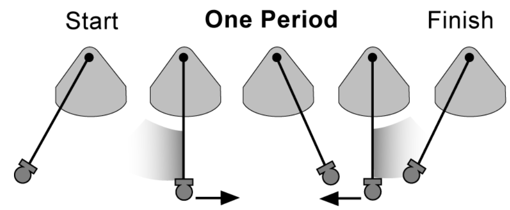
Name: ______________________ Date: __________

CONTENT 23.1

23.1 Period and Frequency

READ

The **period** of a pendulum is the time it takes to move through one cycle. As the ball on the string is pulled to one side and then let go, the ball moves to the side opposite the starting place and then returns to the start. This entire motion equals one cycle.



Frequency is a term that refers to how many cycles can occur in one second. For example, the frequency of the sound wave that corresponds to the musical note "A" is 440 cycles per second or 440 hertz. The unit *hertz* (Hz) is defined as the number of cycles per second.

The terms period and frequency are related by the following equation:

$$T = \frac{1}{f} \qquad f = \frac{1}{T}$$

T: Period (seconds); f: Frequency (hertz)

PRACTICE

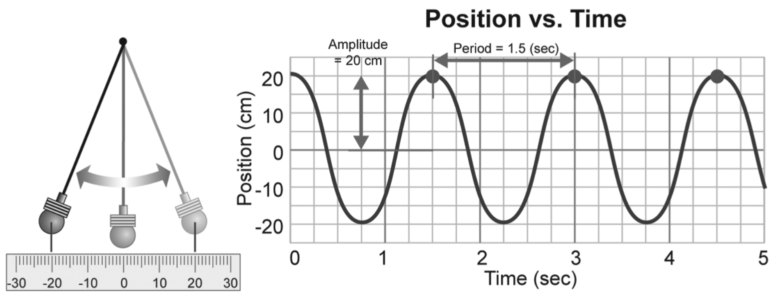
1. A string vibrates at a frequency of 20 Hz. What is its period?
2. A speaker vibrates at a frequency of 200 Hz. What is its period?
3. A swing has a period of 10 seconds. What is its frequency?
4. A pendulum has a period of 0.3 second. What is its frequency?
5. You want to describe the harmonic motion of a swing. You find out that it take 2 seconds for the swing to complete one cycle. What is the swing's period and frequency?
6. An oscillator makes four vibrations in one second. What is its period and frequency?
7. A pendulum takes 0.5 second to complete one cycle. What is the pendulum's period and frequency?
8. A pendulum takes 10 seconds to swing through 2 complete cycles.
   a. How long does it take to complete one cycle?
   b. What is its period?
   c. What is its frequency?
9. An oscillator makes 360 vibrations in 3 minutes.
   a. How many vibrations does it make in one minute?
   b. How many vibrations does it make in one second?
   c. What is its period in seconds?
   d. What is its frequency in hertz?

Name: ____________________ Date: __________

23.1 Harmonic Motion Graphs

READ

A graph can be used to show the amplitude and period of an object in harmonic motion. An example of a graph of a pendulum's motion is shown below.

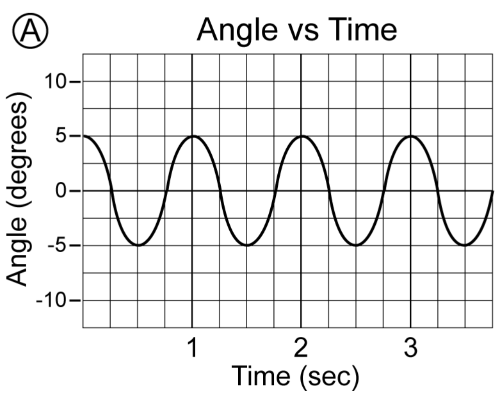


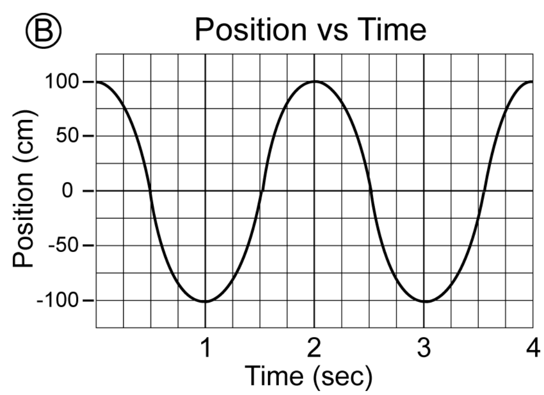
The distance to which the pendulum moves away from its center point is call the **amplitude**. The amplitude of a pendulum can be measured in units of length (centimeters or meters) or in degrees. On a graph, the amplitude is the distance from the *x*-axis to the highest point of the graph. The pendulum shown above moves 20 centimeters to each side of its center position, so its amplitude is 20 centimeters.

The **period** is the time for the pendulum to make one complete cycle. It is the time from one peak to the next on the graph. On the graph above, one peak occurs at 1.5 seconds, and the next peak occurs at 3.0 seconds. The period is 3.0 – 1.5 = 1.5 seconds.

PRACTICE

1. Use the graphs to answer the following questions





   a. What is the amplitude of each vibration?

   b. What is the period of each vibration?

2. Use the grids below to draw the following harmonic motion graphs. Be sure to label the *y*-axis to indicate the measurement scale.

   a. A pendulum with an amplitude of 2 centimeters and a period of 1 second.

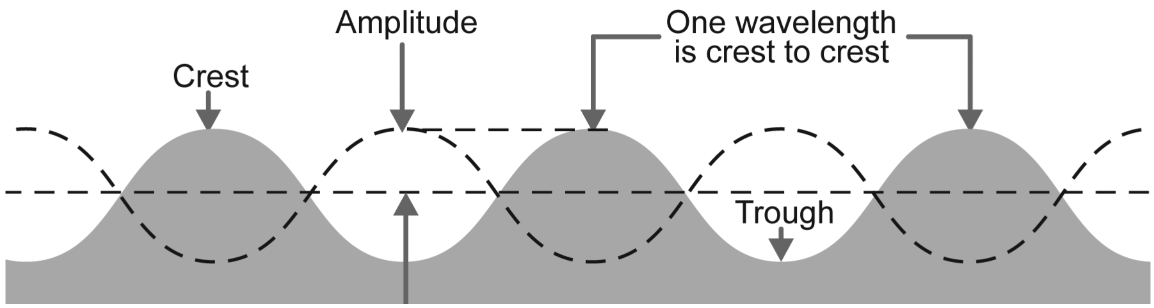
   b. A pendulum with an amplitude of 5 degrees and a period of 4 seconds.

Name: ______________________ Date: __________

23.2 Waves

READ

A **wave** is a traveling oscillator that carries energy from one place to another. A high point of a wave is called a **crest**. A low point is called a **trough**. The amplitude of a wave is half the distance from a crest to a trough. The distance from one crest to the next is called the **wavelength**. Wavelength can also be measured from trough to trough or from any point on the wave to the next place where that point occurs.



The speed of a wave

$$v = f\lambda$$

Speed (m/sec) → v; Frequency (hertz) → f; Wavelength (meters) → λ

EXAMPLE

- The frequency of a wave is 40 Hz and its speed is 100 meters per second. What is the wavelength of this wave?

  Solution:

$$\frac{100\text{ m/s}}{40\text{ Hz}} = \frac{100\text{ m/s}}{40\text{ cycles/s}} = 2.5\text{ meters per cycle}$$

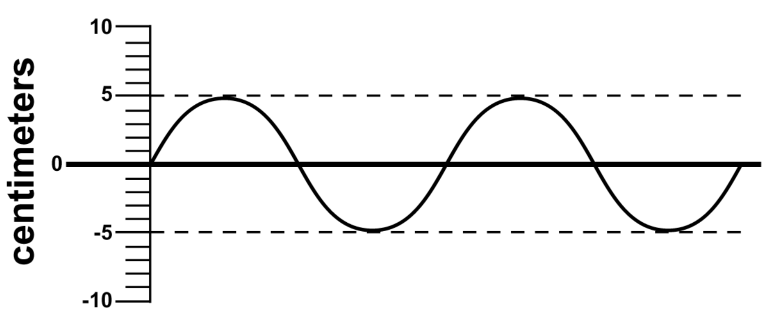
The wavelength is 2.5 meters.

PRACTICE

1. On the graphic at right label the following parts of a wave: one wavelength, half of a wavelength, the amplitude, a crest, and a trough.

