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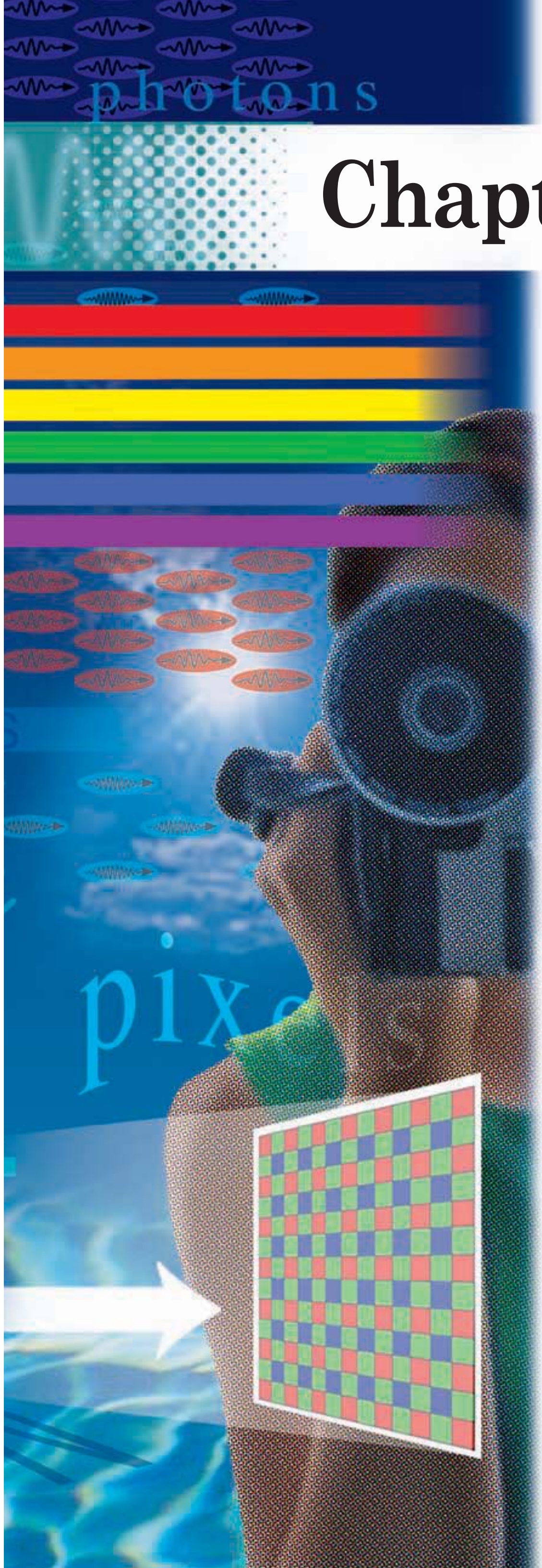

Chapter 22 Light and Color

Television brings you images of objects and places that you may not otherwise have ever seen. What's more, the images move with full sound and color as if you really were there. For example, the color of a blue sky in one part of the world gets sent to you at home so that you can see it. The vibrant colors of a flower get from the flower to the television to your eyes.

What creates color? Does the flower give off red and orange light like a neon sign? How is color seen by our eyes?

To answer these questions, start with a short experiment. Take a colorful object like a shirt or a toy. Look at your object in the light. Then, look at the same object in a totally dark room. What do you see? How do the colors compare in the light versus in the dark? Your answer and your observations will prepare you for this chapter, where you will learn about light and color.

Key Questions

- ✓ How do computers and DVDs make color using just numbers?
- ✓ What is color and how do our eyes see color?
- ✓ Where does light come from?

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22.1 Properties of Light

Every time you see something, light is involved. Whether you are looking at a light bulb or a car or this book, light brings visual information to our eyes. In fact, the very act of "seeing" means receiving light and forming images in your mind from the light received by your eyes. In complete darkness, we cannot see anything! This chapter is about light—where it comes from and its properties including color and its interactions.

Vocabulary

incandescence, fluorescence, intensity

Objectives

- ✓ Describe the properties of light.
- ✓ Review the term light intensity.
- ✓ Learn about the speed of light.
- ✓ Be able to compare light and sound waves.

What is light?

Light is a form of energy

Today we believe that light, like sound and heat, is a form of energy. We have learned how to make light and use light to do all sorts of useful things. Like most of science, our understanding of light starts with what light does and what its properties are (Figure 22.1). We know that:

- light travels extremely fast and over long distances,
- light carries energy and information,
- light travels in straight lines,
- light bounces and bends when it comes in contact with objects,
- light has color, and
- light has different intensities, and can be bright or dim.

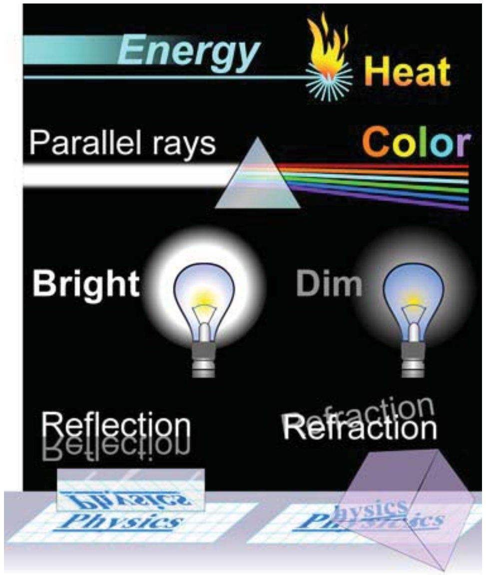

Figure 22.1: *Some words and properties that are associated with light. What words do you use to describe light?*

Seeing and reflected light

What physically happens as you see this page? Light in the room reflects off the page and into your eyes. The reflected light carries information about the page that allows your brain to construct an image of the page. You see because light in the room *reflects* from the page into your eyes. If you were inside a perfectly dark room with no light, you would not be able to see this page at all because the page does not give off its own light. *We see most of the world by reflected light.*

Light from atoms

The electric light For most of human history people relied on the sun, moon, and fire to provide light. Thomas Edison's electric light bulb (1879) changed our dependence on fire and daylight forever. The electric light is one of the most important inventions in the progress of human development.

Light is produced by atoms Whether in an electric bulb or in the sun, light is mostly produced by atoms. Remember from chapter 9, atoms absorb and emit energy by rearranging electrons. Eventually, any excess energy that an atom has is released. This energy release or transfer is analogous to a ball rolling down hill. Unlike a ball, an atom releases the extra energy usually — but not always — as light!

Incandescent light bulbs In order to get light *out* of an atom you must put some energy *into* the atom first. One way to do this is with heat. When atoms get hot enough some of the thermal energy is released as light. The process of making light with heat is called **incandescence**. Incandescent bulbs pass electric current through a thin metal wire called a filament. The filament heats up and gives off light. The atoms of the filament, convert electrical energy to heat and then to light. Unfortunately, incandescent bulbs are not very efficient. Only a fraction of the energy of electricity is converted into light. Most of the energy becomes heat (Figure 22.2). Some incandescent bulbs are actually designed to make heat.

Fluorescent light bulbs Another common kind of electric light is a fluorescent bulb (Figure 22.3). Fluorescent bulbs are used in schools, businesses and homes, because they are much more efficient than incandescent bulbs. Compared with a standard incandescent bulb, you get four times as much light from a fluorescent bulb for the same amount of electrical energy. This is possible because fluorescent bulbs convert electricity directly to light without generating as much heat.

How fluorescent bulbs make light To make light, fluorescent bulbs use high-voltage electricity to energize atoms of gas in the bulb. These atoms release the electrical energy as light, in a process called **fluorescence**. The atoms in a fluorescent bulb give off high-energy ultraviolet light, the same kind that gives you a sunburn. The ultraviolet light is absorbed by other atoms in a white coating on the inside surface of the bulb. This coating re-emits the energy as white light that we *can* see. Even with the two-step process, fluorescent bulbs are still four times more efficient at producing light than incandescent bulbs.

