Introduction to Chapter 15

Cameras, telescopes, and our eyes are all optic devices. Rays of light are everywhere and optic devices bend and bounce these rays to produce all the colors and images that you can see. This chapter will introduce you to the science of optics.

Investigations for Chapter 15

15.1 Seeing an Image

What does magnification really mean and how do you plot a reflected image?

We see images based on what happens to light. In this Investigation you will discover how light can be bent by a lens to magnify an image, or bounced by a mirror to produce a reflected image. Plotting the rays of light from an object will allow you to understand what a mirror or lens is doing.

15.2 The Human Eye

How does a lens form an image?

A lens can bend light to create amazing images. The actual bending of the light in our eye is caused by a clear lens that can change shape slightly. The shape-changing lens in the eye allows us to see close up or far away. In this Investigation, you will work with lenses to focus light and create images.

15.3 Optical Technology

How are optics used in everyday life?

Fiber optics are becoming one of the most important and versatile aspects of optical technology. Fiber optics work on a simple principle. If light is traveling in a material like glass or water, and enters into air, it can become trapped in the material. In this Investigation you will explore total internal reflection, the process that makes fiber optics possible.
Learning Goals

By the end of the lesson, you will be able to:

- Describe the function of the human eye.
- Describe the difference between objects and images.
- Describe and demonstrate the formation of an image.
- Draw a ray diagram for a lens.
- Calculate the magnification of a lens.
- Describe the index of refraction and explain how it is applied in the making of lenses.
- Identify the characteristics of reflection.
- Draw a reflected ray.
- Predict how light will bend when its speed changes.
- Understand internal reflection.
- Identify uses of fiber optics.

Vocabulary

<table>
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<th>Angle of Incidence</th>
<th>Focal Length</th>
<th>Index of Refraction</th>
<th>Reflected Ray</th>
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<td>Angle of Refraction</td>
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<td>Converging</td>
<td>Focus</td>
<td>Normal</td>
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<td>Critical Angle</td>
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<td>Diverging</td>
<td>Incident Ray</td>
<td>Real Image</td>
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15.1 Seeing an Image

Try this quick experiment: Take a magnifying lens and look through it at your thumb. You can adjust the distance until the thumb is big. You are actually seeing a big thumb. You are bending the light that is coming from your thumb, so that you see a huge thumb. Imagine how big your hand would be if your thumb really was that big. It would be a giant hand!

Now imagine that a few cells of your thumb were under a microscope. You can see the individual cells of your skin. You can see parts of the cell and they look big. Now imagine how big your thumb would be if all the cells were actually that big. Wow! You have the hand of super giant! Of course, your hand is actually the same size it always was, though what you see is a super giant hand. One branch of optics is the study of how to manipulate light to create images that are different from the original object.

What is optics?

<table>
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<tr>
<th>Definition of optics</th>
<th>The study of how light behaves is called <strong>optics</strong>. Optics deals with the collection and use of light to create <strong>images</strong>. The category of optics covers devices that direct light like lenses, mirrors, cameras, telescopes, and microscopes. It includes events of light like rainbows, sunsets, and eclipses. Ultimately, all of the light from these sources gets to your eye. We will see that the eye itself is an optical instrument.</th>
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<tr>
<td>Lenses, mirrors, and prisms</td>
<td>Your eye contains a lens. A lens is one kind of optical device that is used to bend light. By bending the light so that it comes together (<strong>converging</strong>), you can magnify an image and by bending the light so that it spreads apart (<strong>diverging</strong>), you can get a smaller image. A mirror is a familiar optic device; you probably used one this morning. Mirrors reflect light and allow us to see ourselves. Flat mirrors show a true-size image. Curved mirrors cause light to come together or spread apart. A fun house at the circus uses curved mirrors to make you look thin, wide, or upside down. Curved mirrors distort images. The curved side-view mirror on a car, for example, makes the cars behind you look farther away than they really are. A prism is another optic device that can cause light to change directions. Traditionally, a prism is used to separate the colors of light and to demonstrate how light bends (<strong>refracts</strong>) as it travels through different media (figure 15.2).</td>
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Light rays

What is a light ray?
It is convenient to think about light in terms of rays. A ray of light can be considered an imaginary arrow that follows a single beam of light. This simplification allows us to analyze where the light travels. We only need to follow the rays. Very often we will need to follow several rays of light to determine what will happen.