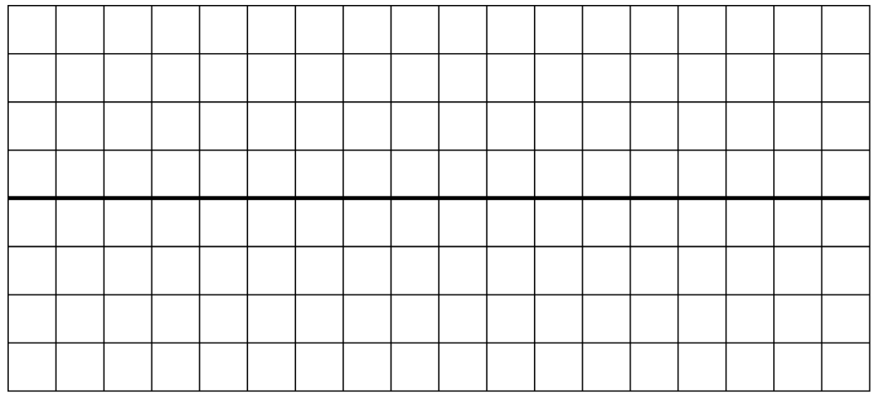
   a. How many wavelengths are represented in the wave above?

   b. What is the amplitude of the wave shown above?

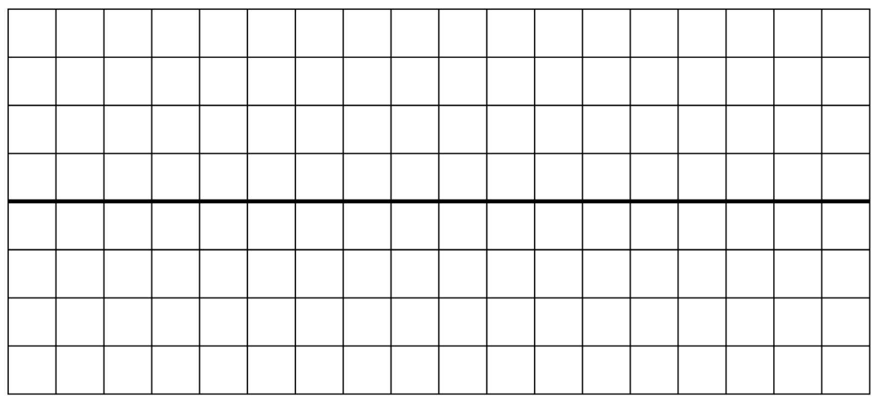


2. Use the grids below to draw the following waves. Be sure to label the *y*-axis to indicate the measurement scale.

   a. A wave with an amplitude of 1 cm and a wavelength of 2 cm



   b. A wave with an amplitude of 1.5 cm and a wavelength of 3 cm



3. A water wave has a frequency of 2 hertz and a wavelength of 5 meters. Calculate its speed.

4. A wave has a speed of 50 m/s and a frequency of 10 Hz. Calculate its wavelength.

5. A wave has a speed of 30 m/s and a wavelength of 3 meters. Calculate its frequency.

6. A wave has a period of 2 seconds and a wavelength of 4 meters.Calculate its frequency and speed. *Note: Recall that the frequency of a wave equals 1/period and the period of a wave equals 1/frequency.*

7. A sound wave travels at 330 m/s and has a wavelength of 2 meters. Calculate its frequency and period.

8. The frequency of wave A is 250 hertz and the wavelength is 30 centimeters. The frequency of wave B is 260 hertz and the wavelength is 25 centimeters. Which is the faster wave?

9. The period of a wave is equal to the time it takes for one wavelength to pass by a fixed point. You stand on a pier watching water waves and see 10 wavelengths pass by in a time of 40 seconds.

   a. What is the period of the water waves?

   b. What is the frequency of the water waves?

   c. If the wavelength is 3 meters, what is the wave speed?

Name: ______________________ Date: __________

CONTENT 23.2

23.2 Waves and Energy

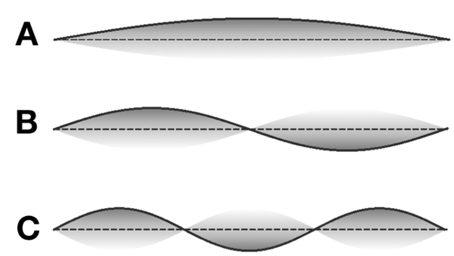
READ

A wave is an organized form of energy that travels. The amount of energy a wave has is proportional to its frequency and amplitude. Therefore, higher energy waves have a higher frequency and/or a higher amplitude. Remember that the frequency is measured in hertz. The frequency of 1 Hz equals one wave cycle per second.

EXAMPLE

For each set of diagrams, identify which of the standing waves has the highest energy and which has the lowest energy.

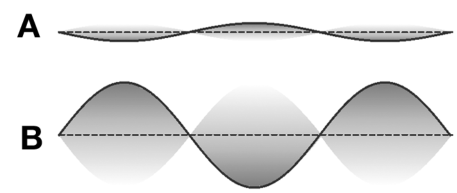
Frequency and energy



Answers for frequency and energy:

Standing wave	Frequency	Energy
A	lowest	lowest
B	medium	medium
C	highest	highest

Amplitude and energy



Answers for amplitude and energy:

Standing wave	Frequency	Energy
A	lowest	lowest
B	highest	highest

PRACTICE

1. When you drop a stone into a pool, water waves spread out from where the stone landed. Why?

2. Ian and Igor have opposite ends of a jump rope and perform the following demonstration. First they moved the rope up and down one time a second, then two times a second, and then three times a second. Describe the trend in frequency for the jump rope and the trend in energy used by Ian and Igor for this demonstration.

3. One wave has a frequency of 30 Hz and another has a frequency of 100 Hz. Both waves have the same amplitude. Which wave has more energy?

4. On a calm day ocean waves are about 0.1 meter high. However, during a hurricane, ocean waves might be as much as 14 meters high. If both waves have the same frequency, during which set of conditions do the waves have more energy?

5. Which wave has more energy: a wave that has an amplitude of 3 centimeters and a frequency of 2 Hz or a wave with an amplitude of 3 meters and a frequency of 2 Hz?

6. The loudness of sound is related to its amplitude. Which sound wave would have the least energy: a low-volume wave at 1,000 Hz or a high-volume (loud) wave at 1,000 Hz?

7. The frequency of microwaves is less than that of visible light waves. Which type of wave is likely to have greater energy?

8. Standing wave C in the first graphic above represents 1.5 wavelengths. Draw a standing wave that represents 2 wavelengths. Compare the energy and frequency of this standing wave to A, B, and C.

Name: ______________________________ Date: __________

CHALLENGE! 23.3

23.3 Wave Interference

READ

Interference occurs when two or more waves are at the same location at the same time. For example, the wind may create tiny ripples on top of larger waves in the ocean.The **superposition principle** states that the total vibration at any point is the sum of the vibrations produced by the individual waves.

Constructive interference is when waves combine to make a larger wave. Destructive interference is when waves combine to make a wave that is smaller than either of the individual waves. Noise cancelling headphones work by producing a sound wave that perfectly cancels the sounds in the room.

PRACTICE

This worksheet will allow you to find the sum of two waves with different wavelengths and amplitudes. The table below (and continued on the next page) lists the coordinates of points on the two waves.

1. Use coordinates on the table and the graph paper (see last page) to graph wave 1 and wave 2 individually. Connect each set of points with a smooth curve that looks like a wave. Then, answer questions 2–9.
2. What is the amplitude of wave 1?
3. What is the amplitude of wave 2?
4. What is the wavelength of wave 1?
5. What is the wavelength of wave 2?
6. How many wavelengths of wave 1 did you draw?
7. How many wavelength of wave 2 did you draw?
8. Use the superposition principle to find the wave that results from the interference of the two waves.
   a. To do this, simply add the heights of wave 1 and wave 2 at each point and record the values in the last column. The first four points are done for you.
   b. Then use the points in last column to graph the new wave. Connect the points with a smooth curve. You should see a pattern that combines the two original waves.
9. Describe the wave created by adding the two original waves.

x-axis (blocks)	Height of wave 1 (*y*-axis blocks)	Height of wave 2 (*y*-axis blocks)	Height of wave 1 + wave 2 (*y*-axis blocks)
0	0	0	0
1	0.8	2	2.8
2	1.5	0	1.5
3	2.2	–2	0.2
4	2.8	0	

x-axis (blocks)	Height of wave 1 (*y*-axis blocks)	Height of wave 2 (*y*-axis blocks)	Height of wave 1 + wave 2 (*y*-axis blocks)
5	3.3	2	
6	3.7	0	
7	3.9	–2	
8	4	0	
9	3.9	2	
10	3.7	0	
11	3.3	–2	
12	2.8	0	
13	2.2	2	
14	1.5	0	
15	0.8	–2	
16	0	0	
17	–0.8	2	
18	–1.5	0	
19	–2.2	–2	
20	–2.8	0	
21	–3.3	2	
22	–3.7	0	
23	–3.9	–2	
24	–4	0	
25	–3.9	2	
26	–3.7	0	
27	–3.3	–2	
28	–2.8	0	
29	–2.2	2	
30	–1.5	0	
31	–0.8	–2	
32	0	0	

CHALLENGE!
23.3

Wave 1 + Wave 2

Wave 2

Wave 1

Name: ____________________ Date: __________

CONTENT 24.1

24.1 Decibel Scale

READ

The loudness of sound is measured in decibels (dB). Most sounds fall between zero and 100 on the decibel scale making it a very convenient scale to understand and use. Each increase of 20 decibels (dB) for a sound will be about twice as loud to your ears. Use the following table to help you answer the questions.

