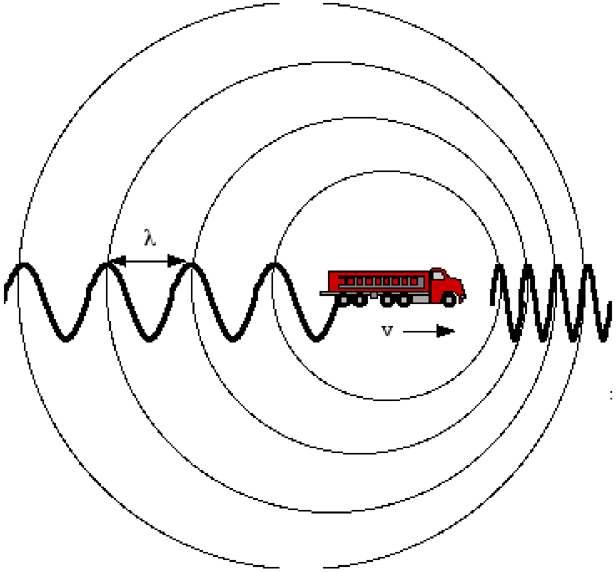
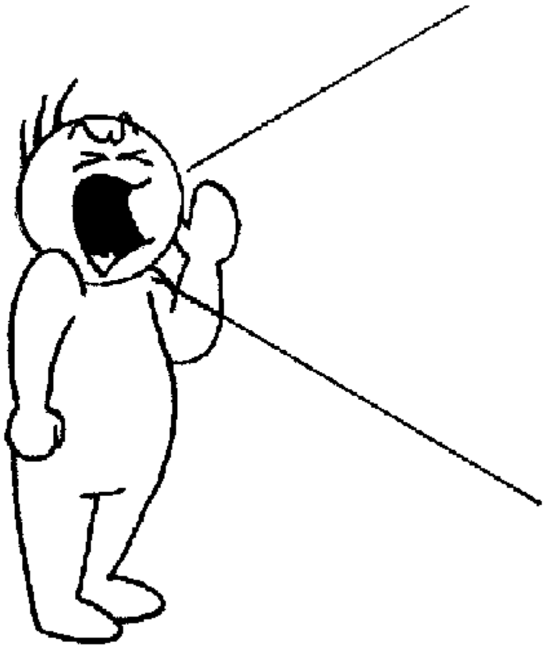
# PHYSICS 2204

## UNIT 4: Section 2

## Sound Waves and Electromagnetic Radiation





**Section 2 Topic 1**

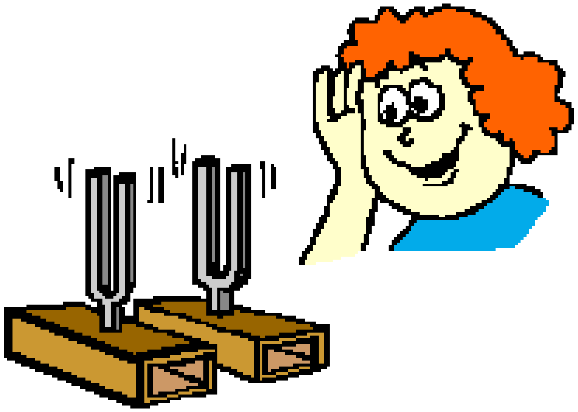
- Production and Transmission of Sound Waves

Text: Section

# Sound Waves

- The basis for an understanding of sound, music and hearing is the physics of waves.

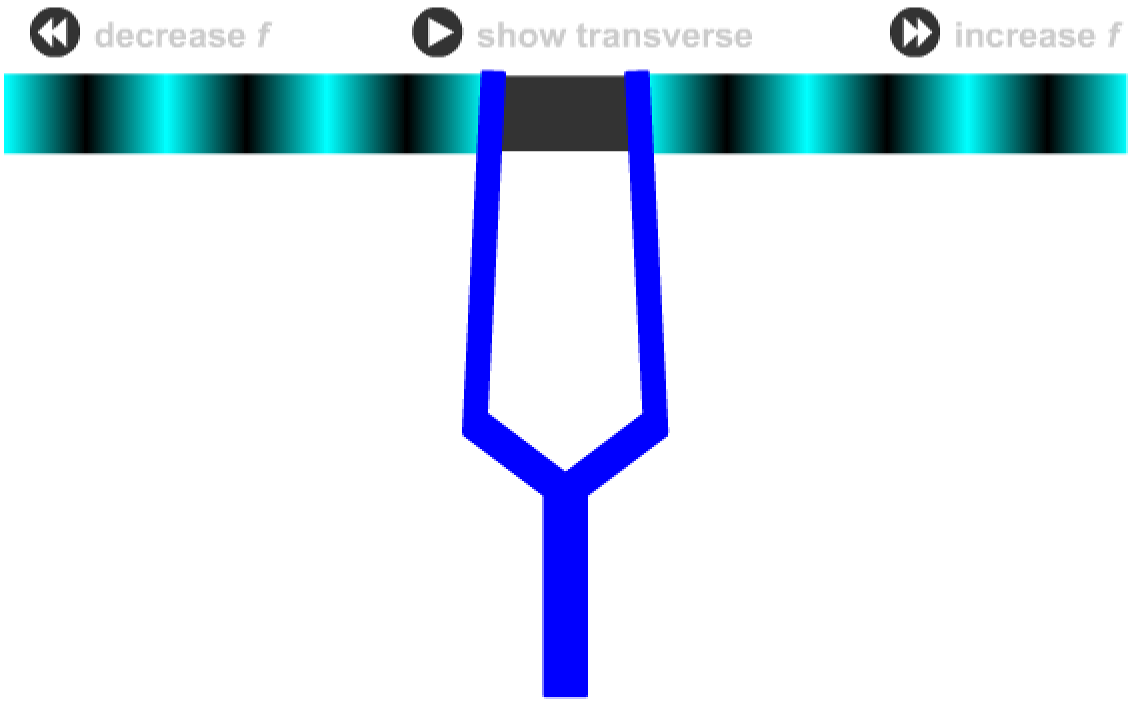
- Sound is a wave which is created by vibrating objects and propagated through a medium from one location to another.



- Humans cannot hear all vibrations.

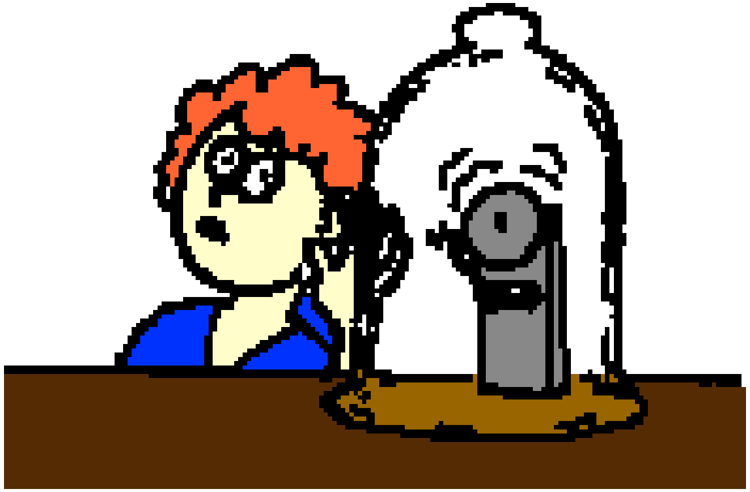
- vibrations  smaller than 20 cycles/s or 20 Hz
- vibrations larger than 20,000 Hz ( certain whistles)
- Thus the range of human ear is 20 – 20, 000 Hz

A popular "sound maker" in a physics laboratory is the tuning fork




- As the tines of the tuning forks vibrate back and forth, they begin to disturb surrounding air molecules. The air molecules are being compressed into COMPRESSIONS and rarefied into RAREFACTIONS. These disturbances are passed on to adjacent air molecules by the mechanism of particle interaction.

- Unlike light, SOUND NEEDS A MEDIUM TO TRAVEL IN.
- Sound cannot travel through a vacuum.



The sound produced by the bell cannot be heard since sound cannot travel through a vacuum.

- Although there are exceptions, it can be generally said that sound travels fastest in certain solids, less rapidly in many liquids, and quite slowly in most gases.

Speed of Sound in Some Materials
(normal atmospheric pressure)

| | | |
|---|---|---|
| air ($20^{o}$ C)<br>344 m/s | air ($0^{o}$ C)<br>332 m/s | helium ($20^{o}$ C)<br>1005 m/s |
| water (pure)<br>1440 m/s | water (seawater)<br>1560 m/s | iron<br>5000 m/s |

- sound travels faster in warm air than in cold air. The molecules of warm air are moving faster (have more kinetic energy), a feature which promotes the transmission of the compressions and rarefactions.

- The speed of sound can be determined at ANY temperature, $T$, by the equation.

$$v = (332 + 0.6\,T) \quad \text{m/s}$$

# Example 1

rew step

According to the formula, what would be the speed of sound in air at $15^{o}$ C?

Read the question

List the givens

Plan a strategy

Carry out the plan

Communicate

# Example 2

rew step

Suppose that you measured the speed of sound in air to be 348.8 m/s. According to the formula, what air temperature would this correspond to?

Read the question

List the givens

Plan a strategy

Carry out the plan

Communicate

## Infra - and Ultra-sonic

- Frequencies lower than 20-25 Hz are called **infrasonic** because their frequency is too low to be audible.

- Usually, when referring to sounds of different frequency we use the word pitch instead of the word frequency. Pitch is the effect of frequency on our ears. A high frequency sound has a high pitch. A low frequency sound has a low pitch.

- Sound frequencies that are beyond the range of human hearing, i.e., beyond 20,000 Hz, are called **ultrasonic frequencies.**

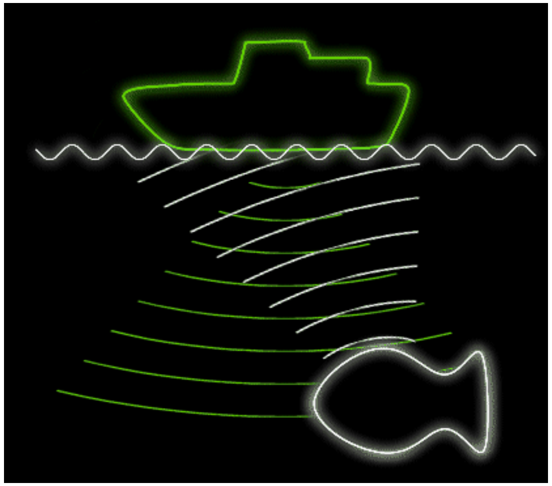
- The typical frequency range of human hearing is 20 Hz to 20,000 Hz. Strictly . Therefore, we can not hear **infrasonic** or **ultrasonic frequencies.**

## Sonar

Sonar stands for SOund NAvigation Ranging. It is used in navigation, forecasting weather, and for tracking aircraft, ships, submarines, and missiles.

Sonar devices work by bouncing sound waves off objects to determine their location. A sonar unit consists of an ultrasonic transmitter and a receiver.

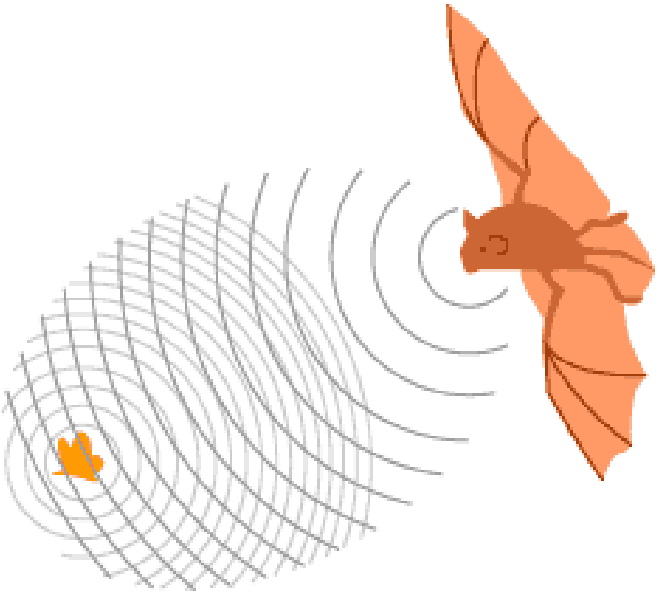
To measure water depth, for instance, the transmitter sends out a short pulse of sound, and later, the receiver picks up the reflected sound. The water depth is determined from the time elapsed between the emission of the ultrasonic sound and the reception of its reflection off the sea-floor.

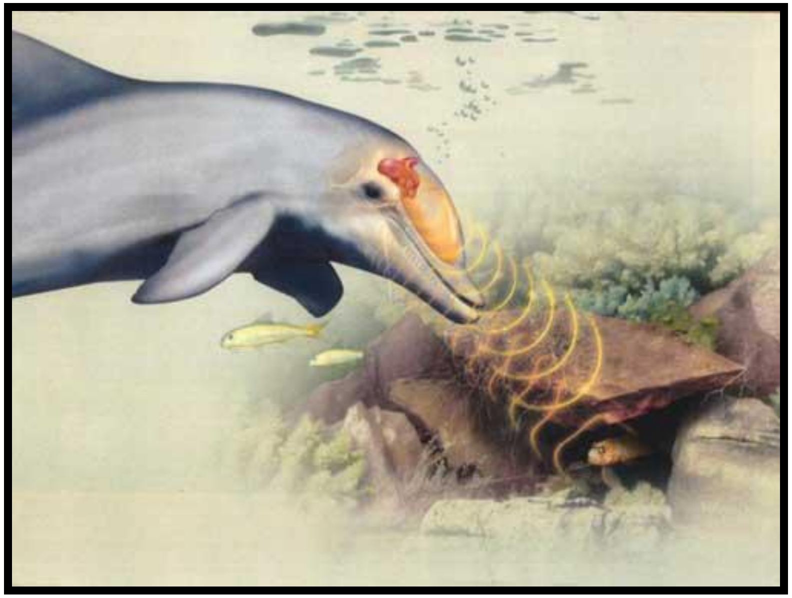


## Echolocation

In 1944, Donald R. Griffin coined the term echolocation. Echolocation is the use of echoes of sound produced by certain animals to detect obstacles and food.  Some of these animals are bats, porpoises, some kinds of whales, several species of birds, and some shrews.

The first step in echolocation is emitting a sound.  Then, a highly refined auditory system detects the returning echoes (the sounds that bounced of the object) and determines the position of the object.

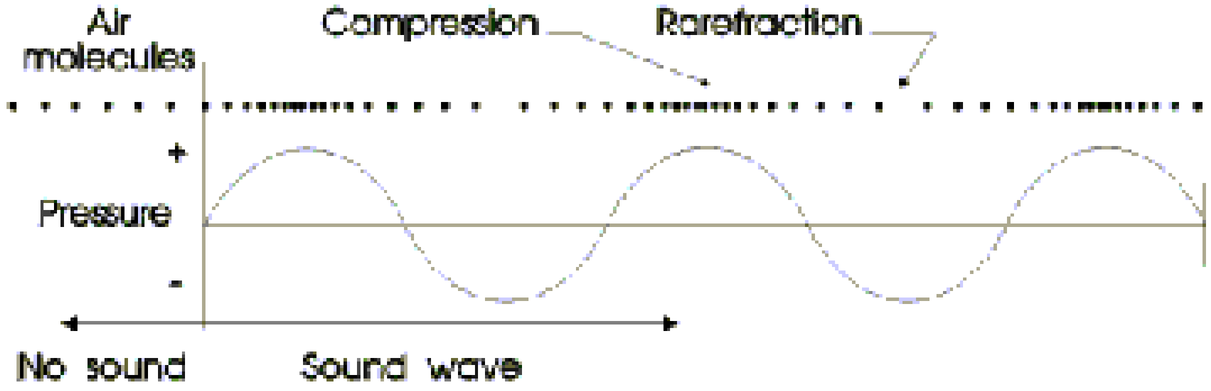




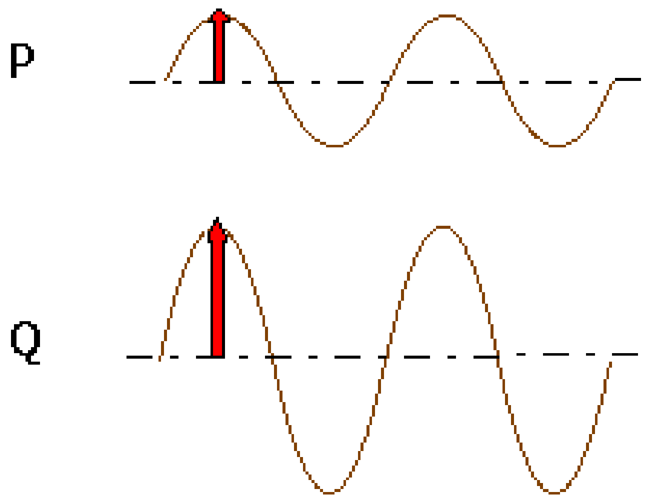
## The physics of sound:

Sound waves are longitudinal but for simplification we will show them as a transverse wave.   We will represent the crests as compressions and the troughs as rarefactions.

Why do you think some sounds are different?



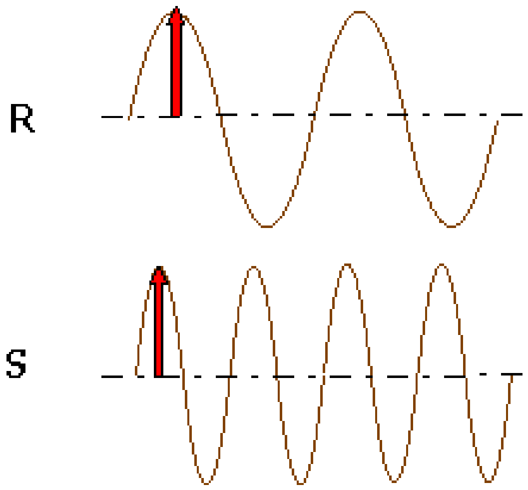
# Intensity




- P and Q have the same frequency (just count the wavelengths) but the volume or intensity of Q is twice that of P.
- Volume (intensity) depends on amplitude

This could represent a trumpet playing the same note but Q is much louder

# Pitch

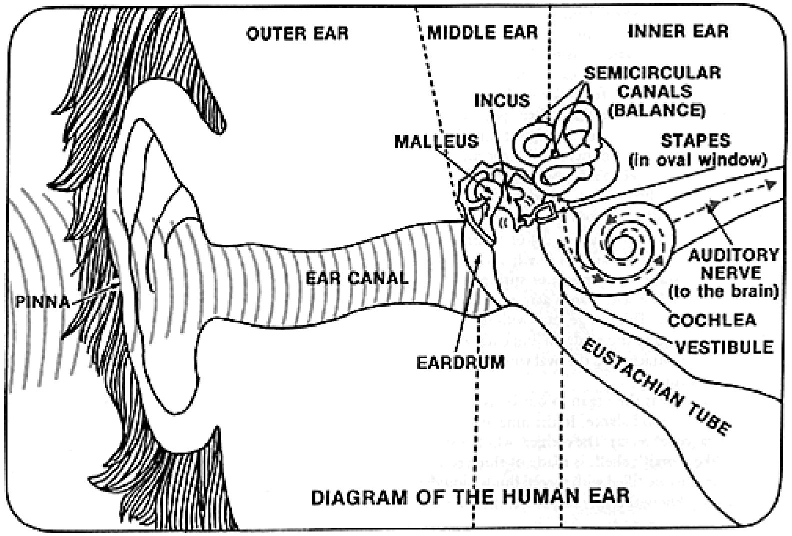



- Sounds R and S have the same volume or intensity but the frequency if S is twice that of R

- Sound R could represent a sound from a tuba and sound S  could be a sound from a piccolo-  they are both being played at the same intensity but have a different pitch.
- Pitch depends on frequency

## What determines how loud we perceive a sound to be?

- Loudness will depend on both the intensity and pitch of the sound. Frequencies between 1000 Hz and 5000 Hz are perceived to be louder than any other frequencies. This has something to do with the shape of the ear canal leading into our ear drums. The shape of the canal is such that the frequency range 1000 Hz - 5000 Hz is amplified more than any other frequencies.

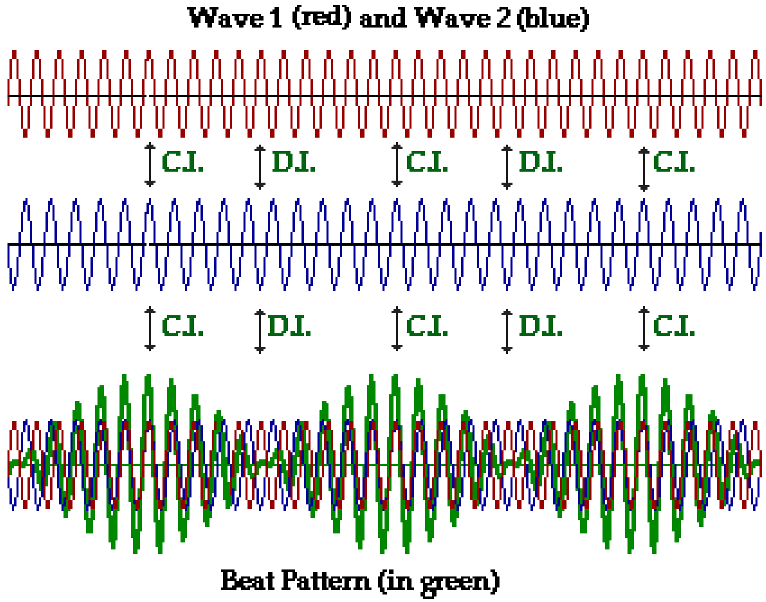



- In an orchestra you will perceive the flute to be louder than a tuba. Our ears are more sensitive to the higher frequency sound of the flute than they are to the lower frequency of the tuba.

