-control systems.

TYPES OF CAMERA LENSES

Lenses are normally classified by focal length and maximum aperture—for example, a 100mm f/4 lens. You'll also see the focal lengths referred to by categories such as wide-angle, telephoto, and normal.

A normal lens has a focal length about equal to the diagonal of the film. "Normal" then depends on the film size. With a 35mm format, the normal lens has a focal length of approximately 43mm, Fig. 47. More often, though, you'll find that 35mm cameras come with 50mm normal lenses. The first Leicas used 50mm lenses, and the focal length has since become somewhat a tradition.

With a 2 1/4" format, 80mm is generally considered the normal focal length. The 80mm lens produces a larger image than does the 50mm lens. But, with a larger film format, the proportion of image size to negative size remains approximately the same.

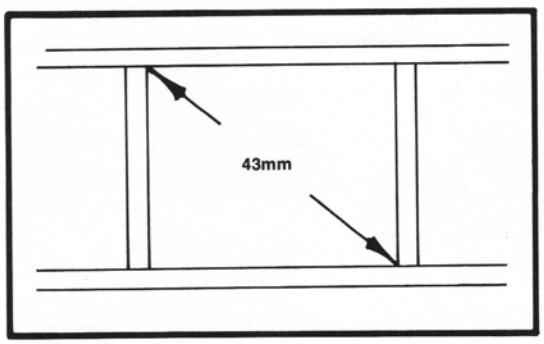


Figure 47

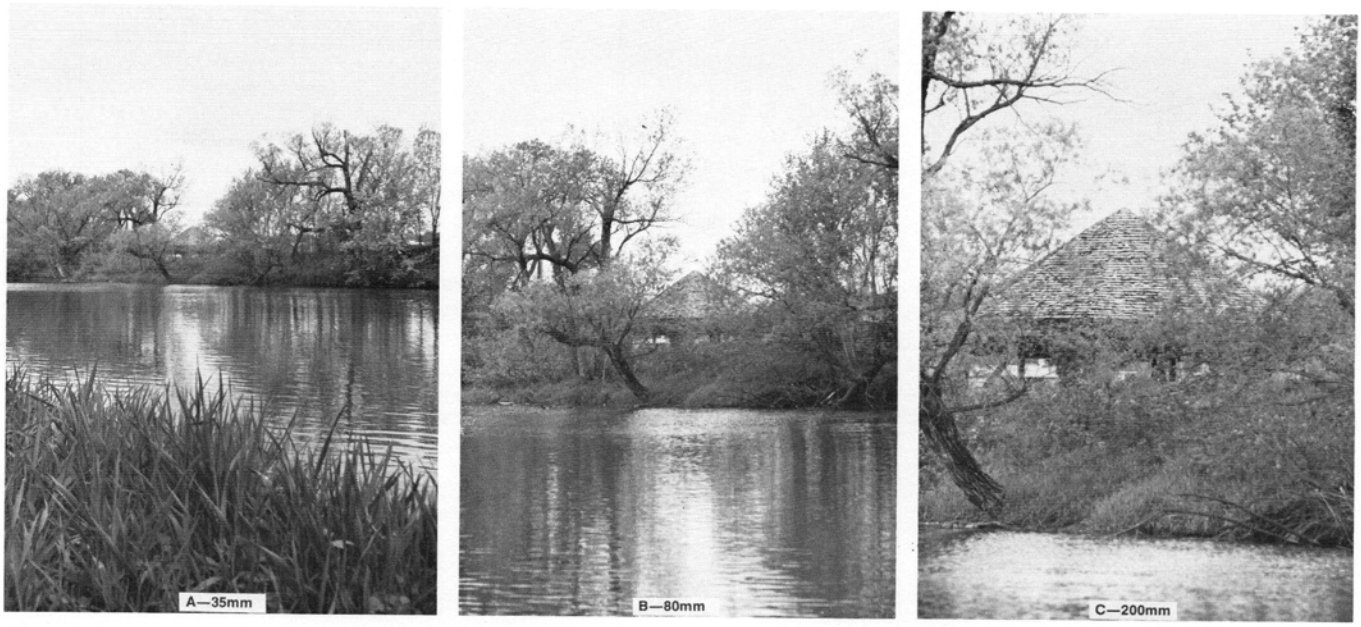


Figure 48

We've just indicated the main reason for changing focal length—to change the size of the image. The longer the focal length, the larger the image. Fig. 48 illustrates the effect of changing the focal length.

The following formula expresses the relationship between the object size and the image size:

$$\frac{O}{o} = \frac{I}{i}$$

where O = object size, I = image size, o = distance between lens and subject, and i = distance between lens and image (focal length). You can increase the distance between the lens and the image by increasing the focal length. So, if you want an image that's twice as large, you can cut the distance to the subject in half. Or you can double the focal length.

Notice in Fig. 48 that changing the focal length also changes the field of view. The shorter the focal length, the more of the subject you get on the film. Increasing the focal length then increases the image size while narrowing the field of view. Fig. 49 shows the relationship between field of view and focal length.

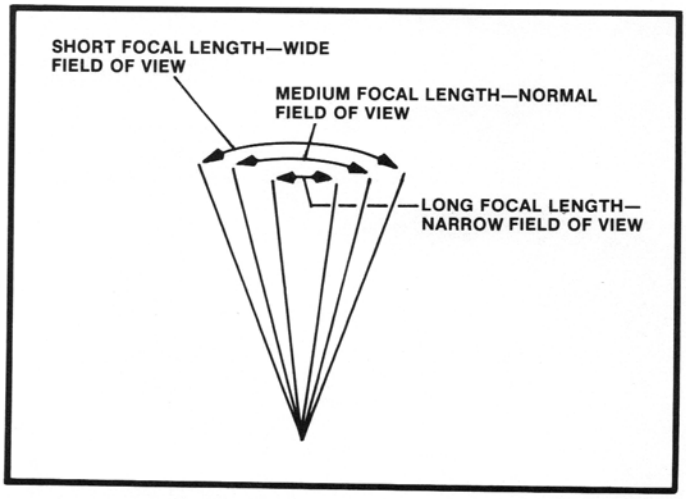


Figure 49

A normal lens produces a field of view that's around 52°. With a shorter focal length, you get a larger field of view. A wide-angle lens, Fig. 50, has such a short focal length that it produces a field of view of around 90° or more. Some wide-angle lenses cover fields of more than 180°. These lenses are often known as "fish-eye" lenses because of their bulging front elements.

Figure 50 **A 28mm wide-angle (left) compared to a 50mm normal lens (on the camera) and a 135mm telephoto (right).**

THE TELEPHOTO LENS

Increasing the focal length, as you've seen, increases the image size. But a long focal-length lens becomes unwieldy—the lens can get so long that it's awkward to use. The telephoto lens gains the effect of a long focal length in a relatively compact size.

Fig. 51 shows the basic design of the telephoto lens. A negative lens sits within the focal length of the positive lens. So, before the positive lens can bring the light rays together, the negative lens refracts the light as shown in Fig. 51. The light rays then converge at plane B.

To find the equivalent focal length, extend the refracted ray of the negative lens as shown by the dashed line, Fig. 51. The equivalent focal length extends from point A to point B. Without the telephoto effect, a lens would have to be quite a bit longer to have the same focal length. The optical center of a positive lens alone would have to be at point A, Fig. 51.

Some lenses use the same principle to gain a wide-angle effect. The negative lens then sits in front of the positive lens, making the lens-to-image distance greater than the equivalent focal length. You'll see this design referred to as an "inverted telephoto lens."

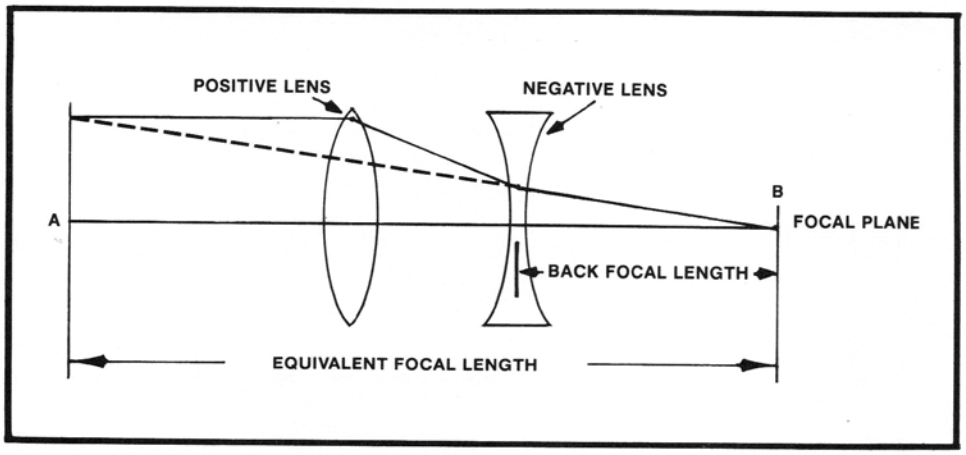


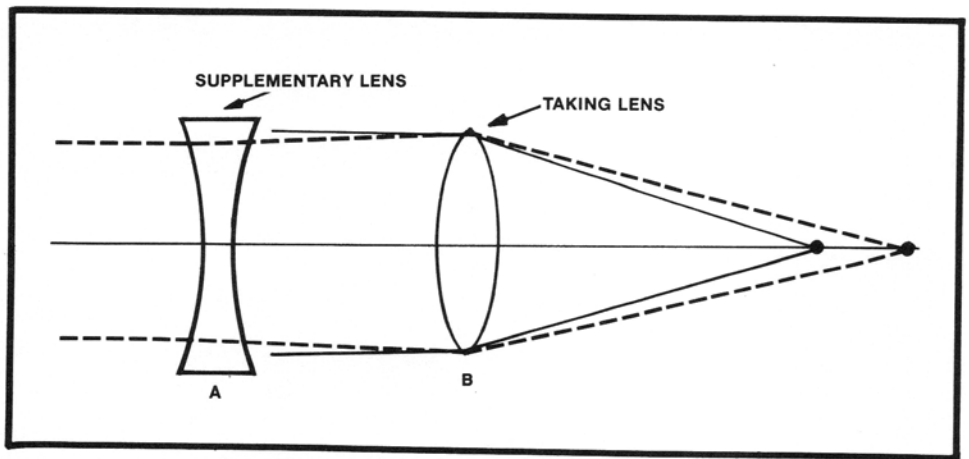
Figure 51

CHANGING THE FOCAL LENGTH

It's possible to change the focal length of a multiple-element lens by changing the spacing between elements or groups of elements. Light rays then converge or diverge a different amount before being refracted by the following element.