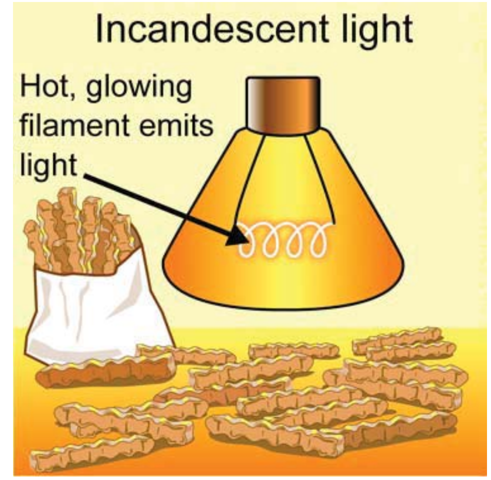

Figure 22.2: *An incandescent light bulb generates light by heating a metal filament. The atoms inside the filament convert electrical energy to heat and then to light.*

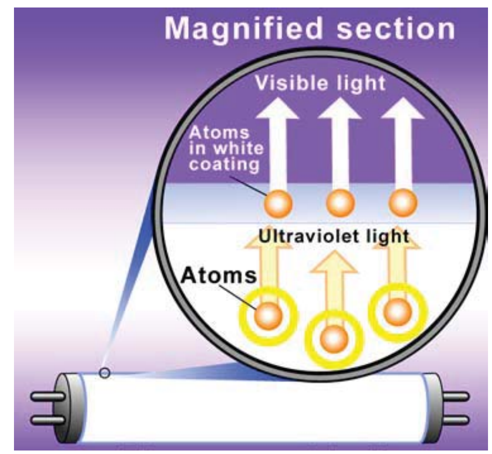

Figure 22.3: *Fluorescent lights generate light by exciting atoms with electricity in a two-step process. First invisible ultraviolet light is produced which causes atoms to emit visible white light.*

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Light carries energy and power

Light radiates in all directions

You can see a bare light bulb from anywhere in a room because the bulb emits light in all directions. When the rays of light are represented by arrows, the light coming from a bulb looks like (Figure 22.4). You can see the paper of this page from different places because the page reflects light in all directions.

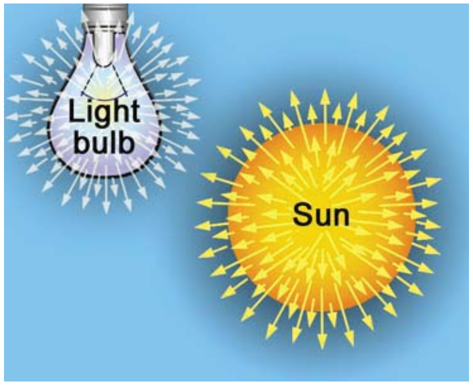


Figure 22.4: *Light emitted from the sun or from a light bulb travels in straight lines from the surface.*

Light intensity

From experience, you know that as you move away from a source of light, the amount of light decreases. We use the word **intensity** to describe the amount of light energy per second falling on a surface. For example, on a summer day, the amount of sunlight falling on a single square meter of surface is 500 watts. The intensity of this light is 500 watts per square meter (500 W/m^2). *Light intensity is the power of light per unit area* (Figure 22.5).

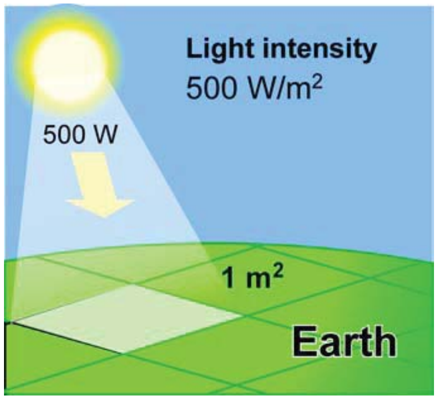
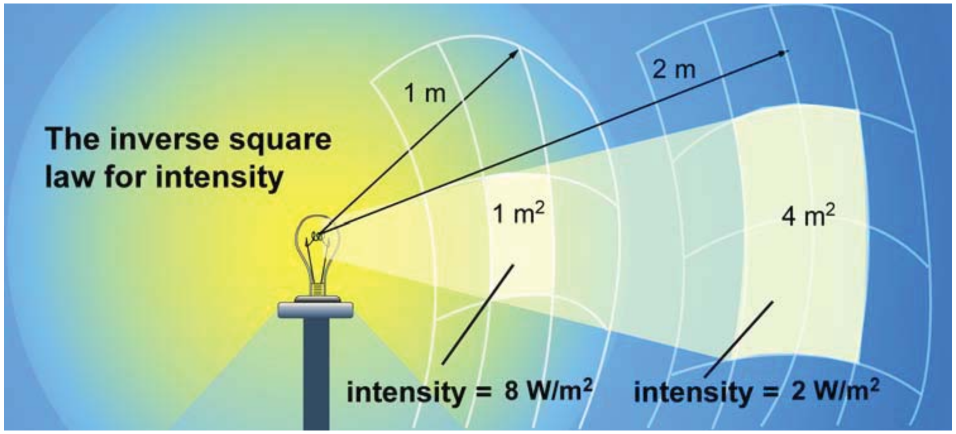


Figure 22.5: *Light intensity is the amount of energy per second falling on a surface. In the summer, the intensity of sunlight reaches 500 watts per square meter on Earth's surface.*

Light intensity follows an inverse square law

For a small source of light, the intensity decreases as the square of the distance from the source increases. In other words, light intensity follows an *inverse square law* — as the distance from a light source increases, the light intensity decreases by the square of the distance from the source.

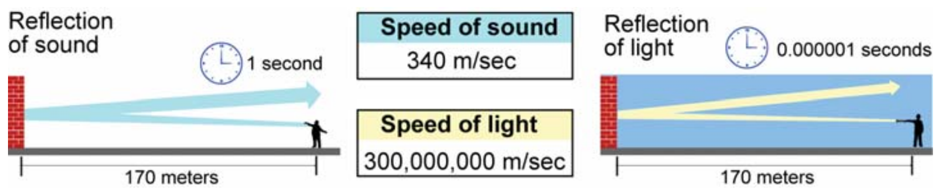
The diagram below shows the inverse square law. At a radius of one meter, 8 watts of light fall on a one meter square area. The light intensity is 8 W/m^2. The intensity at 2 meters is one-fourth the intensity at one meter or 2 W/m^2. Increasing the distance by a factor of 2 *reduces* the intensity by a factor of 2^2 or 4. Tripling the distance (from 1 to 3 meters) would reduce the intensity by a factor of 3^2 or 9. The intensity at 3 meters would be 8/9 or 0.889 W/m^2.



The speed of light

Comparing the speeds of sound and light

Consider what happens when you shine a flashlight on a distant object. You do not see the light leave your flashlight, travel to the object, bounce off, and come back to your eyes. But that is exactly what happens. You do not see it because it happens so fast. For example, suppose you shine a flashlight on a mirror 170 meters away. The light travels to the mirror and back in about one millionth of a second (0.000001 sec). Sound travels much slower than light. If you shout, you will hear an echo one second later from the sound bouncing off a wall 170 meters away and back to your ears. Light travels almost a million times faster than sound.



The speed of light, $c = 3 \times 10^8$ m/sec

The speed at which light travels through air is approximately 300 million meters per second. Light is so fast it can travel around the entire Earth 7 1/2 times in 1 second. The *speed of light* is so important in physics that it is given its own symbol, a lower case *c*. When you see this symbol in a formula, remember that $c = 3 \times 10^8$ m/sec.

Why you hear thunder after you see lightning

The speed of light is so fast that when lightning strikes a few miles away, we hear the thunder several seconds after we see the lightning. At the point of the lightning strike, the thunder and lightning are simultaneous. But just a mile away from the lightning strike, the sound of the thunder is already about 5 seconds behind the flash of the lightning. You can use this information to calculate how far you are away from a thunderstorm (see the sidebar at right).

Accurate measurement of c

Using very fast electronics, the speed of light can be measured accurately. One technique is to record the time a pulse of light leaves a laser and the time the pulse returns to its starting position after making a round trip. The best accepted experimental measurement for the speed of light in a vacuum is 299,792,458 m/sec. For most purposes, we do not need to be this accurate and may use a value for *c* of 3×10^8 m/sec.