# Beats

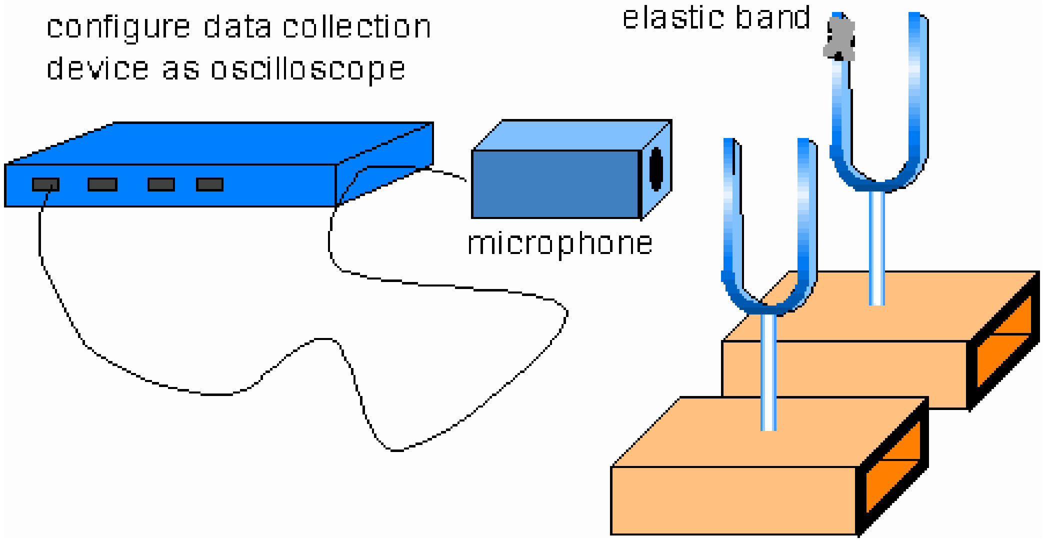
- If you use two identical tuning forks, and strike both forks at the same time, you will hear the steady hummmmmmmmm. However if we make one tuning fork slightly out of tune with the other and strike both forks again. You will hear a hum-hum-hum-hum sound that is produced when two sounds are almost identical. This sound is known as beats. The more "out-of-tune" the forks the faster the beats will be. There will be more hum-hums per second.

- Beats are the periodic and repeating fluctuations heard in the intensity of a sound when two sound waves of very similar frequencies interfere with one another.

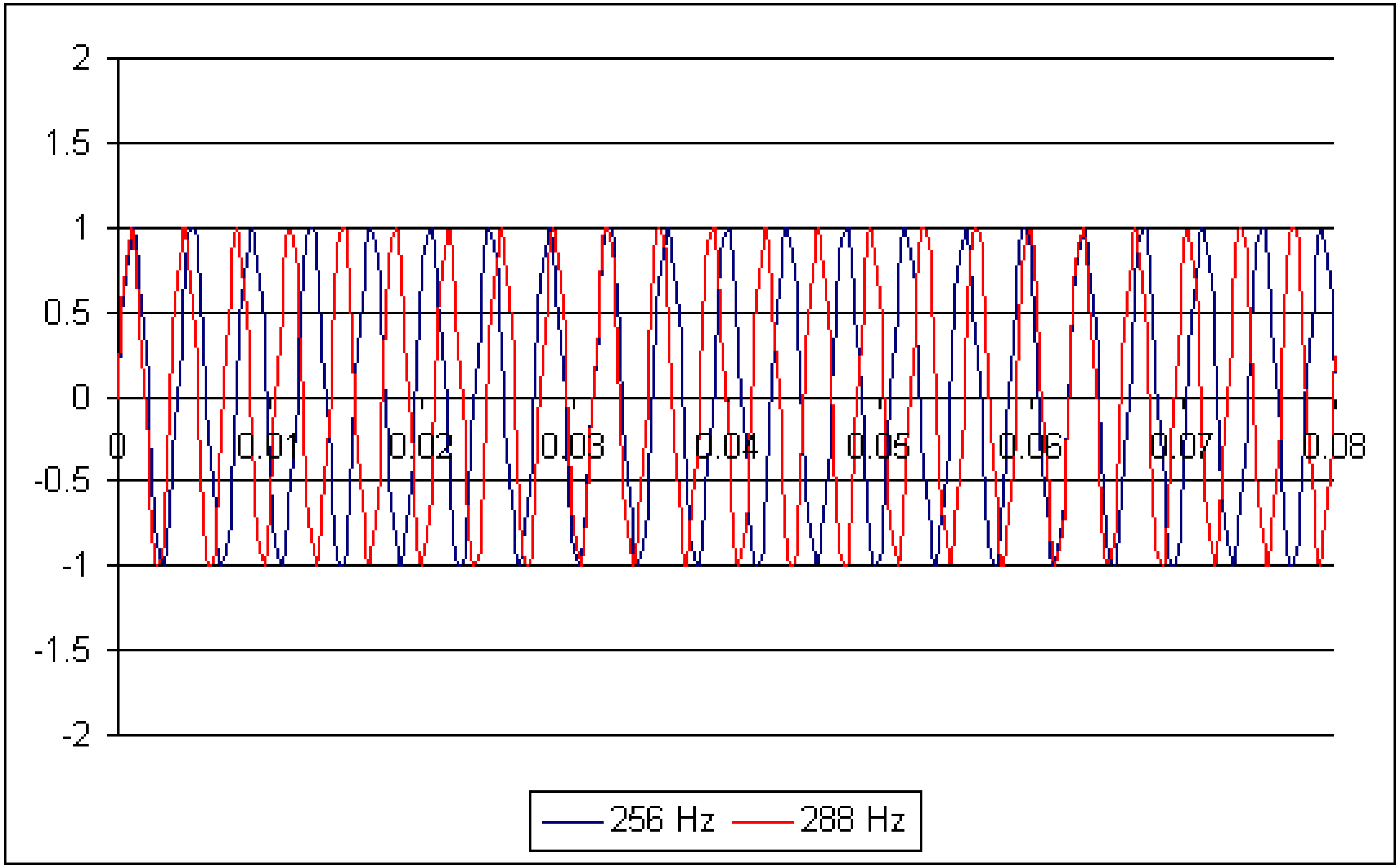


# Why do beats occur?

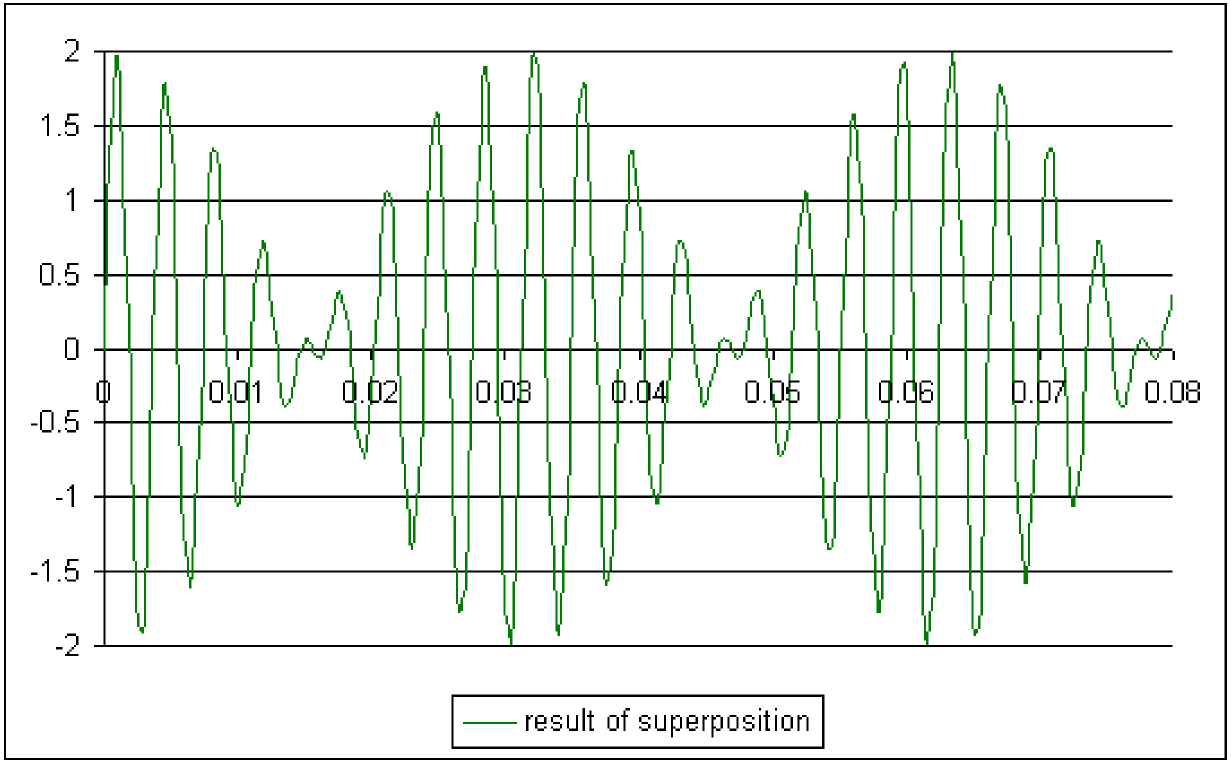
- The picture below shows an apparatus than can be used to graphically display beats. Two identical tuning forks are placed on stands than can resonate. A rubber band is attached to one fork to make it slightly more massive. The fork therefore vibrates with a slightly lower frequency.



- Look at the two waves in the picture below. Notice that the two wavelengths are unequal. The blue trace shows the waves of a 256 Hz sound and the red trace shows the waves of a 288 Hz sound.



- The graph below shows the result when the displacements are added. Notice that some times the waves were in phase and the result was constructive interference. At other times the waves were out of phase and the result was destructive interference.



## Beat Frequency

- ***the greater the difference between the frequency of the two sounds, the greater the frequency of the beats.***

- beat frequency refers to the rate at which the volume is heard to be oscillating from high to low volume.
- When two sounds of frequencies 256 Hz and 288 Hz are heard together, you hear 32 beats in 1 second. In other words the frequency of the beats, or the beat frequency is 32 per second or 32 Hz.

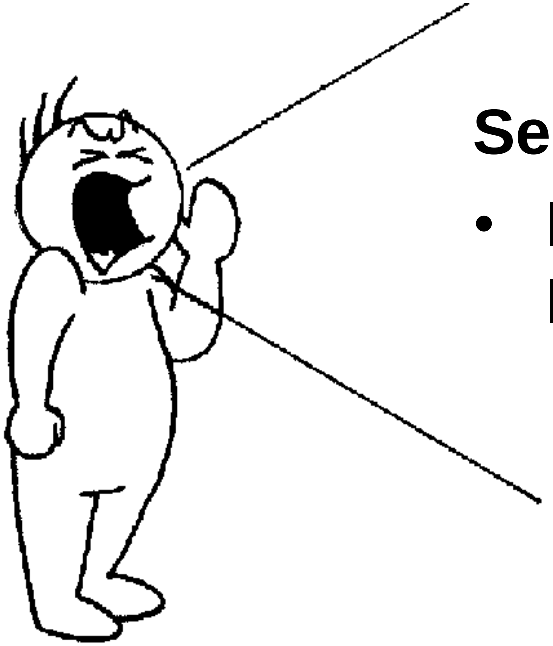
  - the beat frequency is equal to the difference of the two original frequencies.
  - Beat frequency = $f_1 - f_2$

# Activity

- Read Text Pages: 444 - 459

- Extra Practice Questions:
- Text 453--#1-#3
  p. 458--#1-#2
  p. 477--#1-#10, #21
  p. 478--#33-#43
  p. 511--#1

- Worksheet: Production and Transmission of Sound Waves

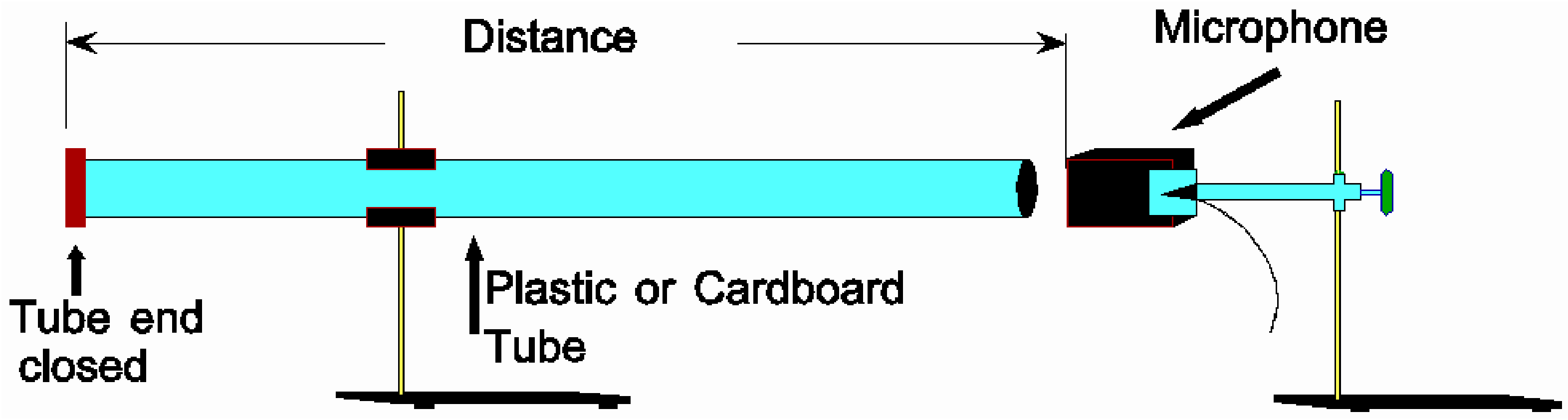


**Section 2 Topic 2**

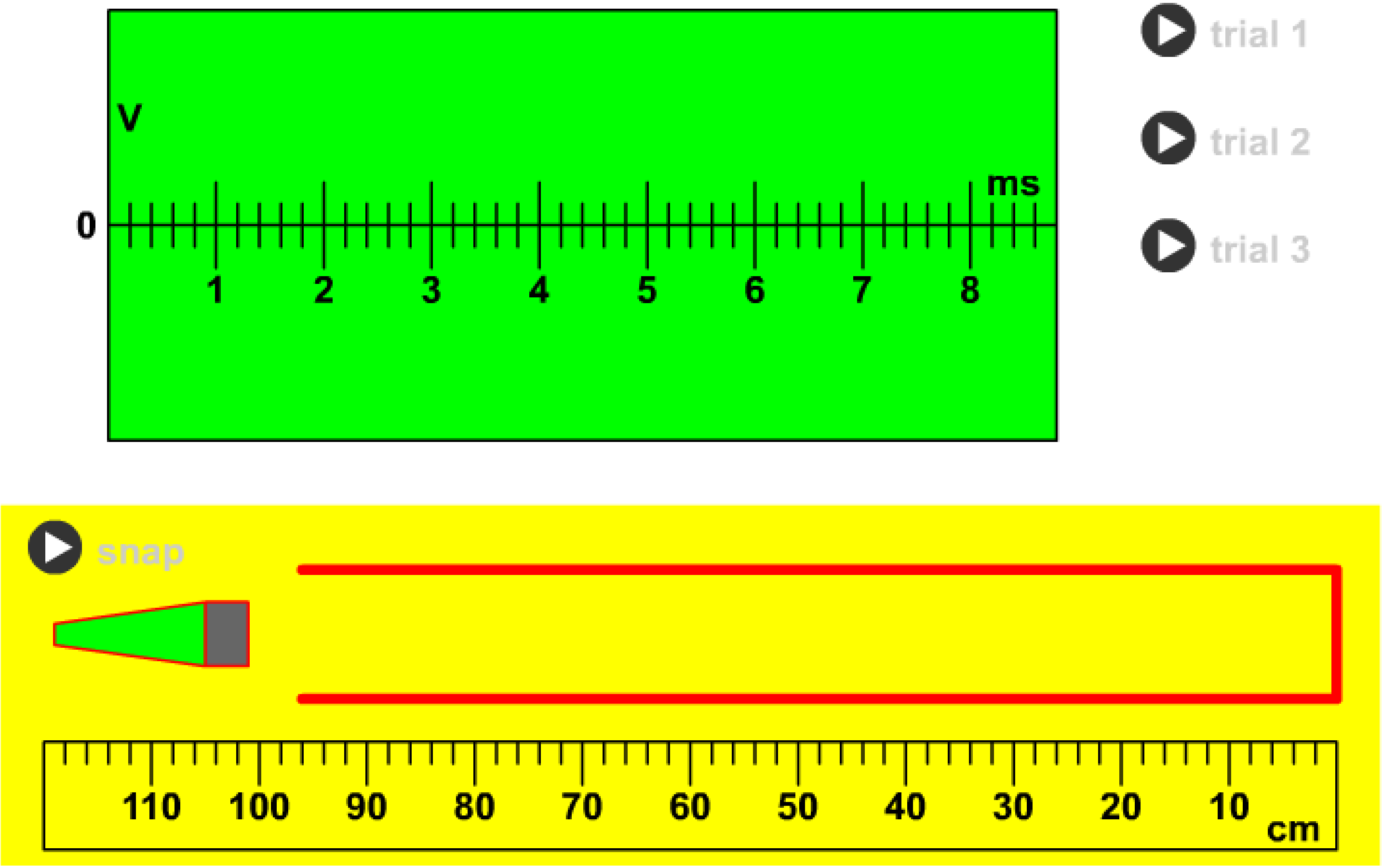
- Measuring the Speed of Sound using Echoes

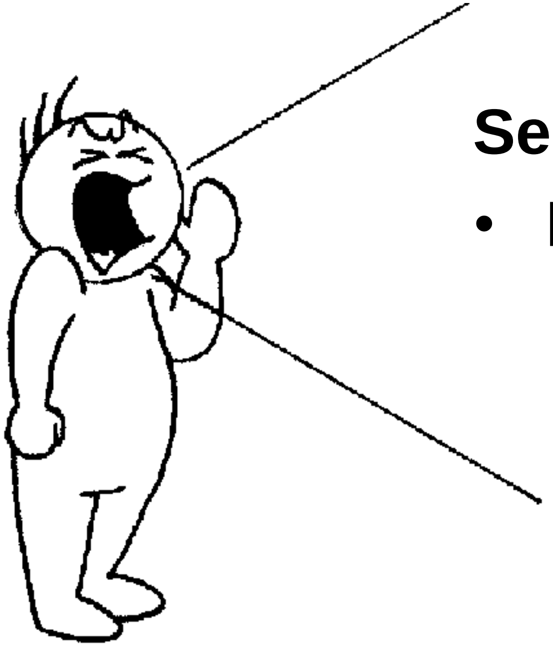
Text: Section

- Echoes can be used to measure the speed of sound in air. The principle is quite simple -make a noise and measure the amount of time that elapses before you hear the echo. One-half of this measured value is therefore the time that the sound required to reach the object that produced the echo. The time, along with the distance to the object, can then be used to determine the speed of sound.



- Use the on-screen ruler and the time (milliseconds) for the echo to determine the speed of sound.  Be sure to average the 3 trials.





**Section 2 Topic 3**

- Resonance of sound

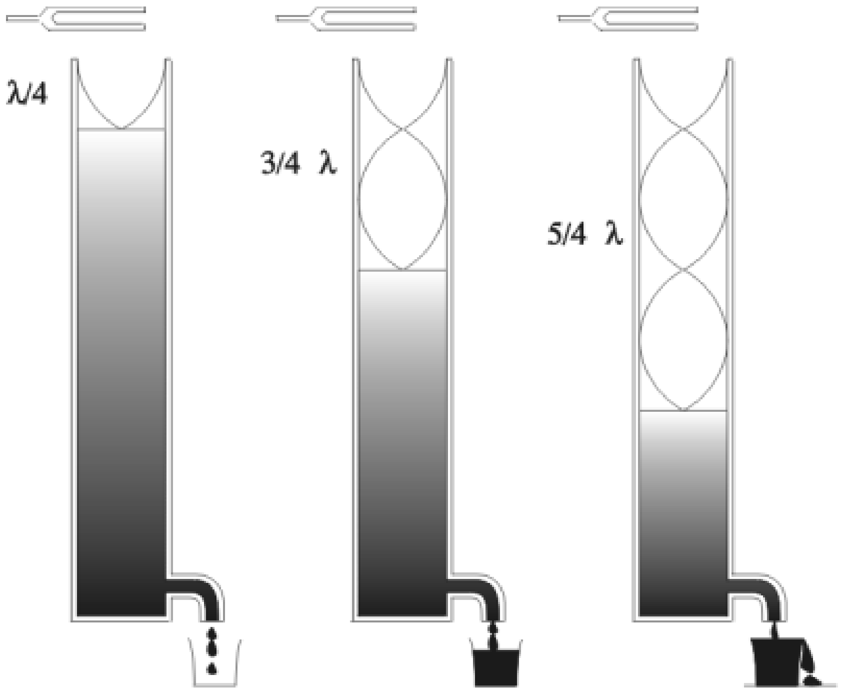
Text: Section

# Resonance Of Sound

## Topic 1: Resonance in a Tube Open at One End

- Picture a long pipe filled with water which can be drained through a tube in the bottom. Hold a vibrating tuning fork over the mouth of the pipe while at the same time allowing the water to drain from the pipe. At certain points as the water falls, the hum of the tuning fork becomes much louder.

- **What can be happening?**



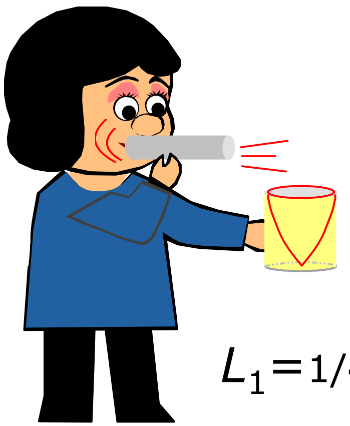
## What can be happening?

- In the pipe there are TWO waves. One is leaving the fork and going down; the other is the reflected wave coming back from the bottom of the pipe. These two waves will interfere with each other. Where the two waves interfere constructively, the air molecules will have a large displacement from their ordinary "rest" positions. Where air molecules are not so free to move they will interfere destructively.

- The length of the air column of this first resonant length is 1/4 of the wavelength of the sound from the fork.

  - As the water drains further and further, different antinodes are created at the mouth of the pipe, BUT ONLY AT THE PARTICULAR LENGTHS AS SHOWN. These resonant lengths are 3/4, 5/4,7/4 (and so on) of the wavelength of the sound.

## We can use two formula's to determine the length and wavelength for each resonant frequency in a Tube Open at One End



$L_1 = 1/4\ \lambda$

$L_2 = 3/4\ \lambda$

$L_3 = 5/4\ \lambda$

$$L_n = \frac{2n-1}{4}\lambda \quad \text{or}$$

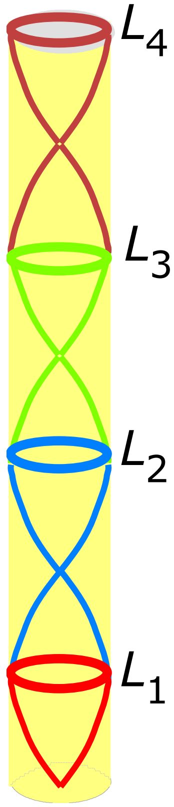
$$\lambda = \frac{4L_n}{2n-1}$$

Note that the expression $(2n - 1)$ always has an "odd" value for tubes closed at one end.

# Example 1: Making Music in the Woods

On a nice summer day when the temperature is 23° C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?

Draw a picture:




The first 4 resonant lengths for a tube closed at one end.

Remember the resonance formula for a tube closed at one end:

$$L_n = \frac{2n-1}{4}\lambda \quad \text{or} \quad \lambda = \frac{4L_n}{2n-1}$$

# Example 1: Making Music in the Woods

On a nice summer day when the temperature is 23° C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?

