UNIT 5
Light and Optics

Chapter 14
Light and Color

Introduction to Chapter 14

We live in a world where light and color play a pivotal role in the very survival of life on this planet. Plants use sunlight to make sugar. Our ability to see helps us gather food. These processes and many others hinge on the unique properties of light. This chapter will introduce you to some of light's unique characteristics.

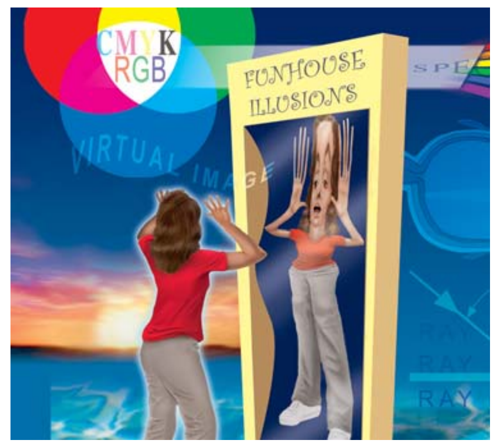
Investigations for Chapter 14

14.1	**Introduction to Light**	*How can you make light and how can you study it?*

In this Investigation you will look through a diffraction grating at a light source to see all the different colors that make up light. This leads us to the question "What makes different colors?" The different colors of light will be explained in terms of the energy of electrons falling from higher energy to lower energy inside atoms. Different atoms have different energy levels and produce different colors.

14.2	**Color**	*What happens when you mix different colors of light?*

All of the colors of light that you see are really a combination of three primary colors: red, blue and green. In this Investigation, you will discover how to make all colors of light by mixing the three primary colors. You will also use a tool called a spectrometer to analyze light. This instrument allows you to break light into its "fingerprint" wavelengths.



Learning Goals

By the end of this chapter, you will be able to:

- ✔ Describe the atomic origin of light.
- ✔ Explain the difference between incandescence and fluorescence.
- ✔ Identify uses for the other categories of electromagnetic energy.
- ✔ Compare the speed of sound to the speed of light.
- ✔ Identify the parts of the eye that see black and white, and color.
- ✔ Describe the physical reason for different colors in terms of the wavelength and energy of light.
- ✔ Identify and explain the RGB color model.
- ✔ Identify and explain the CMYK color model.
- ✔ Understand the mixing of light and pigment.
- ✔ Compare how a color printer makes color and how a color monitor makes color.

Vocabulary

chemical reaction	fluorescent	photoluminescence	subtractive primary colors
cone cells	incandescence	pixel	terahertz
cyan	magenta	polarizer	visible light
electromagnetic spectrum	nanometers	rod cells	yellow

14.1 Introduction to Light

What is light? How do we see? These questions intrigue us because, from infancy through adulthood, we are drawn to bright, flashing lights and brilliant, sparkling colors. “Bright and shiny” is a common phrase that refers to this attraction. Although light is only a small part of the sensory energy around us, many people would say sight is the most important of our five senses.

We see objects by their reflected light

What is light?

Light is a wave that we see

Light is a wave that we can see with our eyes. Besides helping us to see the world around us, light has many other qualities that we use.

- Light can carry heat and warmth.
- Light has color.
- Light can be bright or dim.
- Light travels almost unimaginably fast and far.
- Light travels in straight lines, but can be bent by lenses or reflected by mirrors.

How do we see?

What happens when you see a car? Sunlight bounces off the car and into your eyes. Your eyes send signals to your brain, which creates an *image* of the car. Because the brain is so important in forming images, different people see things differently. This is one reason why paintings and drawings of a landscape or person are not the same when created by different people.

There are forms of “light” we cannot see

The light we see, visible light, is only one part of the *electromagnetic spectrum*. Radio waves, ultraviolet rays, microwaves, and X rays are also *electromagnetic waves*. Although we can’t see them, these waves are used in a variety of ways including food preparation (microwaves), communication (radio waves and microwaves), medicine (X rays), and space exploration (see sidebar, right).

George Carruthers

After earning a Ph.D. in aeronautical and astronomical engineering from the University of Illinois in 1964, Dr. George Carruthers began working for the Naval Research Laboratory in Washington, D.C. There, he developed new tools to study space using ultraviolet rays. Using his tools, astronomers detected molecular hydrogen in deep space, leading to a better understanding of the total amount of matter in the universe.

In 1972, a special camera that Carruthers invented was used on the Apollo 16 mission to the moon. Called the Far-Ultraviolet Camera/Spectrograph, it took pictures that revealed important new information about deep space objects and Earth’s outer atmosphere.After the mission, NASA awarded Carruthers its Exceptional Scientific Achievement medal.

Carruther’s inventions have been used to study comets, stars, nebula, and other deep space objects. He was inducted into the National Inventors Hall of Fame in 2003.

What makes light?

Atoms make light

We know of many things that give off light: the sun, fireflies, lightning, fire, incandescent and fluorescent bulbs are a few examples. But what actually makes the light? The thing that is common to all these different sources of light is that they are made up of atoms. Almost everything that creates light is made of atoms.

Atoms, electrons, and energy levels

You may remember that each atom contains smaller particles within it: a nucleus made up of protons and neutrons at the center of the atom and electrons at the outside edge of the atom. The electrons are always arranged in *levels*, like layers of onion skin. The electrons in each level have a different amount of energy. The farther away the electrons are from the nucleus, the more energy they have. Electrons can gain energy and rise to a higher level in the atom. When this happens, they can also fall back to a lower level in the atom and release energy.

Glow-in-the-dark stuff

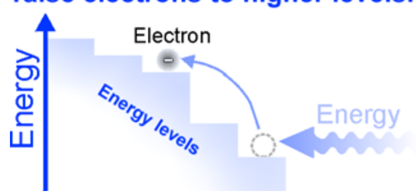
Consider an amazing but very common material, glow-in-the-dark plastic. If this material is exposed to light, it soon gives off its own light. What is happening?

An example of making light

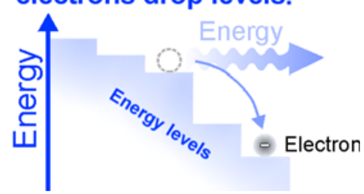
Embedded in glow-in-the-dark plastic are atoms of the element *phosphorus*. When light hits phosphorus atoms, some of the electrons absorb the light, rise to a higher energy level and then stay up there. Slowly, the electrons fall back down and give off their stored light. Because the electrons fall back over a long period of time, glow-in-the-dark stuff gives off light for many minutes. When all the electrons have finally fallen to the lowest levels, no more light comes out. To "recharge" your glow-in-the-dark material, you have to expose it to light again.

When phosphorus gives off light the process is called **photoluminescence**. The word "photo" means light and the word "luminescence" means glowing. Light energy has led to the production of light by something else.

Energy is required to raise electrons to higher levels.



Energy is given off when electrons drop levels.



Glow sticks

Glow sticks are a great example of atoms emitting light. When you bend a glow stick, two chemicals are mixed. The active chemical is called Luminal. When Luminal mixes with the other chemicals in the glow stick, a reaction takes place, causing electrons to fall from high energy levels to lower levels.

The energy released is almost completely in the form of light. After all the electrons have fallen to their lowest energy levels, the light stick stops glowing. You can slow the reaction down by cooling the chemicals in cold water or the freezer.

If you activate two glow sticks and put one in hot water and the other in ice water, you can graphically see how reaction rate is linked to temperature.

More about energy levels and light

What is an energy level?

Think about Earth orbiting the sun. Earth is attracted to the sun by the force of gravity, but it is not pulled into the sun because it has kinetic energy from moving in its orbit. Electrons in atoms also have kinetic energy. The energy of electrons keeps them in stable energy levels, like orbits (Figure 14.1). That is why they don't fall into the nucleus.

Why are there energy levels?

The question "Why are there energy levels?" is hard to answer. When we look at nature and study atoms, we find energy levels. Niels Bohr built a model of the atom to help us understand how energy levels work. He used something called quantum mechanics to explain his model. We know that the energy of electrons in atoms comes in levels. We can use quantum mechanics to calculate what the energy levels are. We know how to use our knowledge of energy levels to make lasers and TV screens. But, fundamentally, we don't know *why* quantum mechanics works or why there are energy levels. Maybe someday you will find out and win the Nobel Prize!

Light from chemical reactions

If an atom has some electrons in a high energy level and they somehow fall into a lower energy level, the atom will give off energy that our eyes might see. This happens all the time. When wood is burning, a chemical reaction takes place between the atoms in the wood and the atoms of oxygen in the air. Chemical reactions move electrons around. If any electrons move to lower levels, light can come out. The warm flickering light from a candle comes from trillions of tiny electrons falling down energy levels as the wick combines with oxygen and burns.

Light from lightning and the sun

When electricity moves through the air, it can cause the atoms in the air to rearrange their electrons. This can also produce light, which we call lightning. We cannot see the electricity (although we could certainly feel it), but we can see the light that is created. The light from the sun comes from moving electrons in the sun's very hot outer layers. Because reactions inside the sun release a lot of energy, the sun makes several kinds of electromagnetic waves, including infrared light, visible light, and ultraviolet (UV) light. These waves move through space and reach the Earth, sustaining life by bringing heat and light.

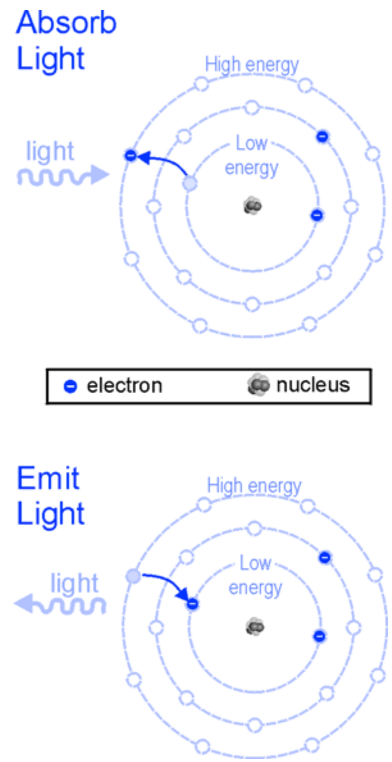


Figure 14.1: *If we want an atom to give off light, we need at least one electron that can fall back down to an empty spot at lower energy.*

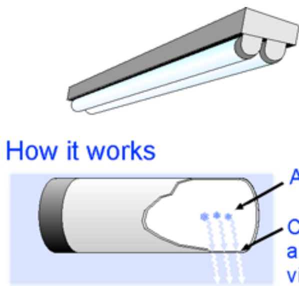
1) We can have an atom absorb some light and move an electron to high energy.

2) We can let the electron fall back down and the atom emits light.

Electric lights

Incandescent light bulbs

The light we use at night or indoors is usually made with electricity. When electricity passes through materials, it heats them up. If the atoms get hot enough, some of the energy moves electrons from low energy levels to higher ones. The electrons fall back down immediately and give off energy as light. The process of making light with heat is called **incandescence**. This is how incandescent light bulbs work. The filament in the light bulb is heated white-hot by electricity. The hot filament emits light. These bulbs actually produce more heat energy than light energy. (Heat, not light, is why these bulbs are used to help chicken eggs hatch!)



Fluorescent light bulbs

The other common kind of electric light bulb is the **fluorescent** bulb. We are seeing many more fluorescent bulbs today because they are much more efficient. Compared with a standard (incandescent) bulb, you get four times as much light from a fluorescent bulb for the same amount of electricity! The reason is that not as much energy is lost as heat. In a fluorescent bulb, high-voltage electricity energizes atoms in a gas with a diffuse spark, much like lightning. Much more of the electrical energy is used to raise electrons and less is used to heat the atoms.