Drawing light rays in diagrams
Light waves are like the waves you see in the ocean as they move continually toward the beach. Rays are represented by lines that are perpendicular to the wave fronts. The lines have arrows that show you which way the light is moving. When you see a ray drawn on a diagram, you should know that technically, the ray isn’t really one ray of light but a series of light waves. Figure 15.3 uses an arrow to represent which way the light waves are moving.

Rays come from objects
When we see an object, every point on the object reflects many rays of light. Let’s consider an example to demonstrate what this means. Look at the clock in your classroom, and focus on the number seven. If you walk around the room, you will find that you can still see the number seven. This demonstrates how light from a single point (in this case, the number seven) can be seen from different angles. This is true because light is reflected to all angles in the room. Figure 15.4 is an illustration of how light rays are reflected off a vase.
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15.1 Seeing an Image

Figure 15.5: The difference between objects and images.

The light rays from the object are bent when they go through the lens. Our brain does not know the rays were bent. We “see” the rays as having traveled in straight lines.

The image appears larger because the lens has bent the light rays so they appear to come from a larger object. This is the principle of the magnifying glass.

Figure 15.6: A magnifying glass makes a virtual image that appears larger than the object.

Images

Rays come together in an image

Suppose you could collect all the rays from one point on an object, bringing them all together again. You would have created an image. An image is a place where many rays from the same point on an object meet together again in a point. A camera works by collecting the rays from an object and bending them so they form an image on the film.

Objects and images

It is helpful to think about optics in terms of objects and images. Objects are any real physical things that give off or reflect light rays. Images are “pictures” of objects that are formed in places where light rays from the object meet. The focus is the place where all the light rays from the object meet to form the image.

Light travels in straight lines

Normally, light travels in straight lines. Most of the time, when you see some object, it is because the light traveled in a straight line from the object to your eye. As long as nothing is in the way, you can be sure the object is precisely where you perceived it to be. This is because the light rays did not bend.

To make images, we often need to bend light rays. Light is sometimes bent between an object and your eye. This bending will usually make the image appear different from the object in size or location. A good example is seeing a fish under water. The light waves from the fish bend as they travel from the water to the air. Due to the bending rays, the image of the fish appears in a different place from where the fish is actually swimming.

Light rays can be bent

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Light rays can be bent
Optical systems

What is an optical system?
An optical system collects light and uses refraction and reflection to form an image. When we use an optical system, we do not see the actual object. What we really see is an image. When light is bent through an optical system before it gets to our eyes, the image we see might not represent the actual object as it truly is.

Refraction
Refraction is the bending of light that occurs when light crosses a boundary between two different substances. Usually one is air and the other is a clear material such as glass, plastic, or even water. A lens is a special shape of clear solid material that uses refraction to cause light to come together or spread apart. A magnifying glass on a sunny day can be used to illustrate how one type of lens works (figure 15.7).

Reflection
A mirror reflects rays of light so that they change their path. Reflection happens when objects or waves can “bounce” off a surface. Whenever a wave strikes a surface, part of the energy is reflected. By changing the shape of a mirror you can also cause light to come to a focus, just like with a lens (figure 15.8).

The telescope
A telescope is a collection of lenses that can magnify an image. When you look through a telescope, the rays of light are bent and appear as if they were coming from an image much closer than the actual object. A telescope is an optical system that makes objects appear larger than they are, and sometimes upside down!

Why we see magnified images
The illusion created by a telescope happens because we perceive that light travels in a straight line. If the device bends light so that it appears to have come straight from a large object, then we see a magnified image.
The functions of an optical system

Most optical devices have two important functions.
1. They collect light rays.
2. They bend the collected light rays to form an image.