Given: $T = 23^{o}$ C
$L_4 = 29$ cm $= 0.29$ m
$n = 4$ $f = ?$

Solution:

Step 1—find speed of sound:

$$\begin{aligned} v &= [332 + 0.6T] \text{ m/s} \\ &= [332 + 0.6 \times 23] \text{ m/s} \\ &= [332 + 14] \text{ m/s} \\ &= 346 \text{ m/s} \end{aligned}$$

Step 2—find $\lambda$:

$$\begin{aligned} \lambda &= \frac{4L_4}{2n-1} \\ &= \frac{4 \text{x} 0.29 \text{ m}}{2\text{x}4 - 1} \\ &= \frac{1.2 \text{ m}}{7} = 0.17 \text{ m} \end{aligned}$$

Step 3—find $f_4$:

$$f = \frac{v}{\lambda} = \frac{346 \text{ m/s}}{0.17 \text{ m}} = 2035 \text{ /s} = 2.0 \text{ kHz}$$

Some lips!!

## Example 2: Impressing Grandpa

You decide to impress Grandpa but showing him how fast sound travels. You have a piece of plastic pipe with an adjustable closed end, and a 312 Hz tuning fork. The piece of pipe resonates in the 2nd resonant length when it is adjusted to a length of 81.0 cm. What is the speed of sound on that day?

Given:

$f$ = 312 Hz

$L_2$ = 81 cm = 0. 810 m

$n$ =2 $v$ = ?

Solution:

Step 1—find λ:

$$\lambda = \frac{4L_2}{2n-1} = \frac{4 \text{ x } 0.810\,\text{m}}{2\text{x}2 - 1} = \frac{3.24\,\text{m}}{3} = 1.08\,\text{m}$$

Step 2—find $v$:

$$v = f\lambda = 312\,\text{Hz}\; x\; 1.08\,\text{m} = 312\,/\text{s}\; x\; 1.08\,\text{m} = 337\,\text{m/s}$$

The speed of sound is 337 m/s

# Example 3: Really Impressing Grandpa

Tell Grandpa you are going to use the piece of plastic pipe in example 2 to measure the air temperature.

Given:

$v$ = 337 m/s

$T$ = ?

Solution:

Step 1—find $T$:

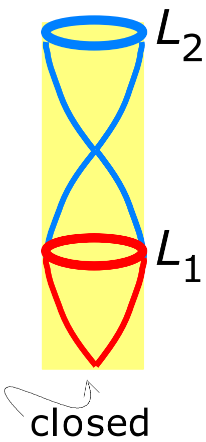
$$\begin{aligned} v &= [332 + 0.6T]\ \text{m/s} \\ 337\ \text{m/s} &= [332 + 0.6\,T]\ \text{m/s} \\ 337 &= 332 + 0.6\,T \\ 337 - 332 &= 0.6\,T \\ T &= \frac{337 - 332}{0.6} = \frac{5}{0.6} \\ T &= 8.3\,^{\circ}C \end{aligned}$$

The air temperature is 8.3° C.

# Example 4: Where the Length is the unknown

On a day when the speed of sound is 345 m/s, a 440 Hz tuning fork causes a tube closed at one end to vibrate in the second resonant length. How long is the tube?

Picture




Given:

$v = 345$ m/s

$f = 440$ Hz

$n = 2$

$L_2 = ?$

Solution:

Step 1—find $\lambda$:

$$\lambda = \frac{v}{f} = \frac{345}{440} = 0.78\,\mathrm{m}$$

Step 2—find $L_2$:

$$L_n = \frac{2n-1}{4}\lambda$$

$$L_2 = \frac{2x2-1}{4} \text{ x } 0.78\,\mathrm{m}$$

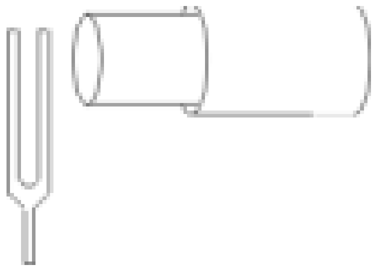
$$L_2 = \frac{3}{4} \text{x } 0.78\,\mathrm{m} = 0.59\,\mathrm{m}$$

The tube is 59 cm long.

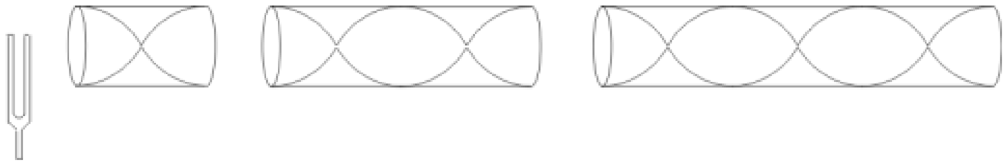
## Resonance in Tubes Open at Both Ends

- If you roll two pieces of paper so that one can slip into the other and place a vibrating tuning fork near one end and adjust the length of the tube you will hear a sound louder than usual.

- If you are using a 512 Hz tuning fork, the overall length of the tube will be about 33 cm. Let us see if we can figure out why this must be so.



- **Since the pipe is opened at both ends, the air molecules at both ends can vibrate freely. (This could only happen at one end in the closed pipe). As the pipe is adjusted, the loops or antinodes must appear at the open ends as shown in the following diagrams.**

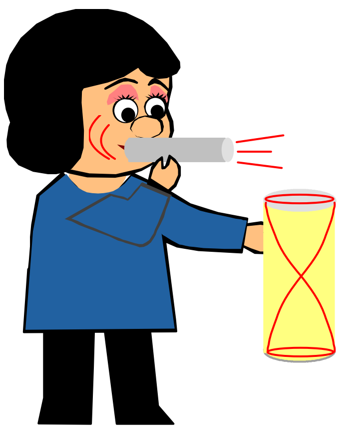


- **Isn't it interesting that now we have the tube increasing by HALF wavelengths? (For the pipe closed at one end the measurements were in QUARTER wavelengths.) So, the resonant lengths of open air columns are**

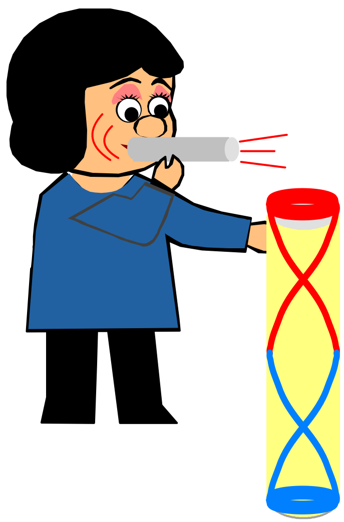
$$\frac{1}{2}\lambda,\quad \lambda,\quad \frac{3}{2}\lambda,\quad 2\lambda,\quad \frac{5}{2}\lambda \quad \text{and so on...}$$

- **If you look closely, you will see another difference: for open air columns all the half wavelengths are resonant lengths; for the column closed at one end only the odd number of quarter wavelengths are resonant lengths. Just look back to check this.**

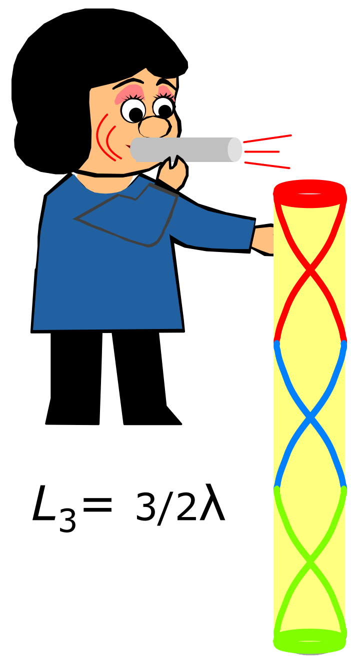
We can use two formula's to determine the length and wavelength for each resonant frequency in a Tube Open at both Ends



$L_1 = 1/2\ \lambda$



$L_2 = \lambda = 2/2\ \lambda$



$L_3 = 3/2\lambda$

$$L_n = \frac{n}{2}\lambda \quad \text{or}$$

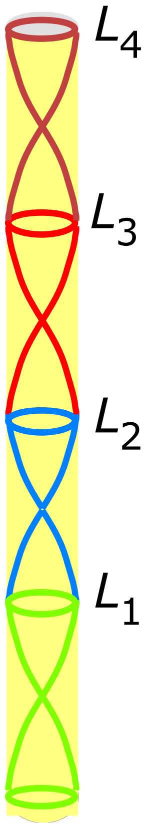
$$\lambda = \frac{2L_n}{n}$$

Note that $n$ can be ANY positive whole number for tubes OPENED at BOTH ends.

## Example 1: Making Music in the Woods (this time with a tube OPENED at both ends)

Draw a picture:

On a nice summer day when the temperature is 23º C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall and has NO BOTTOM. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?




The first 4 resonant lengths for a tube opened at both ends.

Remember the resonance formula for a tube opened at both ends:

$$L_n = \frac{n}{2}\lambda \quad \text{or} \quad \lambda = \frac{2L_n}{n}$$

# Example 1: Making Music in the Woods (this time with a tube OPENED at both ends)

On a nice summer day when the temperature is 23$^{o}$ C, you purse your lips and whistle across the top of an empty pop bottle that is 29 cm tall and has NO BOTTOM. What must be the frequency of your whistle to make the air in the bottle vibrate in the fourth resonant length?

Given:

$T$ = 23$^{o}$ C
$L$ = 29 cm = 0.29 m
$n$ =4 $f$ = ?

Solution:

Step 1—find speed of sound:

$$\begin{aligned} v &= [332 + 0.6T]\ \text{m/s} \\ &= [332 + 0.6 \times 23]\ \text{m/s} \\ &= [332 + 14]\ \text{m/s} \\ &= 346\ \text{m/s} \end{aligned}$$

Step 2—find $\lambda$:

$$\begin{aligned} \lambda &= \frac{2L_n}{n} \\ &= \frac{2L_4}{4} \\ &= \frac{2 \times 0.29\,\text{m}}{4} = 0.15\,\text{m} \end{aligned}$$

Step 3—find $f_4$:

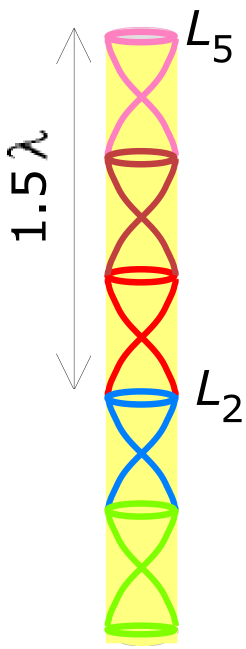
$$f = \frac{v}{\lambda} = \frac{346\,\text{m/s}}{0.15\,\text{m}} = 2306\,/\text{s} = 2.3\,\text{kHz}$$

Some lips!!

# Example 2: Finding air temperature by using a tube opened at both ends

When a 512 Hz tuning fork is sounded near one end of a tube **opened at both** ends, the difference between the $2^{nd}$ and $5^{th}$ resonant lengths is found to be 99 cm. What is the temperature of the air in the tube?

Picture?




Given:

$f = 512$ Hz

$L_5 - L_2 = 99$ cm $= 0.99$m

$T = ?$

Solution:

Step 1—find $\lambda$:

$$1.5\lambda = L_5 - L_2 = 0.99\,\text{m}$$

$$\lambda = \frac{0.99\,\text{m}}{1.5} = 0.66\,\text{m}$$

Step 2—find $v$:

$$v = f\lambda = 512\,/\text{s} \times 0.66\,\text{m}$$

$$v = 338\,\text{m/s}$$

Step 3—find $T$:

$$v = [332 + 0.6T]\ \text{m/s}$$

$$338\ \text{m/s} = [332 + 0.6T]\ \text{m/s}$$

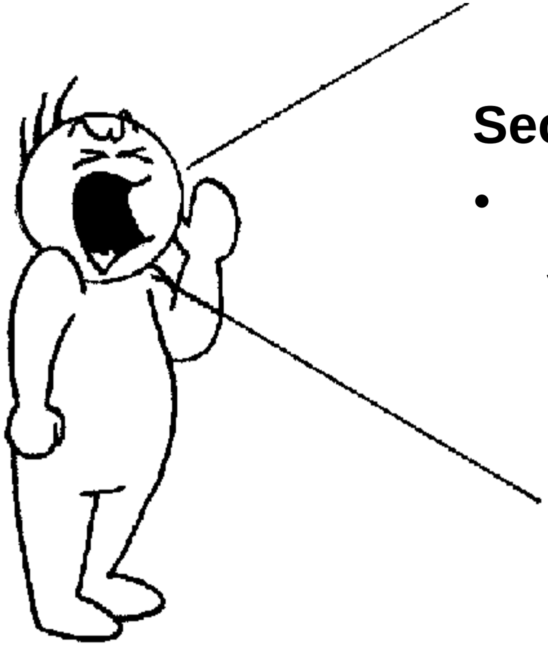
$$338 = [332 + 0.6T]$$

$$T = \frac{338 - 332}{0.6} = 10^{o}\,C$$

The air temperature is $10^{o}$C.

# Activity

- Worksheet: Resonance of Sound
- Quiz



**Section 2    Topic 4**

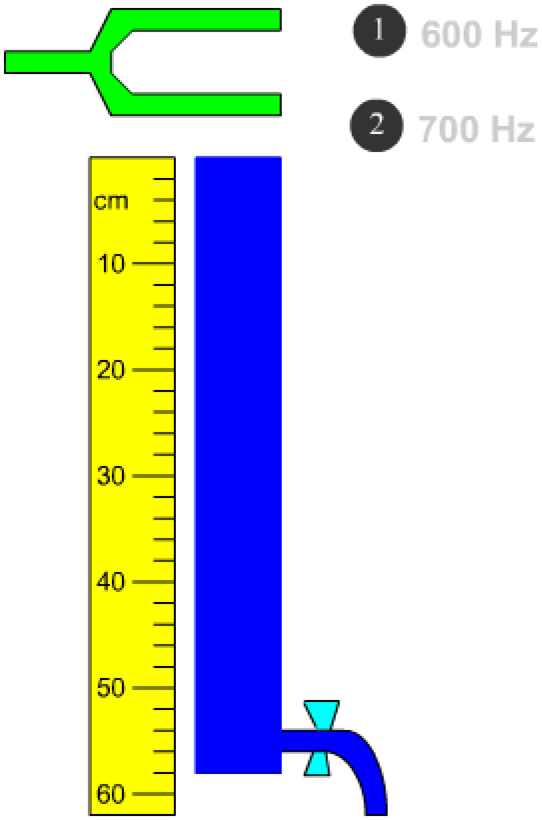
- Using Resonance in Tubes to Measure the Speed of Sound in Air

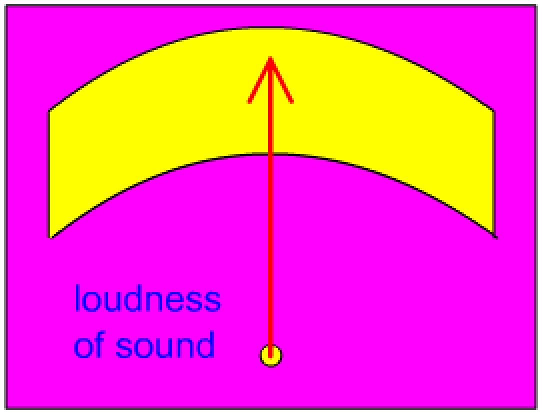
Text: Section

## Using Resonance in Tubes to Measure the Speed of Sound in Air

The tube below contains water. A tap at the bottom can be opened to let water out and control the length of the air column in the tube.

Remember: Resonance will occur when the length of the air column is several precise lengths. These blengths correspond with lengths of 1/4 λ, 3/4 λ, 5/4 λ and so on ..

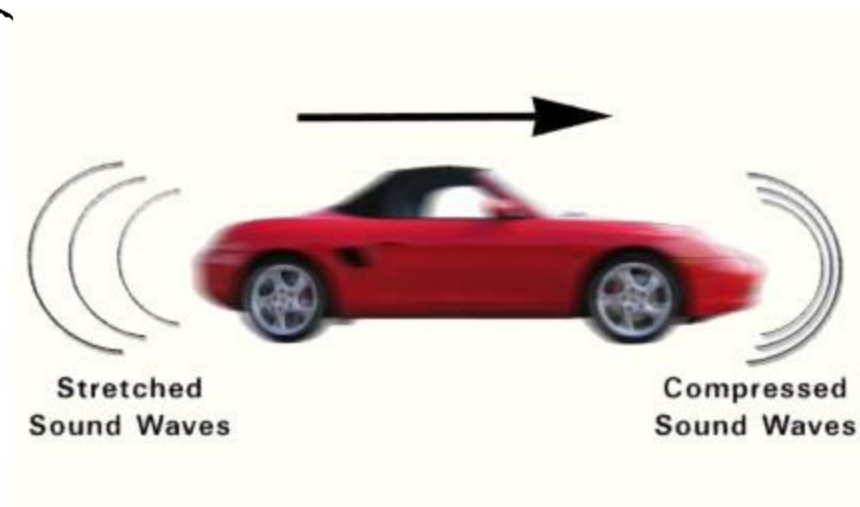


## Section 2 Topic 5

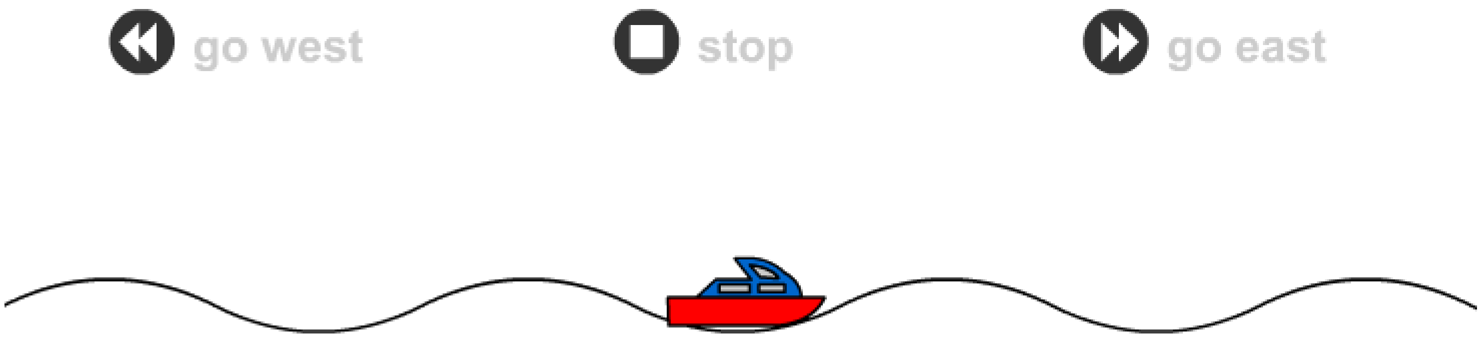
- The Doppler Effect and Sound

Text: Section



## The Doppler Effect and Sound

Determine what happens to the frequency of the waves as the boat moves east and west.

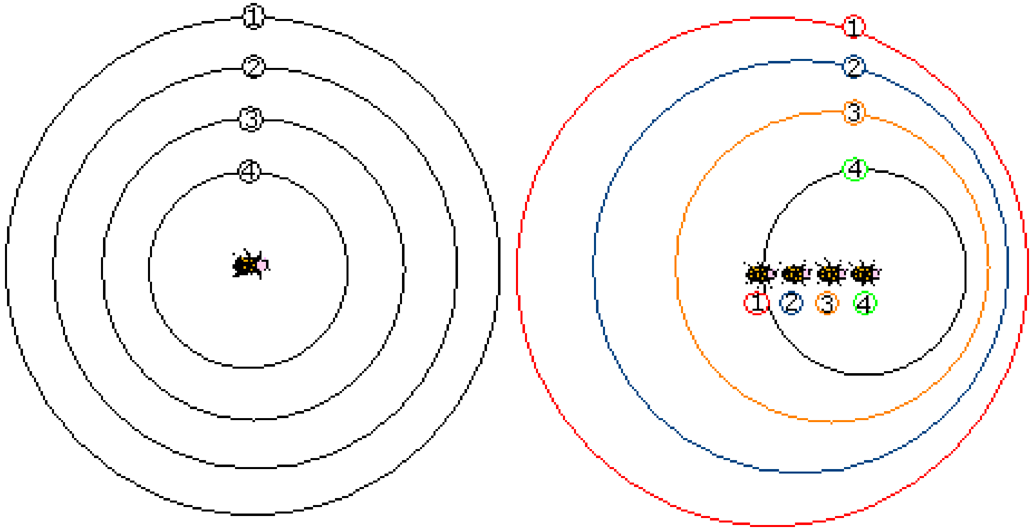



- The apparent (perceived) difference of the wave frequency caused by relative motion between the waves and the observer is called the Doppler Effect.

# The Doppler Effect and Sound

- The Doppler effect is a phenomenon observed whenever the source of waves is moving with respect to an observer.

- The movement causes an apparent upward shift in frequency for the observer when the source is approaching and an apparent downward shift in frequency when the source is receding.