Light is faster than sound

The speed of light very fast — about 300 million meters per second or 186,000 miles per second. In fact, based on Einstein's theory of special relativity, we believe nothing in the universe can travel faster than the speed of light.

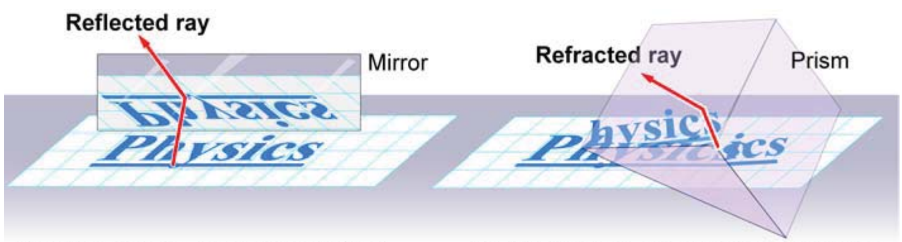
In one second, light travels 186,000 miles and sound travels only one-fifth of a mile. At 15°C, the speed of sound is about 340 m/sec or 0.21 miles per second. You can use the speed of sound to determine how far away a lightning strike has occurred.

When you see lightning, begin counting seconds until you hear thunder. Multiply the number of seconds you count by 0.21. The result is an estimate of the distance the lightning strike is from you in miles.

Light can bounce (reflection) and bend (refraction)

Light rays can bounce and bend

When light moves through a material it travels in straight lines. Diagrams of light utilize one or more imaginary lines we call *light rays* to show how light travels. When light rays move from one material to another, the rays may bounce or bend. *Reflection* occurs when light bounces off of a surface. *Refraction* occurs when light bends crossing a surface or moving through a material. Reflection and refraction cause many interesting changes in the images we see.



Light rays are reflected in a mirror, causing an inverted image. Light rays are refracted (or bent) by a prism, causing the image to be distorted.

Reflection creates images in mirrors

When you look in a mirror, objects that are in front of the mirror appear as if they are behind the mirror. Light from the object strikes the mirror and reflects to your eyes. The image reaching your eyes appears to your brain as if the object really *was* behind the mirror. This illusion happens because your brain "sees" the image where it would be if the light reaching your eyes had traveled in a straight line.

Refraction changes how objects look

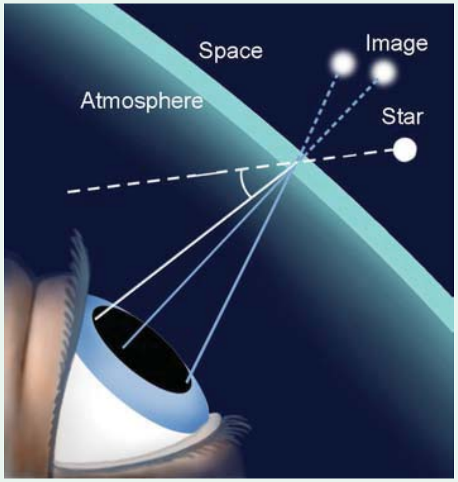
When light rays travel from air to water they refract. This is why a straw in a glass of water looks broken or bent at the water's surface. Look at some objects through a glass of water; move the glass closer and farther away from the objects. What strange illusions do you see?

22.1 Section Review

1. Why can we see an object in a room from any position?
2. If a room were completely dark, could you see your hand? Explain using the idea of reflection.
3. List three observations that show light carries energy.
4. Can light be reflected and refracted at the same time? If so, give an example.

Twinkling of stars

Another example of refraction of light is the twinkling of a star in the night sky. To reach your eyes, starlight must travel from space through Earth's atmosphere which varies in temperature and density. Cold pockets of air are more dense than warm pockets. Starlight is refracted as it travels through the various air pockets. Since the atmosphere is constantly changing, the amount of refraction also changes. The image of a star appears to "twinkle" or move because the light coming to your eye follows a zig-zag path to your eyes due to refraction.



22.2 Vision and Color

Light reaches your eyes in one of two ways. Light can come directly from an object that produces its own light, such as a light bulb or glow stick. In this case the color of the light depends on the colors produced by the object. Light can also be reflected from objects that do not produce their own light, such as clothes or plants. With reflected light the color is produced by selectively subtracting out some colors. In this section, you will learn about color and how our eyes see color.

Vocabulary

white light, color, photoreceptors, cones, rods, additive color process, additive primary colors

Objectives

- ✓ Describe white light and color.
- ✓ Learn how our eyes see light and interpret color.
- ✓ Learn about the additive color process.
- ✓ Learn that light is both a wave and made of particles called photons.

Color and energy

White light When all the colors of the rainbow are combined, we do not see any one color. We see light without *any* color. We call this combination of all the colors **white light** (below). White light is a good description of the ordinary light that is all around us most of the time. The light from the sun and the light from most electric lights is white light. The colors that make up white light are called *visible light*. There are other forms of light that we cannot see, such as infrared and ultraviolet light.

What is color? Why does some light appear red and other light appear blue? **Color** is how we perceive the energy of light. This definition of color was proposed by Albert Einstein. All of the colors in the rainbow are light of different energies. Red light has the lowest energy we can see, and violet light the highest energy. As we move through the rainbow from red to yellow to blue to violet, the energy of the light increases.

Color and energy What do we mean when we talk about the energy of light? Think about the very hot, blue flames from a gas stove or a gas grill. The atoms of gas in the flame have high energy so they give off blue light. The flame from a match or from a burning log in the fireplace is reddish-orange. These flames are not nearly as hot as gas flames, so the atoms have a less energy. The low energy light from a match flame appears red or yellow (Figure 22.6).

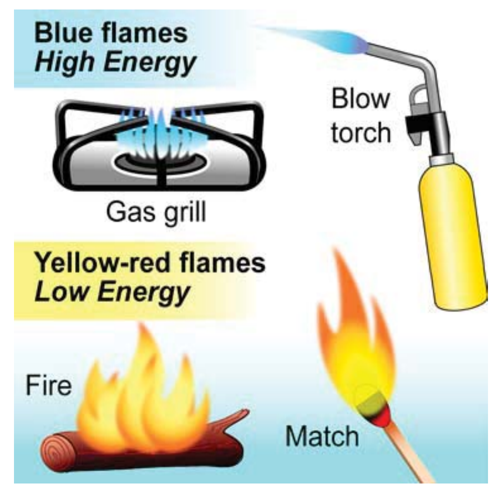


Figure 22.6: *High energy flames such as the ones from a gas grill produce blue light. Fire flames are lower energy and produce reddish-yellow light.*

How the human eye sees light

How we see color

The energy of light explains how we see colors. Light enters your eye through the lens (Figure 22.7) then lands on the retina. On the surface of the retina are light-sensitive cells called **photoreceptors**. When light hits a photoreceptor cell, the cell releases a chemical signal that travels along the optic nerve to the brain. In the brain, the signal is translated into a perception of color. Which signal gets sent depends on how much energy the light has. Some photoreceptors respond only to low energy, others to medium energy and a third type to higher energy.

Cone cells respond to color

Our eyes have two types of photoreceptors, called *cones* and *rods*. **Cones** (or *cone cells*) respond to color (Figure 22.8) and there are three types. One type responds best to red light. Another type responds best to green light and the last type responds best to blue light. We see a wide range of light colors depending on how each kind of cone cell is stimulated. For example, we see white light when all three types of cones (red, green, blue) are equally stimulated.

Rod cells respond to light intensity

The second kind of photoreceptor, **rods** (or *rod cells*), respond only to differences in intensity, and not to color (Figure 22.8). Rod cells detect black, white, and shades of gray. However, rod cells are more sensitive than cone cells especially at low light levels. At night, colors seem washed out because there is not enough light for cone cells to work. When the light level is very dim, you see "black and white" images transmitted from your rod cells.

Black and white vision is sharper than color vision

An average human eye contains about 130 million rod cells and 7 million cone cells. Each one contributes a "dot" to the total image assembled by your brain. The brain evaluates all 137 million "dots" about 15 times each second, creating the perception of motion. Because there are more rod cells, fine details are sharpest when there is high contrast between light and dark areas. That is why black and white print is easier to read than colored print. The cone cells are concentrated near the center of the retina, making color vision best at the center of the eye's field of view. Each cone cell "colors" the signals from the surrounding rod cells. Because there are much fewer cone cells, and there are three kinds, our color vision is much less sharp than our black-and-white vision at recognizing fine details.