Getting useful light from a fluorescent bulb is actually a two-step process. The light emitted by the electrons in the gas is mostly ultraviolet, which we cannot see. In a fluorescent bulb the ultraviolet light hits a white coating on the inside surface of the bulb. The coating absorbs the UV light and emits it again as white light. You can buy fluorescent bulbs with different coatings to make the light more blue or more yellow, like natural sunlight.

Please turn out the lights when you leave!

There are about 285,000,000 people living in the United States. If an average house has four light bulbs per person, it adds up to 1,140,000,000 light bulbs. The average bulb uses 100 watts of electricity. Multiplying it out gives an estimate of 114,000,000,000 watts, just for light bulbs.

A big electric power-plant puts out 2,000,000,000 watts. That means 67 big power plants are burning up resources just to run your light bulbs. If everyone were to switch their incandescent bulbs to fluorescent lights we would save 75 percent of this electricity. That means we could save 50 big power plants' worth of pollution and wasted resources!

Light waves and the electromagnetic spectrum

The amount of energy given off by atomic electrons can be tiny or huge. The light we can see, visible light, is only a small part of the possible energy range. The whole range is called the electromagnetic spectrum and visible light is in the middle of it. On the low energy end of the spectrum are radio waves with wavelengths billions of times longer than those of visible light. On the high energy end are gamma rays. These have wavelengths millions of times smaller than those of visible light. We will see that visible light, with a medium energy range, is perfectly suited for sustaining life. That is why our eyes are so well adapted to this part of the spectrum.

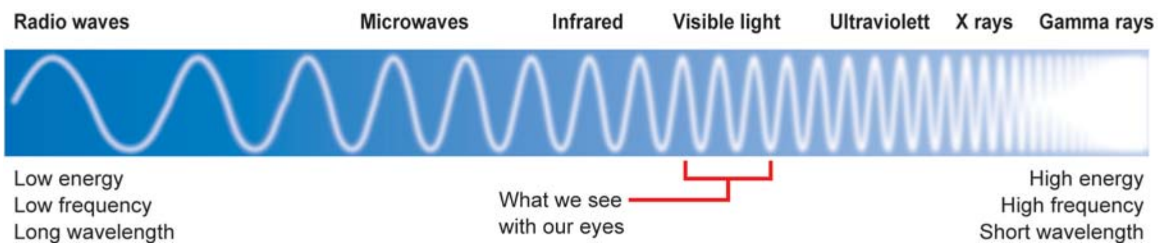


Figure 14.2: *The 140-foot-diameter radio telescope at Green Bank, West Virginia. The giant reflecting mirror is so large because the wavelength is large. Mirrors for optical telescopes can be smaller because the wavelength of visible light is smaller.*

Radio waves Radio waves are used to transmit radio and television signals. Radio waves have wavelengths that range from hundreds of meters down to less than a centimeter. Radio broadcast towers are so tall because they have to be at least 1/4 wavelength long. Your clock radio uses the length of wire that plugs into the wall socket as its antenna. If your station doesn't come in properly, you should untangle that wire. FM radio waves are shorter than AM radio waves so a radio must have two antennas; one is a coil of wire inside the unit, and the other is the expanding metal rod that you pull out when you want to use FM.

Microwaves Microwave wavelengths range from approximately 30 centimeters (about 12 inches) to about one millimeter (the thickness of a pencil lead). In a microwave oven, the waves are tuned to frequencies that can be absorbed by the water in food. The food absorbs the energy and gets warmer. Microwaves are also used for cell phone transmissions.

Figure 14.3: *Cell phones use microwaves to transmit signals.*

Infrared waves Infrared is the region of the spectrum with a wavelength of about one millimeter to approximately 700-billionths of a meter. Infrared waves include thermal radiation. For example, burning charcoal may not give off very much light, but it does emit infrared radiation which is felt as heat. Infrared images obtained by sensors in satellites and airplanes can yield important information on the health of crops and can help us see forest fires even when they are covered by clouds of smoke.

Visible light The rainbow of colors we know as visible light is the part of the spectrum with wavelengths between 700-billionths and 400-billionths of a meter (700 to 400 nanometers). When people talk about "light" in ordinary conversation, they are usually talking about visible light. When scientists talk about "light" they could be referring to any part of the electromagnetic spectrum from microwaves to X rays.

Ultraviolet waves Ultraviolet radiation has a range of wavelengths from 400-billionths of a meter to about 10-billionths of a meter. Sunlight contains ultraviolet waves that can burn your skin. A small amount of ultraviolet radiation is beneficial to humans, but larger amounts cause sunburn, skin cancer, and cataracts. Most ultraviolet light is blocked by ozone in the Earth's upper atmosphere. Scientists are concerned that damage to the Earth's ozone layer could allow more ultraviolet light to reach the surface of the planet, creating problems for humans, plants, and animals.

X rays X rays are high-energy waves which have great penetrating power and are used extensively in medical applications. They are also used to detect faults in the metal welds that hold equipment (like airplanes) together. Their wavelength range is from about 10-billionths of a meter to about 10-trillionths of a meter.

Gamma rays Gamma rays have wavelengths of less than about 10-trillionths of a meter. Gamma rays are generated by radioactive atoms, in nuclear reactions, and are used in many medical applications. Gamma rays have even higher energy than X rays. The energy is so high that it can push electrons right out of the atom and break chemical bonds, including the chemical bonds holding the molecules in your body together. You do not want to be around strong gamma rays without a heavy shield!

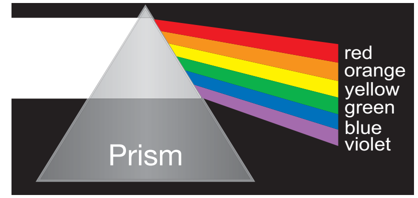


Figure 14.4: *Light carries information about color.*

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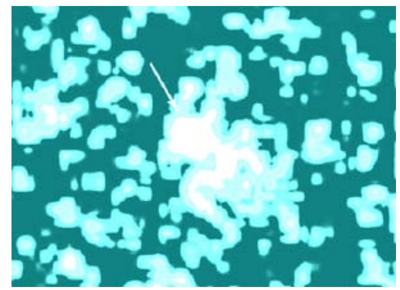


Figure 14.5: *Gamma rays are given off in nuclear reactions on Earth and also in stars. Astronomers are searching for explanations for unusually strong gamma rays that appear and disappear in space. The bright spots show regions of the sky with strong gamma ray emissions.*

The speed of light

Seeing lightning and hearing thunder

How does light get from one place to another? This is a question that has intrigued people for many hundreds of years. Lightning and thunder actually happen at the same time. You see a bolt of lightning and then hear the thunder a few seconds later because light travels much faster than sound.

Measuring the speed of sound

Sound (the thunder) travels so slowly that you could almost time it yourself with a stopwatch. If you stood 170 meters from a large building and shouted at the building, you would hear your own echo about one second later. The sound traveled the 170 meters to the wall, bounced and traveled the 170 meters back to you in one second (Figure 14.6). The speed of sound in air is about 340 meters per second.

Measuring the speed of light

Trying this trick with light is much more difficult. Suppose you shine a light at a mirror 170 meters away (Figure 14.7). You wouldn't even begin to push down on the stopwatch before you saw the reflected light. It only takes light about a millionth of a second to get to your mirror and back. When scientists did eventually come up with a way to measure the speed of light, they used mirrors more than 20 miles apart. Even with such a long distance they needed a fancy spinning mirror to measure the speed of light.

Using this spinning mirror, scientists discovered that the speed of light is about 300 million (300,000,000) meters *per second*. If you were to walk around the earth at the widest part, you would have to walk about 12,756 km, or 12,756,000 meters. It would take you a very long time to walk that far, but since light travels so fast, a beam can circle the earth about 7.5 times in one second!

The universal speed limit

The speed of light is special because nothing in the universe travels faster than light. This idea forms part of Albert Einstein's theory of relativity. This brilliant theory explains that space and time are tied together. One of the ways that Einstein developed his theory was by asking himself about how light behaves. He wondered what light would look like if it were to stop and stand still (he imagined himself observing a beam of light while traveling as fast as light himself). Using what he knew about light, Einstein showed that it was impossible to stop light or even to observe a stationary beam of light.

Sound echo

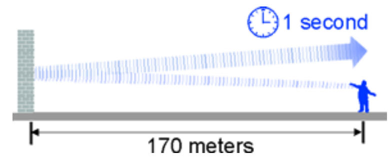


Figure 14.6: *A sound echo takes about one second from a wall that is 170 meters away.*

Light echo

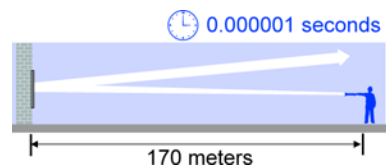


Figure 14.7: *The reflection of light from a mirror 170 meters away reaches you in 0.000001 seconds. Light travels much faster than sound.*

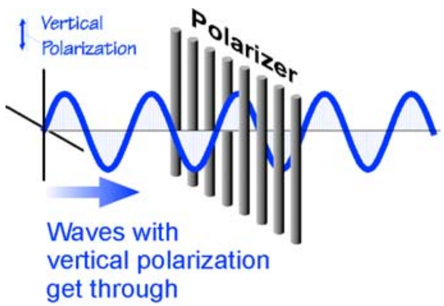
Polarization

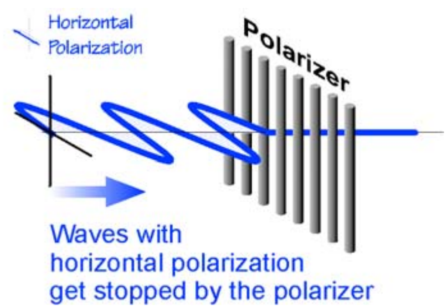
Polarization

Polarization is a useful property of light waves. Light is a transverse wave of electricity and magnetism. To understand polarization, think about shaking a taut string up and down to make a vertical wave. We say a light wave with an up-down electrical pattern is "polarized" in the vertical axis. If you vibrate the string side to side, you create a horizontal wave. A light wave with a side-to-side electrical pattern is "polarized" in the horizontal axis. Polarization at an angle between vertical and horizontal can be understood as being part vertical and part horizontal, like the sides of a triangle. Each atom usually emits light at a different polarization; therefore, most of the light you see is a mixture of polarizations. We call this light "unpolarized" since no single polarization dominates the mixture.

How we use polarization of light

A polarizer is a partially transparent material that lets only one polarization of light through. Microscopically, polarizers behave like a grid of tiny wires. Light that is electrically aligned with the wires can pass through. A vertical polarizer only lets light with vertical polarization pass through. Horizontally polarized light is blocked. At different angles, a polarizer allows different polarizations of light to pass through (Figure 14.8).





Using two polarizers

If you use two polarizers, you can control the flow of light (Figure 14.8). Light coming through the first one is polarized in a known direction. If the axis of the second polarizer is in the same direction, the light gets through. If the second polarizer is not in the same direction, some or all of the light cannot get through. You can control how much light gets through by adjusting the angle of the second polarizer relative to the first one.