Both functions are important. If you are interested in astronomy, for example, most of the things in the night sky don’t produce enough light for our eyes to see. Not only does a telescope make things appear larger, it also collects more light so we can see fainter objects.

The ray diagram

To figure out how an optical system works we often draw ray diagrams. Ray diagrams trace how several light rays behave as they go through the system. The rays come straight from an object and are bent or bounced as they encounter a lens or mirror. By tracing the rays through the system we are usually looking to find what kind of image will be produced.

Some typical questions that we use ray diagrams to answer are:
1. Where is the focus (or is there a focus)?
2. Will the image be magnified or reduced in size?
3. Will the image be upside down or right side up?
4. Will the image be inverted left to right?

A plastic bag lens

Water is capable of bending light. Take a clear plastic bag and fill it with water. Now look through it. What you see is called an image. The shape of the optic device determines the shape of the image. Squeeze the bag in different places and see how the image changes.
Reflection and mirrors

Mirrors create a virtual image

When you look in a mirror, you see an image. The image appears to be behind the mirror and is reversed from left to right. For example, if you hold a stop sign in front of a mirror, the letters appear backward. Why does this occur?

The light rays that travel from the “S” in the stop sign hit the mirror at an angle and are reflected back to your eye at an equal but opposite angle.

Your brain assumes that this reflected ray traveled to your eye in a straight line from an “object” behind the mirror. As a result, the image of the “S” appears to have come from the opposite direction as the actual letter on the stop sign.

Incident and reflected rays

To investigate mirrors further, we will talk about incident and reflected rays. The **incident ray** is the ray that comes from the object and hits the mirror. The **reflected ray** is the ray that bounces off the mirror (figure 15.9). There is a rule that tells us how to predict the direction of the reflected ray once we know the incident ray’s direction.

The law of reflection

The rule that determines the reflected ray is called the **law of reflection**. This law is very simple: Light rays bounce off a mirror at the same angle at which they arrive. The only tricky part is defining the angles. To keep things clear we always define angles relative to the **normal**. In optics, the normal is a line perpendicular to the mirror (figure 15.9).

If a light ray comes in at an angle of 30 degrees from the normal, it bounces off at the same angle, 30 degrees. If a ray comes in at zero degrees (straight on) it also bounces back at zero degrees. In other words, the light comes in and reflects out on the same normal.

Figure 15.9: The normal is a line perpendicular to the mirror. The incident ray is the ray that comes in to the mirror. The reflected ray is the ray that bounces off the mirror.

Figure 15.10: The law of reflection states that the angle of incidence ($\theta_1$) is equal to the angle of reflection ($\theta_2$). By throwing a ball against a wall, how could you demonstrate that $\theta_1 = \theta_2$?
**Refraction and lenses**

**Refraction**  
When light crosses the boundary between two different (transparent) materials the rays may bend. We call the bending *refraction*. Refraction happens because the wave fronts move more slowly in materials other than air (figure 15.11). As we already learned, if we change the shape of wave fronts we can turn a wave.

**What is a lens?**  
A *lens* is a shape of transparent material, like glass, that is used to bend the light rays. Figure 15.12 shows how the curved surface of a lens works. We choose the shape of the lens depending on how strongly we want to bend the light. Lenses come in many different shapes and strengths.

**Focal point and focal length**  
Almost all lenses are shaped to have a very useful property. Light rays that enter a lens parallel to its axis will bend to meet at a point called the *focal point*. The distance from the center of the lens to the focal point is called the *focal length*. The focal length of a lens determines how powerful the lens is and how it can be used to focus light.

**Converging and diverging lenses**  
There are two kinds of lenses we will examine. *Converging lenses* bend the parallel light rays passing through them inward toward the focal point. *Diverging lenses* bend the parallel light rays passing through them outward away from the focal point. A parallel beam coming into a diverging lens is bent away from the focal point.
Forming images with lenses

Why are lenses useful?

Lenses are used in eyeglasses, microscopes, telescopes, and other devices to form images. An image, as you have learned, forms when light rays emitted or reflected from one point on an object meet at a point again. Ray diagrams can be used to show where the image will form, how large the image will appear, and whether it is upside down or right side up.