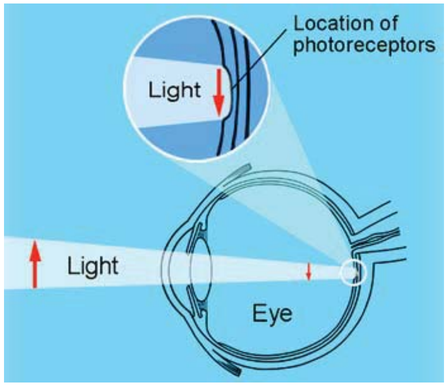


Figure 22.7: *The photoreceptors that send color signals to the brain are in the back of the eye.*

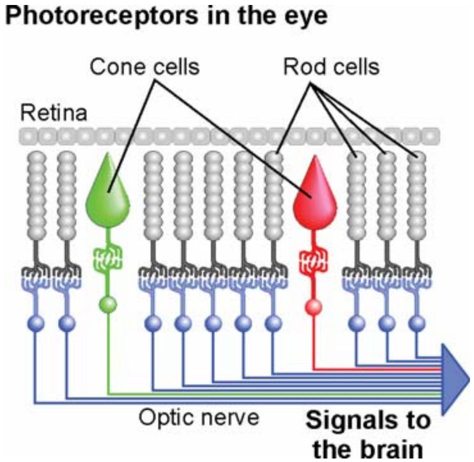


Figure 22.8: *The human eye has two types of photoreceptors—cones and rods. Cones respond to color and rods respond to the intensity of light.*

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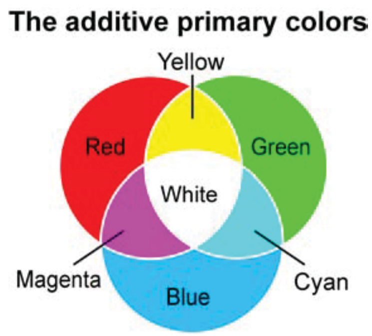
How we see colors

The additive color process

Our eyes work according to an **additive color process** — three photoreceptors (red, green, blue) in the eye operate together so that we see millions of different colors. The color you "see" depends on how much energy is received by each of the three different types of cone cells. The brain thinks "green" when there is a strong signal from the green cone cells but no signal from the blue or red cone cells (Figure 22.9).

How we perceive color

We perceive different colors as a combination of percentages of the three **additive primary colors**: *red*, *green*, and *blue*. For example, we see *yellow* when the brain gets an equally strong signal from both the red and the green cone cells at the same time. Whether the light is actually yellow, or a combination of red and green, the cones respond the same way and we perceive yellow. If the red signal is stronger than the green signal we see orange (Figure 22.10). If all three cones send an equal signal to the brain, we interpret the light we see as white.



Two ways to see a color

The human eye can see any color by adding different percentages of the three additive primary colors. Mixing red and green light is one way the eye sees the color yellow or orange, for example. Keep in mind that you perceive these colors even though the light itself is still red and green. You can also see pure yellow light or orange light that is not a mixture of red and green.

Do animals see 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 octopi and squid can change color better than any other animal, they cannot detect color.

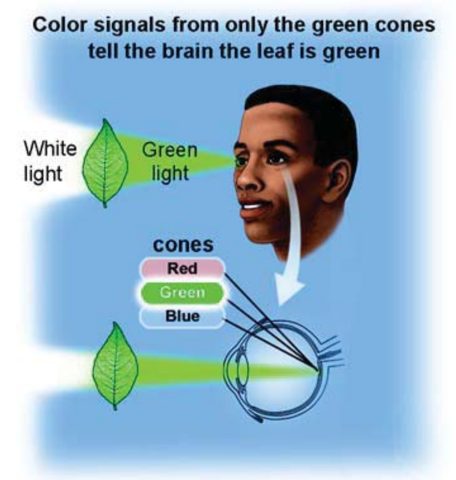


Figure 22.9: *If the brain gets a signal from only the green cone, we see green.*

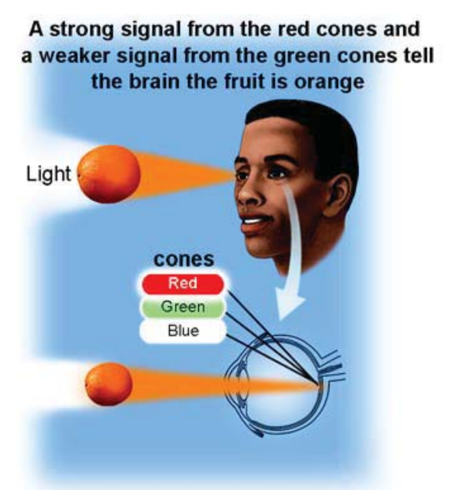


Figure 22.10: *If there is a strong red signal and a weak green signal, we see orange.*

The physics of color and light

Photons Just as matter is made of tiny particles called atoms, light energy comes in tiny bundles called *photons*. In some ways photons act like jellybeans of different colors. Each photon has its own color, no matter how you mix them up. The lowest energy photons we can see are the ones that appear a dull red in color (Figure 22.11). The highest-energy photons we can see are the color of blue tending to deep violet.

Waves Light is also a wave. Like other waves, the frequency of light is proportional to its energy. Red light has lower energy than blue light and also has a lower frequency (Figure 22.12). The frequency of light waves is *very* high compared to sound waves. Red light has frequencies in the range of 460 trillion hertz (460×10^{12}) and blue light in the range of 640 trillion hertz.

Colors You can think of a photon like a very short length of a light wave. Each photon carries the frequency of the light corresponding to its energy. An orange photon has a frequency of 490 trillion Hz, between red and yellow. This energy stimulates the red cone cells strongly and the green cone cells weakly, causing us to see orange. Mixing a little green light with more red light causes the same stimulation of the cone cells. This tricks the brain into "seeing" orange light even though the actual photons are red and green.

22.2 Section Review

1. How do we know that white light is composed of a rainbow of colors?
2. At a fireworks display on the fourth of July you see red, green, and blue fireworks. Which fireworks produce the highest light energy?
3. If humans have only three kinds of color photoreceptors, how can we see so many colors?
4. Why might it be a good idea to put a light in your clothes closet? (Hint: What kind of vision do we have in dim light?)

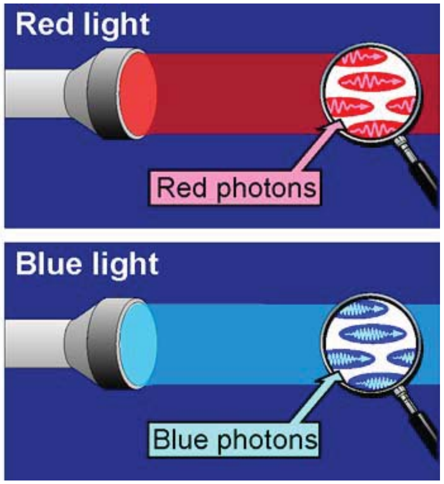


Figure 22.11: *Light is made of tiny bundles of energy called photons.*

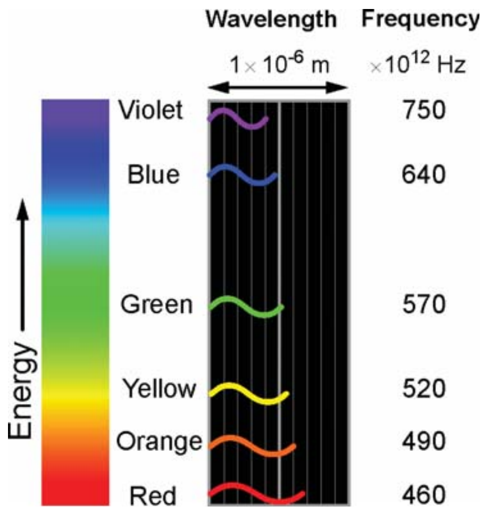


Figure 22.12: *The wavelength and frequency of colors of light.*

22.3 Using Color

You have read about how we see and interpret color. This section is about how a wide range of colors can be created by using a few colors. With the subtractive and additive color processes, color is created and used in publishing books, in television, and in video technology.