Supplementary lenses use the refracting principle to change the focal length. Consider in Fig. 52 that element B is the first element in the taking lens. Normally, without element A, element B brings parallel light rays together as shown by the solid lines.

The dashed lines show what happens when you put a negative supplementary lens (element A) in front of the taking lens. Now the light rays incident to the taking lens are no longer parallel. Rather, they diverge. As a result, the refracting power of element B brings the light rays together behind the normal focal point.



Negative supplementary lens increases focal length. Figure 52

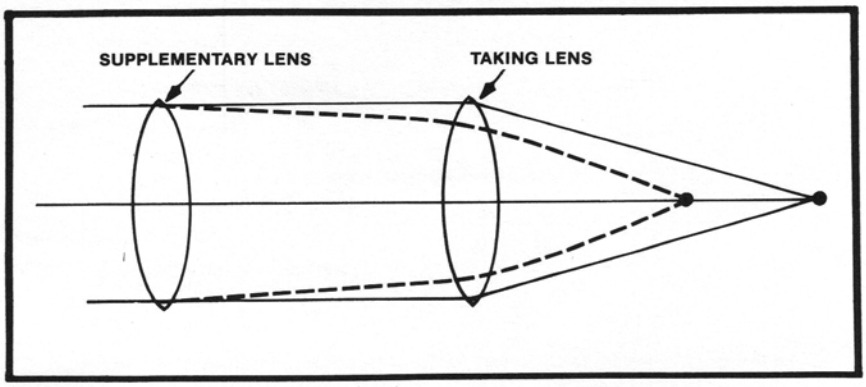


Figure 53 **Positive supplementary lens decreases focal length.**

Similarly, it's possible to decrease the focal length by using a positive supplementary lens, Fig. 53. The positive supplementary lens causes the light rays to converge before they strike the taking lens. And the taking lens brings the light rays together in front of the normal focal point.

The lens extender works in a similar way to increase focal length. But rather than attaching to the front of the lens, the lens extender fits between the camera lens and the body, Fig. 54. Here, the lens extender intercepts the converging light rays before those rays come together.

Without the lens extender, the taking lens brings the rays together at the point shown by the dashed lines, Fig. 54B. However, the lens extender extends the focal length as shown by the solid lines in Fig. 54B. Since the lens extender fits between the taking lens and the body, it provides the additional length needed to image the light at the focal plane.

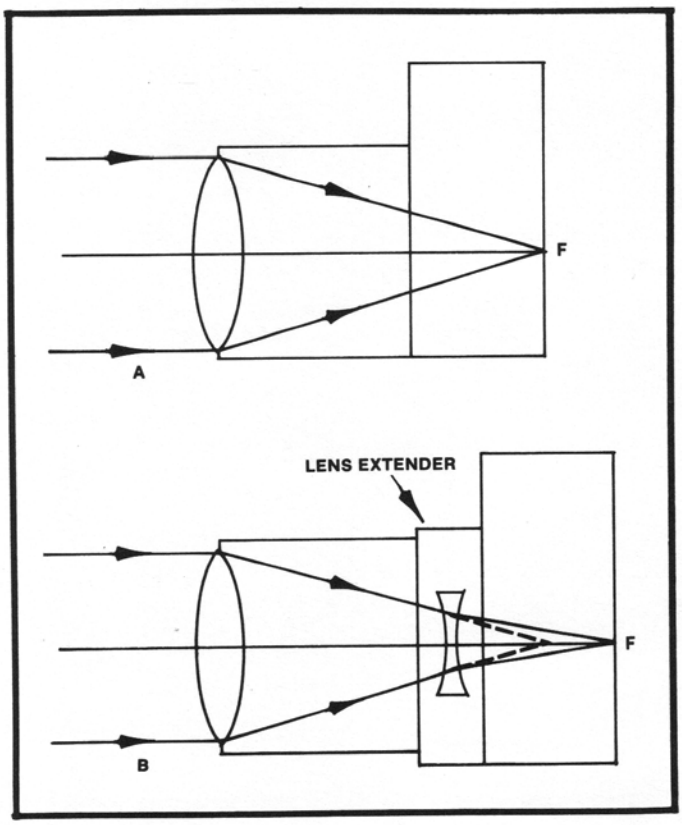


Figure 54

Lens extenders come in different powers. A 2X lens extender doubles the effective focal length. It then makes a 100mm lens out of a 50mm lens, a 400mm lens out of a 200mm lens, etc. A 3X lens extender triples the effective focal length.

In general, lens extenders provide the best results with longer focal-length taking lenses. If you're using a 50mm lens with the lens extender, you may get a loss of definition at the edges. But if you're using the same lens extender with a 100mm lens, you'll probably get a much better image. Why? Because the cone of light reaching the lens extender is smaller in diameter.

A zoom lens uses a similar principle to internally change the focal length. As you rotate the zoom ring, Fig. 55, an internal lens group slides forward or backward along the lens axis. This lens group—the **zooming component**—changes the focal length.

Changing the light path to alter the image size also changes the point of focus. Consequently, the zoom lens has a second movable group—the **compensating component**. As the zooming component moves to change the image size, the compensating component moves to keep the image in focus. You'll learn more about the zoom lens later in your course; it's covered in the lesson, "Practical Optics."

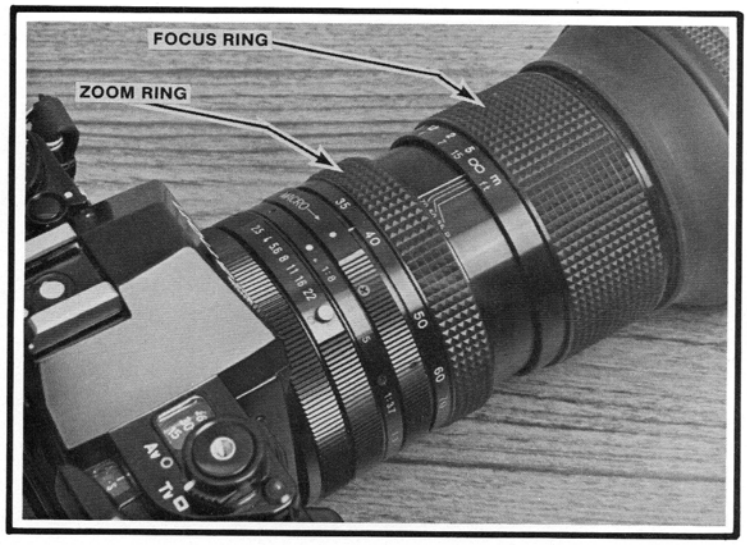


Figure 55

TEST-YOURSELF QUIZ #4

1. The inverse square law states that the light intensity is inversely proportional to the square of the DISTANCE .
2. Name the units in the APEX system used to indicate the following:
   shutter speed TV
   film speed SV
   diaphragm opening AV
   light intensity BV
3. You're using a shutter speed of 1/125 and a diaphragm opening of f/8. When you change the shutter speed to 1/30, what diaphragm opening must you use to retain the same exposure? F16 .
4. A manufacturer of test equipment states that the intensity of the light source is BV 5. At what ASA setting is the light source equal to EV 10? 100 .
5. You're checking an automatic camera on a light source that's calibrated EV 12. Your shutter speed is 1/60. What diaphragm opening should you set to get proper exposure? F8 .
6. The image size is DIRECTLY (inversely, directly) proportional to the focal length.
7. With a telephoto lens, the lens-to-image distance is LESS (greater, less) than the equivalent focal length.
8. A lens extender and the taking lens of the camera, working in combination, form a REAL (real, virtual) image.