What kinds of images are formed?

If an object is placed to the left of a converging lens at a distance greater than the focal length, an inverted image is formed on the right-hand side of the lens. We call this image a real image. Real images can be projected on a smooth surface, like photographic slides onto a wall. Since real images are inverted, slides must be loaded into the carousel upside down, so that the picture appears right side up!

Example: A lens has a focal length of 10 centimeters. An object is placed 15 centimeters to the left of the lens. Trace the rays and predict where the image will be. Is the image bigger, smaller, or inverted?

Step 1: Draw the axis and focal points.

Step 2: Draw three rays from the object’s tip.

Step 3: The image of the object’s tip is found where the three rays meet.

The image is formed 30 cm to the right of the lens. It is magnified and inverted.

If an object is placed to the left of a converging lens at a distance less than the focal length, the lens acts as a magnifying glass. The lens bends the rays so that they appear to be coming from an object larger and farther away than the real object. These rays appear to come from an image, but don’t actually meet, so the images are called virtual images. Mirrors create virtual images.

Galileo and the telescope

Lenses were being made as early as the 13th century to help people see. Galileo did not invent the telescope, but he learned of it around 1608. He was the first to use it as a tool for astronomy, and by 1609 he had created an improved telescope of far better magnification than any in existence.

One of the first things Galileo saw was that the line between dark and light on the Moon was not smooth, but jagged. Galileo correctly recognized that the jagged line was due to tall mountains on the moon casting shadows onto the lighter side. His 400-year-old sketches show incredible detail including craters and the lunar maria (seas).
The index of refraction

The index of refraction

Light waves travel at a slower rate through glass and other transparent materials than through air. This is because the wave has to constantly be absorbed and reemitted by all the atoms in a material (figure 15.13). Since not all atoms are alike, you might expect different materials to slow the light by different amounts. This is indeed true, and we have a ratio called the index of refraction that tells how much the speed of light is reduced when it passes through a material.

The index of refraction is a ratio of the speed of light in a vacuum (or air) compared with its speed in a material. The number is always greater than one because light travels fastest in a vacuum. We use the letter \( n \) to represent the index of refraction.

Higher index means more bending

The higher the index of refraction, the more a light wave bends when crossing in or out of the material. Figure 15.14 gives some typical values of \( n \) for common materials. Light waves are strongly bent by a diamond. It is the high index of refraction that gives diamonds their sparkle and beautiful rainbows of color.

The prism

A prism is a polished shape of glass that you can use to investigate refraction. A common shape for a prism is a triangle. Light coming into any face of the prism is bent by refraction. The light is bent again when it comes out of the prism.

Splitting colors with a prism

The index of refraction varies slightly depending on the color of the light. Blue light is bent more strongly than red light. Because of this you can use a prism to split white light up into different colors. Blue light is on one end of our visible spectrum. Red light is on the other end.
Chapter 15

15.2 The Human Eye

Your eye is an entire optical system that works together with the optic nerve and your brain to help you see images. Some scientists even consider the eye to be part of the brain itself. Everything we have learned about refraction and images applies to the eye.

The parts of your eye work together to help you see objects. The cornea and lens focus light so that an image forms on a special membrane at the back of the eye called the retina. The iris is a circular opening in front of the lens that can change to let more or less light into the eye (figure 15.15). The rod and cone cells that make up the retina sense the images and transmit them via the optic nerve to the brain.

Nerves

What is a nerve? Nerves are the body’s sensors and wires. Some nerves respond to sensation like pressure, heat, cold, pain, or light, and others transmit signals to and from the brain. When you touch something, nerves in your finger link to other nerves and send a message to your brain. You have more nerves in your fingertips than you do on the back of your arm. That is why you will notice that something is hot much faster if you touch it with your fingertip than if you brush against it with your arm. In your ear you have nerves that can detect sound.

Your eye also has nerve cells The rod and cone cells in your eye are also nerves. Rod cells respond to light intensity only, so they see black, white, and shades of gray. Cone cells are sensitive to color but need brighter light. Your cones are located closer to the center of your eye. If somebody were to bring an object from the side of your vision slowly into your line of sight, you could detect the object but not the color.