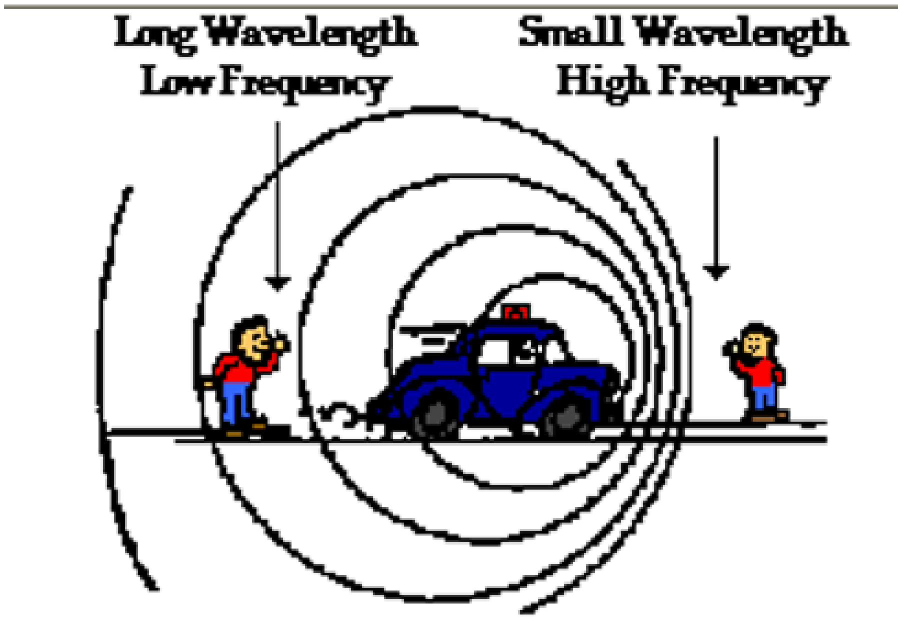



A croaking bug hops right

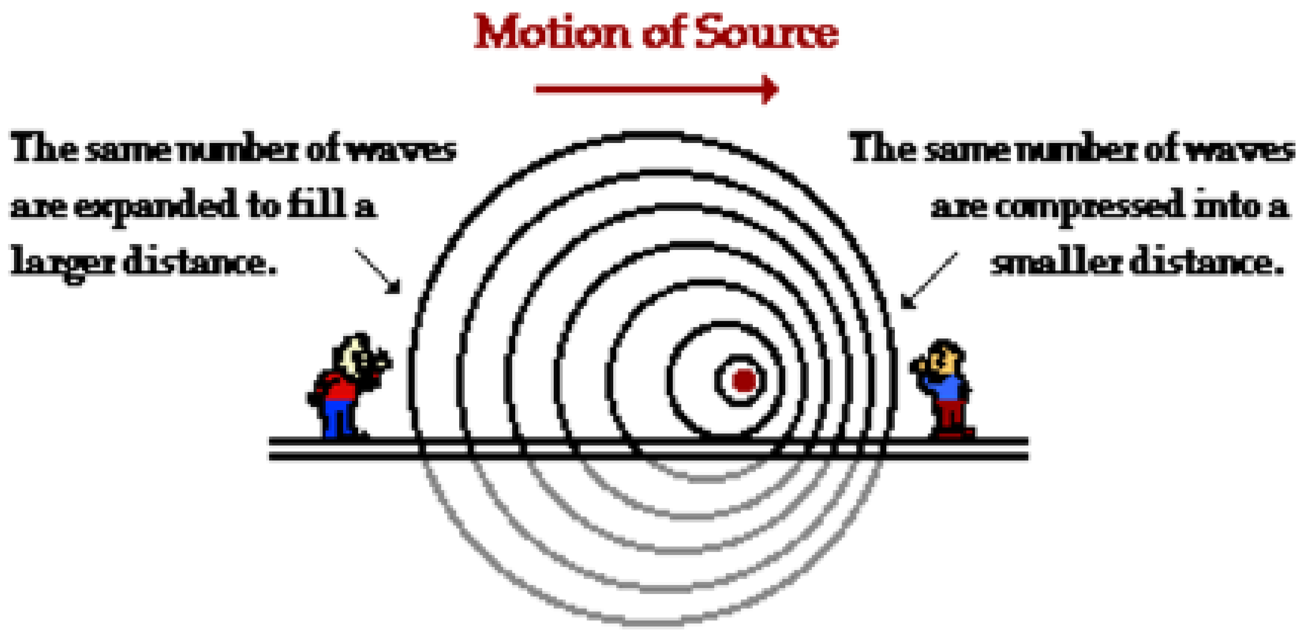
- The Doppler effect may occur in all types of waves however we are most familiar with sound waves. Recall an instance in which a police car was traveling towards you on the highway. As the car approached with its siren blasting, the pitch of the siren sound was high; and then suddenly after the car passed by, the pitch of the siren sound was low.

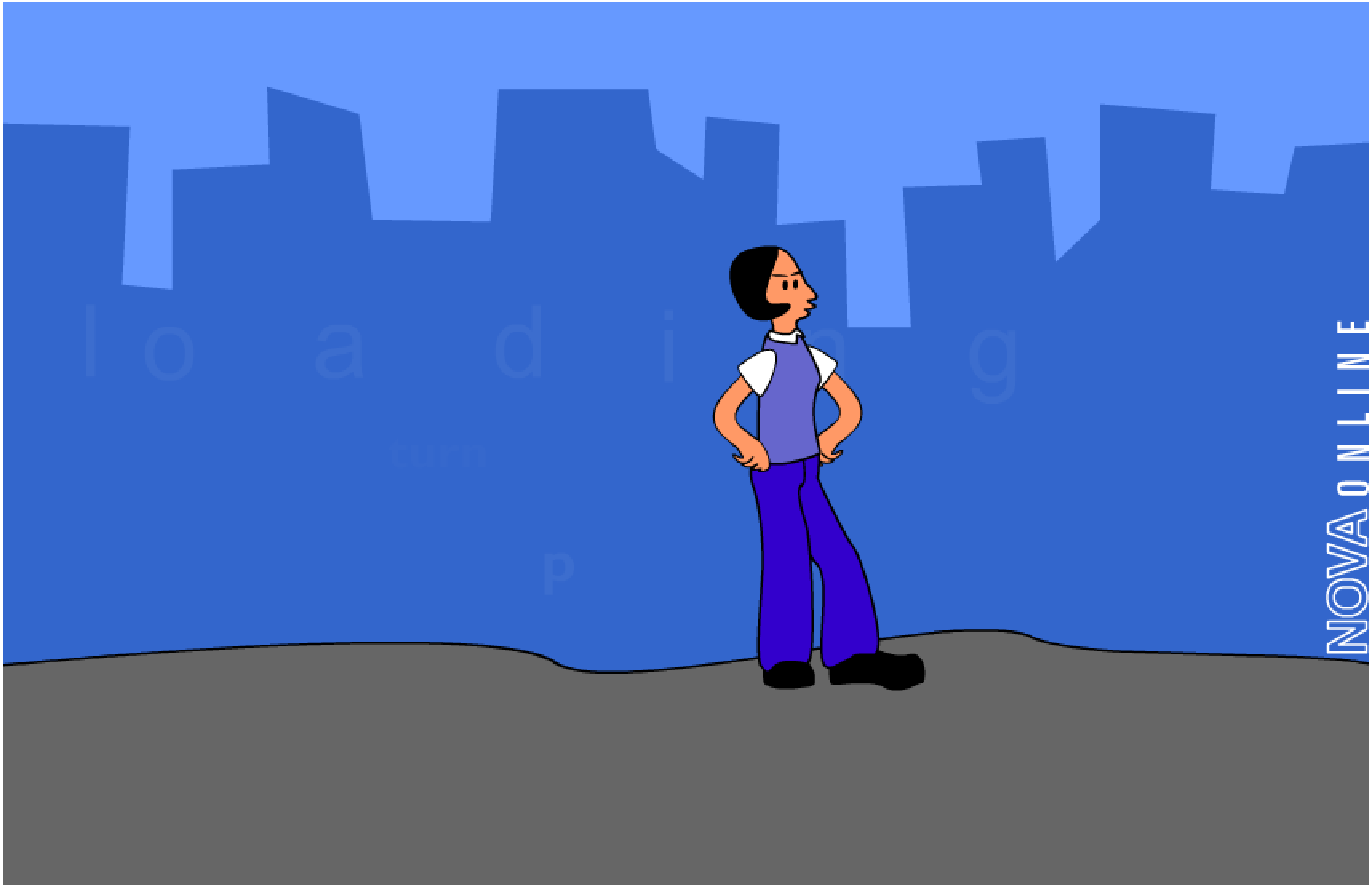
- The Doppler effect is observed because the distance between the source of sound and the observer is changing.

- The source of sound always emits the same frequency.



The Doppler Effect for a moving sound source


Motion of Source
The same number of waves are expanded to fill a larger distance.
The same number of waves are compressed into a smaller distance.


l o a d i n g

- **EQUATIONS FOR PERCEIVED FREQUENCY**

- Two formulas below can be applied only to moving sound sources.

- When the sound source is moving towards the observer–

$$f_2 = \frac{f_1}{\left(1 - \frac{v_{sc}}{v_{so}}\right)}$$

- When the sound source is moving away from the observer–

$$f_2 = \frac{f_1}{\left(1 + \frac{v_{sc}}{v_{so}}\right)}$$

- $f_1$ = the frequency of the sound at the source
- $f_2$ = the observed frequency according to the Doppler Effect
- $v_{so}$ = the speed of sound
- $v_{sc}$ = the speed of the sound source.

- **when the observer is moving while the sound source is stopped**

- **When the observer is moving towards a stationary sound source is**

$$f_2 = f_1\left(1 + \frac{v_o}{v_{so}}\right)$$

- **the observer is moving away from a stationary sound source is**

$$f_2 = f_1\left(1 - \frac{v_o}{v_{so}}\right)$$

- where

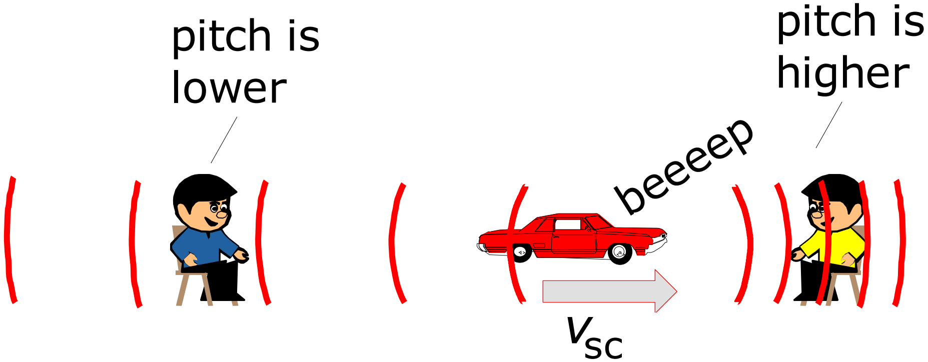
$f_1$ = the frequency of the sound at the source

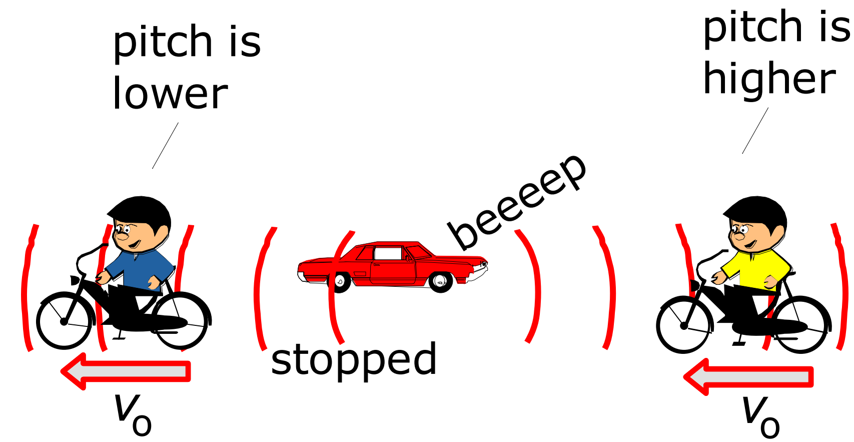
$f^2$ = the observed frequency according to the Doppler Effect

$v_{so}$ = the speed of **so**und

$v_o$ = the speed of the **o**bserver

# Formulae Review
# The Doppler Effect and Sound




$$f_2 = \frac{f_1}{\left(1 + \frac{v_{sc}}{v_{so}}\right)}$$

**Away**

$$f_2 = \frac{f_1}{\left(1 - \frac{v_{sc}}{v_{so}}\right)}$$

**Toward**

$$f_2 = f_1\left(1 - \frac{v_o}{v_{so}}\right)$$

$$f_2 = f_1\left(1 + \frac{v_o}{v_{so}}\right)$$

# Example 1: The Sound Source is Moving Away from the Observer

A car passes and moves away from you at 110 km/hr as you stand on the side of the highway in 28° C weather. The driver gives a long beep on the horn. If the horn makes a 450 Hz sound, what frequency do you hear?

Given:

$v_{sc} = 110 \text{ km/hr} = 31 \text{ m/s}$

$T = 28^{o}\text{ C}$ , $f_1 = 450 \text{ Hz}$

$f_2 = ?$

Because the sound source is moving away, you hear a lower frequency of 413 Hz.

Solution:

Step 1—find $v_{so}$:

$$\begin{aligned} v_{so} &= [332 + 0.6T]\text{ m/s} \\ &= [332 + 0.6 \text{ x } 28]\text{ m/s} \\ &= [332 + 17]\text{m/s} = 349\text{ m/s} \end{aligned}$$

Step 2—find $f_2$:

$$f_2 = \frac{f_1}{\left(1 + \dfrac{v_{sc}}{v_{so}}\right)} = \frac{450\text{ Hz}}{\left(1 + \dfrac{31\text{m/s}}{349\text{ m/s}}\right)} = \frac{450\text{ Hz}}{(1.09)}$$

$$= 413\text{ Hz}$$

# Example 2: The Sound Source is Moving Towards the Observer

A car is approaching you in in 25º C weather in a 100 km/hr zone. The driver gives a long beep on the horn, which you know from the specifications to be a 450 Hz sound. However, you measure the sound to have a 475 Hz pitch. Is the car speeding?

Given:

$T = 25^{o}$ C
$f_1 = 450$ Hz
$f_2 = 475$ Hz
$v_{sc} = ?$

Solution:

Step 1—find $v_{so}$:

$$\begin{aligned} v_{so} &= [332 + 0.6T] \text{ m/s} \\ &= [332 + 0.6 \times 25] \text{ m/s} \\ &= [332 + 15] \text{ m/s} = 347 \text{ m/s} \end{aligned}$$

Step 2—find $v_{sc}$:

$$f_2 = \frac{f_1}{\left(1 - \frac{v_{sc}}{v_{so}}\right)} \Rightarrow 475 = \frac{450}{\left(1 - \frac{v_{sc}}{347}\right)} \Rightarrow 475 = \frac{450}{\left(\frac{347 - v_{sc}}{347}\right)}$$

# Example 2: The Sound Source is Moving Towards the Observer

MORE ROOM for Step 2—find $v_{sc}$:

$$f_2 = \frac{f_1}{\left(1 - \frac{v_{sc}}{v_{so}}\right)} \Rightarrow 475 = \frac{450}{\left(1 - \frac{v_{sc}}{347}\right)} \Rightarrow 475 = \frac{450}{\left(\frac{347 - v_{sc}}{347}\right)}$$

$$475 = 450 \text{ x } \left(\frac{347}{347 - v_{sc}}\right)$$

$$475\,(347 - v_{sc}) = 450 \text{ x } 347$$

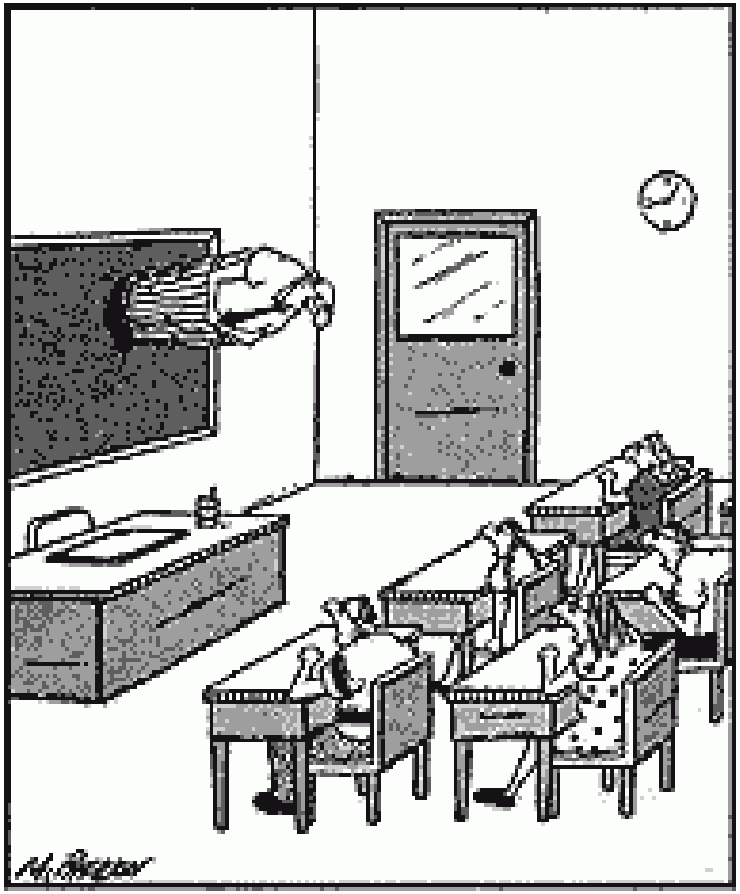
$$165000 - 475 v_{sc} = 156000$$

$$v_{sc} = \frac{165000 - 156000}{475} = 19\,\text{m/s}$$

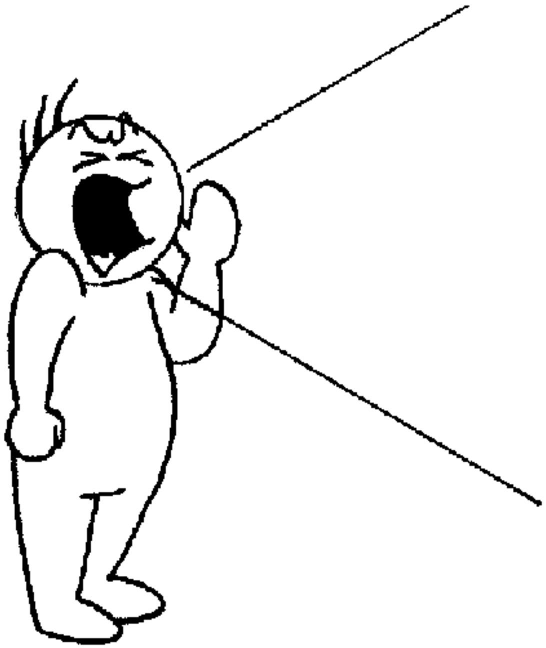
Change 19 m/s to km/hr by multiplying by 3.6. This gives $v_{sc}$ = 68 km/hr. Since the car is in a 100 km/hr zone, it is definitely not speeding.

# Activity

- Worksheet: The Doppler Effect and Sound
- Quiz



"Good morning, and welcome to The Wonders of Physics."



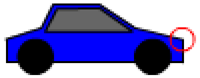
**Section 2 Topic 6**

- Sonic Booms

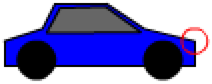
Text: Section

## Review..

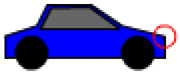
- The picture below show a  stationary car with its horn blowing.



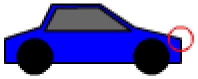
- Next picture shows the wave fronts as the car moves forward. Notice the apparent change in wavelength that will be detected by observers both in front of, and behind, the car.  (Doppler Effect)



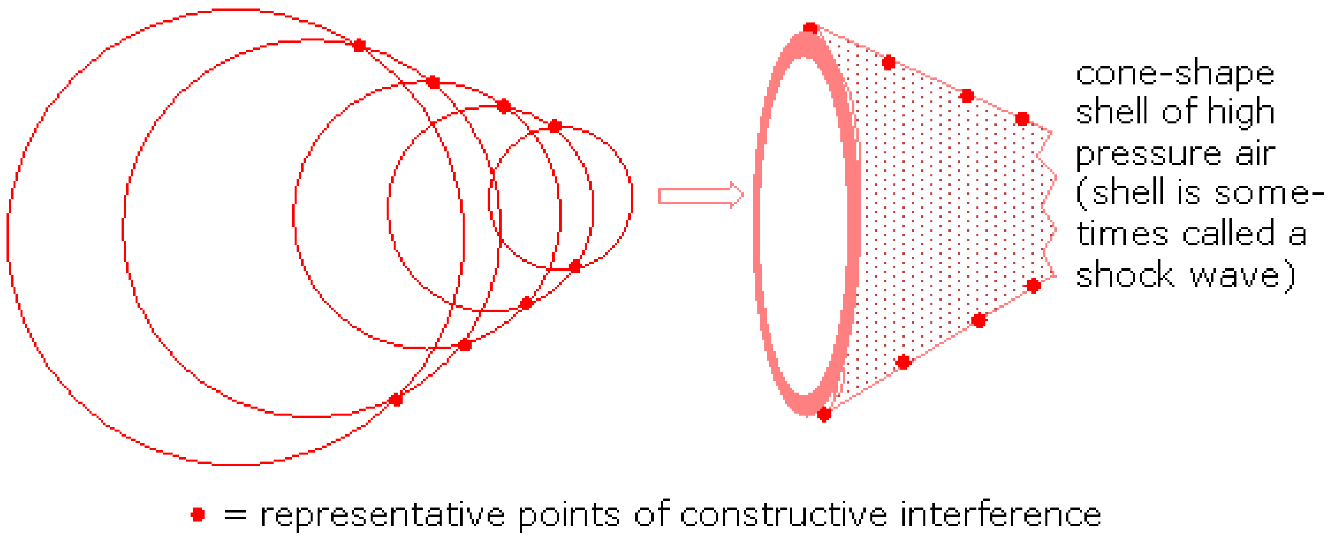
- A "supercar" moves at the speed of sound. Notice that, in front of the car, all of the waves are overlapping. Here, there is a massive amount of constructive interference happening. This results in a region of very high air pressure. Such high pressure causes a resistance to the motion. The special name for this resistance is sound barrier.



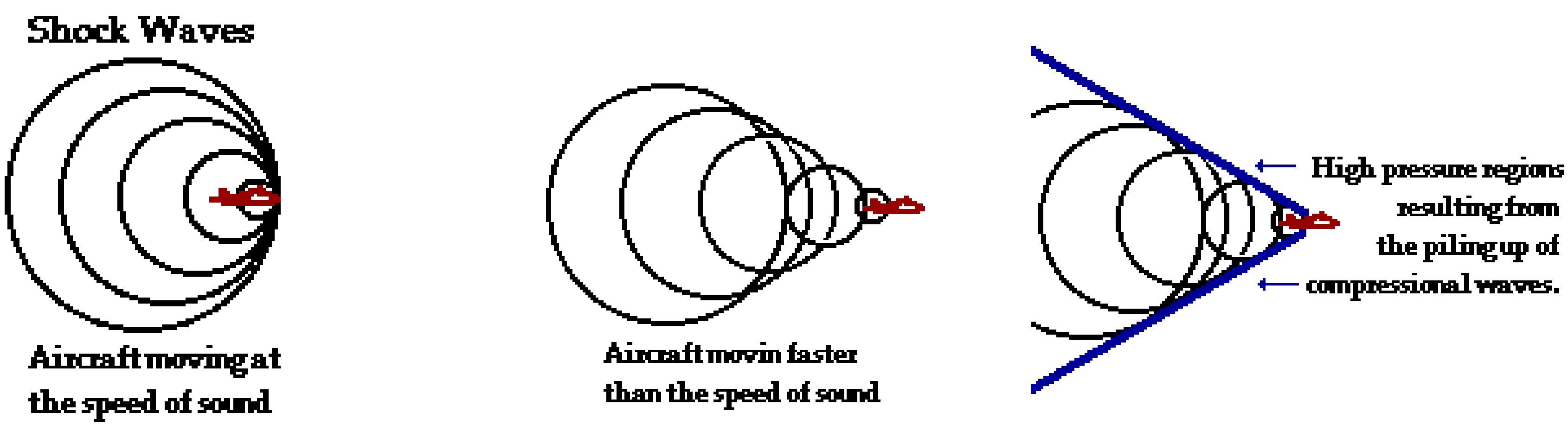
  - Here the car is moving faster than the sound. Because the car is continually going faster than its wave fronts, the circular patterns will have to intersect. At these points of intersection constructive interference will occur.