BV=5
EV=10
SV= EV
BV 5 + SV 5 = EV 10

EV 12 1/60= TV 6 + AV-6 = EV 12
TV+AV=EV

STUDY

STUDY

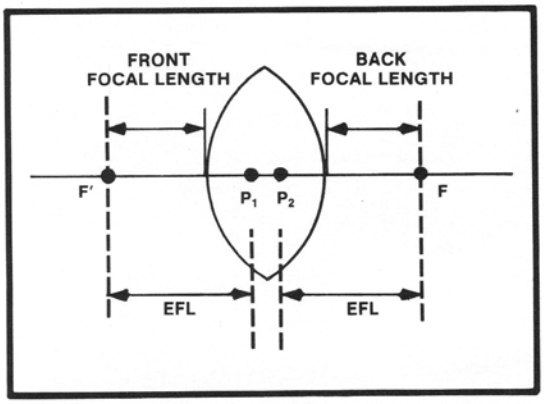


Figure 56

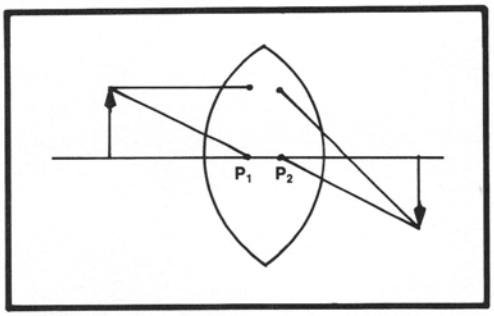


Figure 57

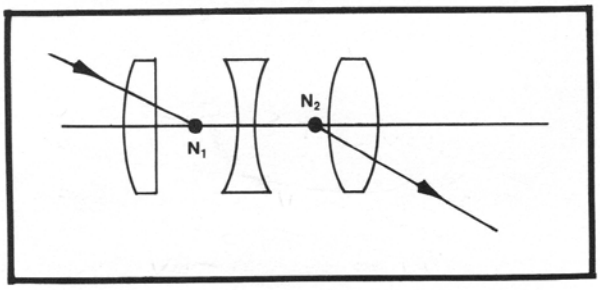


Figure 58

IMAGE FORMATION BY THICK LENSES

To this point, we've only described how a relatively thin lens forms an image. With thick lenses—and with multiple-element lens systems—the principle is a little different.

To service optical systems, you certainly don't have to understand all the complexities of design. However, there are a few more terms you'll encounter in service manuals and technical reports. We'll therefore briefly describe the principles for your reference.

Fig. 56 shows a thick lens. Because of the thickness, we can no longer make the measurements from the center of the lens. Instead, we measure the effective focal length to the two **principal points** on the lens axis—P1 and P2.

The effective focal length is then the distance between P2 and the primary focal point F—or the distance between P1 and the secondary focal point F'. The **back focal length** is the distance between focal point F and the rear surface of the lens. And the **front focal length** is the distance between focal point F' and the front surface of the lens.

P1 and P2 have interchangeable properties (in optical terms, they're conjugate to one another). An entrance ray that passes through the first principal point refracts from the second principal point. It then follows a path that's parallel to the entrance ray, Fig. 57. Fig. 57 shows how to plot the image position from the principal points.

In Fig. 57, the principal points also mark the positions of the **nodal points**. As long as the medium on each side of the glass has the same refractive index, the nodal points coincide with the principal points. An incident ray that arrives at the front nodal point at an angle with the axis will depart from the rear nodal point at a similar angle.

Fig. 58 shows possible nodal-point positions in a three-element lens. Depending on the lens design, the nodal points may be in different positions. They may even be crossed over with the rear nodal point N2 in front of the front nodal point N1. Even so, the optical principle remains the same—the entrance ray that strikes the front nodal point N1 is parallel to the exit ray leaving from the rear nodal point N2. The effective focal length in Fig. 58 is measured from the focal point to the rear nodal point.

IMAGE FORMATION BY A MIRROR

You've seen how the telephoto lens uses refraction to gain the long focal length. Another type of lens gets even more spectacular results by using reflection. The **mirror lens** uses a system of mirrors to fold the light path, thereby providing a very long focal length in a relatively short housing.

To see how the system works, let's first examine how a mirror forms an image. What happens when you look at your reflection in a flat mirror? You see a virtual image that appears to be behind the mirror. Remember, a virtual image doesn't actually exist at the position it appears. But your eye assumes that any light reaching it has traveled in a straight line from the original source.

Fig. 59 shows how the flat mirror forms a virtual image. Here, we've drawn two incident rays from the point source. One ray strikes the mirror perpendicular to the surface; this ray reflects back upon itself. The other ray, striking the surface at an angle, reflects according to the law of reflection.

To find the virtual image, extend the two reflected rays as shown by the dashed lines. Notice that the image appears to exist at a point behind the mirror—as far behind the mirror as the point source is in front of the mirror.

A flat mirror also changes the orientation of the image in one plane. If you look at your reflection in a mirror, you'll notice that your image appears reversed from left to right. A reflex camera takes advantage of the principle by using the mirror as an erecting system. The reflex mirror takes the upside-down image formed by the lens and provides an image on the focusing screen that's right side up.

If the mirror has a curved surface, though, the principle of image formation becomes quite different. The mirror lens uses the type of mirror shown in Fig. 60 to form a real—rather than virtual—image.

In Fig. 60, parallel light rays from an infinity source strike the concave surface of the mirror. The dashed line in Fig. 60 represents the normal—from the center of curvature (C) to the mirror surface. By following the law of reflection, you can locate the reflected rays. The reflected rays converge at point F, the focal point of the mirror.

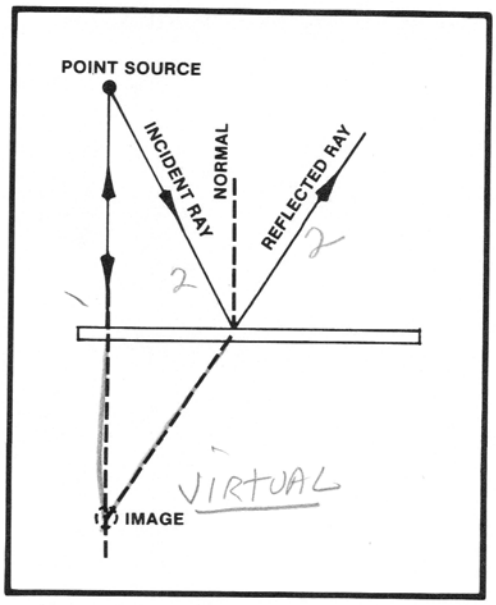


Figure 59

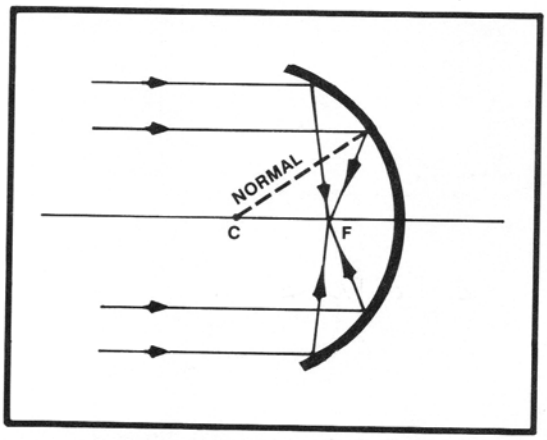


Figure 60

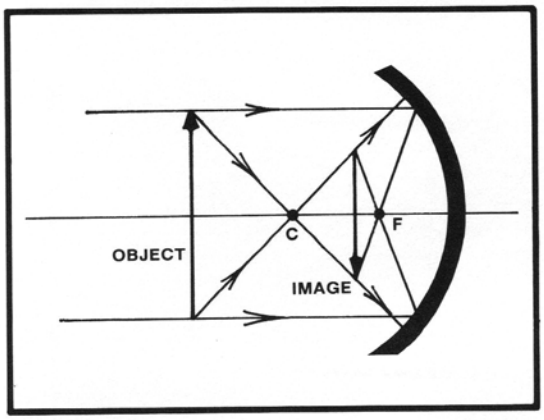


Figure 61

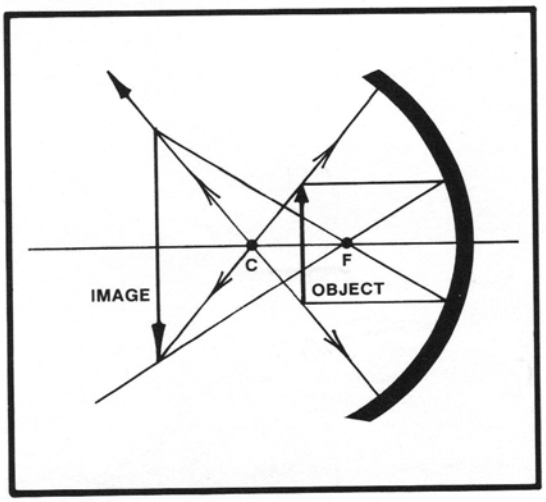


Figure 62

When the object sits outside the center of curvature, the mirror forms a real image, Fig. 61. Notice that the image is upside down and smaller than the object. Fig. 62 shows what happens with an object located between the center of curvature and the focal point. The mirror still produces a real image. But the image is larger than the object.

Moving the object between the focal point and the surface of the mirror results in a virtual image. The virtual image appears on the other side of the mirror. A convex (rather than concave) mirror also provides a virtual image.

But it's the real image provided by the concave mirror that makes possible the mirror lens, Fig. 63. Since the concave mirror has a spherical surface, it suffers from spherical aberration. The aspheric lens, Fig. 63, corrects for the spherical aberration inherent in the mirror system.

Light enters the mirror-lens system through the aspheric corrector lens. The primary mirror now reflects the light to the secondary mirror, Fig. 63. And the secondary mirror, mounted directly to the aspheric lens, reflects the light back to the primary mirror.

The light reflected from the secondary mirror passes through a hole in the center of the primary mirror, Fig. 63 and Fig. 64. Now the light images at point F, Fig. 63. If you extend the complete path of the light ray, Fig. 63, you can see that the mirror-lens system provides a focal length that's much longer than the lens housing.