Figure 15.15: The pupil of the eye is really the opening created by the iris. When there is a lot of light the iris constricts and the pupil gets smaller. When the light level is dim, the iris opens up and the pupil gets larger.
Forming an image

The image on the retina

The lens focuses light on the retina at the back of the eyeball. Since it is a single lens, ray tracing tells you that the image is upside down! Of course, our brains have learned to flip the image right side up, so we don’t notice.

The lens can change focal length

The lens in your eye also has a unique feature which makes it different from the lenses you used in the lab. The lens of your eye is flexible. Small muscles around the edge can stretch it and change its shape. This allows you to focus on objects close by and also focus on objects far away (figure 15.16). As you get older the lens loses some of its flexibility. Many people wear contact lenses or glasses that adjust the light before it gets to their eye. Bifocal glasses have two regions; one to help you see close and the other to help you see far.

How the eye makes an image

The spot on the retina where an image forms is called the fovea. For the average human eye, the fovea has about 120 million rod cells and another 5 million cone cells. Each of these cells contributes one dot, or pixel, to the image received by the brain. The brain puts all the pixels together to perceive an image. This is much like a computer monitor creates images from pixels.

Comparing the eye to a computer monitor

Let’s examine a computer monitor that is 1,600 pixels wide and 1,200 pixels high. Multiplying 1,600 times 1,200 gives a total of 1.9 million pixels. By comparison, the image created by the eye is equivalent to a computer screen 8 times bigger, 13,000 pixels wide, and 9,600 pixels high! The optic nerve carries 64 times more data than a high-resolution computer graphics display.

Stereoscopic vision and depth perception

Stereoscopic vision means that the brain receives two images of the same object, one from each eye. The brain interprets small differences between the images. We use this information to determine distances between objects and how far they are from us. Our ability to judge distances is called depth perception.
Optical illusions

The brain interprets the image

No matter what has actually happened to the light entering our eyes, our brains produce a single image. The image produced is always based on the assumption that light travels in a straight line. It doesn’t matter if you use funny mirrors to bend light in all different directions or use a lens to make rays of light appear to come from places they weren’t really coming from. The brain always creates an image of an object that would have existed if the rays had come straight to your eye.

The virtual image in a mirror

This is why a virtual image in a mirror works. The rays that reach your eye after bouncing off the mirror travel along lines that seem to come from the virtual image. Your brain places the image where the rays appear to come from. If you are standing three feet in front of a mirror, you see a virtual image standing three feet behind the mirror (six feet from you).

Optical illusions

There are many well-known optical illusions where the brain interprets an image to be something that it is not. Such illusions trick the brain by using cues such as light and shadow. For example, how is your brain tricked by the drawing in figure 15.19? The elephant may look normal at first glance. However, clever shading and lines create an image that cannot exist in reality. The artist M.C. Escher was famous for creating “impossible” images that trick the brain into seeing a three-dimensional object that is physically impossible.

Figure 15.18: Objects that are smaller are often interpreted by the brain as being farther away. A perspective grid uses this visual cue to create the illusion of depth.

Figure 15.19: What has the artist done to make this normal-looking elephant an optical illusion?
15.3 Optical Technology

We use a wide range of optical technology every day. Glasses and contact lenses are obvious examples. Light-emitting diode (LED) lights and remote controls are other examples. Internet and telephone signals are transmitted using optical fibers and lasers. Your compact disc player uses a laser and a sophisticated miniature optical system. People are even trying to build optical computers that use light rather than electricity. It is very likely that your future will keep you in daily contact with optical technology.

Fiber optics

Bouncing a rock off the water
Have you skipped a stone on a pond? First, you need to find a flat stone. Now you hold the stone between your thumb and forefinger. Pull your arm back and throw the stone. If you throw it just right, the stone will bounce off the surface of the water! To be successful, you have to throw the stone at a very large angle of incidence. It’s amazing that you can throw a rock at water and have the water bounce the rock back into the air. You don’t usually think of water being able to bounce a rock but, if the angle is right, the rock bounces instead of sinks.