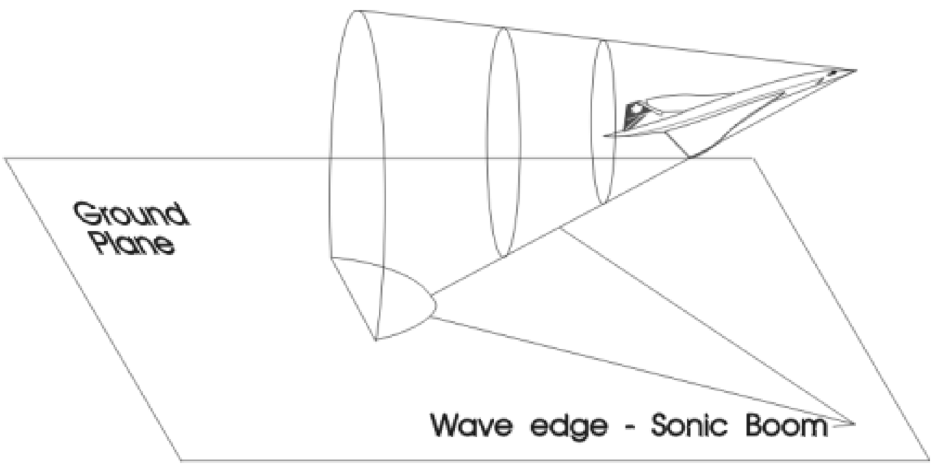
- Countless number of such point result in a cone of constructive interference as shown on the right.

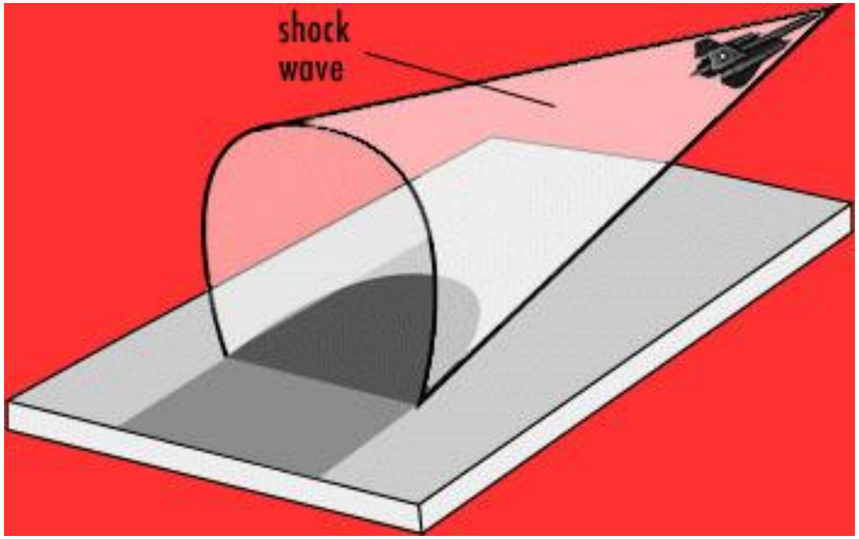



- In reality the supercar would be replaced with an airplane



- For an airplane, 3 dimensions diagram is needed because the plane is in a 3-dimensional "sea of air". The plane produces a cone shape wake when it travels faster than the speed of the sound. The pressure is very high. When the "shell" of the cone intersects with the ground, the impact of this pressure on our ear drums produces a thunder-like noise that we call a sonic boom.




- Chuck Yeager was the first person to break the sound barrier when he flew faster than the speed of sound in the X-1 rocket-powered aircraft on October 14, 1947.

- An F/A-18 Hornet passing through the sound barrier.
- Not only were the water vapor, density and temperature just right, but there just happened to be a camera in the vicinity to capture the moment.


- A rare case of  a F-14 Tabby cat  breaking the sound barrier.

# Mach Number and the Sound Barrier

- When airplanes (or supercars) go faster than the speed of sound, a special unit of speed is used--it is the **Mach number**. A day when the speed of sound is 340 m/s, a plane is traveling at 680 m/s, its speed is Mach 2.


$$\text{MACH number} = \frac{\text{plane speed}}{\text{sound speed}} = \frac{v_p}{v_{so}} = \frac{v_p}{[332 + 0.6T]_{m/s}}$$

# Example 1: Changing Mach No. into m/s and km/hr.

A plane is traveling at Mach 2.3 when the atmospheric tempera-ture is 3.4° C. What is its speed in m/s and km/hr?

Given:

Mach no. = 2.3

$T = 3.4^o$ C , $v_p = ?$

Solution:

Step 1—find $v_{so}$:

$$v_{so} = [332 + 0.6T] \text{ m/s}$$
$$= [332 + 0.6 \times 3.4] \text{ m/s}$$
$$= [332 + 2.04] \text{m/s} = 334 \text{ m/s}$$

Step 2—find $v_p$ :

$$\text{Mach no.} = \frac{v_p}{v_{so}}$$

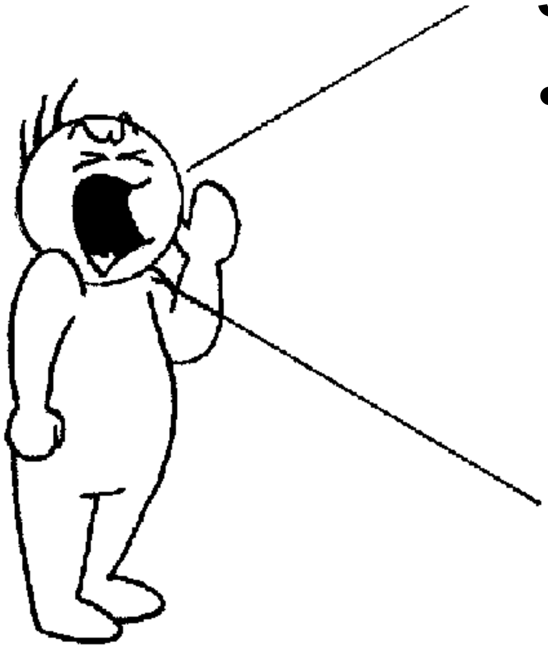
$$v_p = \text{Mach no.} \times v_{so}$$
$$= 2.3 \times 334 \text{ m/s}$$
$$= 768 \text{ m/s}$$

Change 768 m/s into km/hr by multiplying by 3.6:

768 x 3.6 = 2760 km/hr !!

# Activity

- Textbook exercises:
  p. 477 #11-#12



**Section 2 Topic 7**

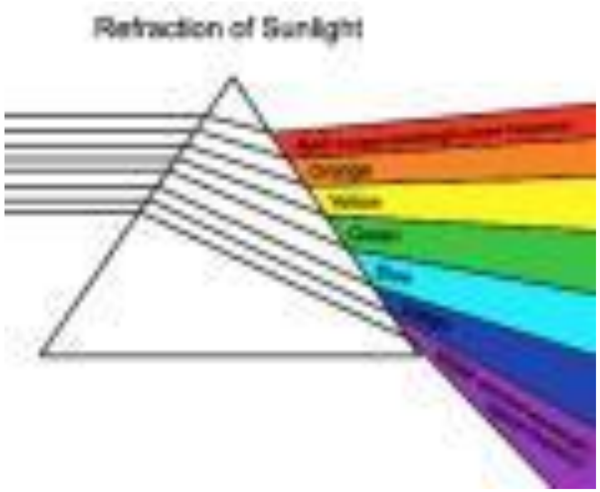
- Light and the Electromagnetic Spectrum

Text: Section

## Light and the Electromagnetic Spectrum

- **Light** is a source of energy that is visible to the eye

- All objects that act as sources of light are called **luminous.**



## Light may be produced in a variety of ways

- **Incandescent sources emit light because they are at high temperatures. ( Examples, Sun, fires, light bulb…)**

- **fluorescent sources: refers to gasses that emit light when they are struck by high energy waves or particles.**

- **phosphorescent source becomes luminous when struck by high energy waves or particles, and remain luminous for awhile.**

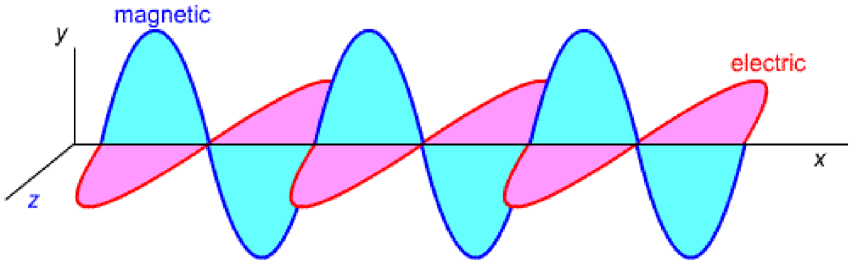

- **Chemiluminescent :is the emission of light as the result of a chemical reaction. There is no significant change in temperature.**

- **bioluminescent : organisms that can emit energy because of chemical reactions ( fish, firflies..etc)**

# The Electromagnetic Spectrum

- **An electromagnetic wave is a transverse wave that has both electric and magnetic properties. It is assumed that the electric part is vibrating at right angles to the magnetic part.**

- **the changing magnetic field creates an electric field which creates another magnetic field which creates another electric field, and so on, and so on. These fields "push" each other along as they keep on creating each other at the speed of light.**




- Light travel at speed c or 3.00 x $10^8$ m/s

- Heinrich Hertz constructed an apparatus that demonstrated that all electromagnetic waves are not visible. These waves, which were found to also travel at c, were found to also display the properties of reflection, refraction, diffraction, interference, just like light.

- the Electromagnetic Spectrum, shows the range of values of $f$ and $\lambda$ for electromagnetic waves

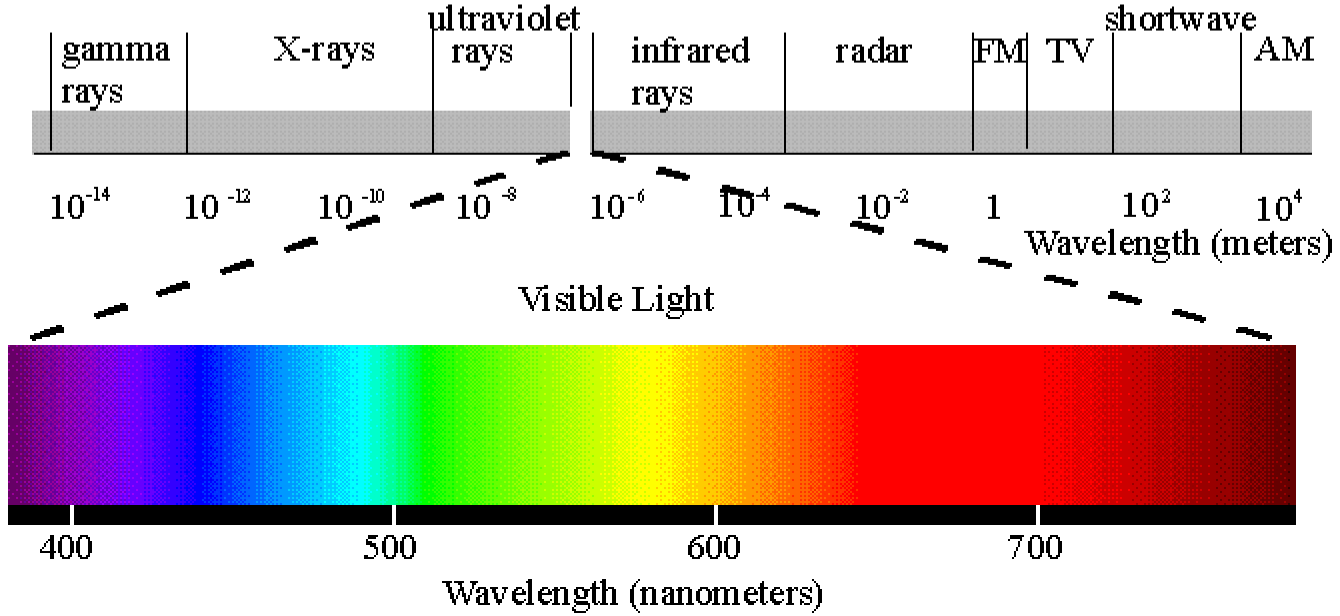
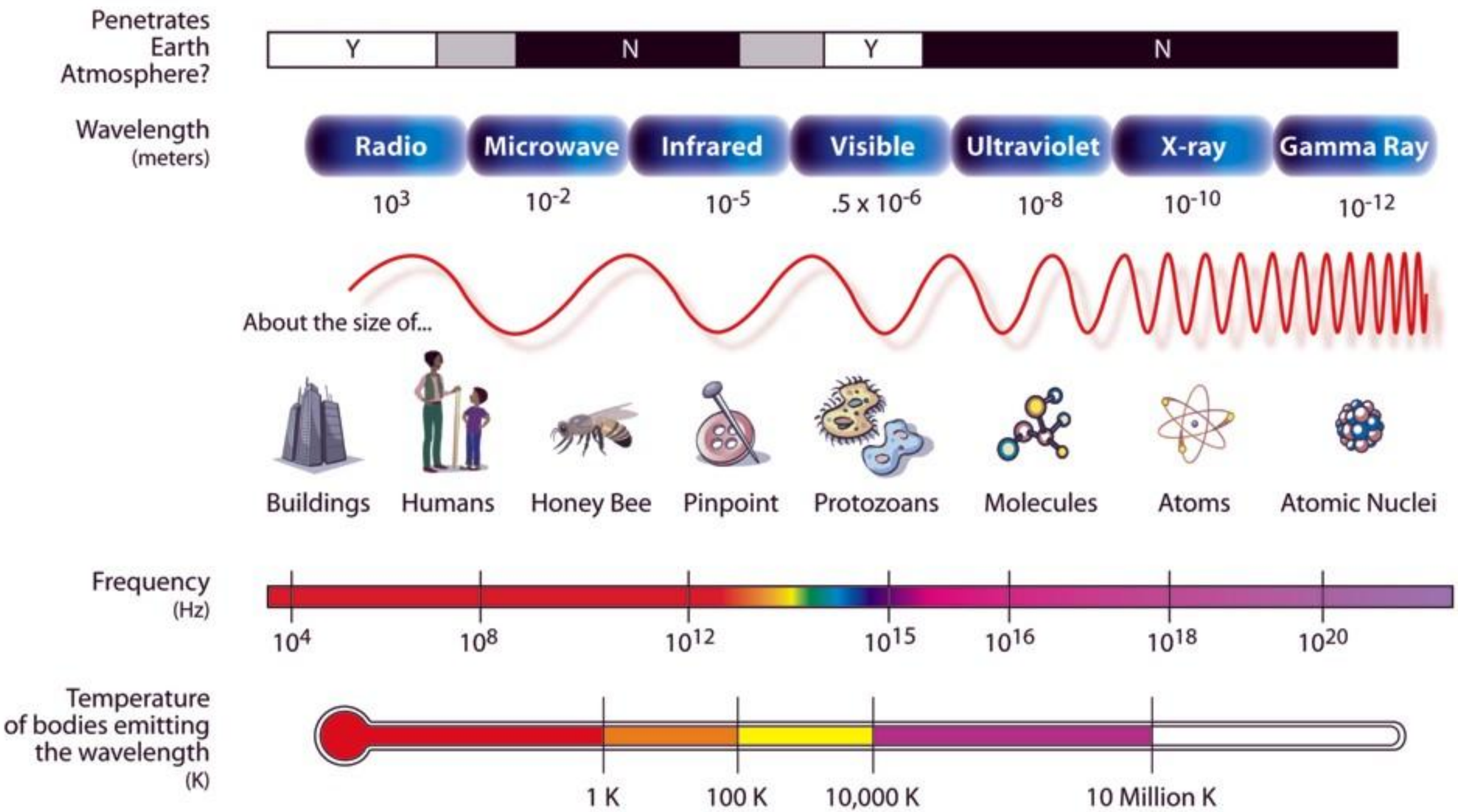
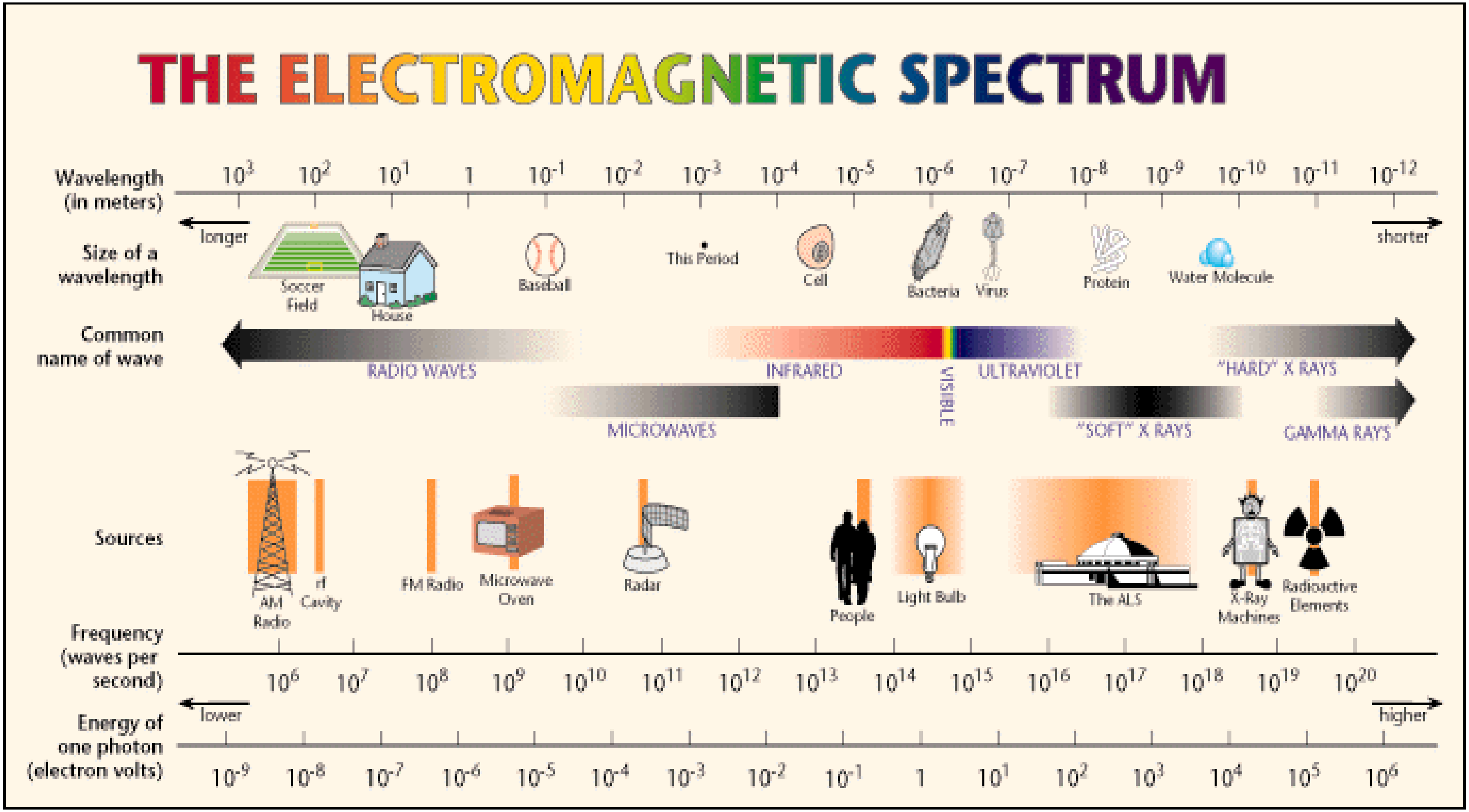



Table of Contents

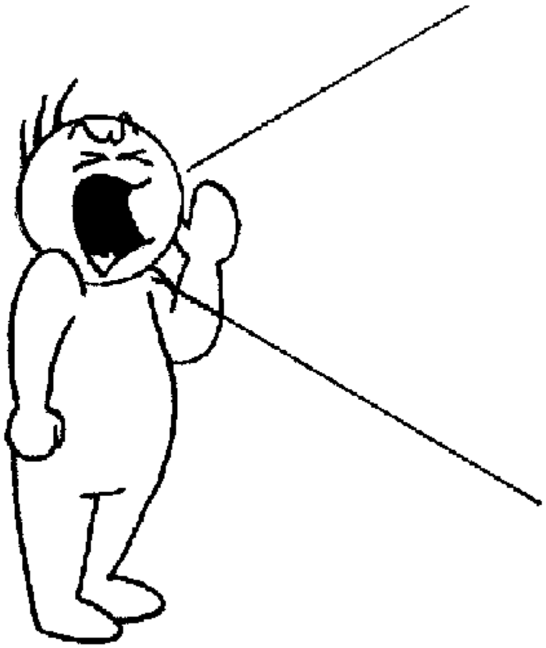
Visual Stimulus

# THE ELECTROMAGNETIC SPECTRUM





THE ELECTROMAGNETIC SPECTRUM
Wavelength (in meters)
$10^3$ $10^2$ $10^1$ 1 $10^{-1}$ $10^{-2}$ $10^{-3}$ $10^{-4}$ $10^{-5}$ $10^{-6}$ $10^{-7}$ $10^{-8}$ $10^{-9}$ $10^{-10}$ $10^{-11}$ $10^{-12}$
longer
shorter
Size of a wavelength
Soccer Field
House
Baseball
This Period
Cell
Bacteria
Virus
Protein
Water Molecule
Common name of wave
RADIO WAVES
INFRARED
VISIBLE
ULTRAVIOLET
"HARD" X RAYS
MICROWAVES
"SOFT" X RAYS
GAMMA RAYS
Sources
AM Radio
rf Cavity
FM Radio
Microwave Oven
Radar
People
Light Bulb
The ALS
X-Ray Machines
Radioactive Elements
Frequency (waves per second)
$10^6$ $10^7$ $10^8$ $10^9$ $10^{10}$ $10^{11}$ $10^{12}$ $10^{13}$ $10^{14}$ $10^{15}$ $10^{16}$ $10^{17}$ $10^{18}$ $10^{19}$ $10^{20}$
lower
higher
Energy of one photon (electron volts)
$10^{-9}$ $10^{-8}$ $10^{-7}$ $10^{-6}$ $10^{-5}$ $10^{-4}$ $10^{-3}$ $10^{-2}$ $10^{-1}$ 1 $10^1$ $10^2$ $10^3$ $10^4$ $10^5$ $10^6$



**Section 2 Topic 8**

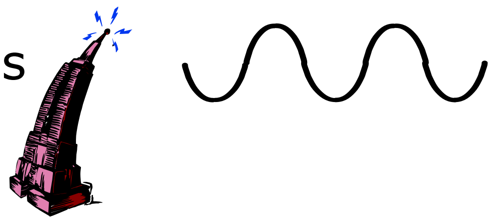
- The Speed of Light and the Doppler Effect