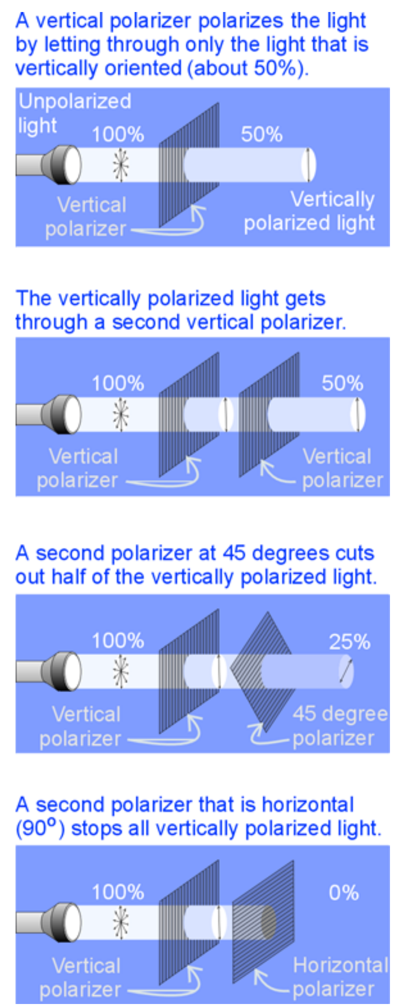


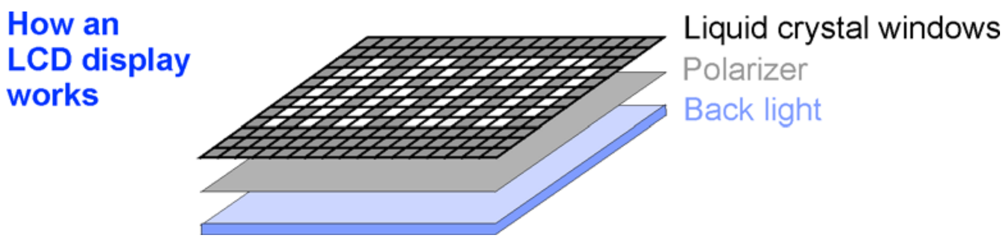
Figure 14.8: *A single polarizer polarizes light by letting through only the portion of the original light that has the right polarization. You can use two polarizers to filter some or all of the light.*

How polarizing sunglasses work

Polarizing sunglasses are used to reduce the glare of reflected light. Light that reflects at low angles from horizontal surfaces is polarized mostly horizontal. Polarizing sunglasses are made from a vertical polarizer. The glasses block light waves with horizontal polarization. Because glare is horizontally polarized, it gets blocked much more than other light which is unpolarized.

Polarizing filters for cameras

Photographers often use polarizing filters on camera lenses. The filters allow them to photograph a river bed or ocean bottom without the interfering glare of reflected light. Polarizing filters are used in landscape photography to make the sky appear a deeper blue color. Can you explain why a polarizer has this effect?



How an LCD computer screen works

The LCD (liquid crystal diode) screen on a laptop computer uses polarized light to make pictures. The light you see starts with a lamp that makes unpolarized light. A polarizer then polarizes all the light. The polarized light passes through thousands of tiny pixels of liquid crystal that act like windows. Each liquid crystal window can be electronically controlled to act like a polarizer, or not. When a pixel is NOT a polarizer, the light comes through, like an open window and you see a bright dot. The polarization direction of the liquid crystal is at right angles to the first polarization direction. When a pixel becomes a polarizer, the light is blocked and you see a dark dot. The picture is made of light and dark dots.

Because the first polarizer blocks half the light, LCD displays are not very efficient, and are the biggest drain on a computer's batteries. New technologies are being developed to make more efficient flat-panel displays.

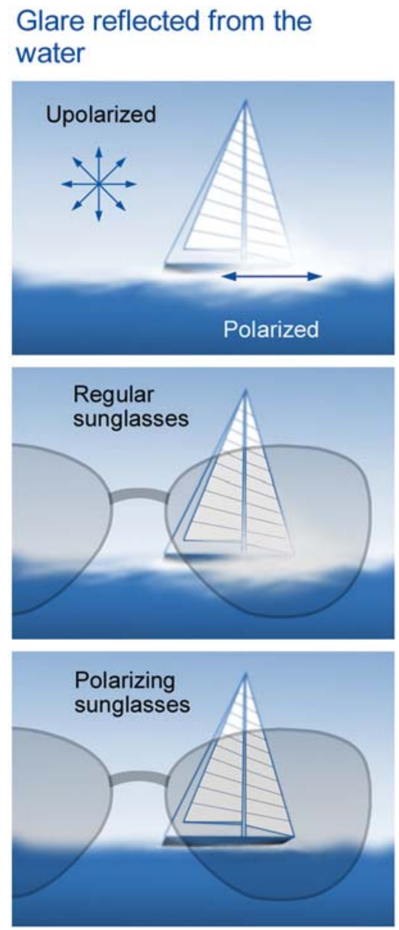


Figure 14.9: *Reflected glare is partly polarized, while the rest of the light you see is usually unpolarized. Regular sunglasses block all the light equally. Polarizing sunglasses block the polarized glare more than other light, enhancing what you see.*

14.2 Color

Color adds much richness to the world. The rainbow of colors our eyes can see ranges from deep red, through the yellows and greens, up to blue and violet. Just as we hear different frequencies of sound as different notes, we see different frequencies of light as different colors. Artists through the ages have sought recipes for paints and dyes to make vivid colors for paintings and clothing. In this section we will explore some of the ways we make and use colors.

Where does color come from?

Frequency and wavelength

To understand color we need to look at light as a wave. Like other waves, light has frequency and wavelength.

Frequency 4.6×10^{14} to 7.5×10^{14} Hz

Wavelength 4×10^{-7} to 6.5×10^{-7} meters

The frequency of light waves is incredibly high: 10^{14} is a 10 with 14 zeros after it! Red light has a frequency of 460 trillion, or 460,000,000,000,000 cycles per second. Because the frequency is so high, the wavelength is tiny. Waves of red light have a wavelength of only 0.00000065 meters (6.5×10^{-7}m). More than 200 wavelengths of red light fit in the thickness of a human hair! Because of the high frequency and small wavelength, we do not normally see the true wavelike nature of light (table 14.1). Instead, we see reflection, refraction, and color.

Table 14.1: ***Wavelength and frequency of light***

Energy	Color	Wavelength (nanometers)	Frequency (THz)
Low	Red	650	462
	Orange	600	500
	Yellow	580	517
	Green	530	566
	Blue	470	638
High	Violet	400	750

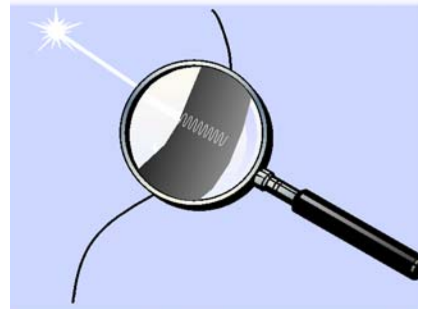


Figure 14.10: *The wavelength of visible light is much smaller than the thickness of a hair! The drawing is greatly exaggerated. In reality more than 200 wavelengths of red light would fit in the thickness of a single hair.*

Big and small numbers

The wavelength of light is so small that we use nanometers to describe it. One nanometer is one-billionth of a meter.

The frequency is so large we need units of terahertz (THz). One terahertz is equal to one trillion cycles per second.

How does the human eye see color?

Energy Scientists discovered something rather interesting near the turn of the 20th century. A German physicist, Max Planck, thought that color had something to do with the energy of light. Red light was low energy and violet light was high energy. Albert Einstein was awarded the 1921 Nobel Prize for proving the exact relationship between energy and color. When light hits some metals, electrons are ejected. If more light is used, more electrons come out, but the energy of each electron does not change. Einstein showed that the energy of an ejected electron depends on the frequency of the light, not the amount of light. His observation proved that the energy of light is related to its frequency, or color.

Energy and color All of the colors in the rainbow are really light of different energies. Red light has low energy compared with blue light. The closer to violet, the higher the energy. Low energy means lower frequency so waves of red light oscillate more slowly than waves of blue light. We see the different energies of light as different colors.

How we see color Scientists have discovered cells in the retina of the eye that contain **photoreceptors** (Figure 14.11). That fancy phrase means that they receive light and release a chemical. When light hits a photoreceptor cell, the cell releases a chemical signal that travels down the optic nerve to the brain. In the brain, the signal is translated into a perception of color.

Rods and cones Our eyes have two different types of photoreceptors, called **rod cells** and **cone cells**. Cone cells respond to color, and there are three kinds. One kind only gives off a signal for red light. Another kind only works with green light and the last kind only works for blue light. Each kind of cone cell is tuned to respond only to a certain energy range of light (Figure 14.12). We get millions of different colors from just three primary colors: red, green, and blue.

Rod cells see black and white The rod cells respond only to differences in brightness. Rod cells essentially see in black, white, and shades of gray. The advantage is that rod cells are much more sensitive and work at very low light levels. At night, colors seem washed out because there is not enough light for your cone cells to work. When the overall light level is very dim, you are actually seeing "black and white" images from your rod cells.

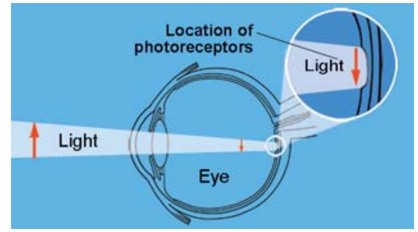


Figure 14.11: *The photoreceptors that send color signals to the brain are at the back of the eye.*

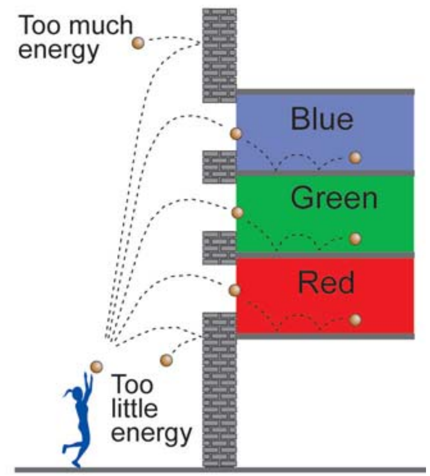


Figure 14.12: *Imagine trying to throw a basketball up into a window. If you get the energy right, it will go in. The three photoreceptors are like windows of different heights. If the light has a certain energy, it lands in the RED window. Higher energy and you get the GREEN window. Even higher energy falls into the BLUE window. If the energy is too low or too high, we don't see the light at all.*

How do we see colors other than red, green, and blue?

How we perceive color

The human eye allows us to see millions of different colors. When the brain receives a signal *only* from the red cone cells, it thinks *red*. If there is a signal from the green cone cells (Figure 14.13) and neither blue nor red, the brain thinks *green*. This seems simple enough.

The additive color process

Now consider what happens if the brain gets a signal from both the red and the green cone cells *at the same time*? These energies add together and the sensation created is different from either red or green. It is what we have learned to call *yellow*. If all three cone cells are sending a signal to the brain at once, we think *white*. This is called an *additive* process because new colors are formed by the addition of more than one color signal from cone cells to the brain.

The additive primary colors

The **additive primary colors** are red, green, and blue (shown in Figure 14.15 on the next page). In reality, our brains are receiving all three color signals just about all of the time. If so, then why aren't we seeing everything in white? Two reasons: There are lots of different places in our field of vision, such as top, bottom, left, and right. The other reason is that the *strength* of the signal matters too. It's too simple to say that red and green make yellow. What if there's a lot of red and only a little green, like in Figure 14.14 (strong red signal, weak green signal)? As you might guess, you will see a color that is quite orange (maybe like the color of orange juice.) There are an unlimited number of adjustments you can make to the strengths of the signals by changing the proportions of red, green, and blue. Thus, you can get millions of different colors.

Color blindness

Some people don't have all three types of cone cells. The condition of color blindness is caused by one or more missing types of cone cells. The most common type of color blindness is the one in which the person lacks the red cone cells. This would imply that everything they see would be in shades of blue, green, cyan, and black, of course. We have to be very careful not to assume too much. Perhaps a person who has this form of color blindness can look at *cyan* (blue-green) and have the same sensation or experience that a person who has normal color vision has when they see white. But then, perhaps not. We really don't know. The *sensation* of color is quite subjective.