When light enters glass, it bends toward the normal
Light, which would normally go through glass, can also be made to bounce off. The key is to get the angle of incidence large enough. If light is traveling in a material with a low index of refraction (air: \( n = 1.00 \)), and it goes into a material with a higher index of refraction (glass: \( n = 1.50 \)), it will bend so that the angle of refraction is less than the angle of incidence. Figure 15.20 shows how a light ray bends toward the normal when going into a material with a higher index of refraction.

When light exits glass, it bends away from the normal
On the other hand, if the light is already in the glass and it is going into air, it will bend so that the angle of refraction is greater than the angle of incidence. This means the light bends away from the normal. In a window, both conditions occur. The light bends toward the normal when it enters and away from the normal when it leaves. That is why light going through a flat sheet of glass comes out in the same direction it went in. We see images through windows almost perfectly clearly because the surfaces are flat.

Figure 15.20:
A You can skip a rock off the surface of water if you throw it at a large angle of incidence.
B A light ray bounces off glass if it encounters the surface at a large angle of incidence. A light ray will enter glass if it encounters the surface at a small angle of incidence.
C With a flat sheet of glass, the refraction going in exactly cancels the refraction going out and the light comes out in the same direction.
Total internal reflection
If the angle of incidence is great enough, light enters but does not leave a material because all the light is reflected back into the material. This angle is called the critical angle, and it depends on the index of refraction. If light approaches the surface at greater than the critical angle, it reflects back. This is called total internal reflection. The critical angle for glass is about 41 degrees.

A pipe for light
Suppose you have a tube of glass and you send light into the end at greater than the critical angle. The light reflects off the wall and bounces back. It then reflects off the opposite wall as well. In fact, the light always approaches the wall at greater than the critical angle so it always bounces back into the tube. You have constructed a light pipe! Light goes in one end and comes out the other. Fiber optics use total internal reflection to trap light into a flexible glass fiber. To connect a fiber optic, you must be careful to feed light in along a cone of the right angle (figure 15.23). Any light outside the cone will leak out the edges because it will not be internally reflected.

Carrying images on a fiber
Bundles of fiber optics can transmit an image without lenses. If all the fibers at one end of a bundle are perfectly aligned at the other end, then they will send an image through the fiber, even if the fiber is tied in a knot!
Imagine you invented a code to signal a far-off friend with a flashlight. You tell your friend to look for a light pulse every second. Two “on” pulses followed by an “off” might mean the letter “a” for example. You could invent a different code for every letter. This is essentially how light wave communications work. The light pulses are carried through very thin, glass fibers and can travel great distances. Most long-distance telephone calls today are carried on these fibers. This kind of technology is called fiber optics. Computers that communicate over fiber optic links can exchange data much faster than using any other means.

Many different colors of light can go through a glass fiber without interfering with each other. In the graphic above, colors of light are shown. The dark bands represent the pulses of each color. A single glass fiber can carry as many as 64 different signals. Each signal is given its own frequency (color) of light. The light from all signals is first combined using a prism and sent through the fiber. At the other end of the fiber, the signal is split into different colors, also using a prism. Each color is then decoded separately.

Almost all Internet data communication is over fiber optic networks that stretch between cities and between important buildings. Most long-distance telephone is also carried over fiber optics. The only part that is still carried on copper wires is the link from your home or desk to the main telephone company station near where you live. Once the signal reaches the telephone station, it is converted to light using lasers. When you make a long distance call, your voice makes a journey thousands of miles over fiber optics.