Text: Section

# The Speed of Light and the Doppler Effect

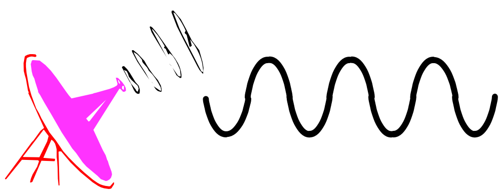
*d* = *vt* becomes *d* =*ct* for Light and All Other Electromagnetic Waves

radio/TV waves



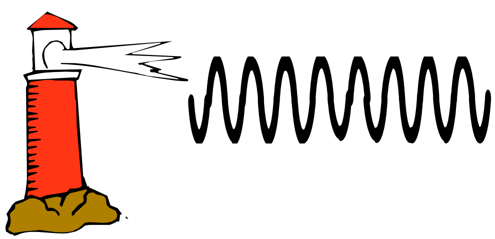
speed = *c* = 3.00 x $10^8$ m/s

microwaves



speed = *c* = 3.00 x $10^8$ m/s

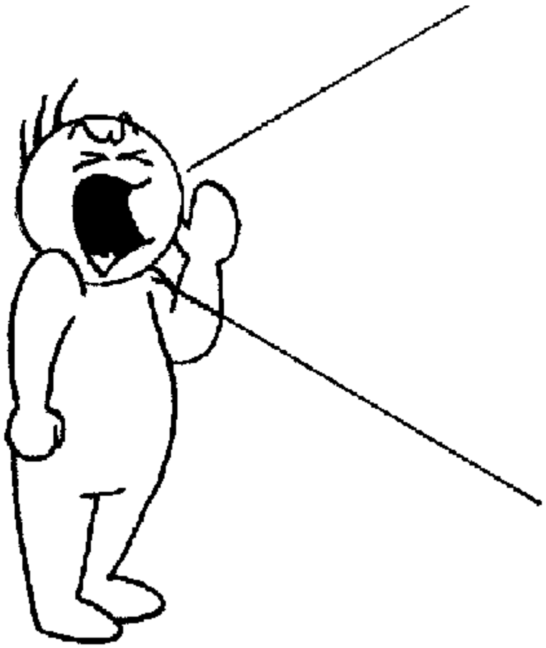
light waves



speed = *c* = 3.00 x $10^8$ m/s

# Activity

- Textbook exercises:
  p. 393--#1-#2
  p. 436--#37



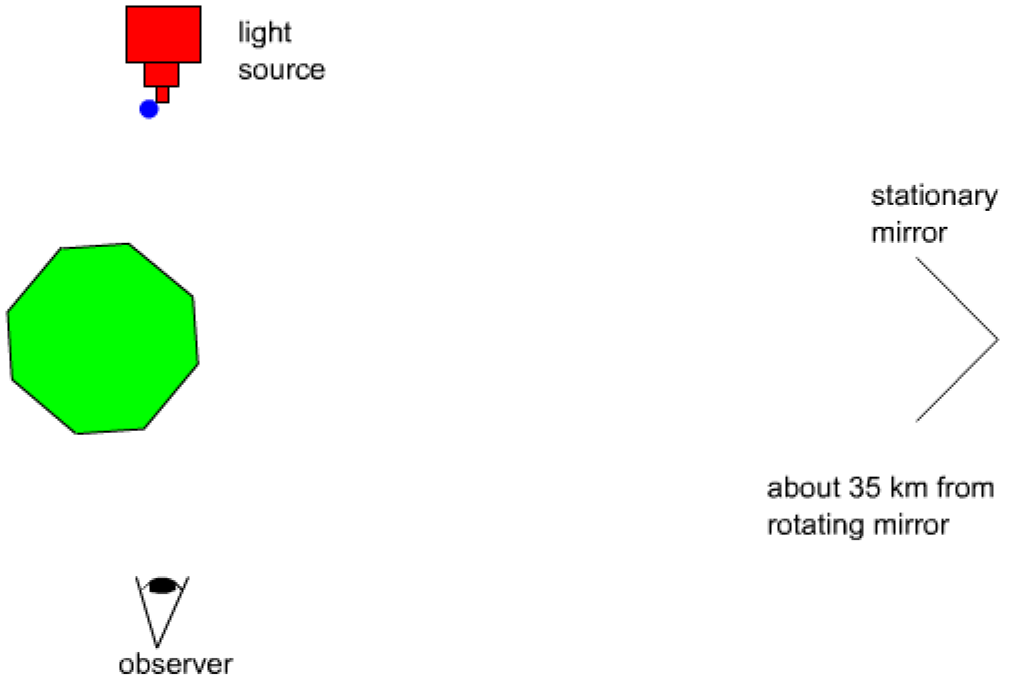
**Section 2 Topic 8**

- The Speed of Light and the Doppler Effect

Text: Section

# Michelson's Work, and a Precise Value of *c*

- Albert Michelson (1852-1931) used the apparatus shown below to carry out a series of experiments that led to a precise value of c.
- He used an eight-sided rotating mirror that reflected light from a source to a stationary mirror about 35 km away.
- Because Michelson knew the time it took the mirror to turn, and the distance traveled by the light, he was able to compute the speed.



# Example : Distances that Boggle the Mind

Other than the Sun, the nearest star to earth is Alpha Centauri which is 4 light years away. How far is that in km?

Given:

$t$ = 4 light years
c = $3.00 \times 10^8$ m/s
$d$ = ?

Change m to km by dividing by 1000:
$d = 3.78 \times 10^{13}$ km
That's 37,800,000,000,000 km !!

Solution:

Step 1—find the number of seconds in 1 year :

$$1\,\text{year} = 365\,\text{days}$$

$$365\,\text{days} = 365 \text{ x } 24 \text{ hr}$$
$$= 8760 \text{ hr}$$

$$8760 \text{ hr} = 8760 \text{ x } 3600\,\text{s}$$
$$= 31536000\,\text{s}$$

Step 2—find $d$:

$$d = ct = 3.00 \times 10^8 \text{ m/s} \text{ x } (\mathbf{4})\,31536000\,\text{s}$$
$$= 3.78 \times 10^{16} \text{ m}$$

# The Doppler Effect and Light

- When applying the Doppler effect to electromagnetic waves you only have to consider two formulas.

$$f_2 = f_1\left(1 \pm \frac{v}{c}\right)$$

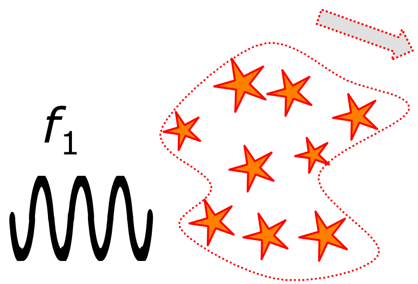
- This time use – for moving away and + for approaching

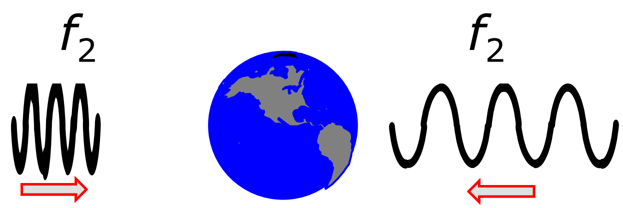
  - $f_2$ = new (perceived) frequency, the frequency of electromagnetic wave that we observe
  - $f_1$ = actual frequency of the electromagnetic emitted from the source
  - v = speed of source
  - c = speed of the electromagnetic wave emitted by the source ($3.00 \times 10^8$ m/s)

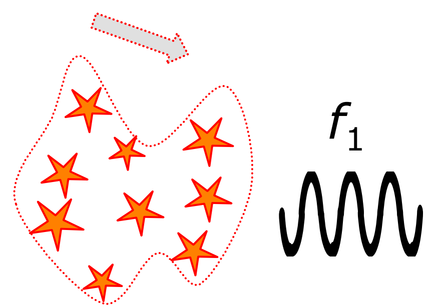
# Formulae Review

galaxy approaching earth

galaxy receding from earth




$$f_2 = f_1\left(1 + \frac{v}{c}\right) \qquad f_2 = f_1\left(1 - \frac{v}{c}\right)$$

# Blue Shift and Red Shift

Because of the Doppler effect the apparent wavelength of light changes as object are moving.

- the apparent wavelength will be shorter than that of the source if the objects were approaching  This would be perceived as a color shift towards the blue end of the spectrum because **blue** has a **short** wavelength (and high frequency)--a phenomena known as "blue-shift".

- Similarly, the apparent wavelength would be longer than that of the source is the objects were receding. This would be perceived as a color shift towards the red end of the spectrum because **red** has a **long** wavelength (and low frequency)--a phenomena known as "red-shift."

# Interesting…

- Based upon observations of many stars, along with a knowledge of the kinds of light that various types of stars tend to emit it has been found that the light from most stars is red shifted. This indicates that most stars are moving away from us.

- Furthermore, it has also been found that the amount of red shift increases with increasing distance to the stars. Since the amount of red-shift is proportional to the speed, it has therefore been determined that the farther away the star, the faster it is receding.

# Example 1: A Receding Light Source

Solution:

An object in space is traveling away from earth at 2.1 x $10^7$ m/s and emitting a frequency of 6.0 x $10^{13}$ Hz. What frequency is observed on earth?

Apply the appropriate expression for the Doppler Effect

$$f_2 = f_1\left(1 - \frac{v}{c}\right)$$

Given:

$v$ = 2.1 x $10^7$ m/s
$f_1$ = 6.0 x $10^{13}$ Hz
c = 3.00 x $10^8$ m/s
$f_2$ = ?

$$f_2 = f_1\left(1 - \frac{v}{c}\right)$$

$$= 6.0 \text{ x } 10^{13}\,\text{Hz}\left(1 - \frac{2.1 \text{ x } 10^7}{3.00 \text{ x } 10^8}\right)$$

$$= 6.0 \text{ x } 10^{13}\,\text{Hz}\,(1 - 0.07)$$

$$= 6.0 \text{ x } 10^{13}\,\text{Hz}\,(0.93)$$

$$= 5.6 \text{ x } 10^{13}\,\text{Hz}$$

The earth observer sees a frequency of 5.6 x $10^{13}$ Hz.

# Example 2: Finding the Speed of a Galaxy

A galaxy is known to emit a wavelength of 710 nm. The observed wavelength on earth is 715 nm. How fast is the galaxy moving?

Given:

$\lambda_1$ = 710 nm = 700 x $10^{-9}$ m
$\lambda_2$ = 715 nm = 715 x $10^{-9}$ m
c = 3.00 x $10^8$ m/s
$v$ = ?

Solution:

Step 1—calculate $f_1$ an $f_2$:

$$f_1 = \frac{c}{\lambda_1} = \frac{3.00 \times 10^8 \text{ m/s}}{710 \times 10^{-9} \text{ m}} = 4.23 \times 10^{14} \text{ Hz}$$

$$f_2 = \frac{c}{\lambda_2} = \frac{3.00 \times 10^8 \text{ m/s}}{720 \times 10^{-9} \text{ m}} = 4.17 \times 10^{14} \text{ Hz}$$

Step 2—choose the appropriate Doppler expression and calculate v:

$$f_2 = f_1\left(1 - \frac{v}{c}\right)$$

# Example 2: Finding the Speed of a Galaxy

A galaxy is known to emit a wavelength of 710 nm. The observed wavelength on earth is 715 nm. How fast is the galaxy moving?

Summary so far:

$$f_1 = 4.23 \times 10^{14}\ \text{Hz}$$

$$f_2 = 4.17 \times 10^{14}\ \text{Hz}$$

Solution (cont'd):

$$f_2 = f_1\left(1 - \frac{v}{c}\right)$$

$$4.17 \times 10^{14}\ \text{Hz} = 4.23 \times 10^{14}\ \text{Hz}\left(1 - \frac{v}{3.00 \times 10^8\ \text{m/s}}\right)$$

$$4.17 \times 10^{14} = 4.23 \times 10^{14} - \frac{4.23 \times 10^{14}}{3.00 \times 10^8\ \text{m/s}}\, v$$

$$\frac{4.23 \times 10^{14}}{3.00 \times 10^8\ \text{m/s}}\, v = 4.23 \times 10^{14} - 4.17 \times 10^{14} = 6.0\, x\, 10^{12}$$

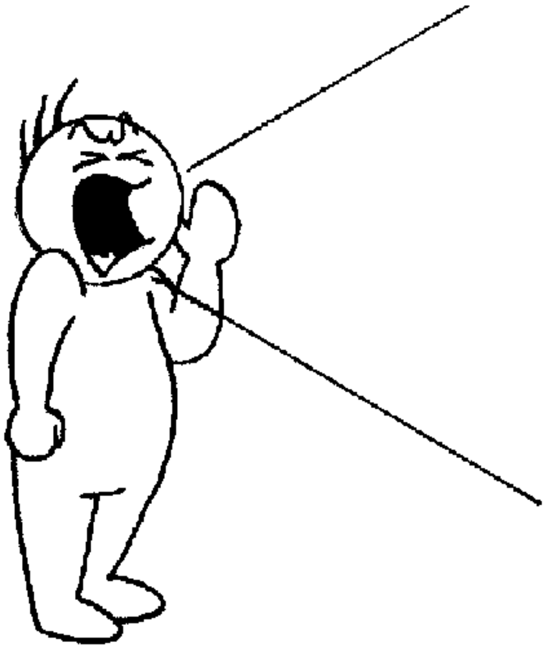
$$v = \frac{3.00 \times 10^8\ \text{m/s}}{4.23 \times 10^{14}} \times 6.0 \times 10^{12}$$

$$= 4.26 \times 10^6\ \text{m/s}$$

The galaxy is moving away at $4.26 \times 10^6$ m/s.

# Activity

- Worksheet - **The Speed of Light and the Doppler Effect**



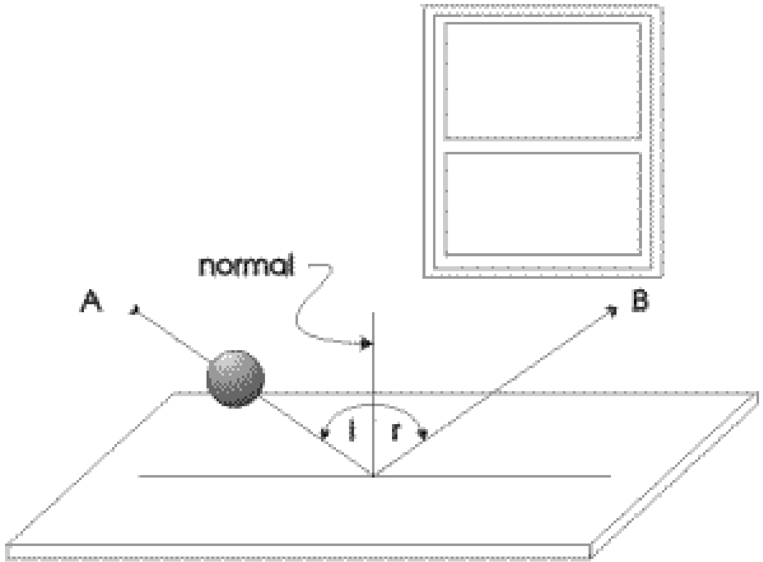
**Section 2 Topic 9**

- Reflection of Light

Text: Section

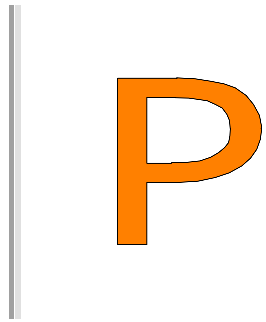
## Reflection by Plane Mirrors

- Remember the law of reflection: the incident ray, the normal and the reflected ray will all be in the same plane.

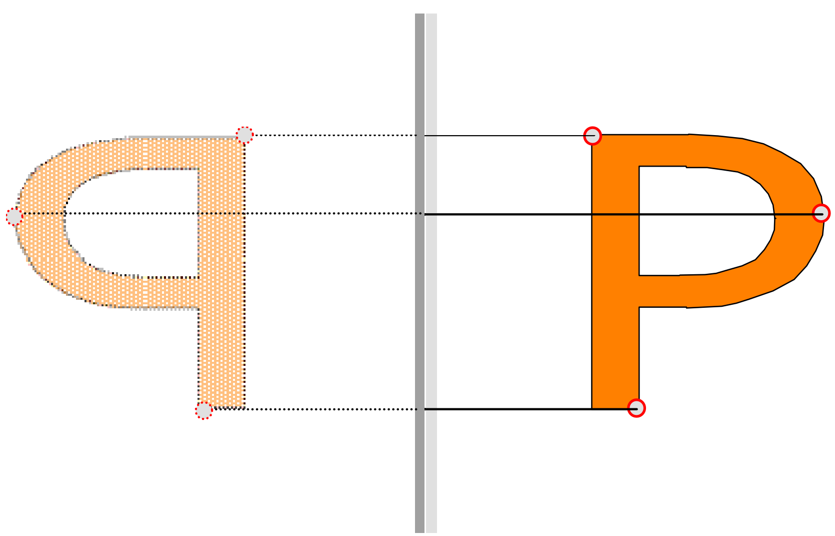


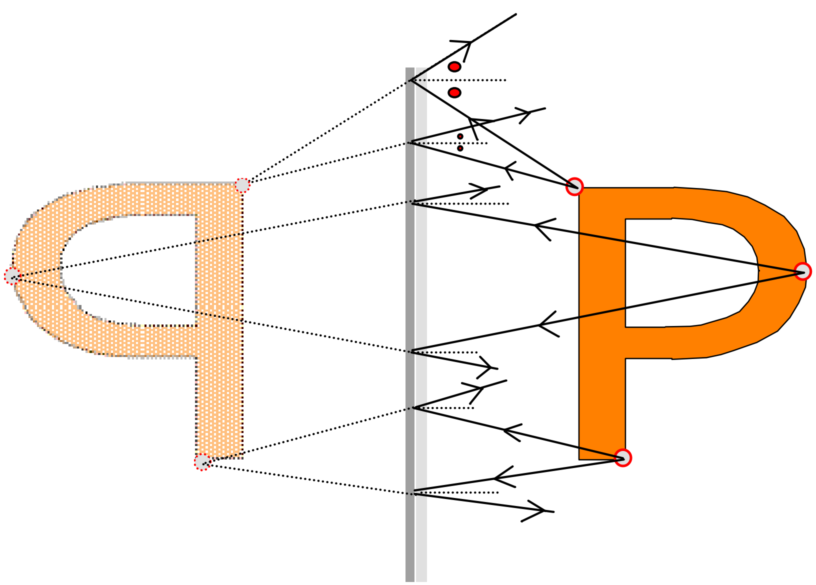

We can use this law to develop a process of forming images with plane mirrors.

There are two methods for finding images in a mirror

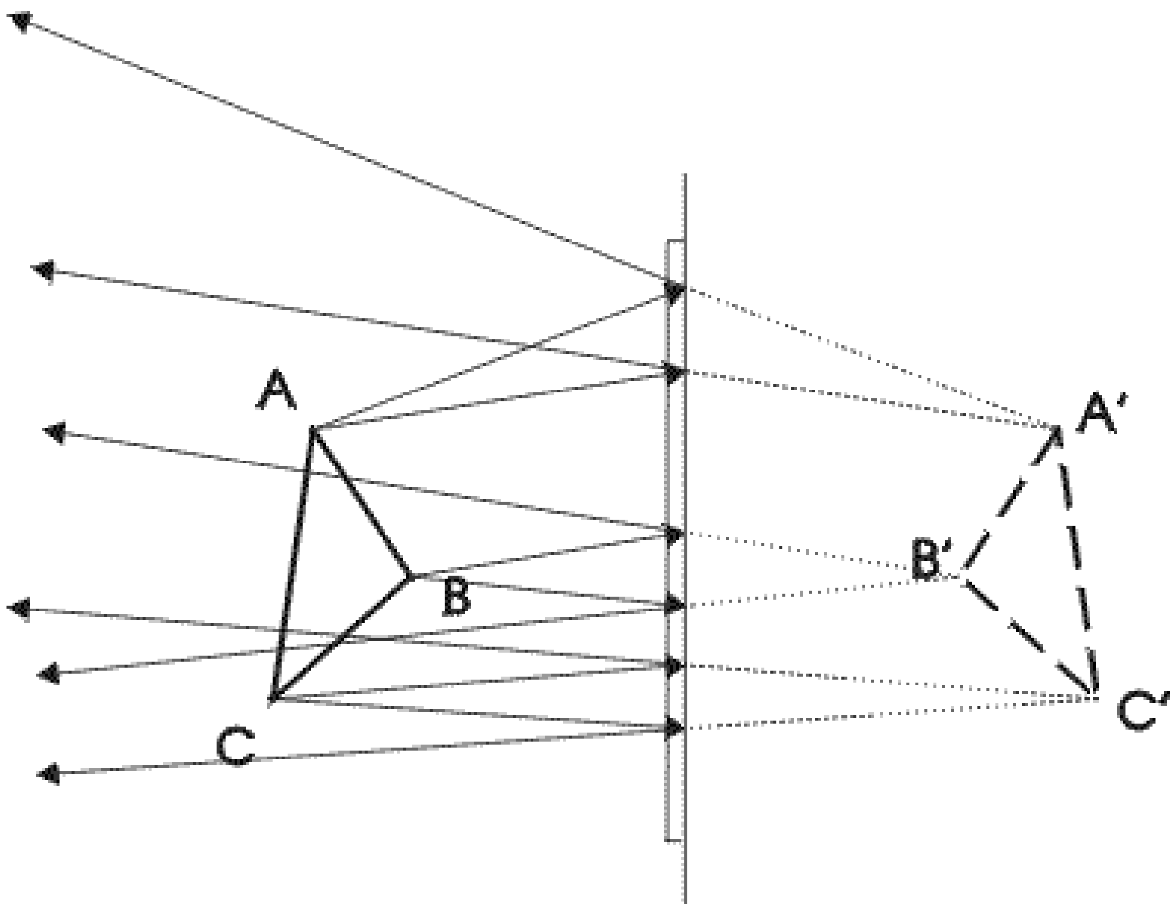


Short way:





The image should be drawn with a dotted line and labeled using ‘primes’