10-15 dB	A quiet whisper 3 feet away
30-40 dB	Background noise in a house
65 dB	Ordinary conversation 3 feet away
70 dB	City traffic
90 dB	A jackhammer cutting up the street 10 feet away
100 dB	Listening to headphones at maximum volume
110 dB	Front row at a rock concert
120 dB	The threshold of physical pain from loudness

EXAMPLE

- How many decibels would a sound have if its loudness was twice that of city traffic?

  Solution:

  City traffic = 70 dB
  Adding 20 dB doubles the loudness.
  70 dB + 20 dB = 90 dB
  90 dB is twice as loud as city traffic.

PRACTICE

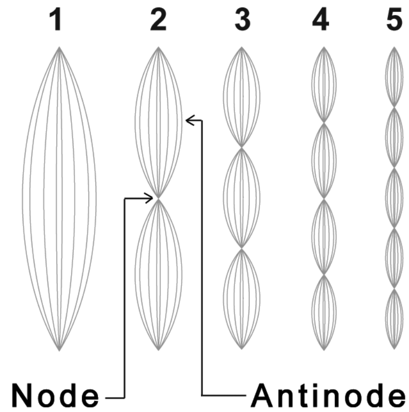
1. How many times louder than a jackhammer does the front row at a rock concert sound?
2. How many decibels would you hear in a room that sounds twice as loud as an average (35 dB) house?
3. You have your headphones turned all the way up (100 dB).
   a. If you want them to sound half as loud, to what decibel level must the music be set?
   b. If you want them to sound 1/4 as loud, to what decibel level must the music be set?
4. How many times louder than city traffic does the front row at a rock concert sound?
5. When you whisper, you produce a 10-dB sound.
   a. When you speak quietly, your voice sounds twice as loud as a whisper. How many decibels is this?
   b. When you speak normally, your voice sounds 4 times as loud as a whisper. How many decibels is this?
   c. When you yell, your voice sounds 8 times as loud as a whisper. How many decibels is this?

Name: ______________________ Date: __________

CHALLENGE! 24.2

24.2 Standing Waves

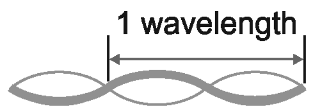
A wave that is confined in a space is called a **standing wave**. Standing waves on the vibrating strings of a guitar produce the sounds you hear. Standing waves are also present inside the chamber of a wind instrument.



A string that contains a standing wave is an oscillator. Like any oscillator, it has natural frequencies. The lowest natural frequency is called the **fundamental**. Other natural frequencies are called **harmonics**. The first five harmonics of a standing wave on a string are shown to the right.

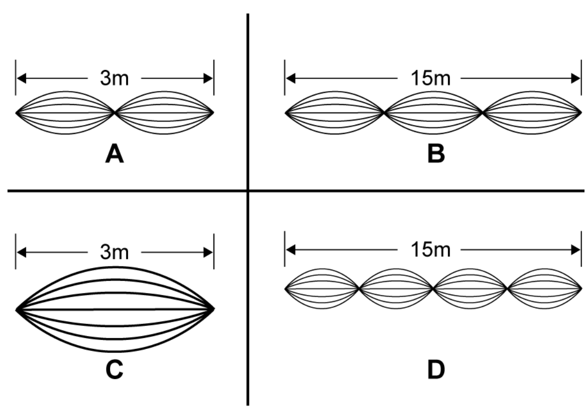
There are two main parts of a standing wave. The **nodes** are the points where the string does not move at all. The **antinodes** are the places where the string moves with the greatest amplitude.

The wavelength of a standing wave can be found by measuring the length of two of the "bumps" on the string. The first harmonic only contains one bump, so the wavelength is twice the length of the individual bump.

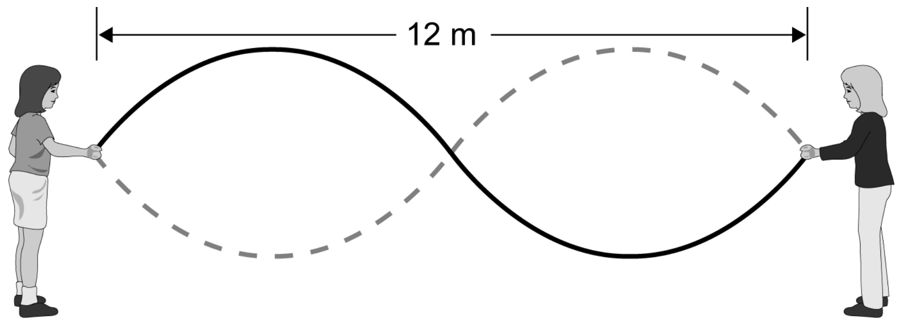


PRACTICE

1. Use the graphic below to answer these questions.
   a. Which harmonic is shown in each of the strings below?
   b. Label the nodes and antinodes on each of the standing waves shown below.
   c. How many wavelengths does each standing wave contain?
   d. Determine the wavelength of each standing wave.



2. Two students want to use a 12-meter rope to create standing waves. They first measure the speed at which a single wave pulse moves from one end of the rope to another and find that it is 36 m/s. This information can be used to determine the frequency at which they must vibrate the rope to create each harmonic. Follow the steps below to calculate these frequencies.



a. Draw the standing wave patterns for the first six harmonics.

b. Determine the wavelength for each harmonic on the 12-meter rope. Record the values in the table below.

c. Use the equation for wave speed ($v = f\lambda$) to calculate each frequency.

Harmonic	Speed (m/s)	Wavelength (m)	Frequency (Hz)
1	36		
2	36		
3	36		
4	36		
5	36		
6	36		

d. What happens to the frequency as the wavelength increases?

e. Suppose the students cut the rope in half. The speed of the wave on the rope only depends on the material from which the rope is made and its tension, so it will not change. Determine the wavelength and frequency for each harmonic on the 6-meter rope.

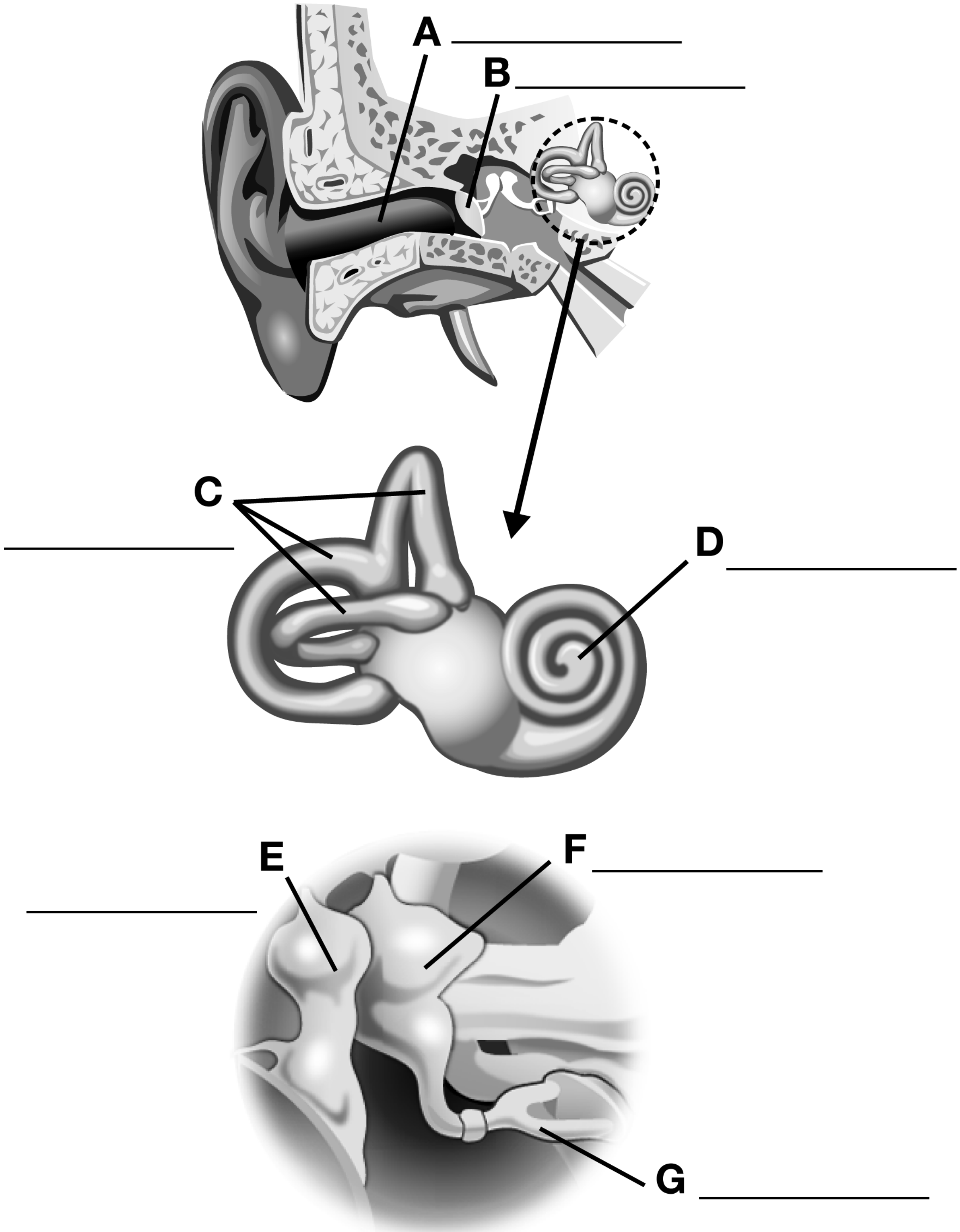
Harmonic	Speed (m/s)	Wavelength (m)	Frequency (Hz)
1	36		
2	36		
3	36		
4	36		
5	36		
6	36		