Someday, a fiber optic cable will come right to your house or apartment. Your telephone, computer, radio, and TV stations will all ride the light waves down the fiber. This is possible because light has such a high frequency. The higher the frequency, the more information you can send. One fiber optic cable can carry more information than used to be carried by a thousand copper wires.
Chapter 15

Lasers

What is a laser? A laser is a special type of flashlight. Lasers typically have a special material. When energized in a specific way, electrons in a laser material move into a higher energy level. Like electrons in the “glow-in-the-dark stuff,” electrons in a laser material do not fall to a lower energy level right away. The operator of a laser can cause electrons in the laser material to be energized or to fall at the same time. If all the electrons fall at the same time, then the light waves that are created are very unique. All the waves will be aligned in phase. The resulting light is one color because all the waves are the same frequency. This light is also very bright because the aligned waves do not spread out quickly. (The term LASER is an acronym; it stands for Light Amplification by Stimulated Emission of Radiation.)

The first laser

The first laser was made using a short rod made out of synthetic ruby. The ruby rod was surrounded by a special flash bulb that was shaped like a coil. Mirrors were placed at each end of the ruby rod. The light from the flash caused electrons in the ruby to rise to an excited orbit. Any energy that was traveling straight down the ruby rod would cause other electrons to fall and add to the energy that was moving. When this light hit the mirror it reflected straight back to continue collecting more and more energy from falling electrons. One mirror was slightly less reflective than the other. When the light was bright enough it would escape.

Helium neon lasers

The lasers you may see at school look like long narrow boxes. They have a gas tube inside of them instead of a ruby rod. The tube is filled with helium and neon gases. These helium neon lasers produce red light and use high voltage electricity to energize the electrons instead of a flash lamp.

Diode lasers

Diode lasers are becoming the laser of choice because of their low cost, reliability, low voltage, and safety. If you have ever played with a laser pointer, you have used a diode laser. Supermarket scanners also use diode lasers. A diode laser can be smaller than a pinhead and can make light from a tiny amount of electricity. There are diode lasers that make red, green, and blue light. Researchers are trying to put red, green, and blue lasers together to make a “laser TV” that could project bright color images.

How bar-code readers work

The bar-code reader at the grocery checkout uses a laser light source and photo diode reader. The laser light is “scanned” across the bar-code label on the items you buy. The photo diode is used to measure the intensity of the light as it reflects back from the label. The black stripes absorb light and white stripes reflect it. The width of each stripe determines its number. The reader is tuned to receive only the specific frequency of light that the laser emits.
## Chapter 15 Review

### Vocabulary review

Match the following terms with the correct definition.

<table>
<thead>
<tr>
<th>Set One</th>
<th>Set Two</th>
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<tr>
<td>1. optics</td>
<td>1. refraction</td>
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<tr>
<td>2. lens</td>
<td>2. reflection</td>
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<td>3. mirror</td>
<td>3. telescope</td>
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<tr>
<td>4. prism</td>
<td>4. real image</td>
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<td>5. light ray</td>
<td>5. virtual image</td>
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<table>
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<tr>
<th>Set Three</th>
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<tr>
<td>1. normal</td>
<td>1. retina</td>
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<td>2. incident ray</td>
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<td>3. stereoscopic vision</td>
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<td>4. angle of incidence</td>
<td>4. total internal reflection</td>
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<tr>
<td>5. angle of reflection</td>
<td>5. fiber optics</td>
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### Definitions

- **Set One**
  1. **optics**: A device that uses reflection to bend light to form an image
  2. **lens**: A device that bends different frequencies of light to separate colors
  3. **mirror**: The study of how light behaves
  4. **prism**: An imaginary arrow used to show the path of a single beam of light
  5. **light ray**: A device that uses refraction to bend light to form an image

- **Set Two**
  1. **refraction**: An image formed by rays of light coming together on a surface like the retina of the eye
  2. **reflection**: The bouncing of light rays from a surface
  3. **telescope**: Bending of light rays that results as light crosses a boundary between two different substances
  4. **real image**: An image formed when light rays seem to come from a point other than where the object exists
  5. **virtual image**: A device (used by Galileo) that uses a collection of lenses to magnify an image

- **Set Three**
  1. **normal**: The ray of light that bounces off a mirror
  2. **incident ray**: The angle measured from the normal to the incident ray
  3. **reflected ray**: A line drawn perpendicular to the surface of a mirror or any surface
  4. **angle of incidence**: The angle measured between the normal and the reflected ray
  5. **angle of reflection**: The ray of light that strikes a mirror