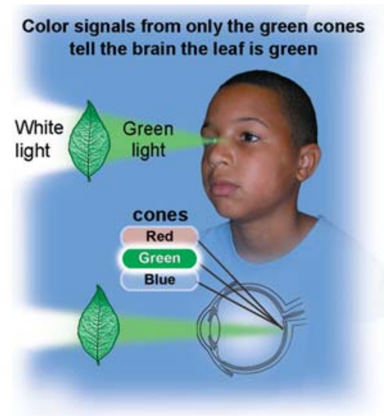


Figure 14.13: *If the brain gets a signal ONLY from the GREEN cone cells, we see "green."*

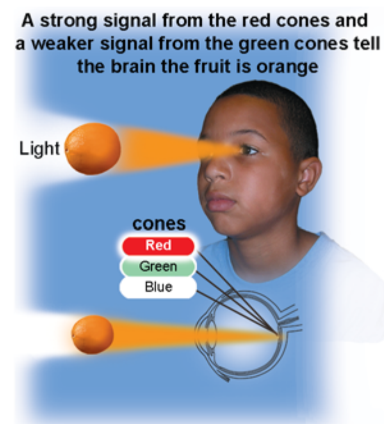


Figure 14.14: *If there is a strong RED signal and a weak GREEN signal, we see orange. All the range of colors can be made from combinations of red, green, and blue at different strengths.*

More on color

Not all animals see the same colors

To the best of our knowledge, primates, (such as chimpanzees and gorillas) are the only animals with three-color vision similar to that of humans. Birds and fish—in particular, tropical varieties—have three or more kinds of photoreceptors. Some birds and insects can also see ultraviolet light which humans cannot detect. Dogs, cats, and some squirrels are thought to have at least two color photoreceptors. Although both squid and octapi can change color better than any other animal, they cannot detect color.

We see mostly reflected light

When we see an object, the light that reaches our eyes can come from two different processes.

1 The light can be emitted directly from the object, like a light bulb or glow stick.

2 The light can come from somewhere else, like the sun, and we only see because of the light that is reflected off of them.

Most of what we see is actually from reflected light. When you look around you, you are seeing light originally from the sun (or electric lights) that has been reflected from people and objects around you. To convince yourself of this, turn off the lights in a room with no windows. You don't see anything. If you remove the source of light, there isn't any light to reflect, so you see nothing.

What gives objects their color?

When we look at a blue piece of cloth, we believe that the quality of blue is in the cloth, which is not actually true. The reason the cloth looks blue is because the pigments in the cloth have taken away (absorbed) all the frequencies of light for colors *other than blue* (Figure 14.16). Since blue vibrations are all that is left, they are the ones that are reflected to our eyes. The blue was never *in the cloth*. The blue was hidden or mixed in with the other colors in white light even before it first hit the piece of cloth. The cloth unmasked the blue by taking away all the other colors and sending only the blue to our eyes.

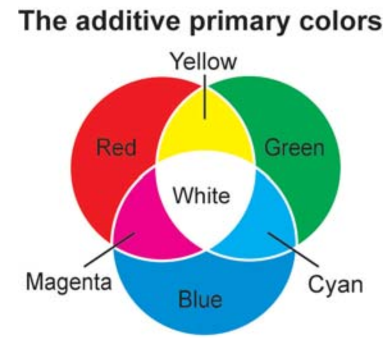


Figure 14.15: *White light is a mixture of all colors. You can make white light by mixing the additive primary colors: red, green, and blue. Thus, when the red, green, and blue cone cells are all equally stimulated, we see white light.*

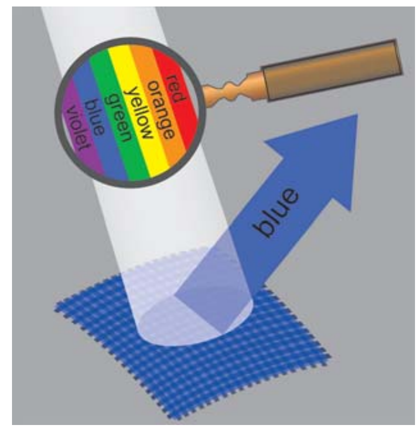


Figure 14.16: *You see blue cloth because the dyes in the fabric absorb all colors EXCEPT blue. The blue is what gets reflected to your eyes so you see the cloth as blue.*

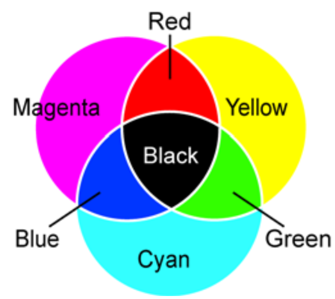
The subtractive color process

Colored fabric gets color from a *subtractive* process. The dyes subtract out colors by *absorption* and *reflect* the colors you actually see. It works because white light is a mixture of red, orange, yellow, green, blue, indigo, and violet. But actually, you need just three primary colors—red, green, and blue—to make white light. How, then, does this work?

The subtractive primary colors

To make all colors by subtraction we also need three primary dyes. We need one that absorbs blue, and reflects red and green. This color is called yellow. We need another dye that absorbs only green, and reflects red and blue. This is a kind of pink-purple color called magenta. The last one absorbs red and reflects green and blue. The third color is called cyan, and is a greenish kind of light blue. Magenta, yellow, and cyan are the three subtractive primary colors. By using different combinations of the three we can make paper look any color because we can vary the amount of red, green, and blue reflected back to your eyes.

The subtractive primary colors



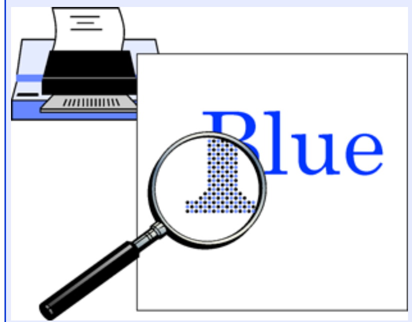
Black

You see black when no light is reflected. If you add magenta, cyan, and yellow you have a mixture that absorbs all light so it looks black. Some electronic printers actually make black by printing cyan, magenta, and yellow together. Because the dyes are not perfect, you rarely get a good black this way. Better printers have a black ink to make black separately.

How to mix green paint

Suppose you want to make green paint. White light falling on your paint has equal parts red, green, and blue. To reflect only the green you need to get rid of the red and blue light. Starting from white paint, you need to add cyan and yellow. The cyan absorbs red, leaving blue and green. The yellow absorbs the blue, leaving only the green, just as you wanted.

Color printers



Color printers work by putting tiny dots on paper. The dots use four colors, cyan, magenta, yellow, and black. Printers refer to these as CMYK where the letter K stands for black.

The dots are so tiny that you see them as a single color. By using only the three subtractive primary colors, printers can reproduce a very wide range of reflected colors. The smaller the dots, the sharper the overall image. Newspapers print about 150 dots per inch (dpi), resulting in photographs being a little blurry. Good color printers print as many as 1,200 dpi.

Why are plants green?

Light is necessary for photosynthesis

Plants are green because of how they use visible light. In a very unique way, plants absorb physical energy in the form of light and convert it to chemical energy in the form of sugar. The process is called photosynthesis. The graph in Figure 14.17 shows the wavelengths of visible light that plants absorb. The *x*-axis on the graph represents the wavelengths of visible light. The *y*-axis on the graph represents the amount of light absorbed by plant pigments for photosynthesis.

Chlorophyll

The green pigment, chlorophyll *a*, is the most important light-absorbing pigment. You can see on the graph that chlorophyll *a* absorbs light at each end of the spectrum. In other words, it reflects most of the green light and uses blue and red light. Plants are green because they reflect green light. In fact, plants will not grow well if they are placed under pure green light!

Why leaves change color

Notice that chlorophyll *b* and carotenoids (orange pigments) absorb light where chlorophyll *a* does not. These extra pigments help plants catch more light. Leaves change color in the fall when chlorophyll *a* breaks down and these pigments become visible. They are the cause of the beautiful bright reds and oranges that you see when leaves change color in the fall.

Plants reflect some light to keep cool

Why don't plant pigments absorb all wavelengths of visible light? The reason for this has to do with why you might want to wear light colored clothes when it is really hot outside. Like you, plants must reflect some light to avoid getting too hot!

Visible light has just the right energy for life

Visible light is just a small part of the electromagnetic spectrum. Why do living things see and use this part the most? In other words, why can't plants grow in dark places? Why can't we see ultraviolet or infrared light?

Visible light, it turns out, is just right for living things to use. The other parts of the electromagnetic radiation spectrum are not as useful. Ultraviolet light, for example, has too much energy. It can break bonds in important molecules. Infrared radiation is mostly absorbed by water vapor and carbon dioxide in the atmosphere. Therefore, this longer wavelength light is not as available as visible light for living things to use.

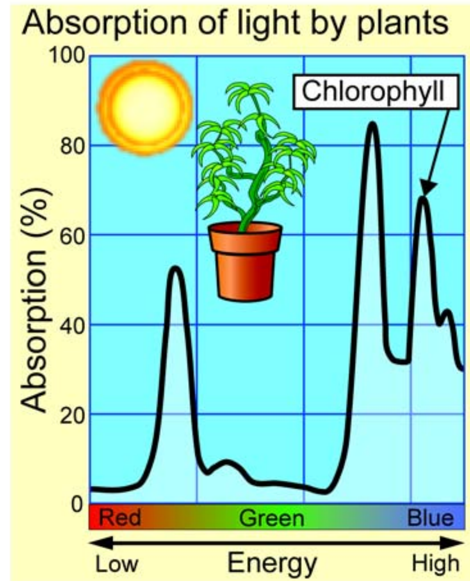


Figure 14.17: *The lines in the graph show which colors of light are absorbed by plant pigments for photosynthesis. Chlorophyll a is used in photosynthesis. Chlorophyll b and carotenoids help absorb light for photosynthesis. The graph shows that blue light and red light are absorbed (two peaks) and green light is not absorbed (flat center). Plants are green because green light is reflected by the pigments in the leaves and other green parts of the plant.*

How does a color TV work?

TV makes its own light

Televisions give off light. They do not rely on reflected light to make color. You can prove this by watching a TV in a dark room. You can see light from the TV even if there are no other sources of light in the room. Computer monitors and movie projectors are similar. All these devices make their own light.

The RGB color process

To make color with a TV you can use red, green, and blue (RGB) directly. You do not need to use the subtractive colors. Take a magnifying glass and look closely at a television screen while it is running. You will notice something interesting. The screen is made of tiny red dots, green dots, and blue dots! Each of the dots gives off light. The colored dots are separated by very thin black lines. The black lines help give intensity to the resultant colors and help make the darker colors darker. By turning on the different dots at different intensities TV sets can mix the three colors to get millions of different colors. From far away, you can't see the small dots. What you see is a nice smooth color picture (Figure 14.18).

If you see a big screen at a sporting event it looks just like a color television. Looking closer, you see that image is actually made up of small colored light bulbs. The bulbs are red, green, and blue, just like the dots in the television screen.

Two complementary color processes

All devices that make their own light use the RGB (red, green, blue) color model. They create millions of colors by varying the strengths of each of the three primaries. Anything that relies on reflected light to make color uses the CMYK (cyan, magenta, yellow, black) color process. This includes printing inks, fabric dyes, and even the color of your skin.

How computers make color

Computers use numbers to represent the values for red, green, and blue. Every pixel, or dot, on your computer screen has three numbers that tell it what color to make. Each color can go from 0 to 256, with 256 being the brightest. The value RGB = (0,0,0) is pure black, no color. Setting RGB = (255, 255, 255) gives pure white, or equal red, green, blue. Using this model, computers can represent 256 x 256 x 256 or 16,777,216 different colors. More than 16 million colors can be made from just three numbers!