f. What effect did using a shorter rope have on the wavelength and frequency?

Name: ______________________________ Date: __________

24.3 The Human Ear

Write the name of the part that corresponds to each letter in the diagram. Then write the function of each part in the spaces on the next page.



CONTENT
24.3

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________

g. ______________________________

Name: ______________________ Date: __________

CHALLENGE! 24.3

24.3 Palm Pipes Project

READ

A palm pipe is a musical instrument made from a simple material—PVC pipe. To play a palm pipe, you hit an open end of the pipe on the palm of your hand, causing the air molecules in the pipe to vibrate. These vibrations create the sounds that you hear.

Materials:

- 1 standard 10-foot length of 1/2 inch PVC pipe for 180°F water.
- Flexible meter stick
- PVC pipe cutter or a hacksaw
- Sandpaper
- Seven different colors of permanent markers for labeling pipes
- Simple calculator

Directions:

1. Cut the PVC pipe into the lengths listed in the chart below. It works best if you measure one length, cut it, then make the next measurement. You may want to cut each piece a little longer than the given measurement so that you can sand out any rough spots and level the pipe without making it too short.

Number	Note	Length of pipe (cm)	Frequency (Hertz)
1	F	23.60	349
2	G	21.00	392
3	A	18.75	440
4	B flat	17.50	446
5	C	15.80	523
6	D	14.00	587
7	E	12.50	659
8	F	11.80	698
9	G	10.50	748
10	A	9.40	880
11	B flat	9.20	892
12	C	7.90	1049
13	D	7.00	1174
14	E	6.25	1318
15	F	5.90	1397

2. Lightly sand the cut ends to smooth any rough spots.

3. Label each pipe with the number, note, and frequency using a different color permanent marker.

4. Hit one open end of the pipe on the palm of your hand in order to make a sound.

CHALLENGE!

24.3

Activities:

1. Try blowing across the top of a pipe as if you were playing a flute. Does the pipe sound the same as when you tap it on your palm? Why or why not?
   Safety note: Wash the pipes with rubbing alcohol or a solution of 2 teaspoons household bleach per gallon of water before and after blowing across them.

2. Take one of the longer pipes and place it in a bottle of water so that the top of the pipe extends above the top of the bottle. Blow across it like a flute. What happens to the tone as you raise or lower the pipe in the bottle?

3. Try making another set of palm pipes out of 1/2-inch copper tubing. What happens when you strike these pipes against your palm? What happens when you blow across the top? How does the sound compare with the plastic pipes?

4. At a hardware store, purchase two rubber rings for each copper pipe. These rings should fit snugly around the pipes. Place one ring on each end of each pipe, then lay them on a table. Try tapping the side of each pipe with different objects—wooden and stainless steel serving spoons, for example. How does this sound compare with the other sounds you have made with the pipes?

5. Try playing some palm pipe music with your classmates. Here are two tunes to get you started:

Happy Birthday														
Melody	C	C	D	C	F	E			C	C	D	C	G	F
Harmony			A		A	B^b					B^b		B^b	A
Melody	C	C	C	A	F	E	D		B^b	B^b	A	F	G	F
Harmony			F		C	B^b					C			A

Twinkle Twinkle Little Star															
Melody	F	F	C	C	D	D	C		B^b	B^b	A	A	G	G	F
Harmony	C	C	A	A	B^b	B^b	A		G	G	F	F	E	E	C
Melody	C	C	B^b	B^b	A	A	G		C	C	B^b	B^b	A	A	G
Harmony	A	A	G	G	F	F	C		A	A	G	G	F	F	C
Melody	F	F	C	C	D	D	C		B^b	B^b	A	A	G	G	F
Harmony	C	C	A	A	B^b	B^b	A		G	G	F	F	E	E	C

6. **Challenge:**
You can figure out the length of pipe needed to make other notes, too. All you need is a simple formula and your understanding of the way sound travels in waves.

To figure out the length of the pipe needed to create sound of a certain frequency, we start with the formula frequency = velocity of sound in air ÷ wavelength, or $f = v/\lambda$. Next, we solve the equation for λ: $\lambda = v/f$.

The fundamental frequency is the one that determines which note is heard. You can use the chart below to find the fundamental frequency of a chromatic scale in two octaves. Notice that for each note, the frequency doubles every time you go up an octave.

Once you choose the frequency of the note you want to play, you need to know what portion of the fundamental frequency's wavelength (S-shape) will fit inside the palm pipe.

To help you visualize the wave inside the palm pipe, hold the center of a flexible meter stick in front of you. Wiggle the meter stick to create a standing wave. This mimics a column of vibrating air in a pipe with two open ends. How much of a full wave do you see? If you answered one half, you are correct.

When a palm pipe is played, your hand closes one end of the pipe. Now use your meter stick to mimic this situation. Place the meter stick on a table top and use one hand to hold down one end of the stick. This represents the closed end of the pipe. Flick the other end of the meter stick to set it in motion. How much of a full wavelength do you see? Now do you know what portion of the wavelength will fit into the palm pipe? One-fourth of the wavelength of the fundamental frequency will fit inside the palm pipe. As a result the length of the pipe should be equal to $1/4\lambda$, which is equal to $1/4(v/f)$.

In practice, we find that the length of pipe needed to make a certain frequency is actually a bit shorter than this. Subtracting a length equal to 1/4 of the pipe's inner diameter is necessary. The final equation, therefore, is: Length of pipe $= \frac{v}{4f} - \frac{1}{4}D$ where D represents the inner diameter of the pipe.

Given that the speed of sound in air (at 20 °C) is 343 m/s and the inner diameter of the pipe is 0.0017 m, what is the length of pipe you would need to make the note B, with a frequency of 494 hertz? How about the same note one octave higher (frequency 988 hertz)? Make these two pipes so that you can play a C major scale.

Chromatic scale in two octaves (frequencies rounded to nearest whole number)													
Note	A	A#	B	C	C#	D	D#	E	F	F#	G	G#	A
Frequency (Hertz)	220	233	247	262	277	294	311	330	349	370	392	415	440
Frequency (Hertz)	440	466	494	523	554	587	622	659	698	740	784	831	880

7. What is the lowest note you could make with a palm pipe? What is the highest? Explain these limits using what you know about the human ear and the way sound is created by the palm pipe.