- **Set Four**
  1. **retina**: A device that uses the stimulation of electrons to create an amplified emission of radiation
  2. **lens**: The back of a human eyeball where an image is formed
  3. **stereoscopic vision**: A light pipe that uses total internal reflection to carry light and signals from one point to another
  4. **total internal reflection**: This part of the human eye bends the light that comes into it
  5. **fiber optics**: This process happens when light inside a glass of water tries to get out but is reflected back into the material

- **f. The ray of light that passes through a mirror**
Concept review

1. A ray of light falls on a lens made of glass. Which of the following (a, b, or c) best describes the path of the light ray leaving the lens?

2. An image is best described as:
   a. A place where light rays leaving one point on an object come together again.
   b. A light source that creates objects.
   c. The splitting of white light into different colors.
   d. A group of light rays leaving from the same point on an object.

3. A ray of light falls on a mirror. Which of the following (a, b, c, or d) best describes the path of the light ray leaving the mirror?

4. Total internal reflection happens when light comes from air and strikes the surface of water.
   a. True   b. False

5. What is the purpose of the iris in the eye?

6. What is the purpose of the optic nerve?

7. What is the purpose of a rod or cone cell?

8. What is the purpose of the lens?

9. Identify which of the following kinds of electromagnetic waves are used by the bar-code scanner at a grocery store.
   a. microwaves   c. radio waves
   b. visible light   d. X rays

10. Identify which of the following kinds of electromagnetic waves are transmitted through fiber optics.
    a. microwaves   c. radio waves
    b. visible light   d. X rays

11. Which creature must take total internal reflection and refraction into account when hunting in its natural environment?
    a. An eagle   c. An alligator
    b. A tiger   d. A wolf
12. Why do you use a ruler to draw rays of light?
   a. The ruler makes the picture look more professional.
   b. The ruler has light that comes out of it.
   c. The ray of light has marks every centimeter like a ruler.
   d. The ray of light travels in a perfectly straight line.

13. How many rays of light do you need to draw to find where an image is located?
   a. Only one ray is needed.
   b. One ray is needed but it must be flashing.
   c. A minimum of two rays is needed to find an image.

Problems

1. What does the term normal mean?
   a. Average
   b. The middle
   c. Perpendicular
   d. All of these are correct

2. The angle between the incident ray and the reflected ray is 60°.
   What is the angle of reflection?
   a. 10°
   b. 20°
   c. 30°
   d. 40°

3. How do you measure the incident angle?
   a. The angle between the incident ray and the normal.
   b. The angle between the incident ray and the surface of the mirror.
   c. The angle between the surface of the mirror and the normal.
   d. The angle between the reflected ray and the surface of the mirror.

4. Which of the arrows in the diagram shows the path taken by a light ray as it travels through the lens?

5. As light goes from air into glass the angle of refraction is:
   a. The same as the angle of incidence.
   b. Less than the angle of incidence.
   c. Greater than the angle of incidence.
   d. Is not related to the angle of incidence.

6. As light goes from glass into air the angle of refraction is:
   a. The same as the angle of incidence.
   b. Less than the angle of incidence.
   c. Greater than the angle of incidence.
   d. Not related to the angle of incidence.
Applying your knowledge

1. Sketch an eyeball. Draw and label all the major parts of the eye.

2. A microscope is a tool scientists use to magnify cells and very small objects. Find a drawing of a microscope and make a sketch of how many lenses there are. What do the following words mean when talking about a microscope?
   a. Eyepiece
   b. Objective
   c. Magnification

3. A telescope can be used for looking at objects on Earth as well as in the sky. What do the following words mean when used to describe the working of a telescope?
   a. Aperture
   b. Magnification
   c. Reflector
   d. Refractor

4. Explain how glow-in-the-dark material works.

5. Explain the things that happen to an atom that cause it to give off light.

6. The rear view mirror on some cars has a message, “Objects may be closer than they appear,” painted on the mirror surface. Explain why car manufacturers thought it was necessary to put this message there.