Vocabulary

subtractive color process, subtractive primary colors, CMYK color process, RGB color process

Objectives

- ✓ Learn about the subtractive color process.
- ✓ Compare the CMYK and RGB processes.
- ✓ Learn about color blindness.
- ✓ Learn how plants use light and color to grow.

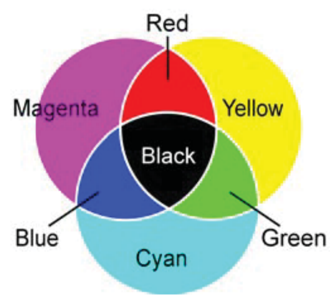
How things appear to be different colors

What gives objects their color?

Why does a blue shirt look blue? We see blue because chemicals (dyes) in the cloth absorbed the other colors in white light and *reflect only the blue to our eyes* (Figure 22.13). The color blue is not *in* the cloth! The blue light you see is the blue light mixed into white light that shines on the cloth. You see blue because the other colors in white light have been absorbed by the cloth.

The subtractive color process

Colored fabrics and paints get color from a **subtractive color process**. Chemicals, known as *pigments*, in the dyes and paints absorb some colors and reflect other colors. Pigments work by taking away colors from white light, which is a mixture of all the colors.



The subtractive primary colors

To make all colors by subtraction we need three primary pigments. We need one that absorbs blue, and reflects red and green. This pigment is called *yellow*. We need another pigment that absorbs green, and reflects red and blue. This is a pink-purple called *magenta*. The third pigment is *cyan*, which absorbs red and reflects green and blue. Cyan is a greenish shade of light blue. Magenta, yellow, and cyan are the three **subtractive primary colors** (Figure 22.13). By using different proportions of the three pigments, a paint can appear almost any color by varying the amount of reflected red, green, and blue light. For example, to make *black*, add all three and all light is absorbed, reflecting none.

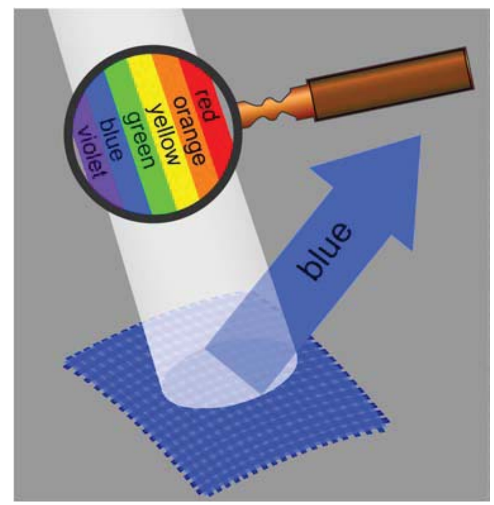
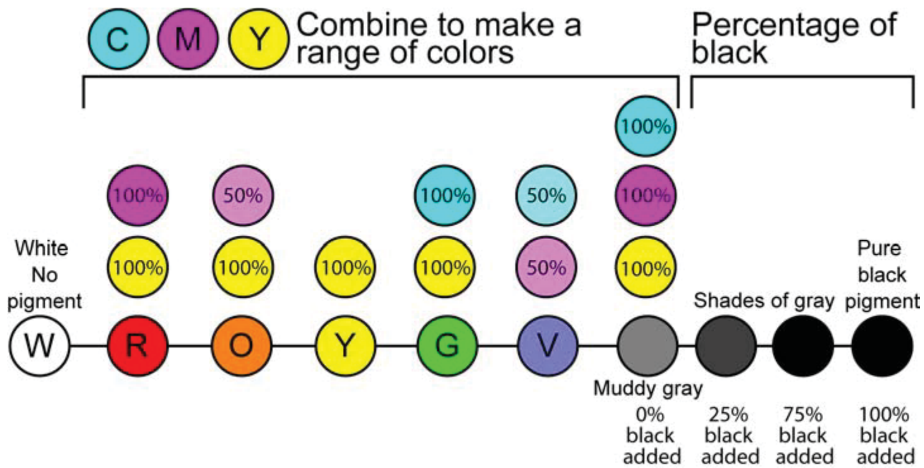


Figure 22.13: *The pigments in a blue cloth absorb all colors except blue. You see blue because blue light is reflected to your eyes.*

The CMYK color process

A subtractive color process

Another name for the *subtractive color process* is the **CMYK color process**. CMYK stands for cyan, magenta, yellow, and black. The letter K stands for black because the letter B is used to represent the color blue.



CMYK are pigments

The CMYK color process is used for making all colors that are seen in reflected light, including printing inks and fabric dyes. The three pigments, cyan, magenta, and yellow are combined in various proportions to make any color. Figure 22.14 shows how CMYK pigments can be combined to make green. Theoretically, mixing cyan, magenta, and yellow should make black, but in reality the result is only a muddy gray. This is why a fourth color, pure black is included in the CMYK process. Figure 22.15 shows how the CMYK process works with an ink-jet printer.

To make	Mix	Because
Red	Magenta and yellow	Magenta absorbs green Yellow absorbs blue Red gets reflected
Blue	Magenta and cyan	Magenta absorbs green Cyan absorbs red Blue gets reflected
Green	Cyan and yellow	Cyan absorbs red Yellow absorbs blue Green gets reflected

White light

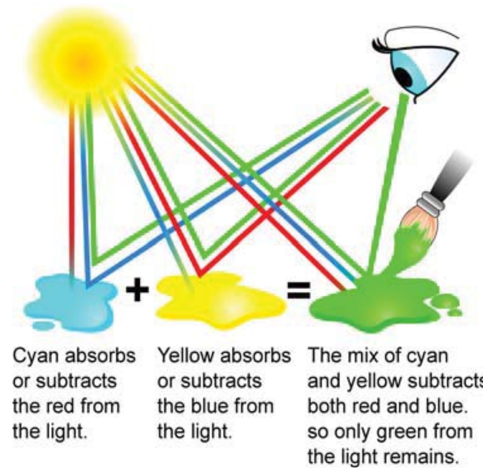


Figure 22.14: *Creating the color green using the cyan and yellow.*

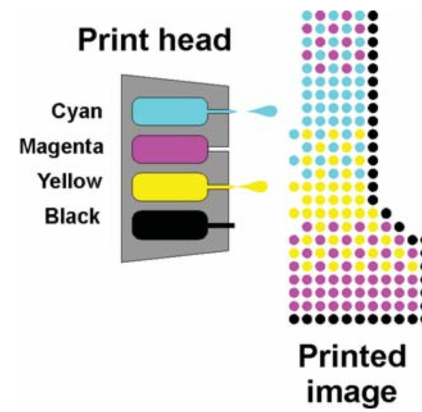


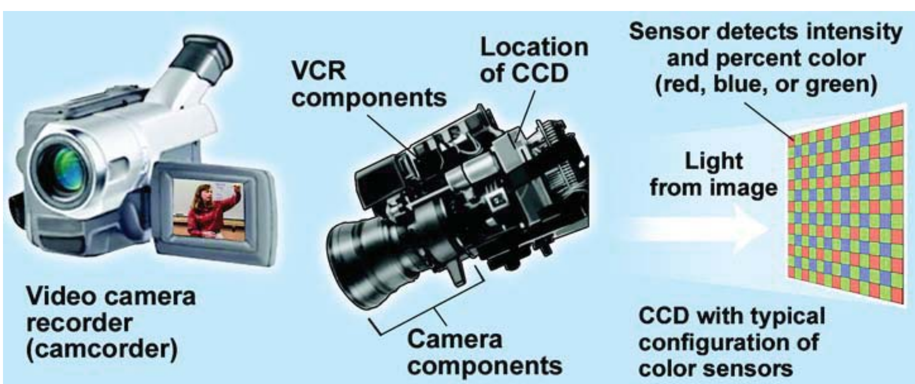
Figure 22.15: *An ink jet printer makes tiny dots of cyan, magenta, yellow, and black to print a full-color image. The dots are so small that your eye sees smooth colors. Look at an ink-jet print under a magnifying glass to see these dots.*

Making a color image

Making a color photograph Modern printing presses use the CMYK color process to produce vivid colors from only four inks. To print a color photograph, the image is converted into four separate images in cyan, magenta, yellow, and black. Each separate image represents what will be printed with its matching CMYK ink. The cyan separation is printed with cyan ink, the magenta separation with magenta ink, and so on. Figure 22.16 shows the four color separations from a color image.