To focus the mirror-lens system, the focusing mechanism moves the primary mirror. Turning a focus knob slides the primary mirror closer to or further from the secondary mirror. In Fig. 64, you can see the threaded focusing shaft mounted to the back of the primary mirror. The primary mirror in Fig. 64 is from a mirror-lens system that has a focal length of 1250mm.

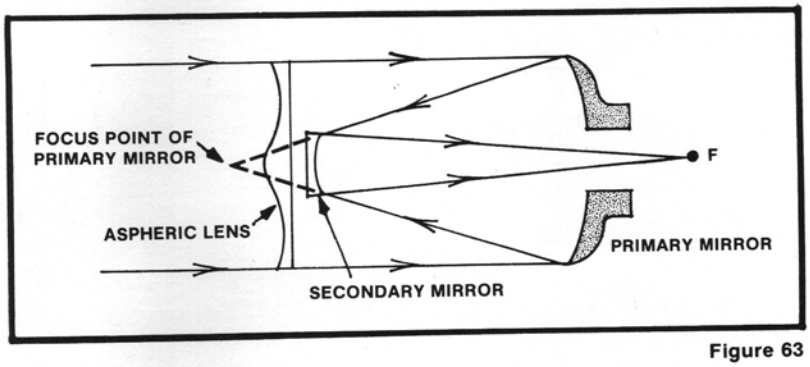


Figure 63

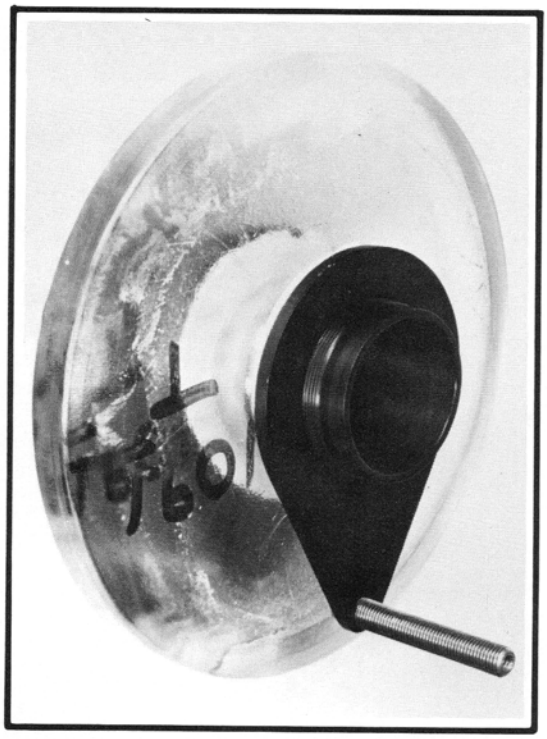


Figure 64

PRISMS

Like the mirror, the prism relies on the principle of reflection, but the reflection takes place inside the glass.

A prism may have one or more reflective surfaces, depending on the design. Light entering one face of the prism strikes the reflective surface. The reflected light then exits the prism through another face (or sometimes through the same face).

For example, Fig. 65 shows the light path through the **right-angle** (or 90°) **prism.** Since the reflective surface sits at a 45° angle, the reflected ray leaves the prism at a 90° angle to the incident ray. You'll find the right-angle prism in viewfinder and rangefinder systems.

The **porro prism,** Fig. 66, has two reflective surfaces. Light enters one side of the prism face. It then reflects from one reflective surface to the other. Finally, the light exits from the other side of the prism face.

As you can see, the porro prism displaces the light—it shifts the position of the light ray by an amount dependent on the distance between the two reflective surfaces. A few SLR's use the porro prism in the viewfinder system. But the most common application for the porro prism is in a pair of binoculars.

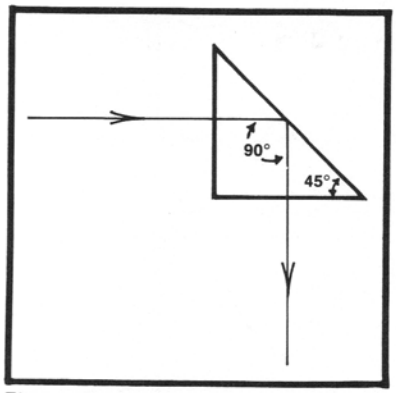


Figure 65

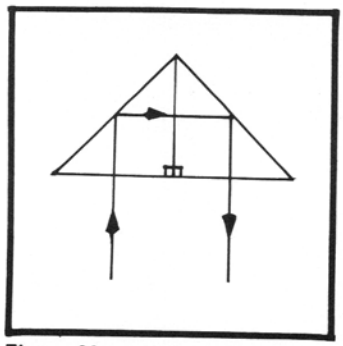


Figure 66

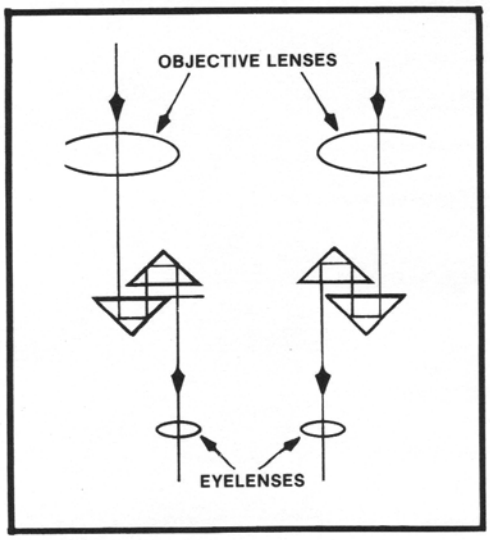


Figure 67

Binoculars use four porro prisms—two on each side, Fig. 67. Notice in Fig. 67 how each pair of porro prisms shifts the light coming through each objective (front) lens. By shifting the light paths, the porro prisms allow the objective lenses to be spaced further apart than the eyelenses. That's how the binoculars get the three-dimensional effect.

But the type of prism you'll encounter most frequently is the pentaprism, Fig. 68. You've already studied the pentaprism in your lesson, "The Camera and Its Variations." Remember, the pentaprism sits above the SLR focusing screen, Fig. 68. Here, it allows eye-level viewing of the focusing-screen image.

A system of mirrors could do just about anything the prism can do. However, since the prism can do everything inside a single piece of glass, it has some advantages. For one, many prisms don't require a silver coating on the reflective surfaces. It's possible to design a prism to totally internally reflect the light—reflect all of the light and refract none of the light.

When the prism surface reflects all of the light incident to it, we call the condition **total internal reflection**. Total internal reflection occurs when the angle of the incident ray exceeds the **critical angle** of the glass. Fig. 69 shows a light ray traveling from inside the glass and striking the glass-air surface at three different angles.

In Fig. 69A, the angle of the incident ray is less than the critical angle of the glass. The light ray then passes through the glass-air surface and refracts as shown.

The angle of the incident ray equals the critical angle in Fig. 69B. Now all of the light travels along the surface of the glass. Exceeding this critical angle results in total internal reflection—the entire light ray reflects back into the glass, Fig. 69C. So, if the angle of incidence exceeds the critical angle, the reflective surface of the prism needs no silver coating.

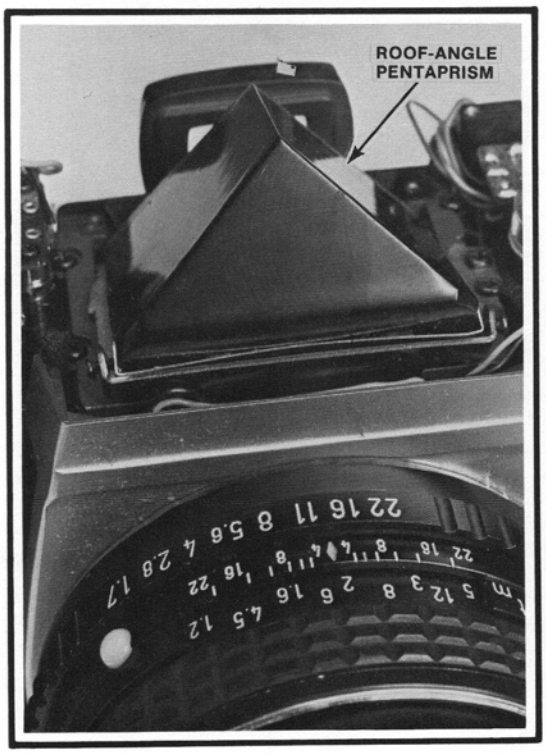


Figure 68

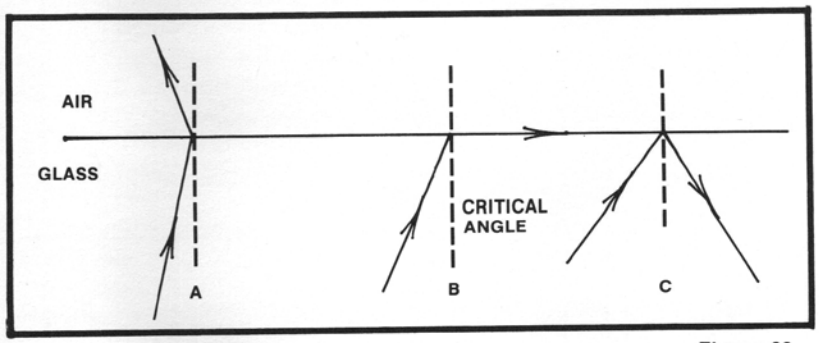


Figure 69

RESOLVING POWER OF LENSES

The standard for judging lens quality has long been resolving power. Resolving power refers to the ability of the lens to distinguish between (resolve) closely spaced lines or points in the image. The test of resolving power is the **resolution test**.