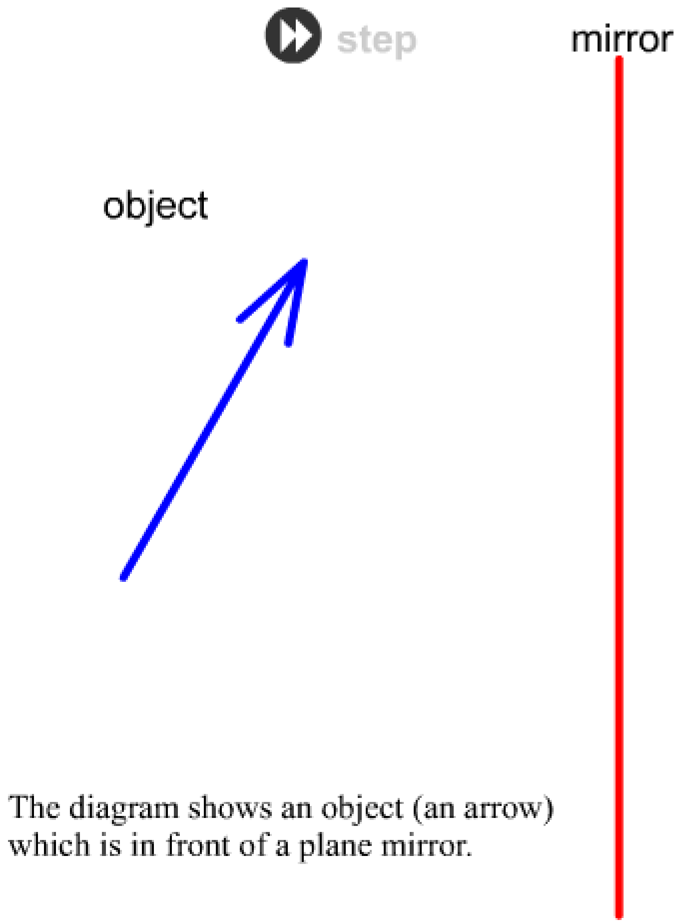


## Reflection by Plane Mirrors

There are a few things we can say about images in plane mirrors:

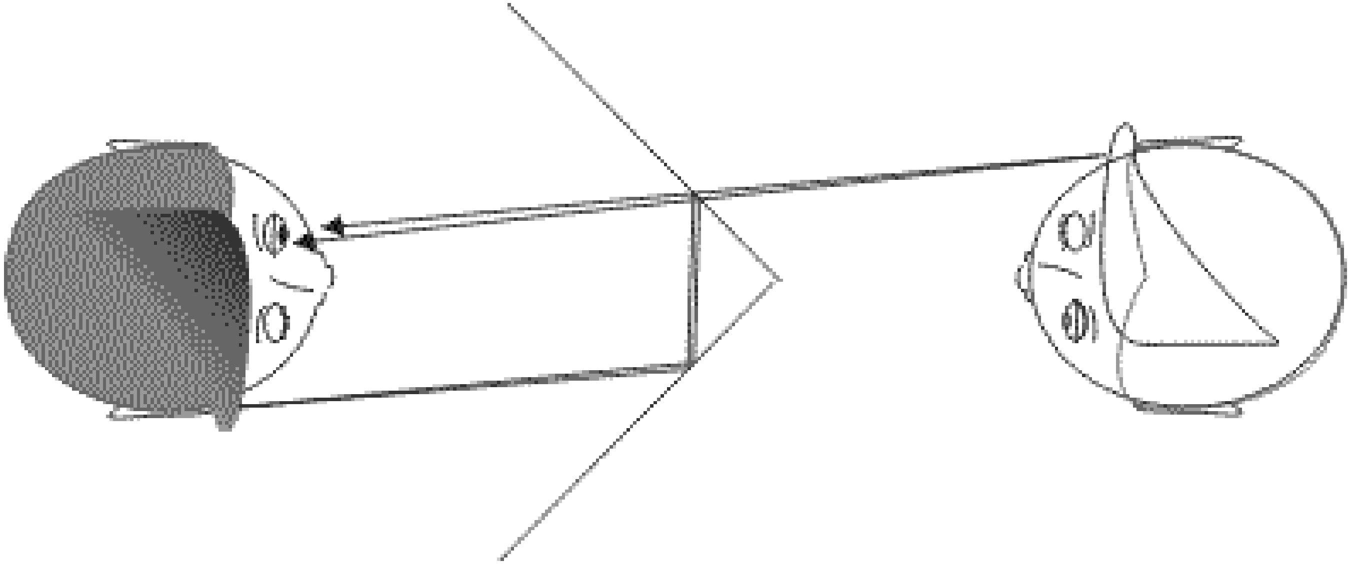
- TYPE: they are not REAL. The reflected rays don't actually meet. They only seem to meet. The image is called a VIRTUAL Image.
- SIZE: the image is the same size as the object.
- Image height = object height $h_i = h_o$
- LOCATION: the image is just as far "behind" the mirror as the object is in front of it. Image distance = object distance or $d_i = d_o$
- ATTITUDE: - The image is erect (not inverted).
  - The image is laterally reversed.

- Review


step
mirror
object
The diagram shows an object (an arrow)
which is in front of a plane mirror.

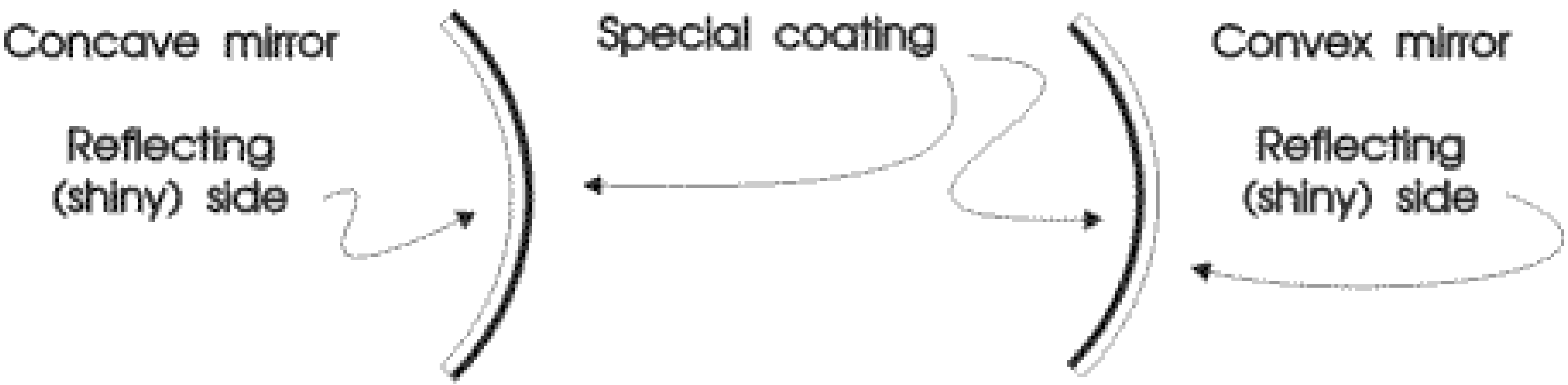
# A Special note about plane mirrors

Corner mirrors allow you to is that you see yourself as you are, as if you were standing behind the mirror looking out, and not inverted left to right.

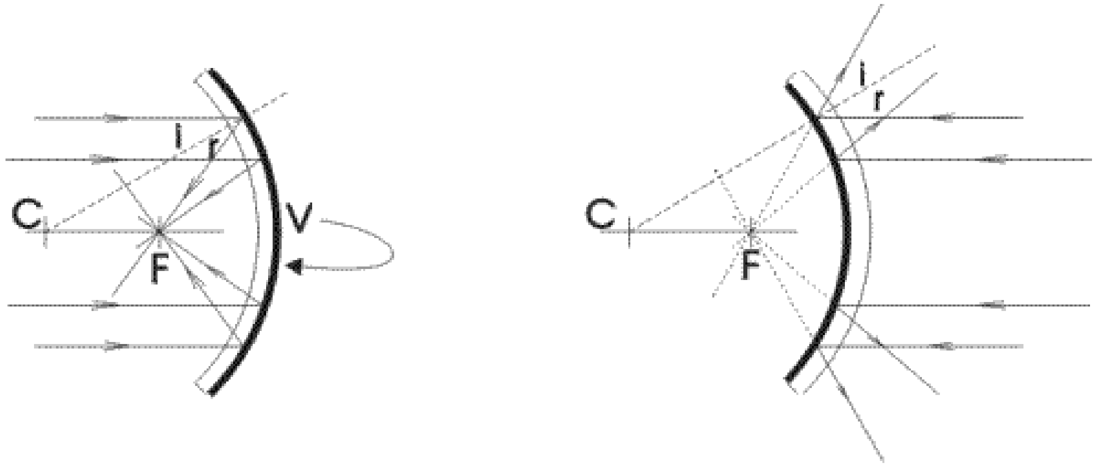


# The Reflection of Light by Curved Mirrors

- Here we will consider the reflection in two types of mirrors:



# Rays and Images in Curved Mirrors




A concave mirror is a converging mirror

A convex mirror is a diverging mirror

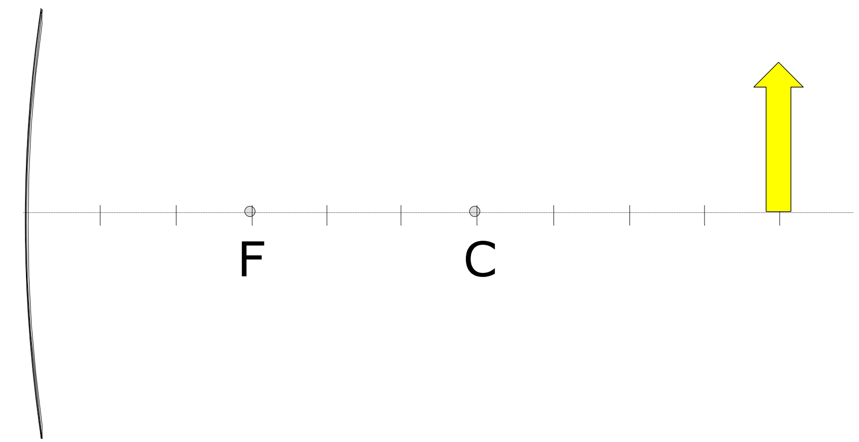
There are a few points to follow when drawing rays for curved mirrors.

- The focal length is **one-half the radius** of curvature
- Parallel rays reflect through the focus
- rays that pass through the focus reflect parallel
- Rays that pass through the center of curvature reflect back.

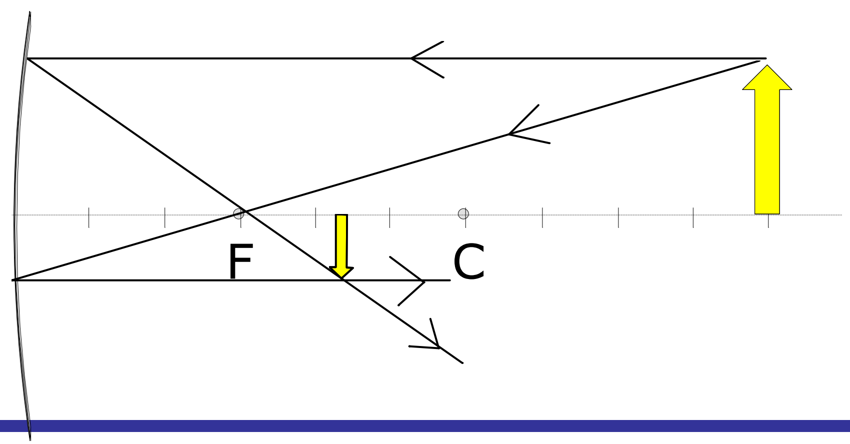
Example: Object is on the far side of the Centre of Curvature of a Concave Mirror

What is the image position and description?

Given:




Solution:

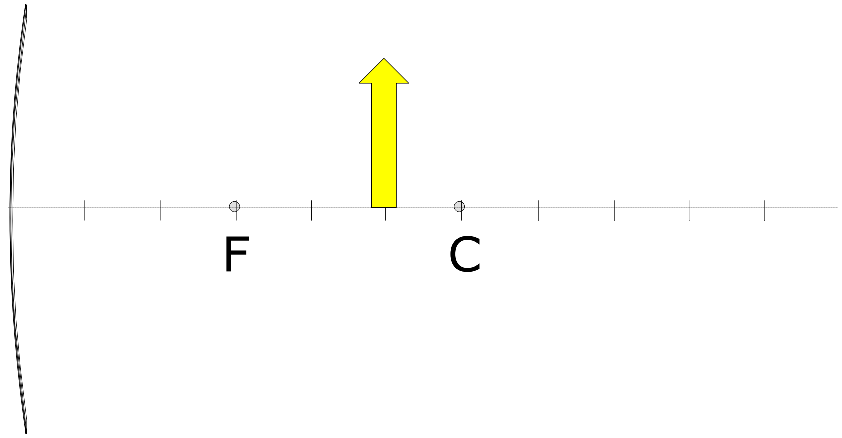



The image is real, inverted, and shorther

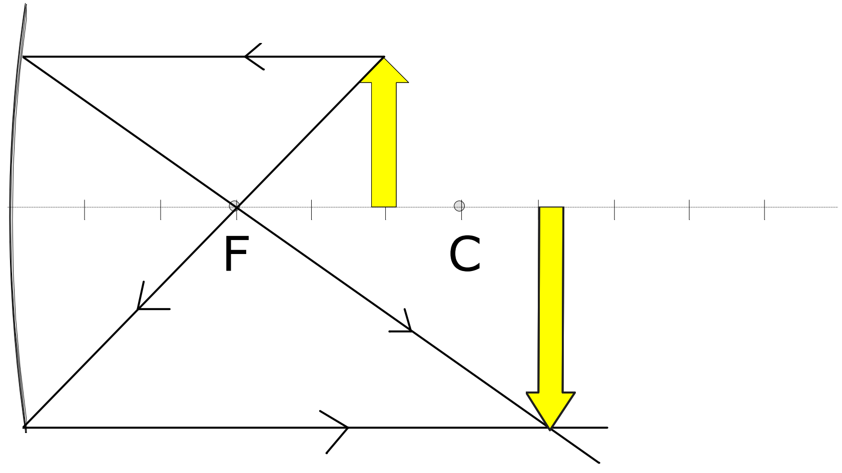
Example 2: Object is between “F” and “C”

What is the image position and description?

Given:



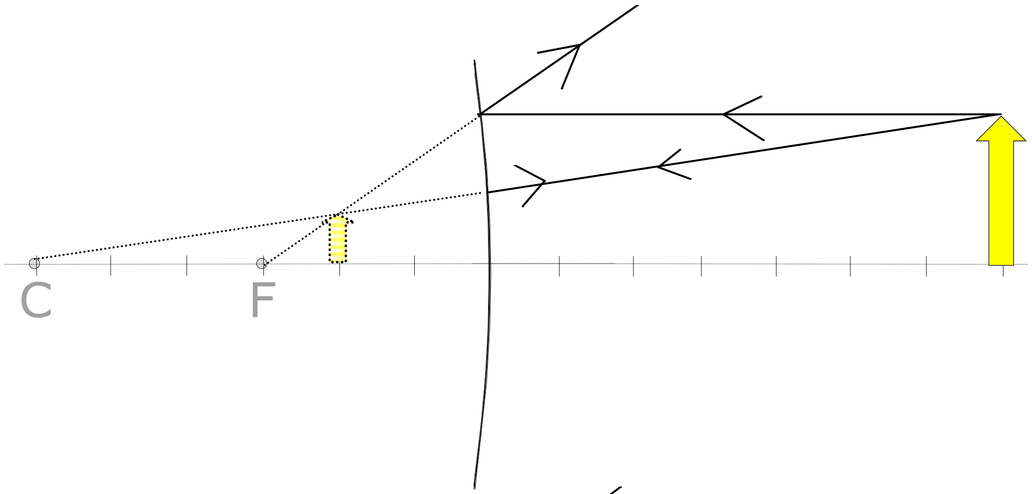

Solution:



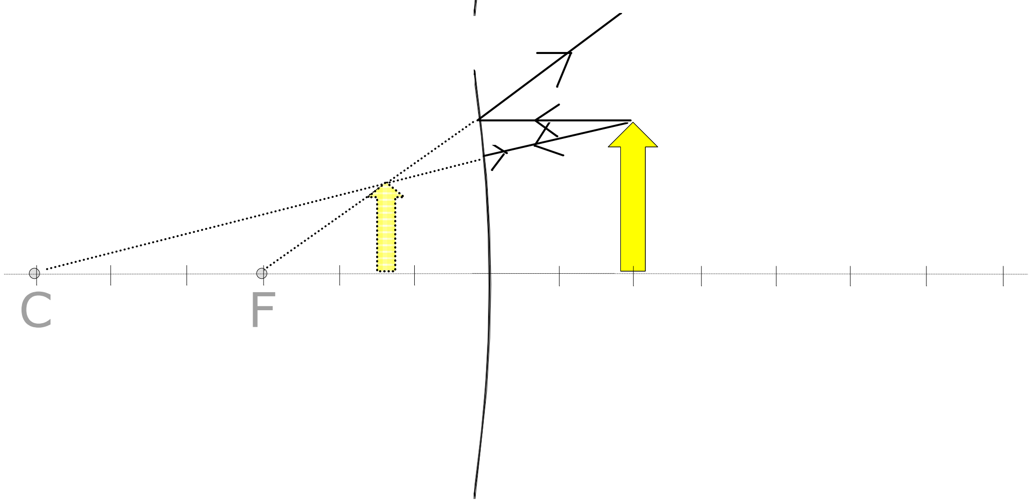

The image is real, inverted, and taller.

Example 3: A Convex Mirror makes Only virtual images

Trial 1

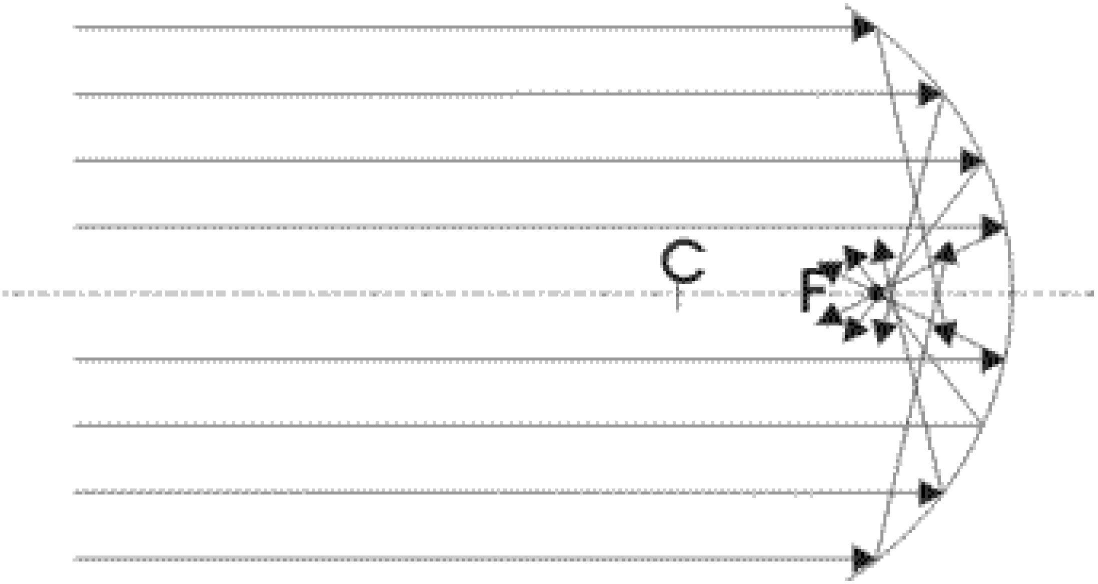



Trial 2



# Spherical Aberration, a Problem for Curved Mirrors

Look at the mirror below

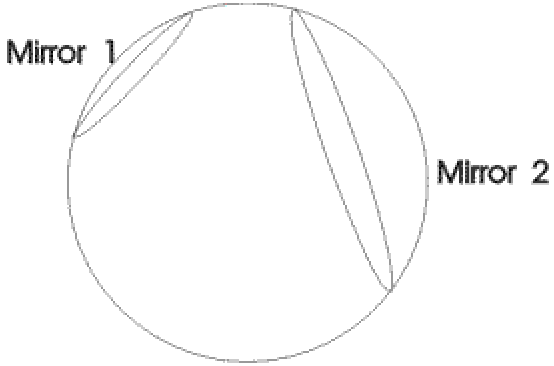



- Can you see that the rays which are closest to the edge of the mirror are focused in a different place from the rays that are closer to the centre of the mirror. This failure of curved mirrors to focus all parallel rays to the same point is called spherical aberration. This causes a "fuzzy" focus.

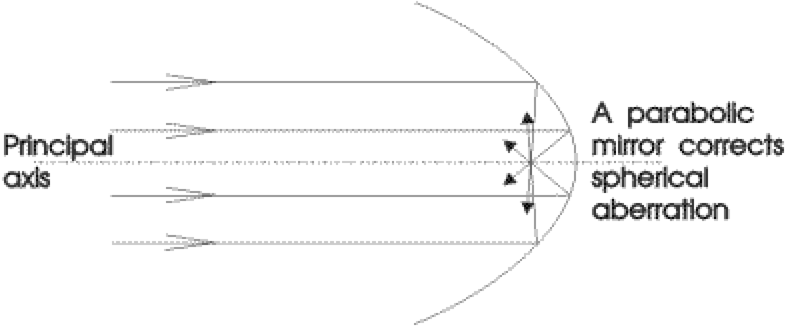
There are three ways to reduce spherical aberration although the first two ways mentioned below are really the same):

- 1. Block out the outer portion of the mirror. (use a doughnut shaped ring)

- 2. Make sure that the mirror you are using is small compared to its radius of curvature. If you were choosing a mirror, take cap #1 and not cap #2 .

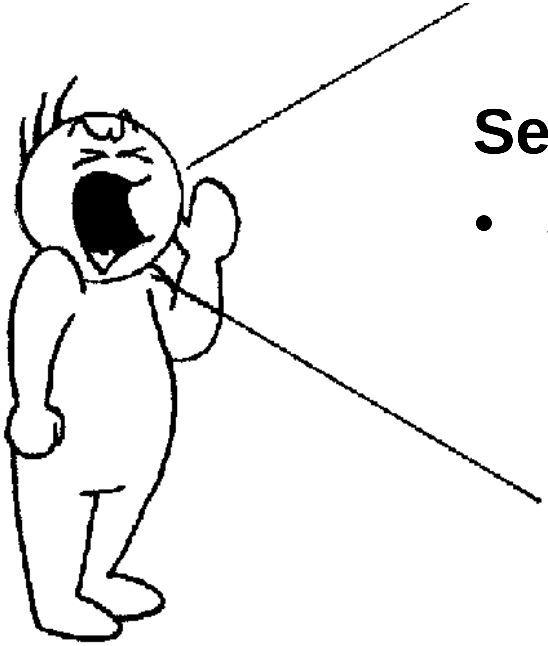



•3. Use a parabolic mirror. These mirrors reflect all rays through the principal focus.