The RGB color process Color images are also created using the **RGB color process**, an additive process that uses red, green, and blue light. The RGB process is used by television screens and computer monitors. A television makes different colors by lighting red, green, and blue pixels to different percentages. For example, a light brown tone is 88 percent red, 85 percent green, and 70 percent blue. A computer monitor works the same way. Each pixel (or dot) has three numbers that tell how much red, green, and blue to use. A digital video image is 720 dots wide times 480 dots high. If each dot has three numbers (R, G, B) a single image takes 1,036,800 numbers to store!

Video camera create color images A video camera-recorder (also called a camcorder) uses the RGB process differently than a TV. Like the rods and cones in your retina, a video camcorder has 300,000 - 500,000 sensors on a small chip called a CCD (Charge-Coupled Device). The sensors on the CCD measure the light intensity and percentages of red, green, and blue in the light coming through the camera lens. This information is recorded 30 times per second. The CCDs in most video camera-recorders are typically 1 centimeter square or less.



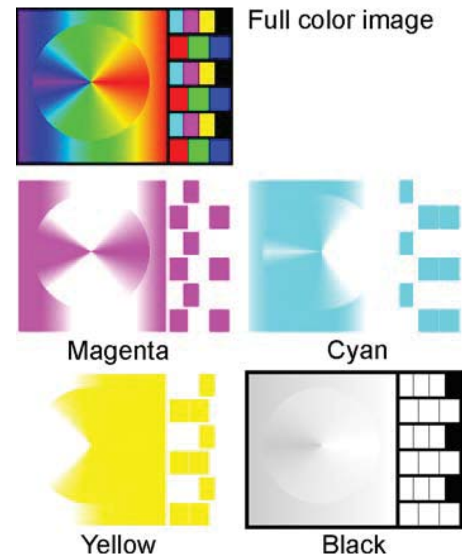


Figure 22.16: *To be printed by a full-color press, an image is separated into separate cyan, magenta, yellow, and black images.*

Figure 22.17: *A television makes colors using tiny glowing dots of red, green, and blue.*

Color blindness

Not everyone sees color the same way You may be surprised to learn that all people do not see color the same way. A condition called color blindness affects about 8 percent of males and 0.4 percent of females. This means that about one out of every 13 men has color blindness and about one out of every 250 women has color blindness.

Color blindness is inherited Although color blindness can be caused by eye disease, it is most often an inherited condition. More males than females have color blindness because of how the genes that determine our sex are inherited. Males have a X and a Y chromosome; females have two X chromosomes. The genes that are related to color blindness are on the X chromosome which males receive only from their mothers; they receive the Y chromosome from their fathers. Because females receive two X chromosomes, they have two chances to inherit the genes for normal color vision.

What is color blindness? People who are color blind have trouble seeing certain colors. The most common condition is red-green color blindness. People with this type of color blindness have trouble seeing reds and greens. Less common is blue-green color blindness. Complete color blindness means that the person can only see shades of gray. Fortunately, this condition is rare.

Living with color blindness It is easy to lead a normal life with color blindness. Having color blindness just means that an individual must look for ways to adapt to situations where color is involved. For example, color is extremely important when driving because traffic lights and street signs are color-coded. Fortunately, in most states, the traffic lights are vertical and the colors are in the same position — red on top, yellow in the center, and green on the bottom. A less serious situations where color is important is in interpreting maps and purchasing clothes. In these cases, color blind people rely on other methods to interpret colors. Interestingly, working with computers requires lots of color. For example, if you are going to make a web site, you will want to include color. For a color blind person this can be tricky. Fortunately, colors are standardized and a color blind person can chose colors using numbers.

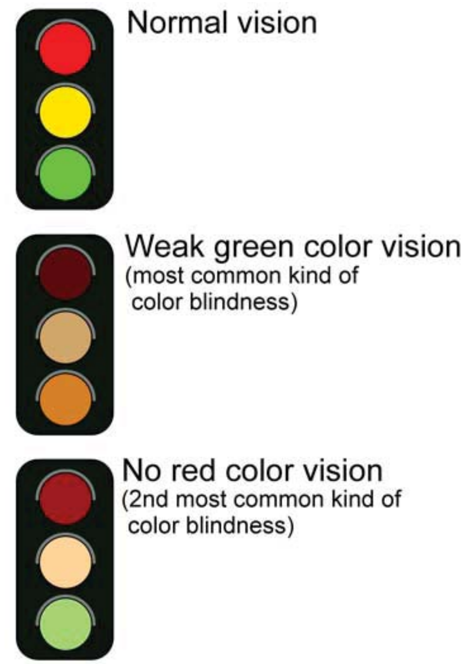


Figure 22.18: *This graphic illustrates how color blindness affects seeing a traffic light. The top of the graphic shows what the traffic light looks like with normal color vision. The middle and bottom graphic show what a traffic light looks like with two of the common forms of color blindness.*

Plants use color

Light is necessary for photosynthesis

Plants absorb energy from light and convert it to chemical energy in the form of sugar. The process is called *photosynthesis*. The vertical (*y*) axis of the graph in Figure 22.19 shows the percentage of light absorbed by a plant. The *x*-axis on the graph shows the colors of light. The heavy line shows how much and which colors of visible light are absorbed by plants. Based on this graph, can you explain why plants look green?

Why most plants are green

The important molecule that absorbs light in a plant is called *chlorophyll*. There are several forms of chlorophyll in a plant and they absorb mostly blue and red light, and reflect green light. This is why most plants look green. This graph also shows that plants need red and blue light to grow. A plant will die if placed under only green light!

Plants reflect some light to keep cool

Why don't plants absorb all colors of light? The reason is the same reason you wear light colored clothes when it is hot outside. Like you, plants must reflect some light to avoid absorbing too much energy and overheating. Plants use visible light because the energy is just enough to change certain chemical bonds, but not enough to completely break them. Ultraviolet light has more energy but would break chemical bonds. Infrared light has too little energy to change chemical bonds.

Why leaves change color

The leaves of some plants, such as sugar maple trees, turn brilliant red or gold in the fall. Chlorophyll masks other plant pigments during the spring and summer. In the fall when photosynthesis slows down, chlorophyll breaks down and red, orange, and yellow pigments in the leaves are revealed!