Originally, astronomers used the resolution test as a measure of the quality of their telescopes. A telescope that can resolve two closely spaced stars has high resolving power. The stars provide infinity point sources of light. But it's not too practical to wait for a starry night to make all resolution tests.

Most resolution tests therefore rely on standard charts—usually the NBS (National Bureau of Standards) chart, Fig. 70. The solid black lines printed on white paper provide high contrast. Notice that the chart has four patterns. Each pattern consists of sets of three lines with varying sizes.

The line spacing in the left-hand pattern is identical to that in the top pattern. Also, the line spacing in the right-hand pattern matches that in the bottom pattern. The numbers 12, 17, 24, 34, 48, and 68 then refer to the line spacing for the left-hand and top patterns. And the numbers 14, 20, 28, 40, 56, and 80 refer to the line spacing in the right-hand and bottom patterns.

At a 25X reduction, those numbers refer to **lines per millimeter**. The numbers have only a relative meaning at any other reduction. To get the 25X reduction, you must position the chart a certain distance from the lens you're testing. That distance is 26f—26 times the focal length of the lens.

Suppose, for example, that you're making a resolution test of a 50mm lens. You place the chart at a distance of 26 x 50mm = 1300mm (1.3 meter) from the lens (1 meter = 39.37"). Next you photograph the chart and examine the negative under magnification.

Perhaps the lines in the two sets marked "80" appear to blend together; they aren't clear and distinct. But you can clearly count three lines in each of the sets marked "68." You can then say that the lens resolves 68 lines per millimeter.

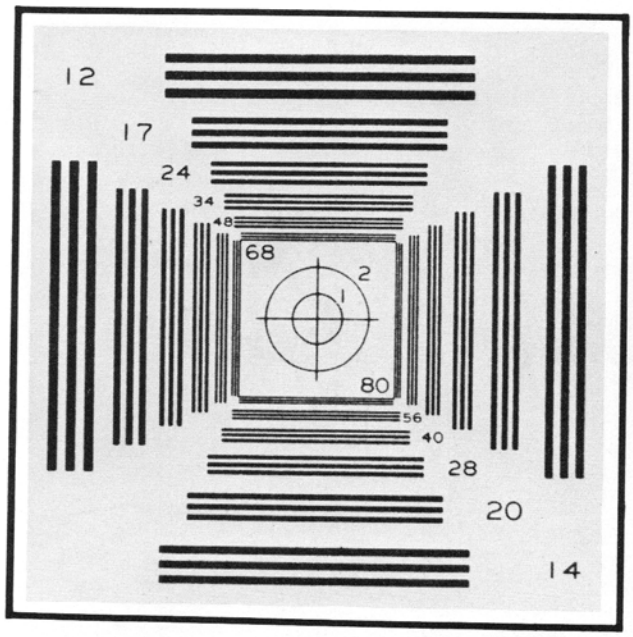


Figure 70

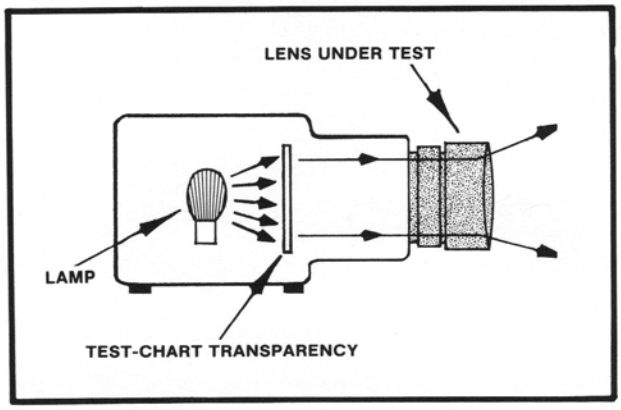


Figure 71

A resolution test with the chart at the center of the field, however, doesn't tell you much. Practically any lens will do a good job at the center—aberrations take their toll at the margins of the lens. A valid test then uses several charts. The charts appear across the entire field of the lens, allowing you to judge resolution at the edges as well as at the center.

Also, a completely valid resolution test eliminates all other variables—for example, the camera. Factories and test labs often use the projection tester (or projection collimator), an instrument that's similar to a slide projector, Fig. 71. The instrument projects a transparency of the test-chart array through the lens under test. You can evaluate the image of the charts on a screen or white wall. Only the lens under test has an effect on the image.

Most shops don't have access to projection testers. An alternative technique is to use a photographic test—actually photograph the test charts and make your evaluations from the negatives. The resolution test now becomes a measure of the lens/camera/film/processing resolving power.

But the photographic test is nonetheless widely used as a measure of lens performance. To restrict the results to a test of the lens, the film must have a high resolving power—at least three times that of the lens. A fine-grain film, such as Panatomic-X or even high-contrast copy film, becomes essential.

It's also necessary to hold other variables to a minimum. You should always use the same fine-grain developer and the same development time. In an ideal situation, you would make all your lens tests with a standard camera body—a body you know to be accurate. But it's usually not practical to have different test bodies for every make of lens you'll be testing.

MAKING THE RESOLUTION TEST

You may on occasion be asked to make a resolution test of a customer's lens. More often, though, you'll be making the test to check for aberrations after a lens repair.

To set up the test, mount a row of charts in the same plane. You can mount the charts directly to the wall. Or you may prefer to mount the charts on a board which you can leave assembled for future tests. If you're using the test to check for aberrations, it's only necessary that the row of charts completely spans the field of view.

However, if you're making a resolution test for a customer, the chart spacing may be more critical. The charts are normally spaced according to angle of coverage, Fig. 72. In Fig. 72, the number of charts allows you to test a lens having a 90° field of view. Also, the spacing permits image evaluations at specific angles from the axis. For comparison purposes, you may wish to place another chart at the 0° position—perpendicular to the axis of the lens.

If you're testing a lens with a narrower field of view, you can use fewer charts. A normal lens with a 50° field of view requires only the charts to the 25° positions. You can also skip some of the chart positions to cover a larger field of view. Perhaps you have ten charts. But you want to test a lens having a 90° field of view. You might then place the charts at the 5°, 15°, 25°, 35°, and 45° positions.

Position the charts by measuring the distance from the 0° line as indicated in Fig. 72. The actual distance depends on the focal length of the lens you're testing. To place the charts 5° off-axis, for example, distance A in Fig. 72 is different for a 50mm lens than it is for a 135mm lens. The table with Fig. 72 shows the proper distance for each position according to focal length.

Suppose that you're locating the 5° charts for a test of a 50mm lens. Multiply the focal length by 2.28. The 5° charts should then be 2.28 x 50mm = 114mm from the 0° line (distance A). The 10° charts (distance B) should be 4.58 x 50mm = 229mm from the 0° line.

Now position the camera on a tripod squarely in front of your test charts. Remember, the distance to the charts should be 26f. Since the charts are at a finite distance (not at infinity), the actual measurement should be to the front nodal point. However, for all practical purposes, you can simply measure to the front surface of the lens you're testing.

Be very critical in positioning the camera. If the camera isn't square to the charts, you'll see a focus error across the field. You can check the squareness by measuring distance CD and distance DE in Fig. 72. The two distances should be the same.

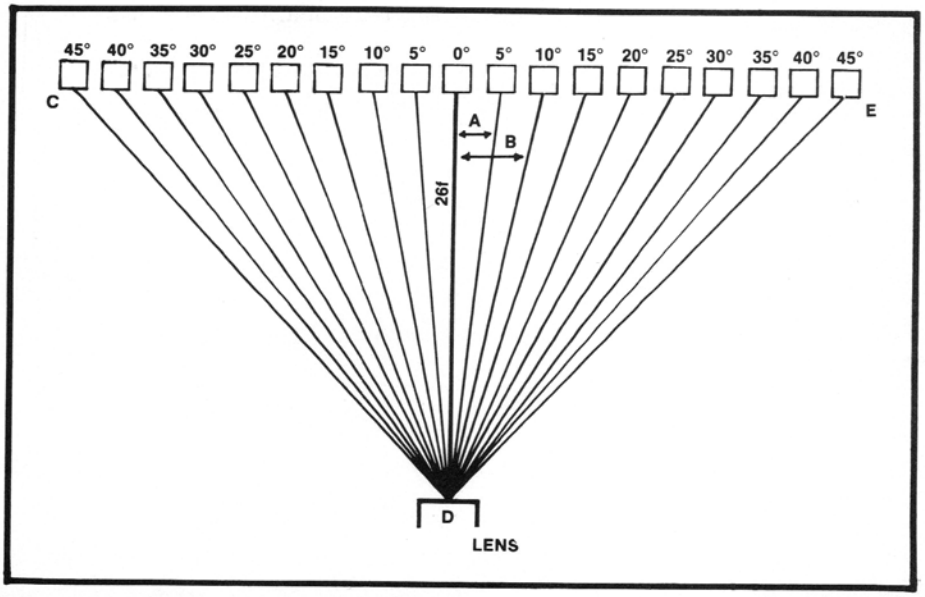


CHART SPACING

0°	—Perpendicular To Axis
5°	—2.28f
10°	—4.58f
15°	—6.96f
20°	—9.46f
25°	—12.1f
30°	—15.0f
35°	—18.2f
40°	—21.8f
45°	—26.0f