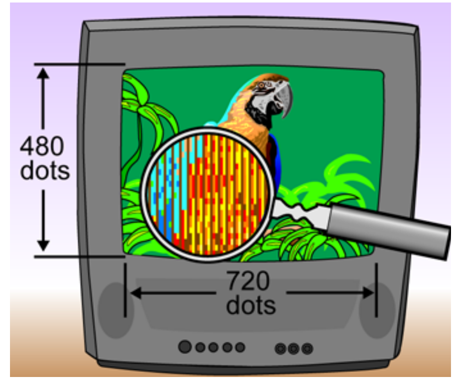


Figure 14.18: *Television makes color using tiny glowing dots of red, green, and blue. All devices that make their own light (like TV) use the RGB color model to make color.*

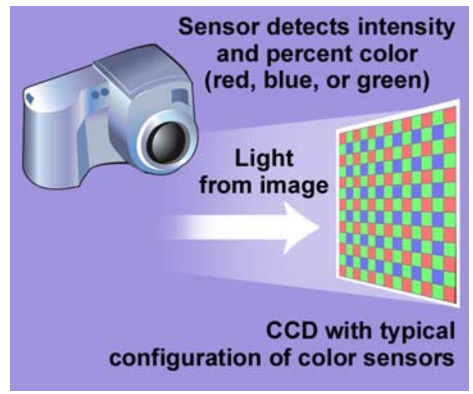


Figure 14.19: *Digital cameras have a device called a CCD that is an array of tiny light sensors, just like the human eye. A 1-megapixel camera has a million of each red, green, and blue sensors on a chip smaller than a dime.*

Chapter 14 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. light	a. A property of electrons inside atoms
2. electromagnetic spectrum	b. A wave we don't necessarily see with our eyes
3. energy level	c. Heating something up so hot it gives off light
4. incandescence	d. Stimulating atoms to emit light using light of another energy
5. fluorescence	e. The range of waves that includes radio waves, light, and X rays
	f. The interaction of two or more waves with each other

Set Two

1. radio waves	a. Electromagnetic waves that we feel as heat
2. infrared	b. Electromagnetic waves that have very high energy and come from nuclear reactions
3. ultraviolet	c. Electromagnetic waves that have very low energy and wavelengths of many meters
4. X rays	d. Electromagnetic waves that can pass through skin and make images of the body
5. gamma rays	e. Electromagnetic waves with more energy than visible light and that cause sunburns
	f. Electromagnetic waves that we see with our eyes

Set Three

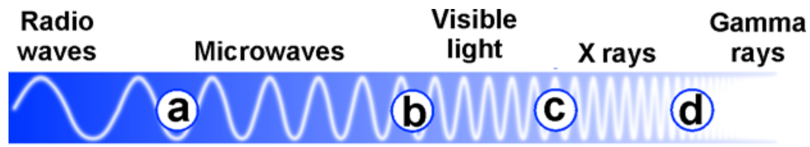
1. polarization	a. How we perceive different frequencies of light within the visible range
2. color	b. Making all colors as mixtures of red, green, and blue light
3. photoreceptors	c. Red, green, and blue
4. primary colors	d. A way of aligning the direction of light wave vibration by blocking some of the waves
5. RGB model	e. Nerves in the eye that are sensitive to light
	f. The wavelength of X rays

Set Four

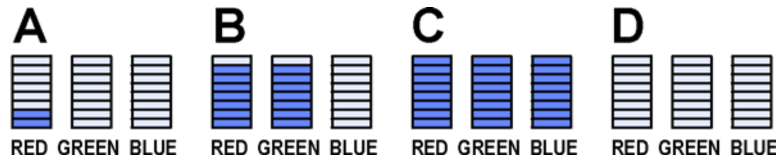
1. magenta	a. A dye that absorbs red light
2. yellow	b. A dye that absorbs green light
3. cyan	c. Making all colors with cyan, magenta, yellow, and black pigments
4. photosynthesis	d. The process plants use to get energy from light
5. CMYK model	e. A dye that absorbs blue light
	f. A wavelength absorbed by the ozone layer

Concept review

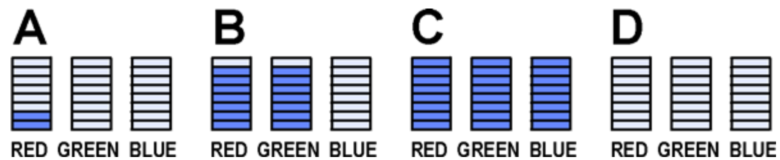
1. What does photoluminescence mean?
2. What does incandescence mean?
3. What must happen to an electron in order for an atom to emit light?
    a. Move from a lower energy level to a higher energy level.
    b. Stay in a high energy level.
    c. Move from a high energy level to a low energy level.
    d. Stay in a low energy level.
4. Identify which of the following produces electromagnetic waves in the gamma ray part of the spectrum.
    a. A nuclear reaction
    b. A cell phone
    c. A radio transmitter
    d. A flashlight
5. Identify which of the following devices uses microwaves. You may choose more than one.
    a. an oven for heating food
    b. a cell phone
    c. a satellite transmitter
    d. a small flashlight
6. A polarizer is:
    a. A filter that separates light.
    b. An ink that absorbs green light.
    c. A sensor in the eye that detects blue light.
    d. A device for creating diffraction.
7. Infrared radiation belongs where in the electromagnetic spectrum diagram below? (Choose a, b, c, or d)



8. Which of the following would produce the sensation of white light?



9. Which of the following would produce the sensation of yellow light?



10. What are the three primary colors of light?
    a. red, green, and blue
    b. red, yellow, and blue
    c. magenta, cyan, and yellow
    d. orange, green, and violet
11. What are the three primary colors of pigments?
    a. red, green, and blue
    b. red, yellow, and blue
    c. magenta, cyan, and yellow
    d. orange, green, and violet

Problems

1. Arrange the following in order of speed from fastest to slowest:

   a. Sound waves   b. Light waves   c. Water waves

2. What color is obtained when the three primary colors of light are combined in equal strengths?

3. Which photochemical receptors in our eyes are stimulated when we see the color yellow?

4. If you wanted to make green paint, you would use which combination of dyes?

   a. cyan and magenta   c. magenta and yellow

   b. cyan and yellow   d. magenta only

5. What does a piece of blue cloth do to the colors in white light that falls upon it?

   a. It absorbs blue light and reflects all the rest of the colors to our eyes.

   b. It absorbs all the colors except blue and reflects only blue light to our eyes.

   c. It absorbs all of the colors in the white light.

   d. It absorbs none of the colors in the white light.

6. What happens to the light energy that is shined upon a black object?

7. Name the four colors used by color computer printers.

8. What are the primary colors used to construct the image on a color TV monitor?

9. When a store clerk adds more colorants (pigments) to a can of white paint, what will be the result?

   a. More colors are taken away from the light we use to view the paint.

   b. More colors are added to the light we use to view the paint.

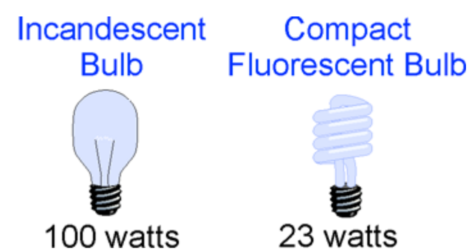
   c. Fewer colors are taken away from the light we use to view the paint.

   d. No change occurs in the light we use to view the paint.

10. Describe wavelength and frequency of green light and why using only green light would not allow plants to grow.

11. Arrange the following in order from LOWEST energy to HIGHEST energy: Gamma rays, visible light, X rays, microwaves, radio waves, infrared light, ultraviolet light.

12. Calculate how much money you would save in one year by changing from an incandescent bulb to a fluorescent bulb. Assume electricity costs 10 cents per kilowatt hour and that the bulb is on all the time for the whole year. The two bulbs in the picture produce the same amount of light.



Applying your knowledge

1. Why does fire give off light?
2. Why would putting out a fire with water stop it from giving off light?
3. How many different kinds of photochemical receptors are found in the eyes of most people? What colors of light do these photochemical receptors respond to? To what location does a photochemical receptor send its signal?
4. What is different about the photochemical receptors in the eyes of people with color blindness?
5. What may be different about the photochemical receptors in the eyes of other animals?
6. Research color blindness using your library or the Internet. How many different kinds of color blindness are there? Find out what kinds of receptors are missing in the eyes of people with the various kinds of color blindness. Find out which tasks are more difficult for them and which ones are actually easier.
7. Design an improvement to a common product to make it easier for color blind people to use. Suggest ways that people with normal color vision can avoid making life unnecessarily difficult for people with color blindness.
8. How do we know anything about the color vision of animals? Look up the studies done on honeybees and report on the experimental methods. Design your own study to find out if dogs or cats can tell one color from another.
9. What makes the colors on a computer screen different from the colors in paint? How can you get red, green, and blue from both?
10. Computer graphic artists use two different color models to represent color. The RGB model has three numbers that represent the strengths of red, green, and blue. The CMYK model uses four numbers that represent the strength of cyan, magenta, yellow, and black.
    a. What are the maximum and minimum values for the numbers that determine color on a computer?
    b. Find a table of colors and identify the numbers you need to make orange in both RGB and CMYK systems.
    RBG: R = _____ B = _____ G = _____
    CMYK: C = _____ M = _____ Y = _____ K = _____
    c. If a picture contains 1,000 pixels, or dots, how much computer memory is needed to store the picture in RGB and CMYK models? Assume that each number takes 8 bits of memory to store.
11. Why is ice sometimes clear and sometimes cloudy white? Experiment with freezing ice in your home freezer. Find out how you can control the transparency of ice.

UNIT 5

Light and Optics

Chapter 15

Optics

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

converging	focal length	index of refraction	real image
converging lens	focal point	lens	reflected ray
diverging	focus	normal	refraction
diverging lens	image	optics	total internal reflection
critical angle	incident ray	ray diagrams	virtual image

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!

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 would 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.

Figure 15.1: *A magnifying glass makes your thumb look as big as if you were a giant!*

What is optics?

Definition of optics

The study of how light behaves is called optics. Optics deals with the collection and use of light to create images. 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.

Lenses, mirrors, and prisms

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 (converging), you can magnify an image and by bending the light so that it spreads apart (diverging), 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 (refracts) as it travels through different media (Figure 15.2).

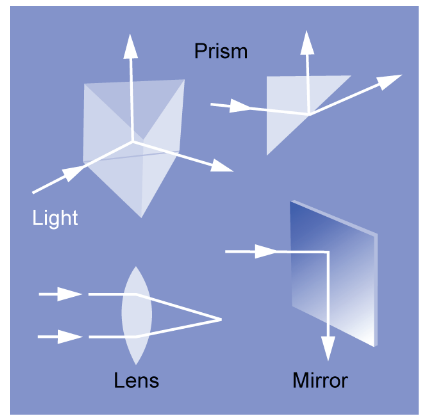
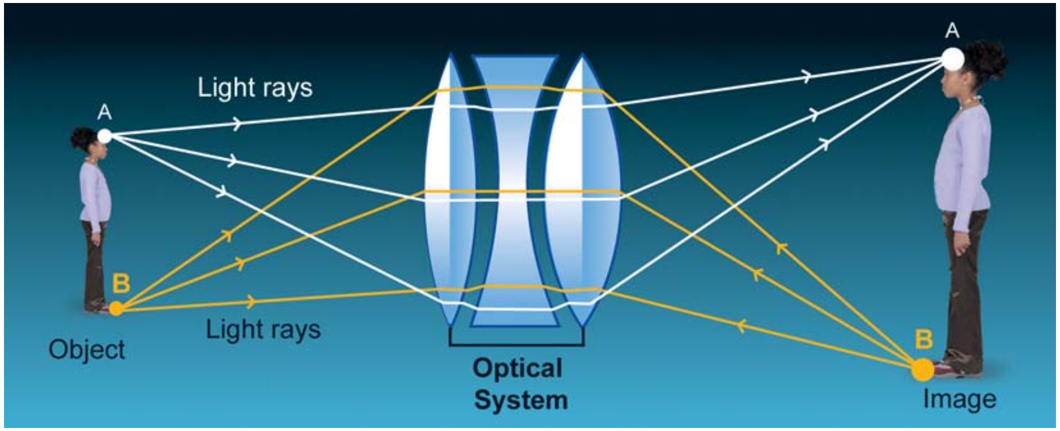


Figure 15.2: *Lenses, mirrors, and prisms are part of the study of optics.*

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.