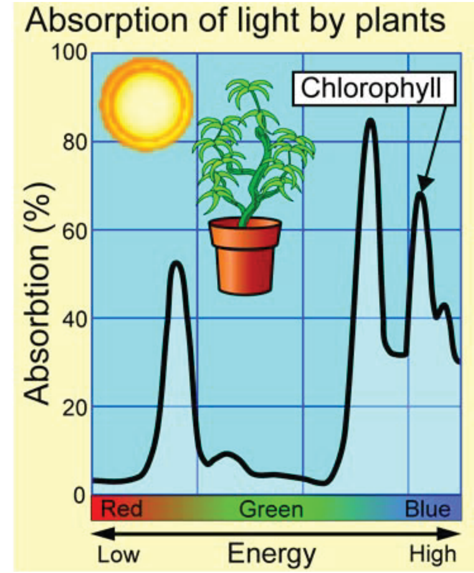


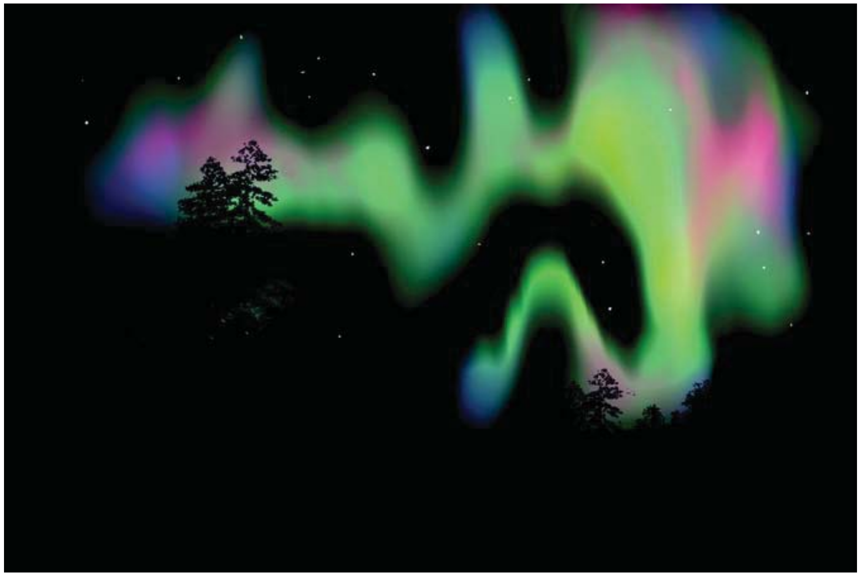
Figure 22.19: *Plants need to absorb light to grow. The plant pigment chlorophyll absorbs red and blue light, and reflects green light. This is why plants look green! Challenge: All plants that use sunlight to grow have chlorophyll, but some do not look green. Come up with a hypothesis to explain this observation.*

22.3 Section Review

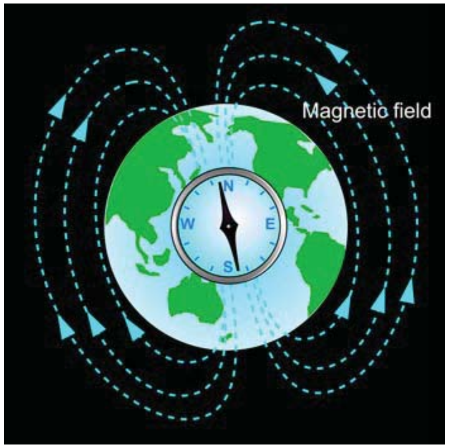
1. Do you think this text book was printed using the CMYK color process or the RGB color process. Explain your answer.
2. If you were going to design the lighting for a play, would you need to understand the CMYK color process or the RGB color process? Explain your answer.
3. Why does static on a television set appear white?
4. How is the color black produced in the CMYK color process versus the RGB color process?
5. Some plants that grow in shady areas have dark green or even purple leaves. Come up with a hypothesis to explain this observation.

The Northern Lights

The northern lights, or *Aurora Borealis* is the northern version of an amazing show of light and color in the sky of Earth's polar regions. Aurora Borealis is Latin for "dawn of the north." The southern hemisphere has a matching show, often the mirror image of what is seen in the north; *Aurora Australis* means "the dawn of the south." The aurora (both northern and southern) owes its existence to the magnetosphere, which protects Earth from dangerous particles given off by the sun.



The magnetic Earth

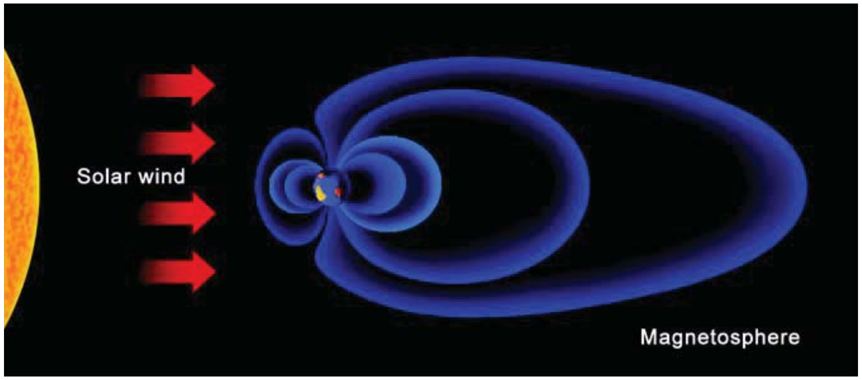


The *magnetosphere* is a giant magnetic field created by Earth that extends thousands of miles into space. You can see evidence of it when you use a compass. The needle points north, aligning with the magnetic field lines. The aurora is caused by interactions between the magnetosphere and the atmosphere—the layer of gases that surrounds our planet.

The stretched out part of the magnetosphere is called the magnetotail. Instead of being empty space, the magnetosphere is populated by ions. These ions are mainly electrons and protons, but also consist of oxygen and nitrogen atoms stripped of an electron, giving them a positive net charge.

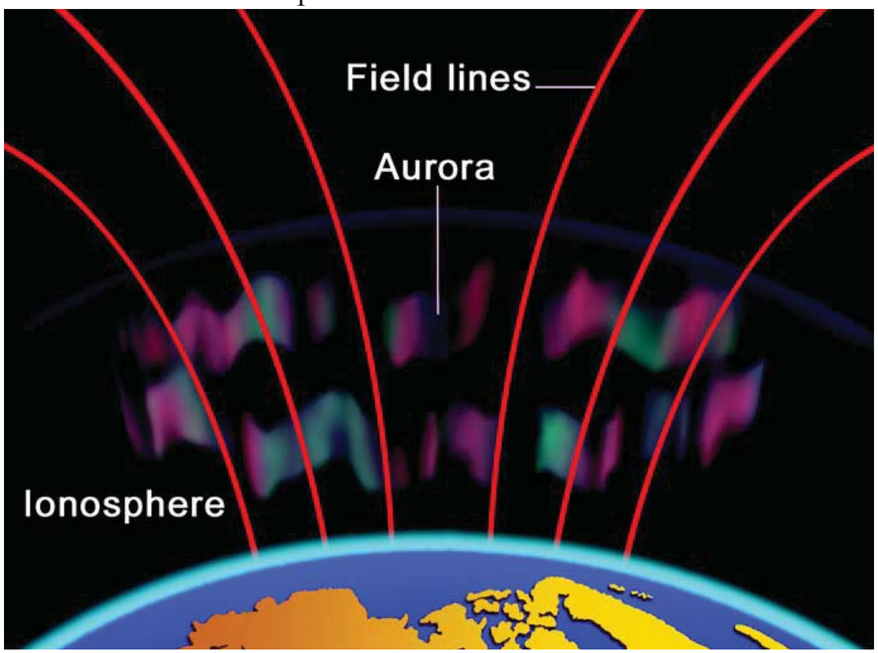
Solar wind

The solar wind is a stream of particles that moves away from the sun in all directions. The magnetosphere acts like a giant shield against almost all of the particles of the solar wind, diverting them around Earth. At about a million miles an hour, the solar wind pushes against the magnetosphere causing Earth's magnetosphere to be compressed on the sun side and stretched out on the other side.



Let the light show begin

Since ions are charged, they are influenced by the electrical force of the magnetosphere and move along its magnetic field. As ions in the magnetosphere travel along the magnetic field lines toward Earth, a gigantic electric current is produced. The particles get closer to Earth as the magnetic field lines converge at the poles and begin to encounter the outer reaches of the atmosphere called the ionosphere. Instead of continuing on through the ionosphere and hitting Earth, the particles begin to collide with the atoms and molecules of the ionosphere.



The energy released during those collisions creates the light of the aurora. Each collision bumps an electron in the struck atom to a higher energy level. When the electron drops back down to a lower energy level it emits a distinctive color of light. Different colors of light are created depending on the element and the energy of the collision.

The effect is like a neon sign. As electrons move through the neon gas in the sign the neon atoms produce a reddish glow. During an aurora, oxygen in the ionosphere emits a green or greenish-yellow light at lower altitudes, but at higher altitudes a brilliant red color. Nitrogen emits a red color at lower altitudes, but higher up in the ionosphere it can produce purple and even blue light. The whole effect can look like ribbons or curtains of colored light.

The sun's influence

Solar flares, coronal mass ejections, and coronal holes all produce huge amounts of particle emissions from the sun. They add to the steady flow of the solar wind and disturb Earth's magnetosphere, resulting in dramatic auroral displays. Hovering hundreds of miles above the north and south magnetic poles is a ring of auroral activity called the auroral oval. Even when we can't see the shimmering curtains of light in the sky, they are still there, extremely dim and detected only with special electronic equipment in satellites. Solar activity also causes the auroral oval to change size and shape during very active periods.