Name: ______________________________ Date: __________

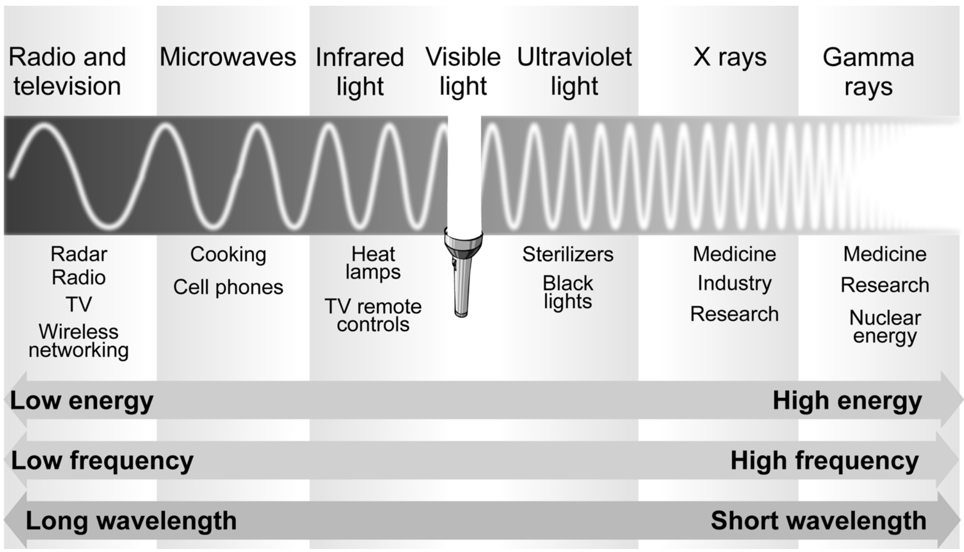
CHALLENGE! 25.1

25.1 The Electromagnetic Spectrum

READ

Radio waves, microwaves, visible light, and x-rays are familiar kinds of electromagnetic waves. All of these waves have characteristic wavelengths and frequencies. *Wavelength* is measured in meters. It describes the length of one complete oscillation. *Frequency* describes the number of complete oscillations per second. It is measured in hertz, which is another way of saying "cycles per second." The higher the wave's frequency, the more energy it carries.

The Electromagnetic Spectrum



Frequency, wavelength, and speed

In a vacuum, all electromagnetic waves travel at the same speed: 3.0×10^8 m/s. This quantity is often called "the speed of light" but it really refers to the speed of all electromagnetic waves, not just visible light. It is such an important quantity in physics that it has its own symbol, *c*.

The speed of light is related to frequency *f* and wavelength λ by the formula to the right.

THE SPEED OF LIGHT
(relationship between frequency and wavelength)

$$c = f\lambda$$

Speed of light (3 x 10^8 m/sec) → c; *Wavelength* (m) → λ; *Frequency* (Hz) → f

The different colors of light that we see correspond to different frequencies. The frequency of red light is lower than the frequency of blue light. Because the speed of both kinds of light is the same, a lower frequency wave has a longer wavelength. A higher frequency wave has a shorter wavelength. Therefore, red light's wavelength is longer than blue light's.

When we know the frequency of light, the wavelength is given by: $\lambda = \dfrac{c}{f}$

When we know the wavelength of light, the frequency is given by: $f = \dfrac{c}{\lambda}$

PRACTICE

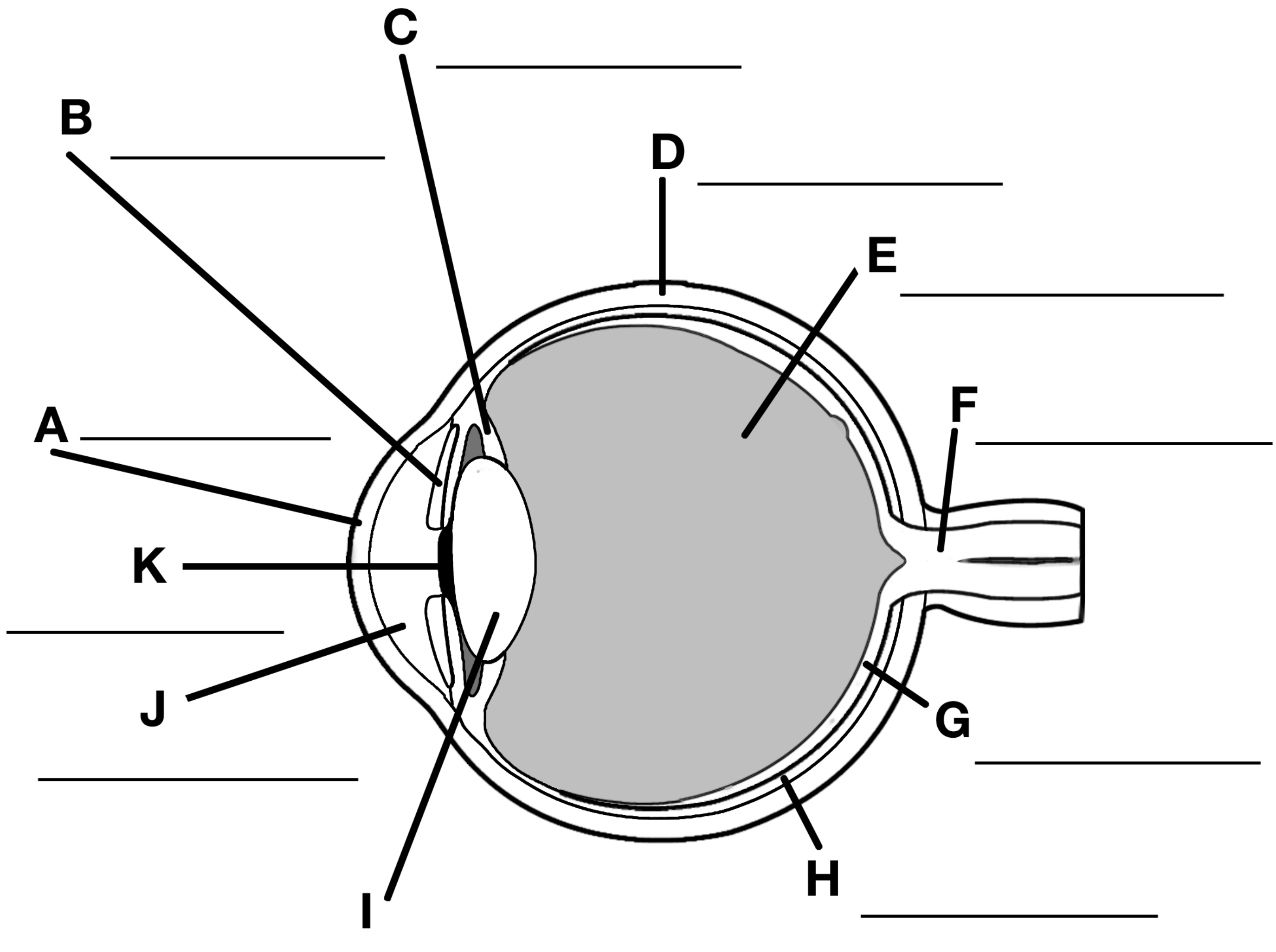
Answer the following problems. Don't forget to show your work.

1. Yellow light has a longer wavelength than green light. Which color of light has the higher frequency?
2. Green light has a lower frequency than blue light. Which color of light has a longer wavelength?
3. Calculate the wavelength of violet light with a frequency of 750×10^{12} Hz.
4. Calculate the frequency of yellow light with a wavelength of 580×10^{-9} m.
5. Calculate the wavelength of red light with a frequency of 460×10^{12} Hz.
6. Calculate the frequency of green light with a wavelength of 530×10^{-9} m.
7. One light beam has wavelength, λ_1, and frequency, f_1. Another light beam has wavelength, λ_2, and frequency, f_2. Write a proportion that shows how the ratio of the wavelengths of these two light beams is related to the ratio of their frequencies.
8. The waves used by a microwave oven to cook food have a frequency of 2.45 gigahertz (2.45×10^9 Hz). Calculate the wavelength of this type of wave.
9. A radio station has a frequency of 90.9 megahertz (9.09×10^7 Hz). What is the wavelength of the radio waves the station emits from its radio tower?
10. An x-ray has a wavelength of 5 nanometers (5.0×10^{-9} m). What is the frequency of x-rays?
11. The ultraviolet rays that cause sunburn are called UV-B rays. They have a wavelength of approximately 300 nanometers (3.0×10^{-7} m). What is the frequency of a UV-B ray?
12. Infrared waves from the sun are what make our skin feel warm on a sunny day. If an infrared wave has a frequency of 3.0×10^{12} Hz, what is its wavelength?
13. Electromagnetic waves with the highest amount of energy are called gamma rays. Gamma rays have wavelengths of less than 10-trillionths of a meter (1.0×10^{-11} m).
    a. Determine the frequency that corresponds with this wavelength.
    b. Is this the minimum or maximum frequency of a gamma ray?
14. Use the information from this sheet to order the following types of waves from lowest to highest frequency: visible light, gamma rays, x-rays, infrared waves, ultraviolet rays, microwaves, and radio waves.
15. Use the information from this sheet to order the following types of waves from shortest to longest wavelength: visible light, gamma rays, x-rays, infrared waves, ultraviolet rays, microwaves, and radio waves.