Figure 72

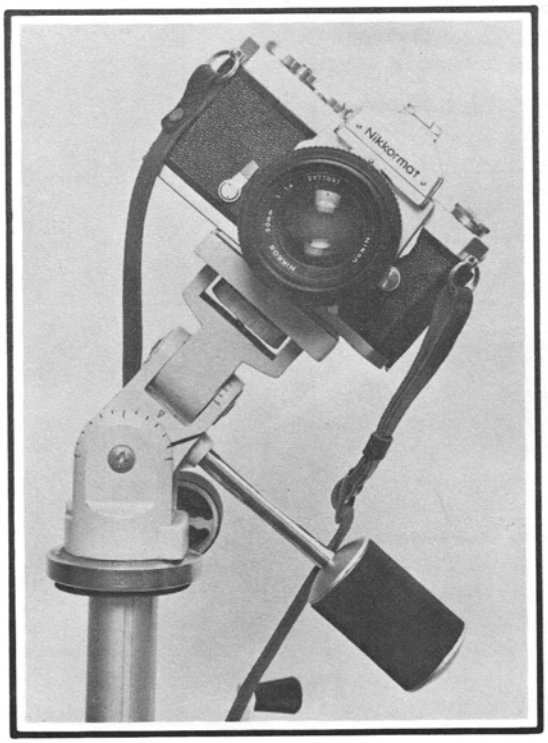


Figure 73

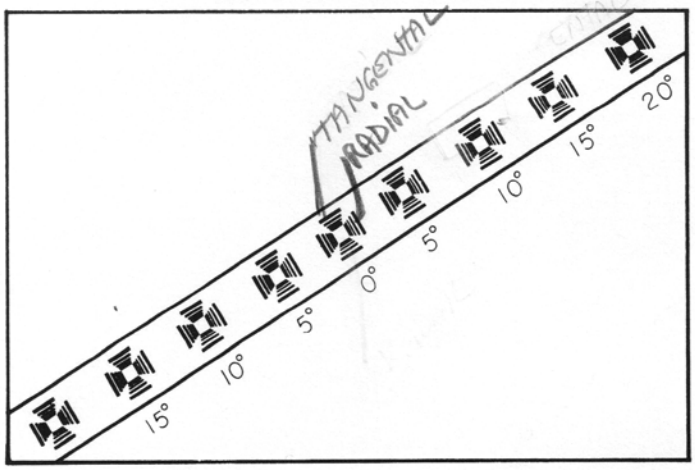


Figure 74

To get even better coverage across the field, you might use multiple rows of charts. Or you can simply tilt the camera, Fig. 73, so that the row of charts runs diagonally—from one corner of the field to the other corner, Fig. 74.

Make sure that you provide even illumination across the complete row of charts for uniform exposure. And focus carefully. Now photograph the row of test charts. Ideally, you should photograph the charts at each diaphragm setting. You can then see the effects the diaphragm opening has on aberrations.

Develop the film and examine the negatives under magnification. Remember, you photographed the test charts at a reduction of 25X. A magnifier of between 10X and 25X is then necessary for determining the resolving power.

Now, starting with the 0° chart or one of the 5° charts, locate the finest line group that the lens resolved—the most closely spaced group in which you can count three separate lines. Can you distinguish between the lines in the "80" group? If not, check the next group—the lines marked "68."

Perhaps you find that you can distinguish between the lines in one "80" set but not in the other "80" set. What does this mean? The lens under test exhibits astigmatism.

Remember, astigmatism means the lens can't bring both radial and tangential lines into focus at the same time. Fig. 75 shows the chart photographed diagonally. The radial lines, if extended, would pass through the center of the image. But the tangential lines would always remain the same distance from the center.

Also compare the results on each side of the 0° chart. For example, compare the two 10° charts with one another—they should be the same. If the results vary from one side of 0° to the other, the film plane probably wasn't parallel to the charts when you made the test. The problem could even be in the camera; perhaps the lens-mounting ring is not parallel to the film plane.

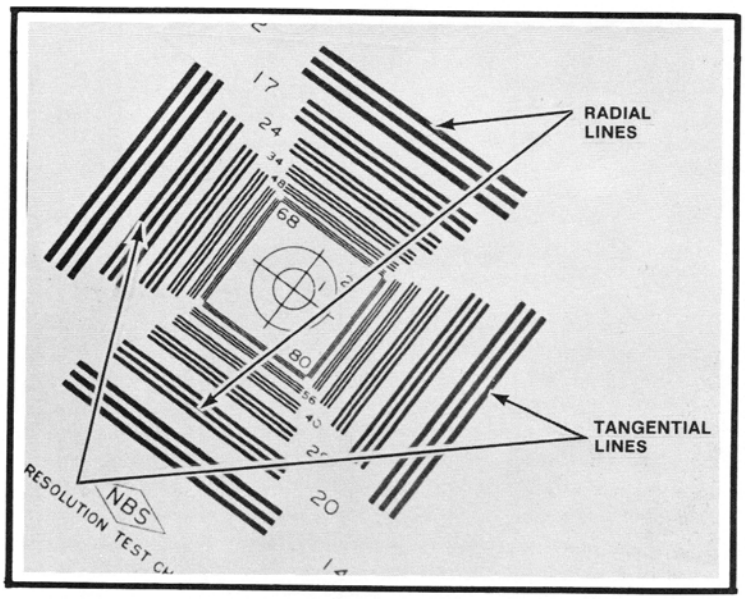


Figure 75

ANALYZING RESOLUTION-TEST RESULTS

For a thorough analysis of the lens performance, record your test results as shown in the following example:

ASTIGMATISM TANGENTIAL LINES ARE NOT IN FOCUS WITH RADIAL LINES.

HIGHEST RESOLUTION

f/stop	Tangential					Radial				
	0°	5°	10°	15°	20°	0°	5°	10°	15°	20°
2	68	56	56	48	28	68	56	56	48	40
2.8	68	68	68	68	56	68	68	68	68	56
4	80	68	56	56	56	80	68	68	68	68
5.6	80	80	68	68	80	80	80	80	80	80
8	80	68	68	68	68	80	68	68	68	56
11	80	80	80	80	68	80	80	80	80	80
16	56	56	56	56	48	56	56	48	48	48
22	56	56	48	48	48	56	56	48	48	40

Notice in our example that the resolving power decreases at the off-axis charts (toward the margins of the lens). That's normal. Also, you can see that the lens gives its highest resolving power at the middle apertures—f/5.6, f/8, and f/11. The sudden drop-off at f/16 shows the effect of diffraction.

At f/4 and f/5.6, you can see some slight effects of astigmatism. Note the difference in resolving power between the tangential lines and the radial lines. Stopping down to f/8 practically eliminates the aberration.

The tangential-line resolving power at f/5.6 also shows some curvature of field. At 10° off-axis, the resolving power decreases slightly. However, at the edge of the field, the resolving power increases.

NOTE →

All lenses exhibit a certain amount of astigmatism and curvature of field. Our example really shows a relatively good lens. The lens performance must be judged by the degree of error—not by the presence of error. And now we're talking in relative terms.

Even a high resolving power only tells you that the lens can reproduce fine detail in the image. It doesn't necessarily tell you how sharp that image will be. To evaluate sharpness, there's another type of test—a test to measure **acutance**.

Acutance defines the ability of the lens to distinguish between adjacent areas of different brightnesses. To test acutance, the lens tester measures the density gradient across the image of a knife edge. A sharp edge means the lens has a high acutance.

A lens can have high resolving power and low acutance—or vice versa. Some people feel that acutance really provides the better measure of lens performance. A lens with high acutance produces an image that looks sharper than does a lens with high resolving power. But, since it's difficult to measure acutance, most lens tests still rely on resolving power as the standard of quality.

Some test labs now use an even more sophisticated test that takes into account all of the factors responsible for a loss of image quality—the modulation transfer function, or MTF. A test instrument supplies a sine-wave signal (like Fig. 1) to the input of the lens. It then measures the percentage of the picture information remaining after the signal has passed through the optical system.

An ideal output wave matches the input wave. However, the aberrations and other limiting factors in the lens cause the output wave to be less than ideal. The amount that the optical system modulates (changes) the input wave determines the MTF. Although the test isn't practical for repair shops, you will see MTF mentioned in test reports.

TEST-YOURSELF QUIZ #5

1. A flat mirror forms a VIRTUAL (real, virtual) image. A concave mirror forms a REAL (real, virtual) image of an object located at the center of curvature.
2. A concave mirror exhibits SPHERICAL aberration.
3. A prism doesn't require a silver coating on its reflective surface if the angle of incidence is greater than the CRITICAL angle of the glass.
4. On the NBS chart, the numbers indicate lines per millimeter if the chart is shot at a certain reduction. What is this reduction? 25 X REDUCTION .
5. To get the reduction in question #4, the chart must be positioned at a distance of 26 times the focal length of the lens you're testing.
6. After making a resolution test, you find that the lens resolves the tangential lines in the "80" group. But it doesn't resolve the radial lines. What aberration does the lens exhibit? ASTIGMATISM .

REPAIRS ON OPTICS

Most of your repairs on lenses will involve the mechanical systems rather than the optical systems. You'll be disassembling lenses to clean and repair focusing mechanisms and diaphragm leaves. But you must disassemble—and properly reassemble—the optical sections in order to reach the mechanical sections.

Remember to disassemble the lens no further than is necessary to make the repair. If you throw optical components out of alignment, you'll make a tough job out of what may have been an easy job.