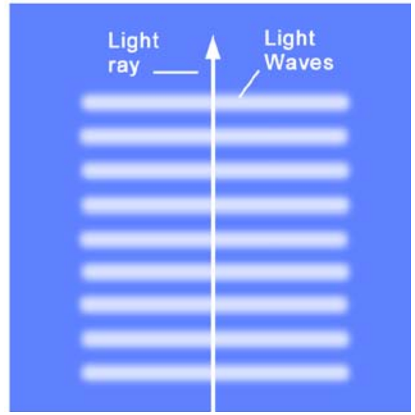


Figure 15.3: *The relationship between rays and wave fronts. The ray is the path of the wave.*

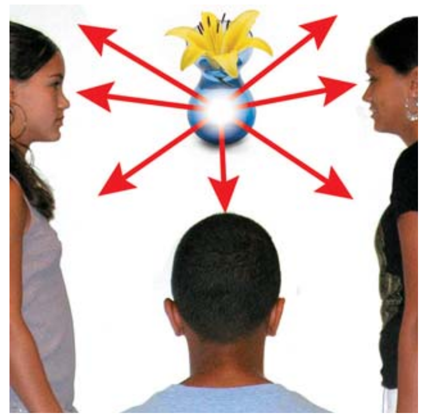


Figure 15.4: *Every point on an object is the source of many light rays that come at all angles to the viewer.*

Images

Rays come together in an image

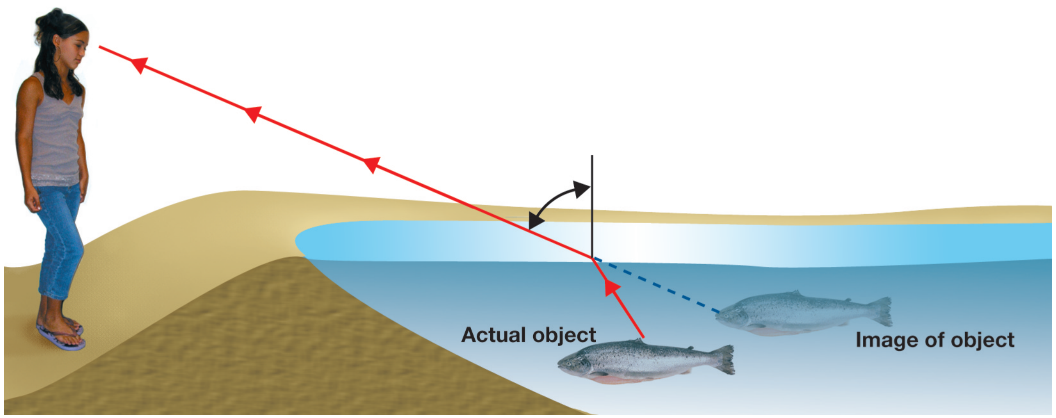
Suppose you could collect all the rays from one point on an object, bringing them all together again. You would have created an image. An image is a place where many rays from the same point on an object meet together again in a point. A camera works by collecting the rays from an object and bending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



Light rays can be bent

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.

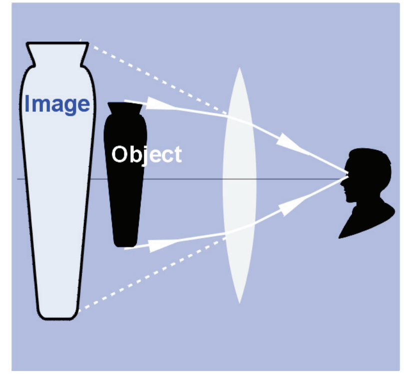


Figure 15.5: *The difference between objects and images. The light rays from the object are bent when they go through the lens. Our brain does not know the rays were bent. We "see" the rays as having traveled in straight lines. The image appears larger because the lens has bent the light rays so they 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.*

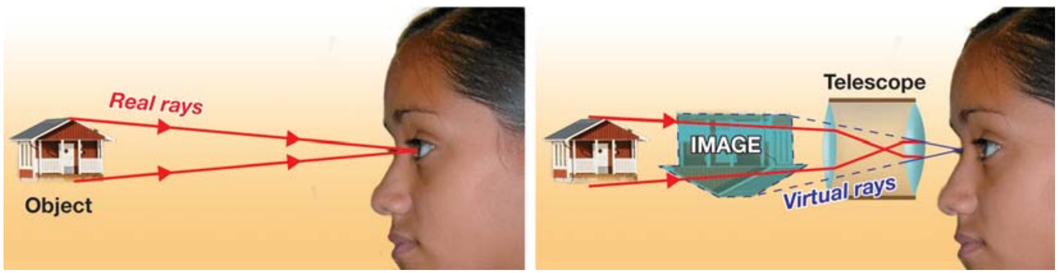
Optical systems

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.

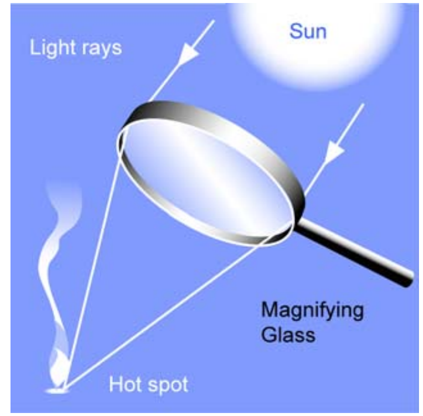


Figure 15.7: *A magnifying glass can bend many rays to come together at a focus. On a sunny day the focus can be quite hot!*

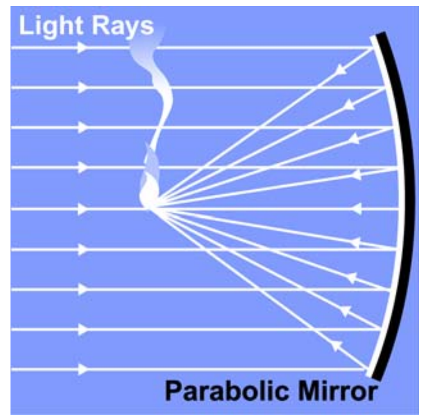


Figure 15.8: *Mirrors also change the direction of light rays. A curved mirror can make light rays from the sun change direction and meet at a focus, just like a lens. This is how solar ovens work.*

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. Those of you who like astronomy might be interested to know that 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 more clearly.

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.

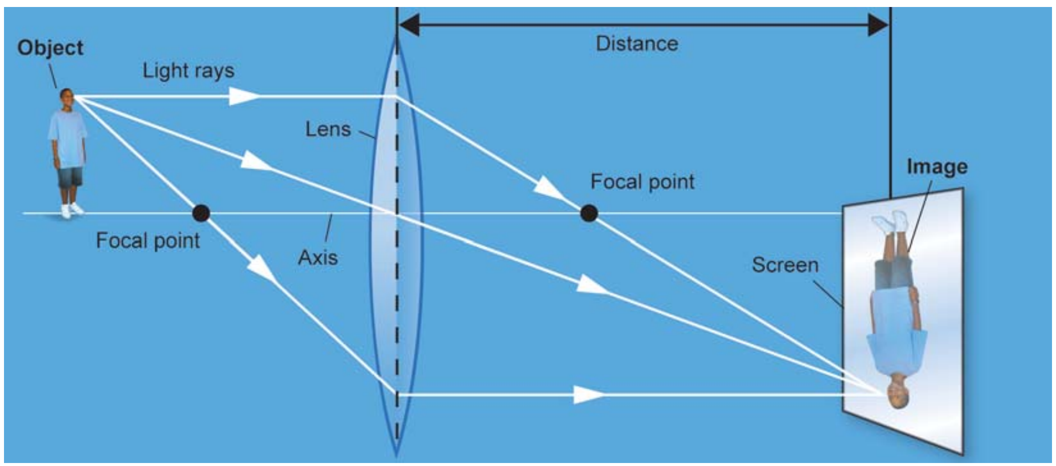
Some typical questions that we use ray diagrams to answer are:

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?



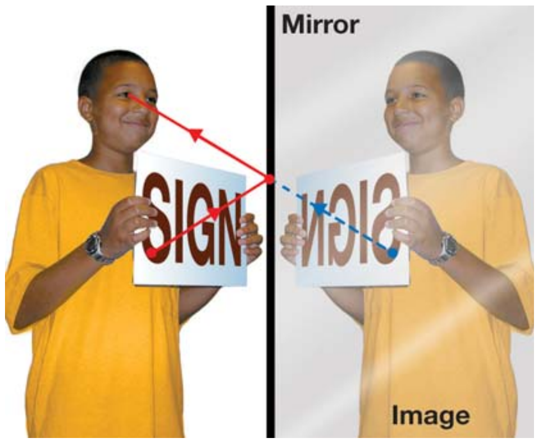
A plastic bag lens

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 sign in front of a mirror, the letters appear backward. Why does this occur?



The light rays that travel from the "S" in the 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 sign.

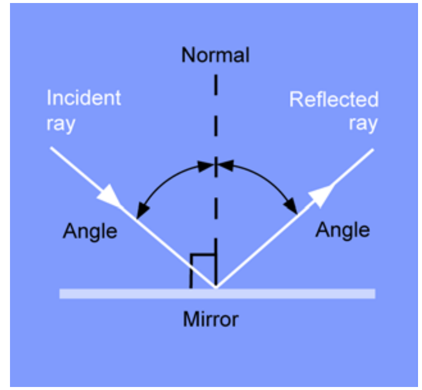


Figure 15.9: *The normal is a line perpendicular to the mirror. The incident ray is the ray that comes in to the mirror. The reflected ray is the ray that bounces off the mirror.*

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 15.10).

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.

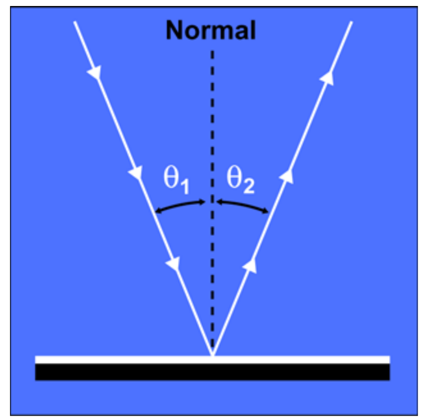
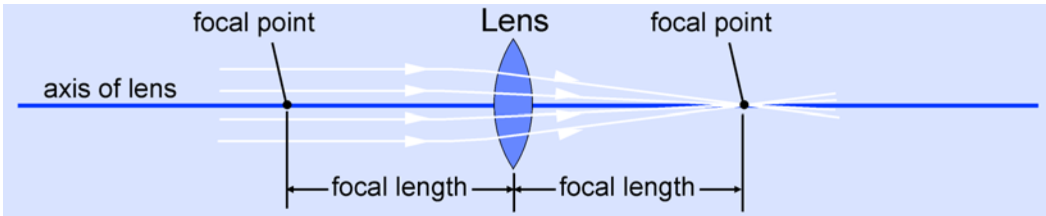


Figure 15.10: *The law of reflection states that the angle of incidence (θ_1) is equal to the angle of reflection (θ_2). How could you throw a ball against a wall to demonstrate that $\theta_1 = \theta_2$?*

Refraction and lenses

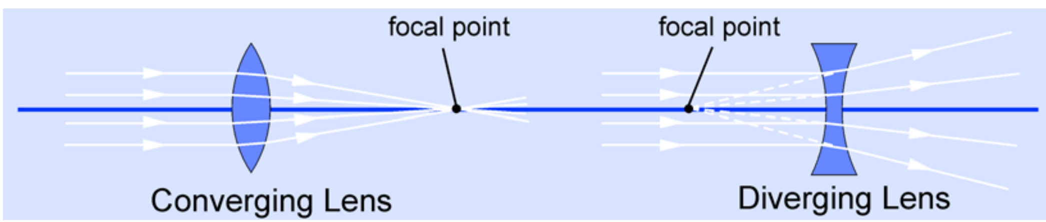
Refraction When light crosses the boundary between two different (transparent) materials the rays may bend. We call the bending refraction. Refraction happens because the wave fronts move more slowly in materials other than air (Figure 15.11). As we already learned, if we change the shape of wave fronts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