Name: ______________________ Date: __________

25.2 The Human Eye

Write the name of the part that corresponds to each letter in the diagram. Then write the function of each part in the spaces on the next page.



CONTENT 25.2

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

e. ______________________________

f. ______________________________

g. ______________________________

h. ______________________________

i. ______________________________

j. ______________________________

k. ______________________________

Name: ______________________________ Date: __________

CONTENT 25.2

25.2 Color Mixing with Additive and Subtractive Processes

READ

The way that color appears on a piece of paper and how your eyes interpret color involve two different color mixing processes. Your eyes see color using an additive color process. The RGB color model is the basis for how the additive process works and involves mixing colors of light. The CMYK color model is the basis for how the subtractive color process works and involves pigments of color which absorb colors of light.

RGB color model			CMYK color model		
Primary colors	**Mixed colors**	**New color**	**Primary colors**	**Mixed colors**	**New color**
red	red + green	yellow	magenta	magenta + yellow	red
green	green + blue	cyan	yellow	yellow + cyan	green
blue	blue + red	magenta	cyan	cyan + magenta	blue
How black is made	Absence of light		How black is made	Pure black pigment	
How white is made	red + green + blue		How white is made	Absence of pigment or use of pure white pigment	

EXAMPLE

- The human eye has photoreceptors for red, green, and blue light. Which of these photoreceptors are stimulated when looking at white paint?
  Solution: All three of these photoreceptors are stimulated equally.
- A laser printer prints a piece of paper that includes black lettering and a blue border. How are these colors made using the CMYK color model?
  Solution: Pure black pigment is used to make the black lettering. If you were to mix the other colors (magenta, yellow, and cyan), you would only get a muddy gray. The blue border was made by mixing cyan and magenta pigments.

PRACTICE

1. A friend asks you to describe the difference between the RGB color model and the CMYK color model. Give him three differences between these color models.
2. How would you see the following combinations of light colors?
   a. red only
   b. blue + red, both at equal intensity
   c. green only
   d. green + blue, both at equal intensity
3. The color orange is perceived by the eyes when both the red and green photoreceptors are stimulated and the red signal is stronger than the green. Given this information, what kind of signals would be received by the eye for the color purple?

4. You see a chair that is painted yellow. Most likely, pure yellow pigment was used to make the paint. However, explain how your eyes interpret the color yellow.

5. White paint purchased at a store is often made of a pure white pigment called titanium dioxide. This white paint reflects about 97% of the light that strikes it. Why might this property of the paint mean that you interpret its color as white?

6. The image you see on a color TV screen is made using the RGB color model. The image is made o thousands of pixels or dots of color. Describe how you could make the following pixels using the RGB color model.
   a. A white pixel
   b. A black pixel
   c. A cyan pixel
   d. A yellow pixel

7. What colors of light are reflected and/or absorbed by a red apple when:
   a. white light shines on it?
   b. only red light shines on it?
   c. only blue light shines on it?

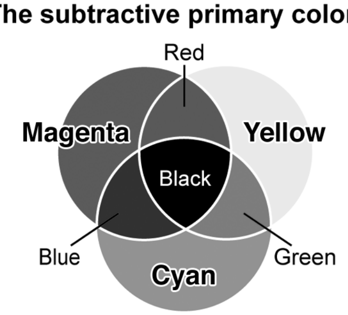
8. The CMYK color model works because the combination of pigments absorb and reflect light. Imagine that white light containing a mixture of red, green, and blue light shines on the combination of CMYK pigments in the table below. Copy the table on your own paper. Indicate in the blank spaces which colors of light the pigments absorb and which color is reflected. Some parts of the table are filled in for you.

CMYK color model		
Mixed colors	**Reflected color**	**Which colors of light are absorbed?**
magenta + yellow	**red**	
yellow + cyan		**blue is absorbed by yellow** **red is absorbed by cyan**
cyan + magenta		

9. If you mix magenta paint and cyan paint, what color will you achieve?

10. A laser printer's ink only includes the colors cyan, magenta, yellow, and black.
    a. Explain how it makes the color green using these pigments.
    b. Then, explain what happens for your eye to interpret this color as green.
    c. This Venn diagram illustrates color mixing for the CMYK color model. Now, make a Venn diagram for the RGB color model. Use color when you make your diagram. Be sure to label the difference between the primary colors and the new colors made by mixing.

The subtractive primary colors

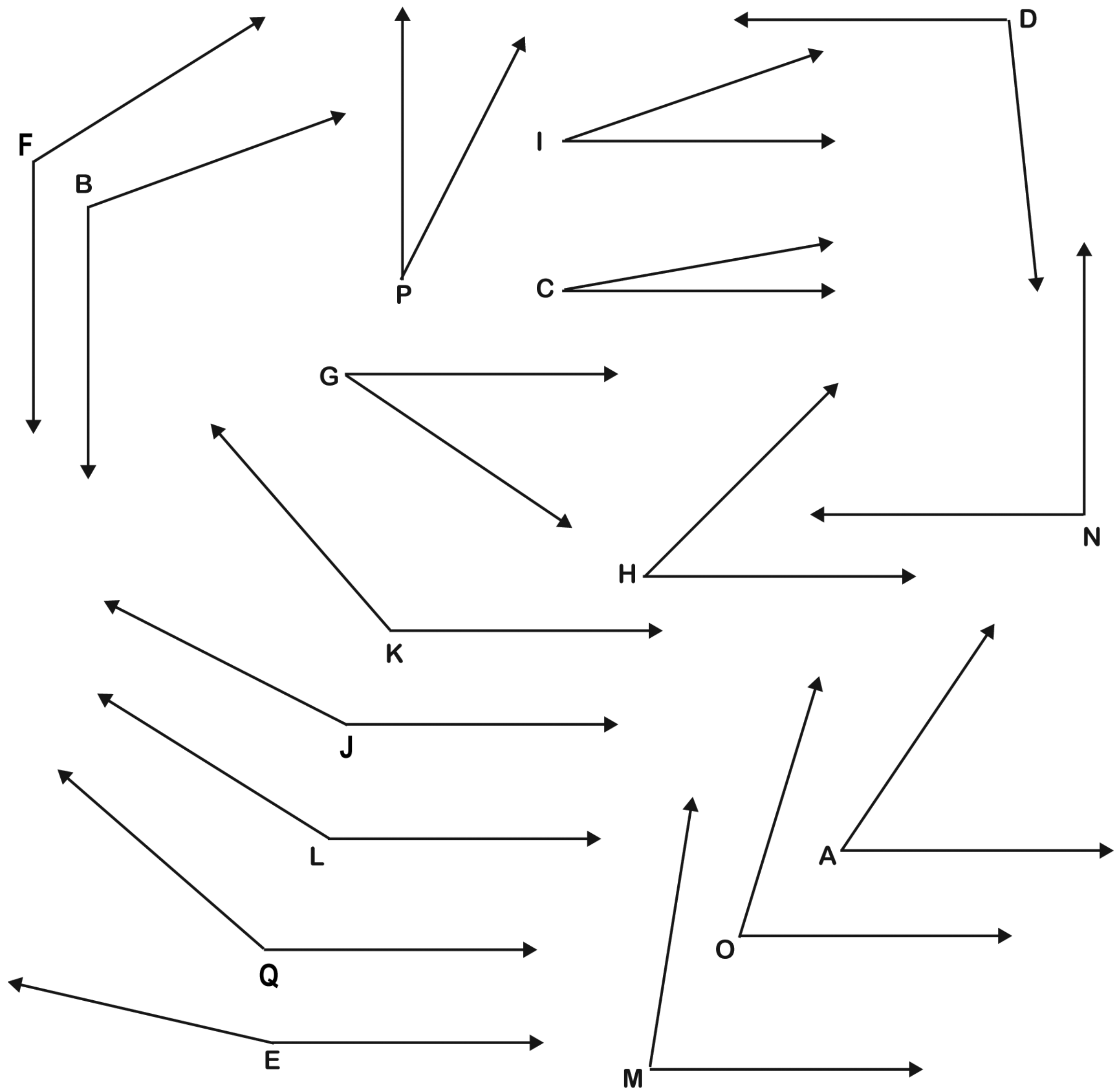


The subtractive primary colors are cyan, magenta, and yellow.

Name: ______________________________ Date: __________

25.3 Measuring Angles with a Protractor

Measure each of these angles (A - Q) with a protractor. Record the angle measurements in the table below.