How about the repairs on the optics themselves? It's normally best to restrict these repairs to cleaning and replacing. With virtually every camera repair, you'll have to clean the surfaces of the optics—taking lenses, eyelenses, mirrors, and prisms. You'll learn the procedures and precautions for cleaning specific types of optical components as you proceed through your course. For now, let's just look at some general techniques.

To remove dust particles, use your hand blower. But to remove fingerprints, you need a lens-cleaning solution to loosen and suspend the grease. Use a good quality lens-cleaning solution that leaves little or no film on the lens surfaces. You can purchase commercial lens cleaners. Or, as you'll learn in "Practical Optics," you can mix your own.

But never apply the lens-cleaning solution directly to the lens surface. Rather, moisten a lens tissue with the solution. The Kimwipes you receive with your course materials work well as lens-cleaning tissues. Many technicians prefer Kimwipes to other types of tissue or to cotton swabs. Cotton swabs tend to leave strands of cotton around the edges of the lens.

Be careful that you don't allow your fingers to touch a section of the Kimwipe that has been moistened with the lens-cleaning solution. The oil from your fingers will mix with the solution, leaving an oil film on the lens surface.

You can avoid touching the moistened Kimwipe by wrapping the tissue around your tweezers. Fig. 76 illustrates the technique. First grasp a section of the tissue with your tweezers as shown in Fig. 76A. Next fold the tissue under the tweezers, Fig. 76B. Be sure to leave some tissue extending from the tips of the tweezers to serve as a pad.

Now wrap the tissue around the tweezers, Fig. 76C. Moisten the pad at the end of the tweezers with the lens-cleaning solution. It takes only a slight amount of lens-cleaning solution to do the job.

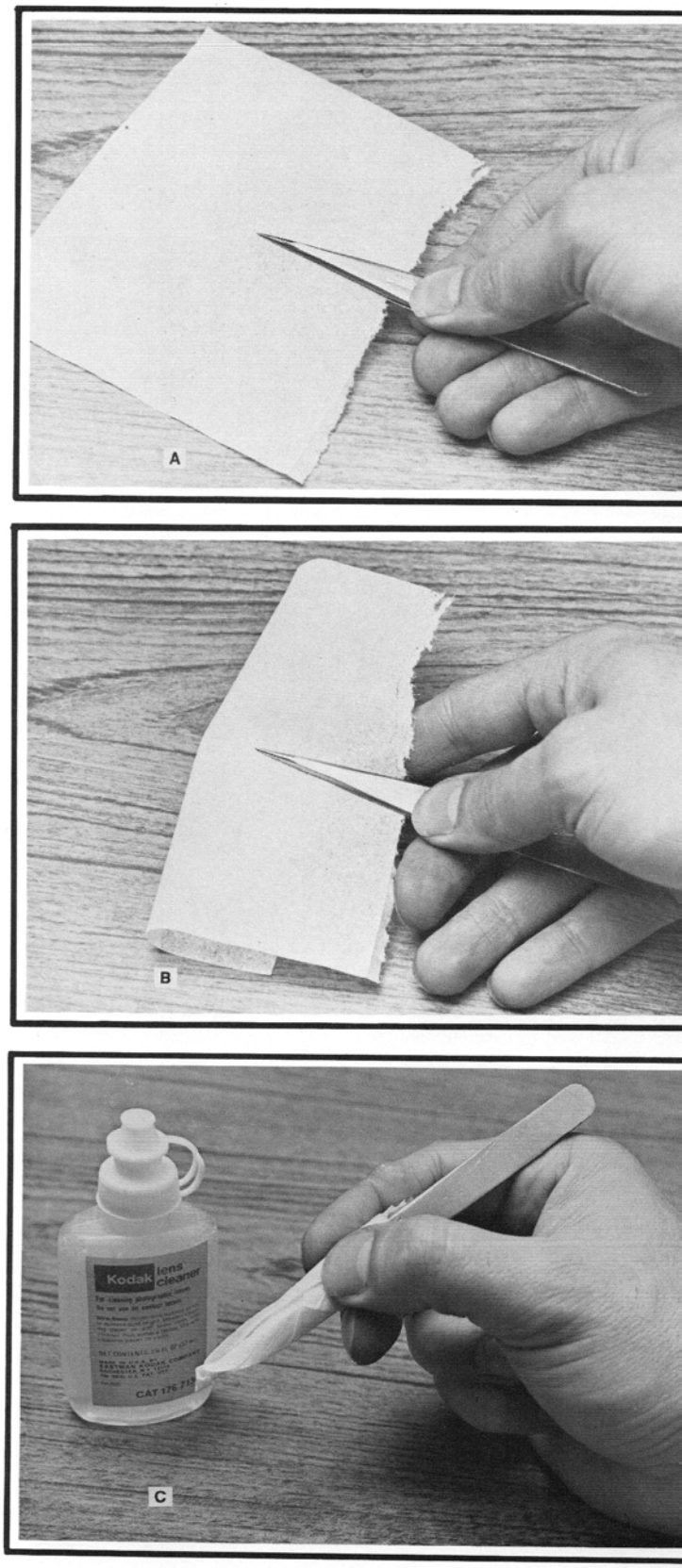


Figure 76

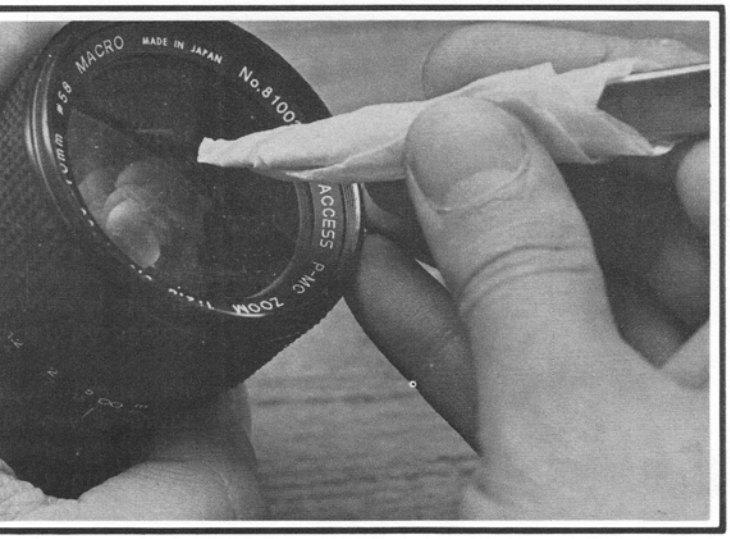


Figure 77

Start cleaning at the center of the lens, Fig. 77. And work in a circular motion from the center to the edges. The circular motion tends to work dirt particles to the edges where you can remove them more easily.

Be very careful that only the tissue pad at the end of your tweezers touches the lens surface. If the metal tips of your tweezers come against the lens, they'll scratch the coating—or even the glass. When cleaning plastic lenses, be even more cautious—it's very easy to scratch plastic.

Remember that you aren't "scrubbing" the lens. Rather, you're letting the lens-cleaning solution do the work of loosening and suspending dirt and grease. You need only the lightest touch of downward pressure.

After applying the lens-cleaning solution, repeat the procedure using a dry, clean Kimwipe. The dry Kimwipe removes the lens-cleaning solution along with the suspended grease. Always use a fresh Kimwipe when you're wiping off the lens-cleaning solution. Using the same Kimwipe just reapplies the dirt to the lens.

Check your work by fogging the lens surface with your breath. If you see streaks in the fog, there's still grease on the lens. In that event, repeat the cleaning procedure.

Some lens cleaners evaporate so rapidly that they leave virtually no film on the lens surface. A lens cleaner containing ether, for example, evaporates so quickly that you can skip the drying step. But many lens cleaners do leave a film. To remove the film, again fog the lens surface with your breath. Then use a clean, dry Kimwipe to wipe off the fog.

Cleaning mirrors requires an even gentler touch—any pressure may damage the silver deposit on the front surface. Use the same cleaning procedure as that we've just described. But apply the lens-cleaning solutions with horizontal strokes rather than circular strokes.

If you live in a very humid climate, you may encounter lenses with fungus damage. The fungus will, in time, damage the coating on the lens—or the silver deposit on the mirror. However, if you can get to the lens in time, you can clean off the fungus before permanent damage occurs.

You may find that your lens cleaner won't remove the fungus. In that case, you'll need a stronger solvent. Acetone may do the job (surprisingly, acetone doesn't damage the lens coating). But many technicians use another trick to remove the fungus—they apply shutter grease to the lens.

The grease often removes the fungus. Once you've removed the fungus, though, you've got another major cleaning job—removing the grease. You may have to apply the lens-cleaning solution several times before you've removed all of the grease from the lens.

What if the lens coating or silver deposit is damaged? Some of the larger shops do have the facilities for recoating lenses and resilvering mirrors. But such repairs are out of the scope of the average shop. It's then best to simply replace the damaged optic. Or you can farm out the repair to a shop that does have the needed equipment.

You'll also have occasion to recement optical components. Aging, heat, humidity, or impact may cause a prism or mirror to come loose from its support. You can recement such components with a clear epoxy. However, the repair becomes a lot tougher when you encounter separated lens elements.

The elements making up a compound lens will separate if the cement holding them together breaks loose. Although you can recement the elements with Canadian balsam or clear epoxy, there's a major problem—how can you align the optical centers of the elements?

Again, your best repair is to simply replace the compound lens. In many situations, however, the manufacturer won't supply portions of an optical system as replacement parts. Why? Because every optical element in the system must be precisely matched.