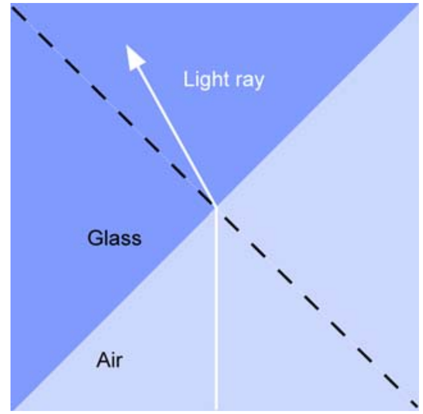


Figure 15.11: *A ray of light is refracted (bent) when it crosses from one material into another.*

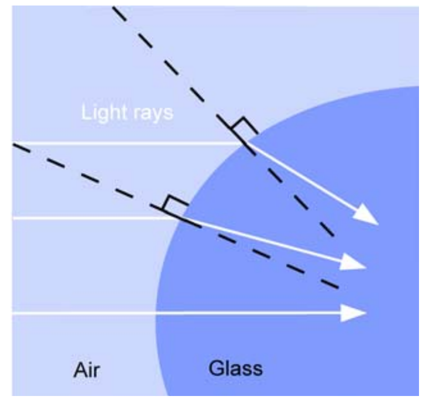


Figure 15.12: *For a curved surface, the amount the ray bends depends on where it hits the surface and the type of material. Rays farther out are bent the most. If the surface is curved just right, all the rays that hit the lens are bent so they meet at the focus.*

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?

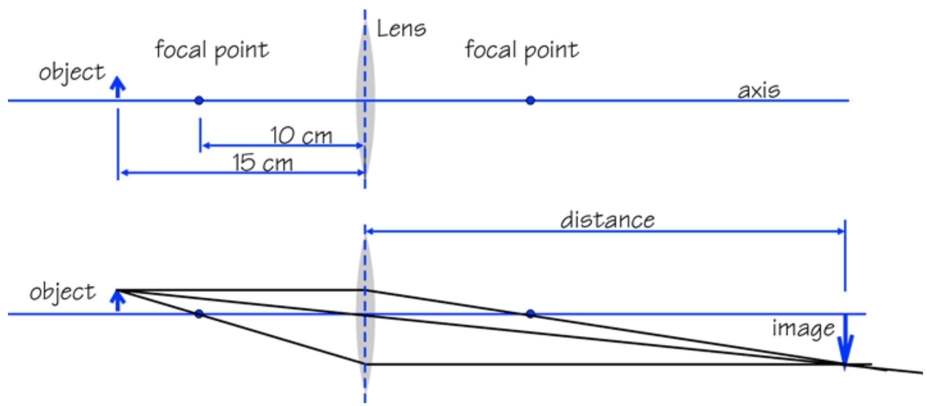
If an object is placed to the left of a converging lens at a distance greater than the focal length, an inverted image is formed on the right-hand side of the lens. We call this image a **real image**. Real images can be projected on a smooth surface, like photographic slides onto a wall. Since real 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.

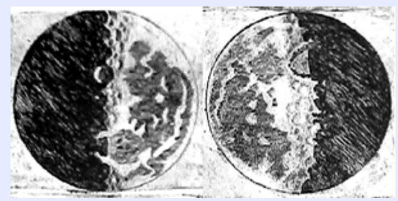


The image is formed 30 cm to the right of the lens. It is magnified and inverted.

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.

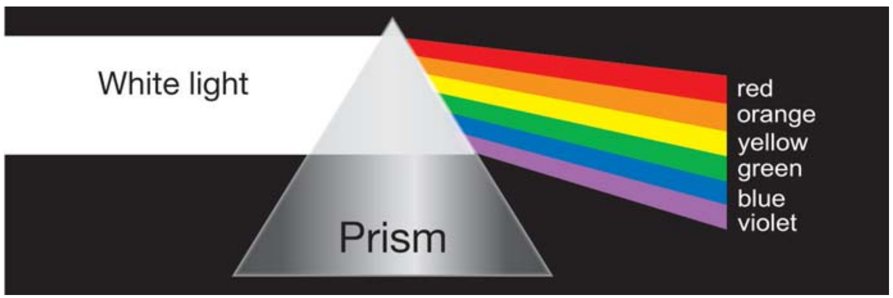
The index of refraction is a ratio of the speed of light in a vacuum (or air) compared with its speed in a material. The number is always greater than one because light travels fastest in a vacuum. We use the letter *n* to represent the index of refraction.

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.

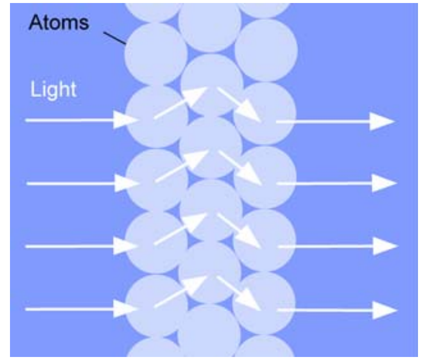


Figure 15.13: *Light travels slower through glass because it is continually absorbed and reemitted by each atom it passes through.*

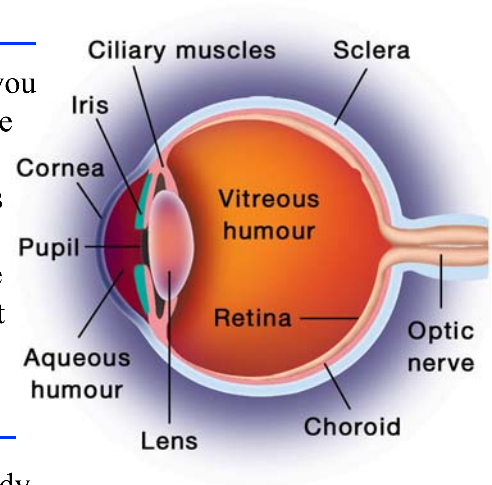
The index of refraction (n)

$$n = \frac{\text{speed of light in air}}{\text{speed in material}}$$

Material	Index (n)
Air	1.00
Ice	1.31
Water	1.33
Ethyl alcohol	1.36
Fused quartz	1.46
Crown glass	1.52
Cubic zirconia	2.20
Diamond	2.41

Figure 15.14: *Index of refraction (n) for some common materials.*

15.2 The Human Eye

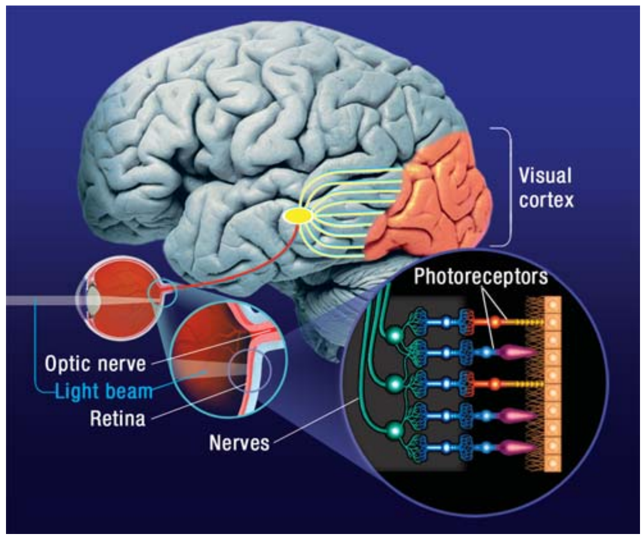


Your eye is an entire optical system that works together with the optic nerve and your brain to help you see images. Some scientists even consider the eye to be part of the brain itself. Everything we have learned about refraction and images applies to the eye. The parts of your eye work together to help you see objects. The parts of the eye are shown in the graphic to the right. The *cornea* and *lens* focus light so that an image forms on a special layer of cells at the back of the eye called the *retina*. The *iris* is a circular opening in front of the lens that can change in size 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 made up of wire-like cells that transmit signals throughout your body. They are linked together in a network throughout your body. 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. 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 special nerve cells called *photoreceptors*. 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.

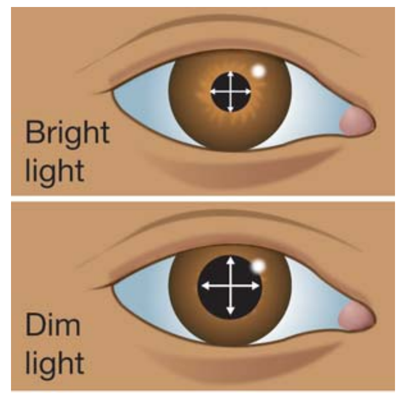
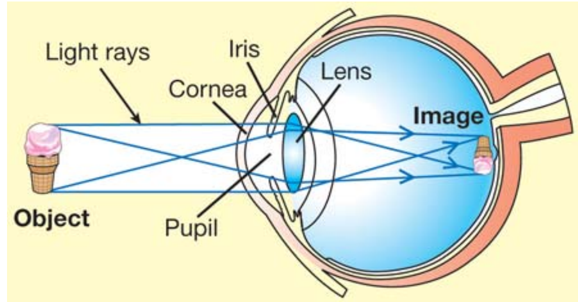


Figure 15.15: *The pupil of the eye is really the opening created by the iris. When there is a lot of light the iris constricts and the pupil gets smaller. When the light level is dim, the iris opens up and the pupil gets larger.*

Forming an image

The image on the retina

The lens focuses light on the retina at the back of the eye. 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.



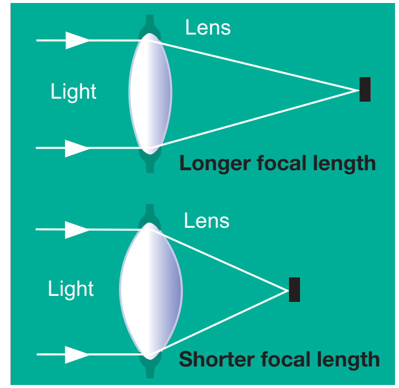


Figure 15.16: *The lens of the eye can change its shape to focus at different distances. The lens is quite tiny, about 4 millimeters thick and 9 millimeters in diameter.*

The lens can change focal length

The lens in your eye also has a unique feature which makes it different from the lenses you use 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.

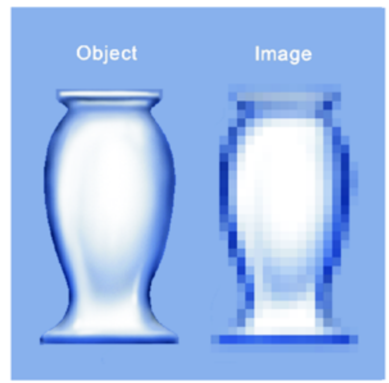


Figure 15.17: *The eye senses images in pixels. Each of the 125 million rod and cone cells sends one dot. The brain assembles the dots into the perception of an image.*

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

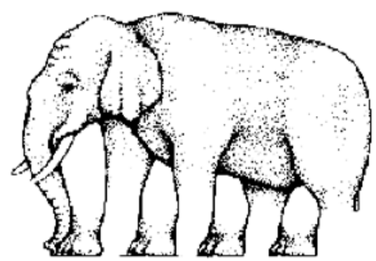
No matter what has actually happened to the light entering our eyes, our brains produce a single image. The image produced is always based on the assumption that light travels in a straight line. It doesn't matter if you use funny mirrors to bend light in all different directions or use a lens to make 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

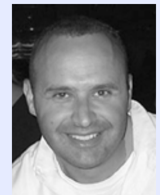
This is why a virtual image in a mirror works. The rays that reach your eye after bouncing off the mirror travel along lines that seem to come from the virtual image. Your brain places the image where the rays appear to come from. If you are standing three feet in front of a mirror, you see a virtual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



Lotfi Merabet



The cornea, iris, and lens of the eye work together to form an image on the retina. But what happens if the rod and cone cells of the retina get damaged? The retina can't transmit information about the image to the brain, and blindness results.