Letter	Angle	Letter	Angle
A		J	
B		K	
C		L	
D		M	
E		N	
F		O	
G		P	
H		Q	
I			

Name: ______________________ Date: __________

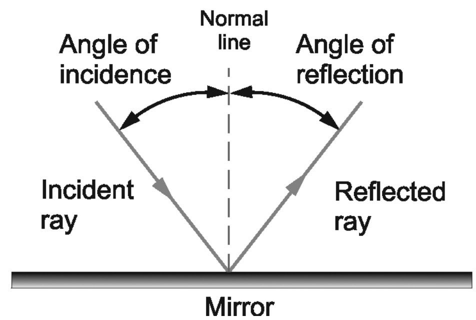
25.3 Reflection

READ

You have seen the law of reflection at work using light and the smooth surface of a mirror. Did you know you can apply this law to other situations? It can help you win a game of pool or pass a basketball to a friend on the court.

In this skill sheet you will review the law of reflection and work on practice problems that utilize this law. Use a protractor to make your angles correct in your diagrams.

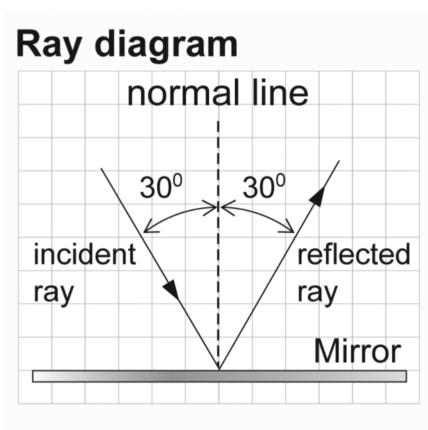
The law of reflection states that when an object hits a surface, its angle of incidence will equal the angle of reflection. This is true when the object is light and the surface is a flat, smooth mirror. When the object and the surface are larger and lack smooth surfaces (like a basketball and a gym floor), the angles of incidence and reflection are nearly but not always exactly equal. The angles are close enough that understanding the law of reflection can help you improve your game.



EXAMPLE

A light ray strikes a flat mirror with a 30-degree angle of incidence. Draw a ray diagram to show how the light ray interacts with the mirror. Label the normal line, the incident ray, and the reflected ray.

Solution:



PRACTICE

1. When we talk about angles of incidence and reflection, we often talk about the normal. The normal to a surface is an imaginary line that is perpendicular to the surface. The normal line starts where the incident ray strikes the mirror. A normal line is drawn for you in the sample problem above.

   a. Draw a diagram that shows a mirror with a normal line and a ray of light hitting the mirror at an angle of incidence of 60 degrees.

   b. In the diagram above, label the angle of reflection. How many degrees is this angle of reflection?

2. Light strikes a mirror's surface at 20 degrees to the normal. What will the angle of reflection be?

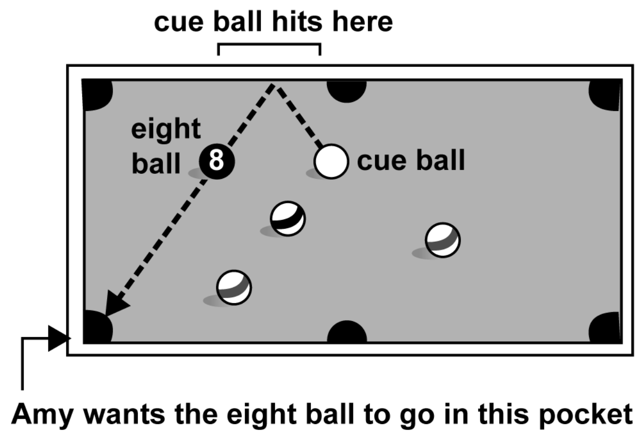
3. A ray of light strikes a mirror. The angle formed by the incident ray and the reflected ray measures 90 degrees. What are the measurements of the angle of incidence and the angle of reflection?

4. In a game of basketball, the ball is bounced (with no spin) toward a player at an angle of 40 degrees to the normal. What will the angle of reflection be? Draw a diagram that shows this play. Label the angles of incidence and reflection and the normal.

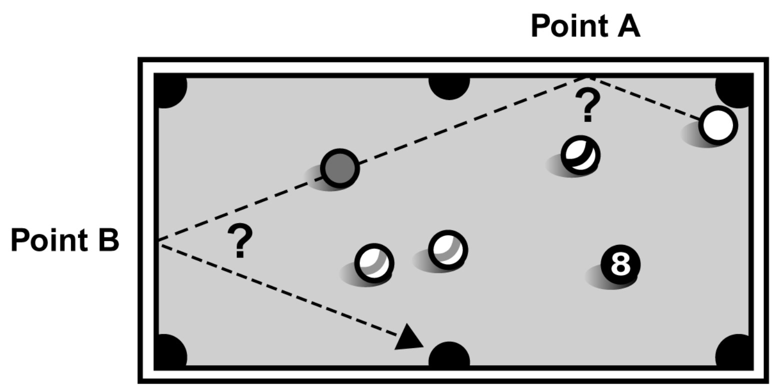
Challenge Questions:

Use a protractor to figure out the angles of incidence and reflection for the following problems.

5. Because a lot of her opponent's balls are in the way for a straight shot, Amy is planning to hit the cue ball off the side of the pool table so that it will hit the 8-ball into the corner pocket. In the diagram, show the angles of incidence and reflection for the path of the cue ball. How many degrees does each angle measure?



6. You and a friend are playing pool. You are playing solids and he is playing stripes. You have one ball left before you can try for the eight ball. Stripe balls are in the way. You plan on hitting the cue ball behind one of the stripe balls so that it will hit the solid ball and force it to follow the pathway shown in the diagram. Use your protractor to figure out what angles of incidence and reflection are needed at points A and B to get the solid ball into the far side pocket.



Name: ______________________________ Date: __________

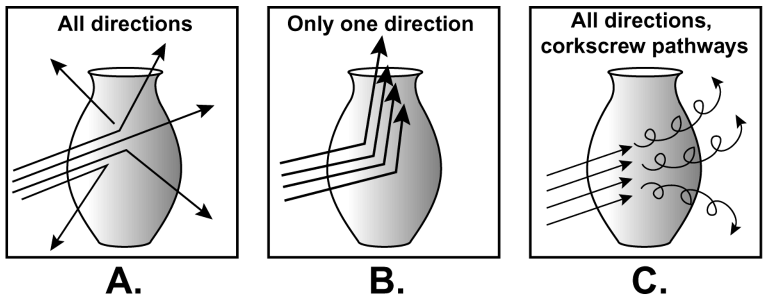
25.3 Using Ray Diagrams

READ

This skill sheet gives you some practice using ray diagrams. A ray diagram helps you determine where an image produced by a lens will form and shows whether the image is upside down or right side up.

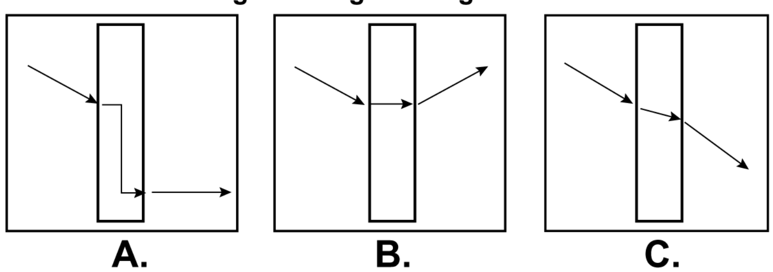
PRACTICE

1. Of the diagrams below, which one correctly illustrates how light rays come off an object? Explain your answer.



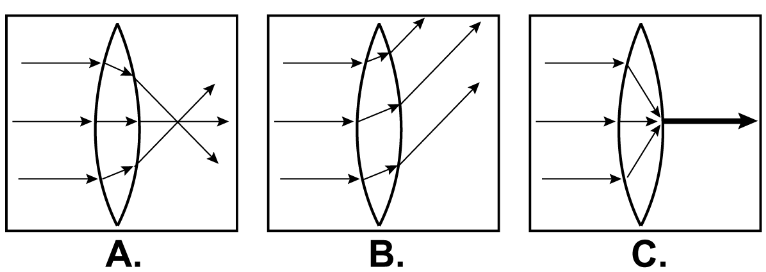
2. Of the diagrams below, which one correctly illustrates how a light ray enters and exits a piece of thick glass? Explain your answer.

Light through thick glass



In your own words, explain what happens to light as it enters glass from the air. Why does this happen? Use the term *refraction* in your answer.

3. Of the diagrams below, which one correctly illustrates how parallel light rays enter and exit a converging lens? Explain your answer.