You might then let a fully equipped optics shop or the manufacturer handle the repair. The customer may even find that it's more economical to buy a new lens. You might be able to visually align the elements well enough to satisfy the customer. But it's very unlikely that the lens will perform as well as it once did.

Perhaps a look at the procedure will emphasize why you should generally avoid recementing elements. The optics technician must first remove the old cement. He cleans the surfaces using alcohol or chromic acid. Next he rinses the surfaces with water and further cleans them with a strong acid. Finally he washes the lenses with water and neutralizes the acid with a weak potassium hydroxide solution.

Now the technician applies Canadian balsam or optical cement to the center of the joint area. He then joins the two surfaces by mating them with gentle pressure. The pressure must spread the cement uniformly between the two surfaces without leaving air bubbles. Air bubbles may also result if the technician uses too much sliding motion while mating the surfaces.

To align the surfaces, the technician normally uses a jig. The jig holds the optical elements in firm alignment while the cement dries. Also, the technician normally uses heat to drive the cement solvent out of the joint. He places the lens in an oven and gently raises the temperature to around 200-250°. After heating the lens for about an hour and a half, he allows the glass to cool slowly. Finally, the technician cleans any excess cement from the joint area by scraping the edges.

As you can visualize, the procedure for recementing separated elements isn't practical for the average repair shop. Even if you had all the equipment, recementing lenses takes a lot of time.

SUMMARY

As you proceed through your program, you'll continue to apply the optical principles covered in this lesson. You'll again encounter mirrors and prisms in your lessons on rangefinders and SLRs. And you'll learn about the actual repairs and adjustments on lenses in your upcoming lesson, "Practical Optics."

You should therefore strive to understand the principles of optics—you'll be drawing on that understanding frequently in your camera-repair work. Bút it's not necessary to memorize specifics and equations. The important point is that you can find such information when you need it.

To summarize the key points of this lesson, read through the glossary of terms. If a definition doesn't seem clear, restudy the appropriate section of your text.

ANSWERS TO TEST-YOURSELF QUIZZES

QUIZ #1

1. aberration
2. visible light
3. dispersion
4. light ray
5. slows down (the glass is more dense than is the air)
6. refracted
7. absorbed
8. angle of incidence

QUIZ #2

1. small
2. infinity (or infinitely distant)
3. focal
4. real
5. virtual, larger
6. virtual

QUIZ #3

1. spherical
2. aspherical
3. chromatic
4. pincushion
5. radial
6. diffraction
7. vignetting

QUIZ #4

1. distance
2. shutter speed — TV (time value)
   film speed — SV (speed value)
   diaphragm opening — AV (aperture value)
   light intensity — BV (brightness value)
3. f/16. To find the new AV, first determine the EV at the combination of 1/125 and f/8. 1/125 = TV 7. And f/8 = AV 6. 7 + 6 = EV 13. You must now retain the same EV while using a shutter speed of 1/30. 1/30 = TV 5. EV 13 - TV 5 = AV 8, or f/16.
4. ASA 100. Subtract BV 5 from EV 10 to find the SV — SV 5. SV 5 = ASA 100.
5. f/8. You need AV 6. AV 6 + TV 6 = EV 12. AV 6 = f/8.
6. directly
7. less
8. real

QUIZ #5

1. virtual, real
2. spherical
3. critical
4. 25X
5. 26
6. astigmatism

GLOSSARY OF TERMS

Aberration A failure of the lens to bring together all of the light rays at the focal point. Aberrations are most evident in the margins of the lens.

Absorption The optical principle whereby a certain amount of light is absorbed when passing through any medium.

Achromat A lens designed to bring together two different wavelengths (colors) to the same point of focus. Practically all modern lenses are achromats.

Acutance A measure of lens performance defining the ability of the lens to distinguish between two adjacent areas of different brightnesses.

Aperture value A unit in the APEX system indicating the diaphragm opening.

APEX The additive system of exposure units, expressed by the formula: AV + TV = BV + SV = EV.

Aspheric The shape of a surface which does not follow the shape of a sphere. In a lens, an aspheric surface may be used to correct spherical aberration.

Astigmatism A lens aberration whereby the lens fails to bring together radial lines and tangential lines to the same point of focus.

Axis A line drawn horizontally through the center of the lens perpendicular to the lens elements. The lens is symmetrical around its axis.

Back focal length The distance between the rear element of a lens and the focal point.

Barrel distortion A lens aberration which causes straight lines to appear curved in the image. The magnification of the lens decreases toward the edges.

Beam An accumulation of light pencils.

Brightness value The unit in the APEX system indicating light intensity.

Chromatic aberration A lens aberration which causes different wavelengths to refract different amounts. Two different colors then fail to come together at the same point of focus.

Color spectrum The different colors of white light arranged according to wavelength—red, orange, yellow, green, blue, indigo, and violet.

Coma A lens aberration which causes an unsymmetrical light patch. The image of a point source flares away like the tail of a comet.

Compensating component The lens system in a zoom lens that moves as you change the focal length to keep the image in the same plane of focus.

Compound lens A lens consisting of two or more elements joined together with cement.

Cone The pencils of light from a point source.

Converging lens A positive lens.

Critical angle The angle of an incident ray traveling from glass to air at which the refracted ray follows the surface of the glass.

Curvature of field A lens aberration resulting in uneven focus across the field.

Definition The quality of the image produced by the lens.

Diffraction The tendency of light to spread into a shadow of the object.

Dispersion The breaking down of white light into the color spectrum.

Divergent lens A negative lens.

Element, lens A single piece of glass or plastic used to refract light. Most lenses have several elements.

Exposure value The combination of shutter speed and diaphragm opening that produces proper exposure to the film according to the scene brightness and the film speed.

Focal length The distance between the optical center or rear nodal point of a lens and the focal point.

Focal plane A plane passing through the focal point perpendicular to the lens axis. The plane at which the film is positioned in a camera.

Focal point A point on the lens axis at which parallel light rays are brought together by the lens.

Front focal length The distance between the front surface of the front lens element and the focal point at the front of the lens.

Image A representation of the object as formed by a lens or pinhole.

Inverted telephoto A wide-angle lens in which the back focus is greater than the focal length. Achieved by placing a negative lens in front of a positive lens.

Inverse square law The law describing the intensity of the light according to the distance (d) from the light source. Expressed as a formula:

$$\text{Intensity of light} = \frac{\text{intensity of light source}}{d^2}$$

Lens A piece of glass or plastic capable of refracting light rays. Also, a complete system of lenses capable of forming an image.

Light ray The path upon which light energy travels.

Negative lens A divergent lens, designed to cause light rays to diverge and form a virtual image. Thicker at the edges than at the center.

Nodal points Two points on the lens axis located so that a ray of light which enters the lens aiming at the front nodal point emerges from the lens aiming away from the rear nodal point and parallel to the ingoing ray.

Normal An imaginary line drawn perpendicular to a surface. Used in calculating refraction and reflection.

Pencil A group of light rays coming from a point source.

Pincushion distortion A lens aberration which causes straight lines to appear curved in the image. The magnification of the lens increases toward the edges.

Porro prism A prism with two reflecting surfaces used in binoculars to increase the distance between the two objective lenses over the distance between the two eyelenses. Also used in some SLR viewing systems to reroute the light.

Positive lens A convergent lens, designed to bring light rays together to a point of focus. Thicker at the center than at the edges.

Radial line A line in the image which, when extended, will pass through the center of the image.

Real image An image which actually exists at the position it appears to exist and can be projected onto a screen. A positive lens and a concave mirror form real images.

Reflection The principle of light whereby a light ray bounces off a surface and continues in a different direction. The law of reflection expresses the angle of the reflected ray—the angle of reflection equals the angle of incidence. A ray perpendicular to the surface is reflected back upon itself.

Refraction The principle of light whereby a light ray passing at an angle into a medium of different density is bent. The law of refraction expresses the direction in which the ray is bent as well as the amount. When passing from a less-dense medium into a more-dense medium, the light ray bends toward the normal; when passing from a more-dense medium into a less-dense medium, the light ray bends away from the normal. The amount that the ray is refracted is given by the following formula where n = the refractive index:

$$\sin r\,(\text{angle of refraction}) = \frac{\sin i\,(\text{angle of incidence})}{n}$$

Resolving power The ability of the lens to distinguish between finely spaced lines or points in the image.

Speed ratio The ratio of the size of the lens opening to the focal length of the lens. Expressed as the f/stop.

Speed value The unit in the APEX system expressing the film speed.

Spherical aberration A lens aberration resulting from the spherical surface of a lens or mirror. The margins of the lens bring the light rays to focus at a different point than do the center regions.

Telephoto lens A lens in which the back focus is only a fraction of the equivalent focal length. Achieved by placing a negative lens behind a positive lens.

Time value The unit in the APEX system expressing the shutter speed.

Total internal reflection The principle whereby all of the light striking a prism reflecting surface is reflected into the prism; none of the light is refracted. The prism achieves total internal reflection if the angle of the incident ray is greater than the critical angle.

Vignetting The lowering of the brightness of the image away from the center due to the obstruction of the light rays by the edges of the elements, the lens-mounting tube, or a lens accessory.

Virtual image An image that does not actually exist at the point where it appears to exist and cannot be projected onto a screen. A negative lens and a flat mirror produce virtual images.

Visible light That portion of the electromagnetic spectrum that stimulates the retina of the human eye.

Zoom lens A lens in which you can change the focal length while the image position remains unchanged.

Zooming component The lens system in a zoom lens which moves to change the focal length.