What if an electronic device could replace the damaged cells? This question intrigues members of the Boston Retinal Implant project. Dr. Lotfi Merabet and Dr. Joseph Rizzo have worked with a team of scientists and engineers to create a device to help restore sight.

The implant they have developed is thinner than a human hair! For the implant to work, the blind person wears special glasses containing a small camera. The camera sends signals to the implant using wireless technology. The implant stimulates nerve cells at the back of the eye to send messages to the brain—taking over the damaged rod and cone cells' job.

The research team hopes that with the implant, people with damaged rod and cone cells will one day be able to recognize shapes and colors and get around on their own in unfamiliar places.

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 ever 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 15.18 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.

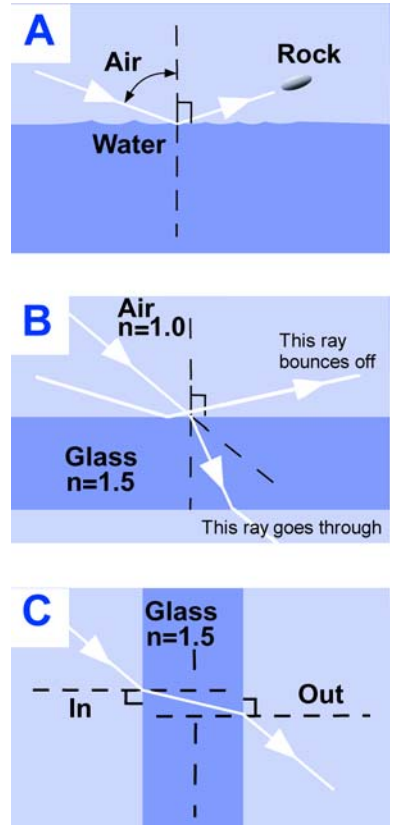
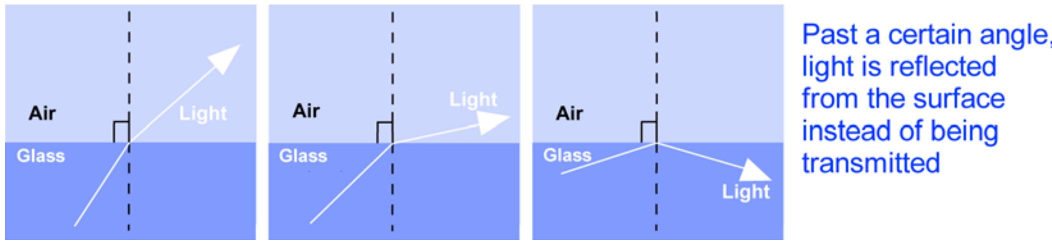


Figure 15.18:
A *You can skip a rock off the surface of water if you throw it at a large angle of incidence.*
B *A light ray bounces off glass if it encounters the surface at a large angle of incidence. A light ray will enter glass if it encounters the surface at a small angle of incidence.*
C *With 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. The angle of incidence 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.



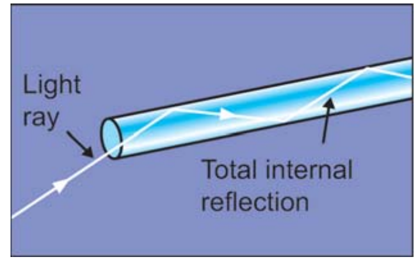


Figure 15.19: *A light pipe traps light by total internal reflection. The light always approaches the wall at greater than the critical angle.*

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 15.20). Any light outside the cone will leak out the edges because it will not be internally reflected.

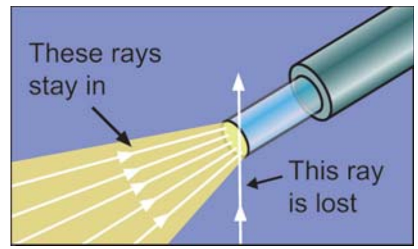
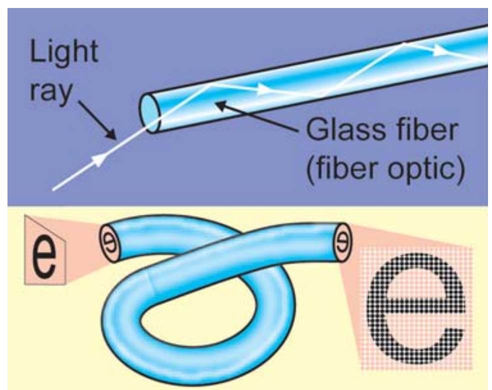


Figure 15.20: *A fiber optic is a thin light pipe that is flexible. Any light that enters the fiber outside a certain angle will be lost since internal reflection of this light will not occur.*

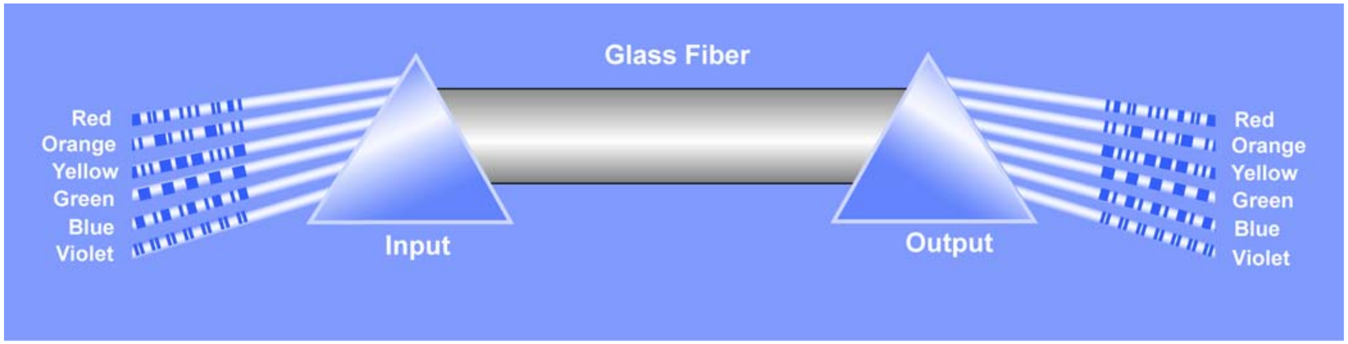
Carrying images on a fiber

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!



Fiber optics technology

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.



Each color carries a signal

Many different colors of light can go through a glass fiber without interfering with each other. In the graphic above, 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.

The Internet

Almost all Internet data communication is carried through fiber optic networks that stretch between cities and between important buildings. Most long-distance telephone communication is also carried through 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.

Fiber optics and the future

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.

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.

Narinder Kapany

Narinder Kapany grew up in northern India, where his high school physics teacher told the class that light travels only in straight lines. Kapany took this statement as a challenge: He wondered if he could figure out a way to bend light.

Kapany tested his idea that light could be transmitted through glass fibers. He spent months experimenting with different types of glass. In 1954 he published his report of successfully transmitting images through fiber optical bundles. Due to this groundbreaking report, Kapany is widely known as the "father of fiber optics."

Kapany received his Ph.D. from the University of London in 1955 and then moved to the United States. He used to be a professor at the University of California-Santa Cruz. His research interests and inventions include fiber-optic communications, lasers, biomedical instruments, solar energy, and pollution monitoring. He has over 100 patents!

Dr. Kapany is also a sculptor and art collector. He is the founding chairman of the Sikh Foundation, which runs programs celebrating Sikh heritage, culture, and art.

Chapter 15 Review

Vocabulary review

Match the following terms with the correct definition. There is one extra definition in the list that will not match any of the terms.

Set One

1. optics
2. lens
3. mirror
4. prism
5. light ray

a. A device that uses reflection to bend light to form an image
b. A device that bends different frequencies of light to separate colors
c. The study of how light behaves
d. An imaginary arrow used to show the path of a single beam of light
e. A device that uses refraction to bend light to form an image

Set Two

1. refraction
2. reflection
3. telescope
4. real image
5. virtual image

a. An image formed by rays of light coming together on a surface like the retina of the eye
b. The bouncing of light rays from a surface
c. Bending of light rays that results as light crosses a boundary between two different substances
d. An image formed when light rays seem to come from a point other than where the object exists
e. A device (used by Galileo) that uses a collection of lenses to magnify an image

Set Three

1. normal
2. incident ray
3. reflected ray
4. angle of incidence
5. angle of reflection

a. The ray of light that bounces off a mirror
b. The angle measured from the normal to the incident ray
c. A line drawn perpendicular to the surface of a mirror or any surface
d. The angle measured between the normal and the reflected ray
e. The ray of light that strikes a mirror
f. The ray of light that passes through a mirror

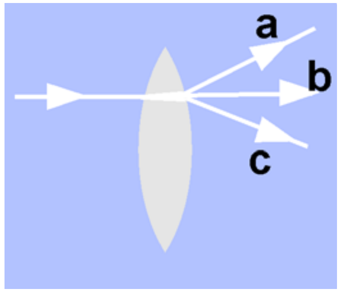
Set Four

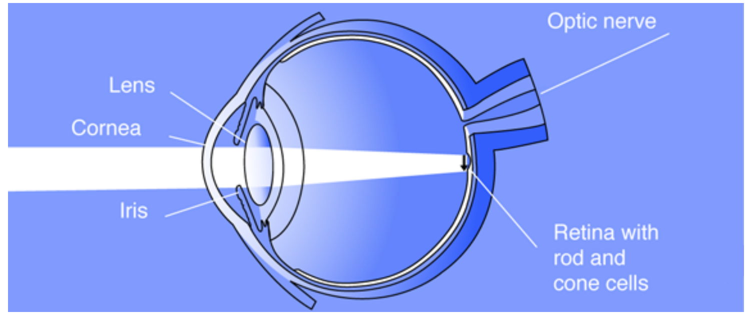
1. retina
2. lens
3. stereoscopic vision
4. total internal reflection
5. fiber optics

a. A device that uses the stimulation of electrons to create an amplified emission of radiation
b. The back of a human eyeball where an image is formed
c. A light pipe that uses total internal reflection to carry light and signals from one point to another
d. This part of the human eye bends the light that comes into it
e. This process happens when light inside a glass of water tries to get out but is reflected back into the material
f. The process by which humans use two eyes to see things with depth

Concept review

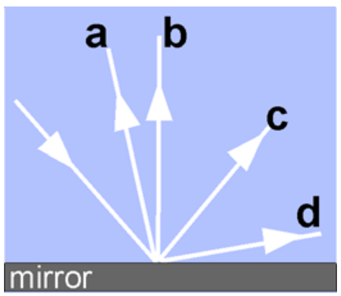
1. A ray of light falls on a lens made of glass. Which of the following (a, b, or c) best describes the path of the light ray leaving the lens?





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 in the eye?

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

8. What is the purpose of the lens in the eye?

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

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

11. Which creature must take total internal reflection and refraction into account when hunting in its natural environment?
    a. An eagle
    b. A tiger
    c. An alligator
    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. Three rays are needed, but they must be flashing.
    c. A minimum of two rays is needed to find an image.

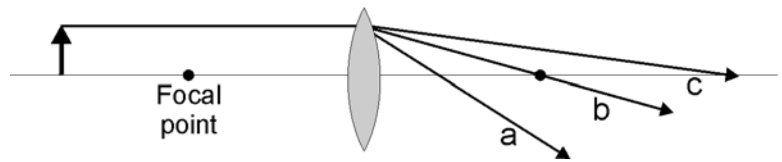
Problems

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.