Questions:

1. Based on what you learned in Unit 6, what causes Earth to have a magnetic field?
2. Why is the aurora observed only in regions that are closer to the north and south poles and not near the equator?
3. Why is a gigantic electric current produced along the field lines? (Hint: think about the definition of electric current)
4. What causes the different colors of light associated with the aurora?
5. Do some research to find out what causes solar flares, coronal mass ejections, and coronal holes.

Table of Contents

Chapter 22 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

photoreceptors	subtractive process	incandescent
CMYK color process	intensity	color
fluorescent	cones	rods
additive primary colors	white light	RGB color process
subtractive primary colors	additive process	

Section 22.1

1. ____ light bulbs produce light by heating a metal filament.
2. The power of light per unit area is light ____.
3. ____ light bulbs produce light by passing electricity through a gas.

Section 22.2

4. ____ in the back of the eye absorb light and create a sense of vision.
5. Creating color by changing the strengths of the signals of three primary colors is a(n) ____ used by TVs.
6. ____ are photoreceptors that respond to color.
7. ____ is made up of all the possible colors of light.
8. A prism separates light into different wavelengths of ____.
9. The three ____ are red, green, and blue.
10. ____ are photoreceptors that respond to black, white, and shades of gray.

Section 22.3

11. Another name for the subtractive color process is the ____.
12. Creating color by relying on the reflected and absorbed light of three primary colors is a(n) ____ used to dye fabric.
13. Another name for the additive color process is the ____.
14. The three ____ are cyan, yellow, and magenta.

Reviewing Concepts

Section 22.1

1. How is an incandescent bulb different from a fluorescent bulb?
2. Why do we see lightning before we hear thunder?
3. Which of the following is *NOT* a quality of light?
   a. high speed
   b. acceleration
   c. color
   d. intensity
4. Describe the role of atoms in producing light in a fluorescent light bulb.
5. In terms of the absorption and reflection of light, describe the difference between a black piece of cloth and a white piece of cloth.
6. What is the difference between reflection and refraction of light?

Section 22.2

7. What is white light in terms of other colors?
8. What determines the color of an object?
9. What are the three additive primary colors?
10. What color of visible light has the least energy? The most energy?
11. Which photoreceptors in your eye respond the most in dim evening light? Which respond the least? How does this explain your vision in this type of light?

Section 22.3

12. Answer *True* or *False* for each of the following sentences. If the answer if *False*, correct the highlighted word to make the sentence *True*.
   a. ____ A green object *reflects* green light. __________
   b. ____ A blue object *absorbs* red and yellow light. __________
   c. ____ A yellow object *reflects* red light. __________
   d. ____ A white object *absorbs* red light. __________
13. What are the three subtractive primary colors?

14. If a store clerk adds more colorants (pigment) to a can of white paint, what happens to the light we use to view the paint?
15. Why is mixing pigments called color subtraction?
16. What colors of light are reflected by the color magenta?
17. In the CMYK color process, why is black pigment used instead of mixing cyan, magenta, and yellow pigments?
18. How does a color printing press produce all the colors of a printed picture?
19. How does a color television screen produce all the colors you see on the screen?
20. An image of a sunset is displayed on a computer screen. This image is then printed onto a piece of paper by a printer. When the paper is held up next to the screen, the images are almost identical. What is the difference between the processes used to create these two images?

Solving Problems

Section 22.1

1. Rewrite the following false statements so that they are true.
   a. Light intensity is measured in units of power per volume of space.
   b. If the intensity of light at 1 meter from a source is 1 W/m^2, it will be 2 W/m^2 at 2 meters from the source.
   c. At 1 meter from a light source, a 1 m^2 area has a light intensity of 0.8 W/m^2. At 3 meters from a light source, a 1 m^2 area will have a light intensity that is 0.4 W/m^2.
2. You are reading a book by the light of a lamp. Compare the intensity of the light on your book at one meter away from the lamp to the intensity of the light on your book at two meters away from the lamp.
3. If four seconds passes between seeing a lightning strike and hearing thunder, about how far away was the lightning?
4. Arrange the following in order of speed from fastest to slowest: sound waves, light waves, water waves

Section 22.2

5. Which star would be hotter, a star that produces blue light or a star that produces red light?
6. Your brain perceives color by an additive process. How would you see the following combinations of light colors?
   a. red + blue
   b. blue + green
   c. red + green
   d. red + blue + green
7. For stage lighting for a play in a theater, a magenta spot of light is created and a green spot of light. What happens when these two spots of light combine?

Section 22.3

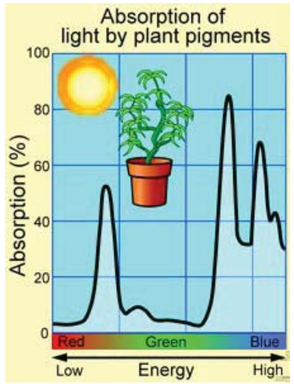
8. Using what you know about the subtractive color process, fill in the rest of the table.

The Three Subtractive Primary Colors

Color	Absorbs	Reflects	
Cyan	Red		
Magenta			
Yellow		Red	Green

9. If you wanted to make green paint, what combination of pigments would you use?
10. How would you create the following colors using inks on paper?
    a. red b. green c. blue d. white
11. If a cloth that appears blue in white light is viewed in a room filled with only blue light, what color will it appear?
12. Identify the color process (RGB or CMYK) used in each step:
    a. Taking a photograph with a digital camera.
    b. Transferring the image to a computer. The image appears on a computer monitor.
    c. Printing the image using a laser printer.
    d. Seeing the image on the paper with your eyes.

13. Answer the following questions using the absorption graph in Figure 22.19 in the text.



   a. Which colors of light are most absorbed the by plants?
   b. Which colors of light are reflected the most by plants?
   c. Based on the information from the absorption graph, explain why a plant will grow more quickly if it is grown in white light rather than green light.
   d. When green pigments in the plants break down in the fall, you can see that leaves have other pigments like red and orange pigments. This effect is very noticeable in the northeastern United States. Come up with a hypothesis to explain why plants might have other pigments in addition to green?

Applying Your Knowledge

Section 22.1

1. A common misconception in physics is related to how we see objects. You have learned in this chapter that it is only possible to see an object under two conditions: (1) when light is present, and (2) if an object gives off its own light. To help address this misconception, do the following:
   a. Conduct a survey of 20 people you know. Ask them the following question: If there is no light in a completely dark room, could you see your hand in front of your face?
   b. What is the correct answer to this question? How many people answered the question correctly? How many people answered it incorrectly?
   c. Make an engaging and creative flyer that would help people understand how we see objects.
2. Even with a two-step process for producing light, fluorescent bulbs are still four times more efficient at producing light than incandescent bulbs. Among the types of incandescent bulbs, the halogen bulbs are most efficient. Find out why and write a short paragraph about halogen bulbs explaining how they work.
3. Calculate the time it takes light and sound to travel the distance of one mile, which is 1,609 meters. Use 340 m/sec for the speed of sound.
4. The distances between stars in space are huge. Because of this, scientists have developed units other than kilometers or meters to measure them. A *light year* is a common measurement unit in astronomy. Even though the name may sound like it, this unit does not measure time. One light year is the distance that light can travel through space in one year. How long is a light year in meters?

Section 22.2

5. Research which colors of light the human eye is most sensitive to. It has been suggested that fire engines be painted with yellow-green paint instead of red paint. Explain why this might be a good idea.
6. Research the color vision of nocturnal animals. What is different about the photoreceptor in the eyes of nocturnal animals?

Section 22.3

7. A blue filter contains blue pigments. What happens to white light the is shone through a blue filter? Explain why.
8. Why do clothes that you try on in a store under fluorescent lighting look different when you get home and try them on under incandescent lighting?
9. Design an improvement to a common product to make it easier for color blind people to use.
10. A color TV makes colors using just red, green, blue light. The following table illustrates how the colors are made. Part of the table is filled in to get you started. Using your understanding of the RGB process, fill in the rest of the table.

Dot color on TV monitor	The color you see on the TV monitor					
	Black	White	Red	Yellow	Green	Blue
Red	off		on	on		
Green		on	off			
Blue						