4. Draw a diagram of a converging lens that has a focal length of 10 centimeters. In your diagram, show three parallel lines entering the lens and exiting the lens. Show the light rays passing through the focal point of the lens. Be detailed in your diagram and provide labels.

Name: ________________________________ Date: __________

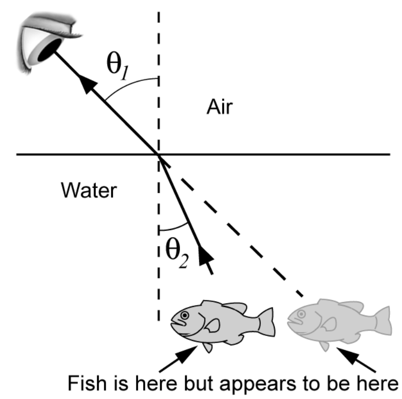
25.3 Refraction

CHALLENGE! 25.3

When light rays cross from one material to another they bend. This bending is called **refraction**. Refraction is a useful phenomenon. All kinds of optics, from glasses to camera lenses to binoculars depend on refraction.

READ

If you are standing on the shore looking at a fish in a stream, the fish appears to be in a slightly different place than it really is. That's because light rays that bounce off the fish are refracted at the boundary between water and air. If you are a hunter trying to spear this fish, you better know about this phenomenon or the fish will get away.



Why do the light rays bend as they cross from water into air?

A light ray bends because light travels at different speeds in different materials. In a vacuum, light travels at a speed of 3×10^8 m/s. But when light travels through a material, it is absorbed and re-emitted by each atom or molecule it hits. This process of absorption and emission slows the light ray's speed. We experience this slowdown as a bend in the light ray. The greater the difference in the light ray's speed through two different materials, the greater the bend in the path of the ray.

The *index of refraction* (*n*) for a material is the ratio of the speed of light in a vacuum to the speed of light in the material.

$$\text{Index of refraction} = \frac{\text{speed of light in a vacuum}}{\text{speed of light in a material}}$$

The index of refraction for some common materials is given below:

Material	Index of refraction (*n*)
Vacuum	1.0
Air	1.0001
Water	1.33
Glass	1.5
Diamond	2.42

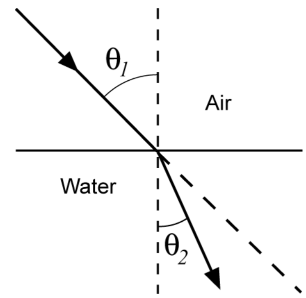
1. Could the index of refraction for a material ever be less than 1.0? Explain.
2. Explain why the index of refraction for air (a gas) is smaller than the index of refraction for a solid like glass.
3. Calculate the speed of light in water, glass, and diamond using the index of refraction and the speed of light in a vacuum (3×10^8 m/s).
4. When a light ray moves from water into air, does it slow down or speed up?
5. When a light ray moves from water into glass, does it slow down or speed up?

READ

CHALLENGE!

25.3

Which way does the light ray bend?



Now let's look at some ray diagrams showing refraction. To make a refraction ray diagram, draw a solid line to show the boundary between the two materials (water and air in this case). Arrows are used to represent the incident and refracted light rays. The normal is a dashed line drawn perpendicular to the boundary between the surfaces. It starts at the point where the incident ray hits the boundary.

As you can see, the light ray is bent *toward* the normal as it crosses from air into water. Light rays always bend toward the normal when they move from a low-*n* to a high-*n* material. The opposite occurs when light rays travel from a high-*n* to a low-*n* material. These light rays bend away from the normal.

The amount of bending that occurs depends on the difference in the index of refraction of the two materials. A large difference in *n* causes a greater bend than a small difference.

1. A light ray moves from water (n = 1.33) to a transparent plastic (polystyrene n = 1.59). Will the light ray bend toward or away from the normal?

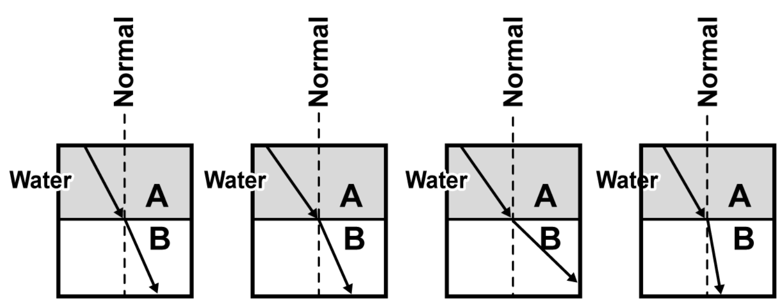
2. A light ray moves from sapphire (n = 1.77) to air (n = 1.0001). Does the light ray bend toward or away from the normal?

3. Which light ray will be bent more, one moving from diamond (n = 2.42) to water (n = 1.33), or a ray moving from sapphire (n = 1.77) to air (n = 1.0001)?

4.

Material	Index of refraction (n)
Helium	1.00004
Water	1.33
Emerald	1.58
Cubic Zirconia	2.17

The diagrams below show light traveling from water (A) into another material (B). Using the chart above, label material B for each diagram as helium, water, emerald, or cubic zirconia.



Name: ______________________ Date: __________

CHALLENGE! 25.3

25.3 Drawing Ray Diagrams

READ

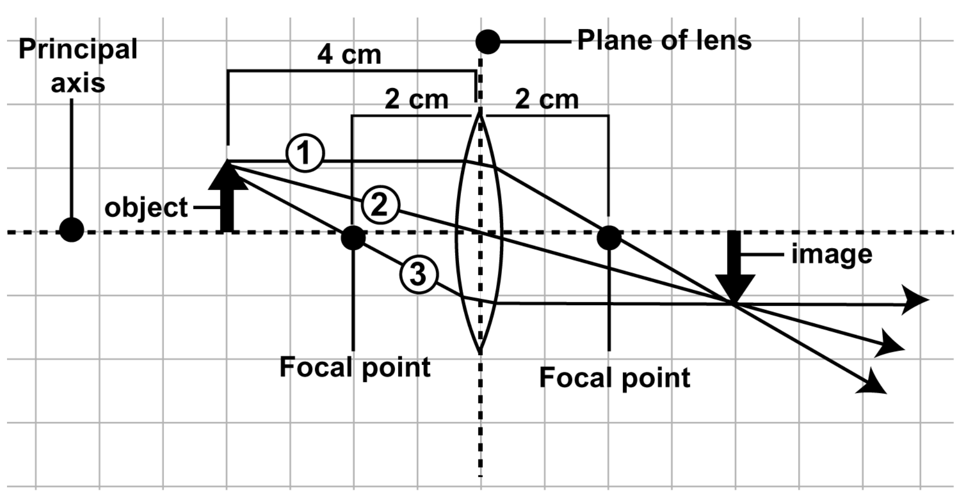
A ray diagram helps you see where the image produced by a lens appears. The components of the diagram include the lens, the principal axis, the focal point, the object, and three lines drawn from the tip of the object and through the lens. These light rays meet at a point and intersect on the other side of the lens. Where the light rays meet indicates where the image of the object appears.

EXAMPLE

A lens has a focal length of 2 centimeters. An object is placed 4 centimeters to the left of the lens. Follow the steps to make a ray diagram using this information. Trace the rays and predict where the image will form.

Steps:

- Draw a lens and show the principal axis.
- Draw a line that shows the plane of the lens.
- Make a dot at the focal point of the lens on the right and left sides of the lens.
- Place an arrow (pointing upward and perpendicular to the principle axis) at 4 centimeters on the left side of the lens.
- **Line 1:** Draw a line from the tip of the arrow that is parallel to the principal axis on the left, and that goes through the focal point on the right of the lens.
- **Line 2:** Draw a line from the tip of the arrow that goes through the center of the lens (where the plane and the principal axis cross).
- **Line 3:** Draw a line from the tip of the arrow that goes through the focal point on the left side of the lens, through the lens, and parallel to the principal axis on the right side of the lens.
- Lines 1, 2, and 3 converge on the right side of the lens where the tip of the image of the arrow appears.
- The image is upside down compared with the object.



PRACTICE

1. A lens has a focal length of 4 centimeters. An object is placed 8 centimeters to the left of the lens. Trace the rays and predict where the image will form. Is the image bigger, smaller, or inverted as compared with the object?

2. **Challenge question:** An arrow is placed at 3 centimeters to the left of a converging lens. The image appears at 3 centimeters to the right of the lens. What is the focal length of this lens? (HINT: Place a dot to the right of the lens where the image of the tip of the arrow will appear. You will only be able to draw lines 1 and 2. Where does line 1 cross the principal axis if the image appears at 3 centimeters?)

3. What happens when an object is placed at a distance from the lens that is less than the focal length? Use the term *virtual image* in your answer.