# Activity

- Worksheet - Reflection of Light



## Section 2 Topic 10

- Snell's Law

Text: Section

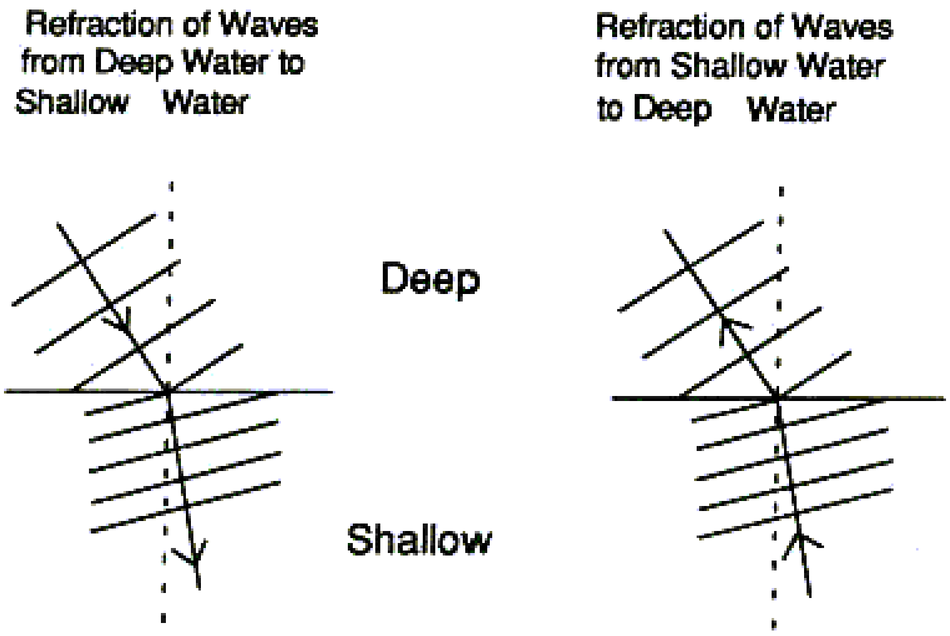
## Remember:

Refraction: the direction of a water wave changes as it moves from one medium to another.

- When waves move from one medium to a second in which the speed is different then the wavelength changes also.

If the waves:

- speed up, then the wavelength is longer
- slow down, then the wavelength is shorter

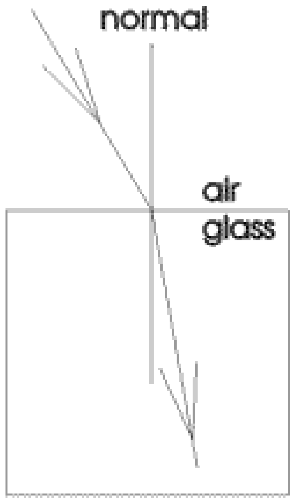


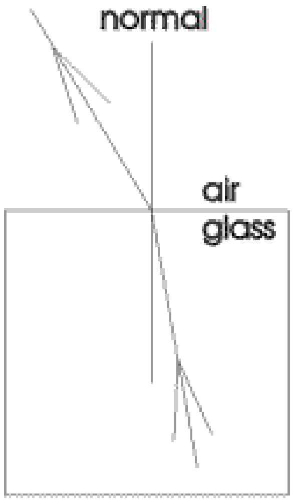
We can make the same two statements about light as we did about water waves:

1. If light moves from one substance to another at an oblique angle and slows down, the direction of the ray will bend toward the normal.

2. If light moves from one substance to another at an oblique angle and speeds up, the direction of the ray will bend away from the normal.

- These statements are illustrated in the diagrams below:

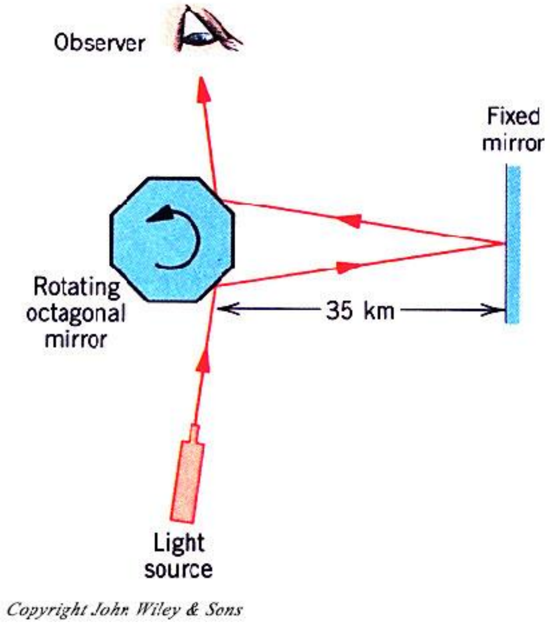


# Light

- The speed of light in a vacuum is 2.997924 x $10^8$ m/s. The speed of light in air is 2.997050 x $10^8$ m/s. These speeds are so close that we use 3.00 x $10^8$ m/s as the speed of light in both a vacuum and air.

- The symbol for the speed of light in a vacuum (or air) is "c". We will use the symbol "*v*" for the speed of light in any other substance.




Michelson's Experiment

## Index of refraction

- Using the symbol h [greek letter eta] or *n,* the *index of refraction* for a substance is the ratio of the speed of light (c) in a vacuum or in air to the speed of light v in the substance:

$$\eta = \frac{c}{v} \quad \text{or} \quad n = \frac{c}{v}$$

Example 1

- The speed of light in a piece of glass called crown glass is $1.97 \times 10^8$ m / s. What is the index of refraction of crown glass?

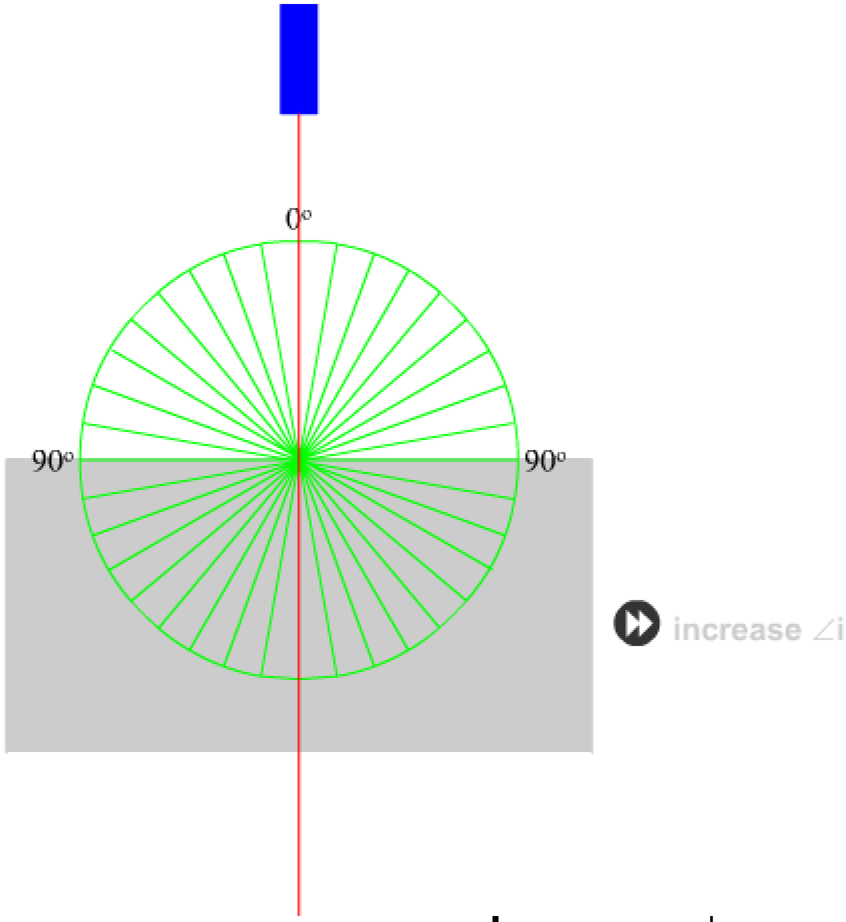
Solution.

$$n_g = \frac{c}{v_g} = \frac{3.00 \times 10^8 \text{ m/s}}{1.97 \times 10^8 \text{ m/s}} = 1.52$$

Note that *n* has no units because m/s cancel. Since *n* = 1.52, we can say that light travels 1.52 times faster in air than in crown glass.

# A Verification of Snell’s Law

Use the animation below to fill out the missing values in the table.




| | | Sin i | Sin r | Sini/sinr |
|---|---|---|---|---|
| 20° | | | | |
| 50° | | | | |
| 80° | | | | |

What did you notice about (sin i)/(sin r) ? Is the ratio constant?

A fellow named Willebrod Snell (1591 - 1626) did find a relationship.

Results like those on the last slide led Snell to conclude that

- for light traveling from material 1 into material 2 the ratio of the sine of the angle in material 1 to the sine of the angle in material 2 is constant and is called the index of refraction.

This statement is known as SNELL'S LAW. The short hand form of Snell's Law is:

$$\frac{\sin i}{\sin r} = \text{constant} = n_{1\rightarrow 2}$$

- The symbol  is read as "the index of refraction as light passes from medium 1 into medium 2".

- Think back (or click back) to the definition of index of refraction on page "a".  The index of refraction of a transparent substance is the ratio.

$$\eta = \frac{c}{v} \quad \text{or} \quad n = \frac{c}{v}$$

- This piece of knowledge allows us to rewrite Snell's Law as

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}\text{ ,} \quad \text{and cross-multipling gives}$$

$$n_1 \sin i = n_2 \sin r$$

# Example 1

rew step

A ray of light is incident from air on a block of glass ($n$ = 1.55) at an angle of 53°. Calculate the angle of refraction in the block.

Read the question

List the givens

Plan a strategy

Carry out the plan

Communicate

Given: $n = 1.55$, $i = 53^{o}$, $R = ?$

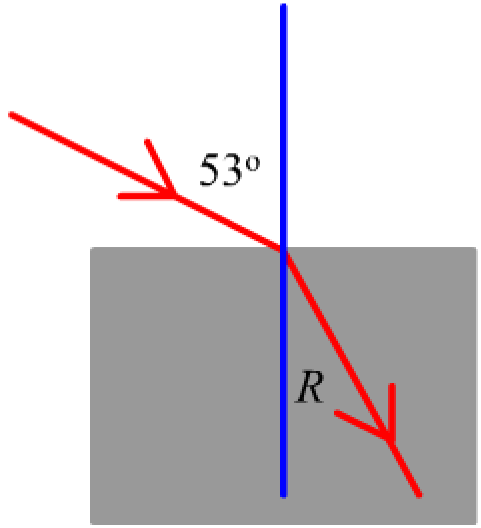
$$\frac{\sin i}{\sin R} = n$$

$$\sin i = n \sin R$$

$$\sin R = \frac{\sin i}{n}$$

$$= \frac{\sin 53^{o}}{1.55} = \frac{0.79863551}{1.55} = 0.5152487162$$

$$i = \sin^{-1}(0.5152487162) = 31^{o}$$



# Example 4

rew step

Read the question

List the givens

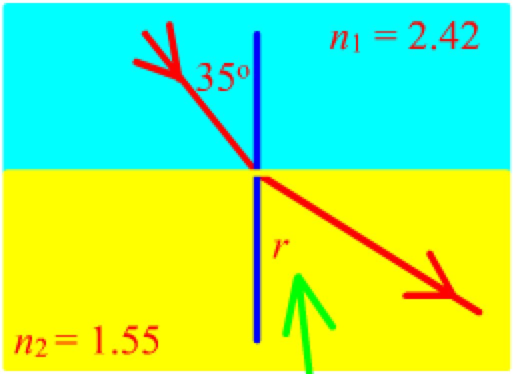
Plan a strategy

Carry out the plan

Communicate

A ray of light is incident from a block of diamond ($n$ = 2.42) to a block of glass ($n$ = 1.55). The angle of incidence is 35°. What is the angle of refraction in the glass?

Given: $n_1 = 2.42$, $n_2 = 1.55$, $i = 35^{\circ}$, $r = ?$




$$n_1 \sin i = n_2 \sin r$$

$$\sin r = \frac{n_1 \sin i}{n_2}$$

$$= \frac{(2.42)(\sin 35^{\circ})}{1.55}$$

$$= \frac{(2.42)(0.5735764364)}{1.55}$$

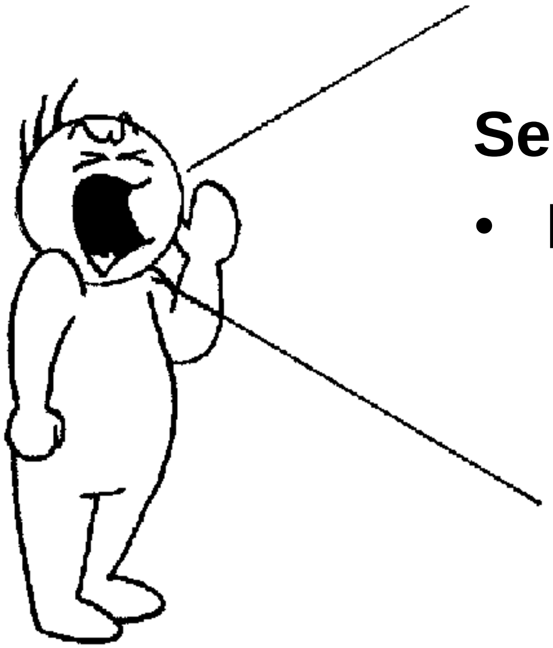
$$= 0.8955193393$$

$$r = \sin^{-1}(0.8955193393) \quad = 64^{\circ}$$

The angle of refraction in the glass block is 64°.

# Activity

- Worksheet: A Verification of Snell's Law
- Quiz



**Section 2 Topic 11**

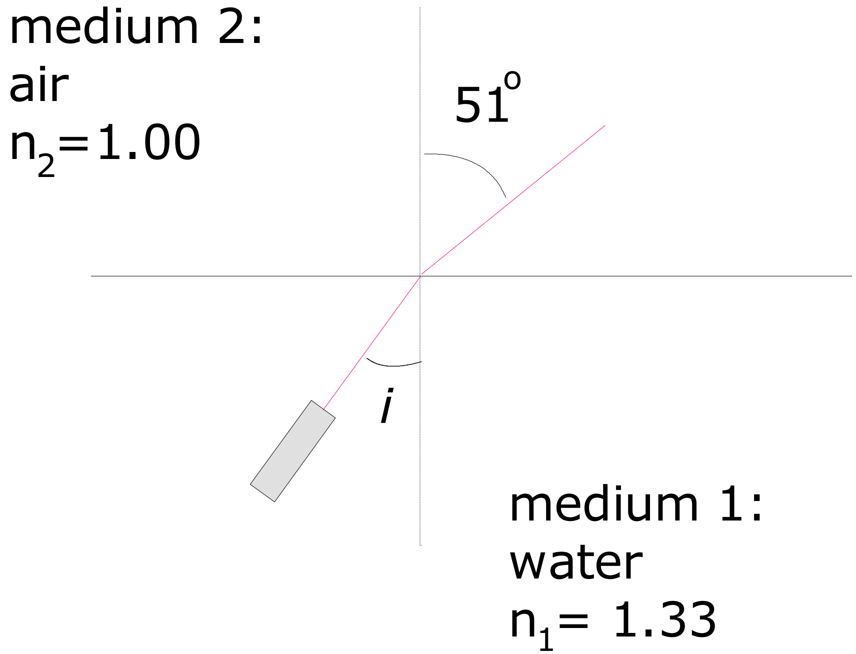
- Refraction of Light

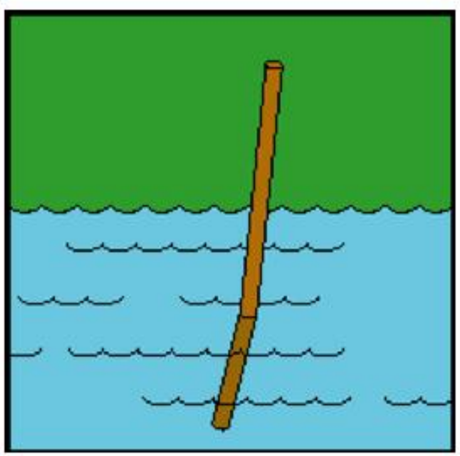
Text: Section

# REFRACTION OF WAVES

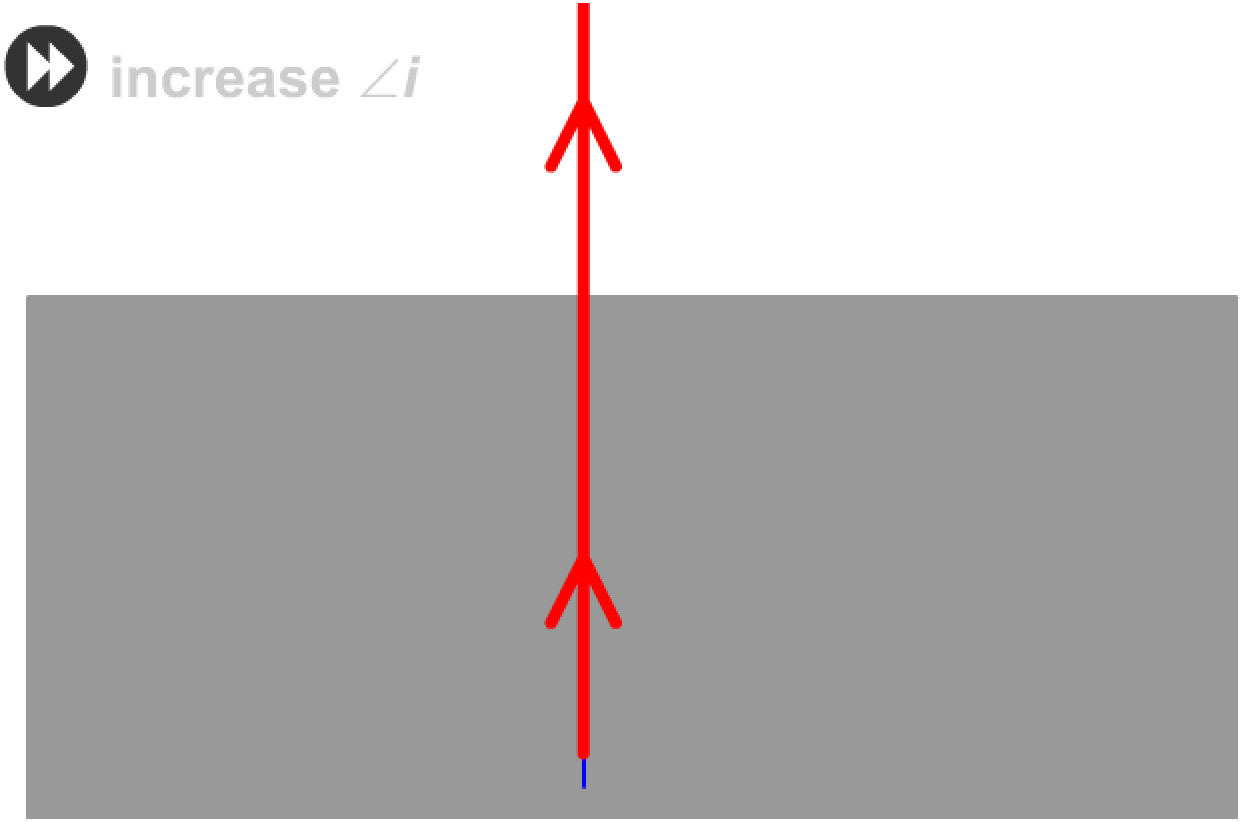
Remember from the last section:
Refraction is the bending of waves as it enters a different medium.

When light travels from more dense to less dense it bends away from the normal.



- If you increase the incident angle as light travels from dense to less dense some interesting happens.



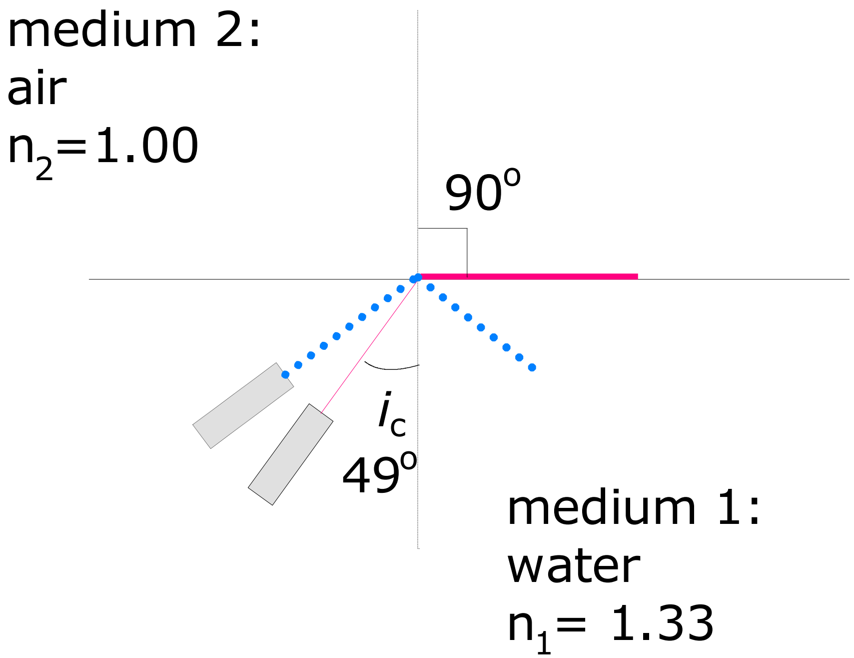

Notice that at one angle of incidence the refracted ray just barely escapes into the air and runs along the interface between the glass and the air. This is known as the critical angle.

- The *critical angle* for a particular material is the angle of incidence for which the angle of refraction is $90^o$.

- The symbol for critical angle is *ic*

When the angle of incidence is greater than the critical angle, or, in short hand: when i > ic.

The ray reflects back into the glass. We call this **total internal reflection**

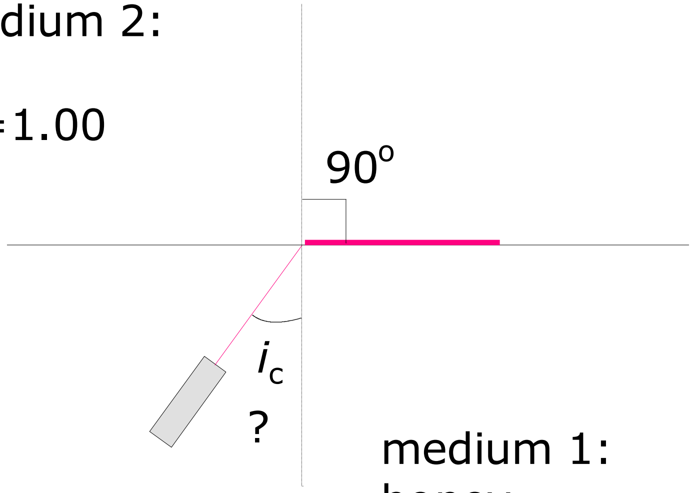


# Example 1: A Very Sweet Problem

The index of refraction of honey is 1.49. What is the critical angle for a ray of light passing from honey into air?

Given: Draw a picture:

medium 2:
air
$n_2 = 1.00$




medium 1:
honey
$n_1 = 1.49$

Solution:

$$\sin i_c = \frac{n_2 \sin r}{n_1} = \frac{1.00 \sin 90^o}{1.49}$$

$$\sin i_c = \frac{1.00 \times 1.000}{1.49} = 0.671$$

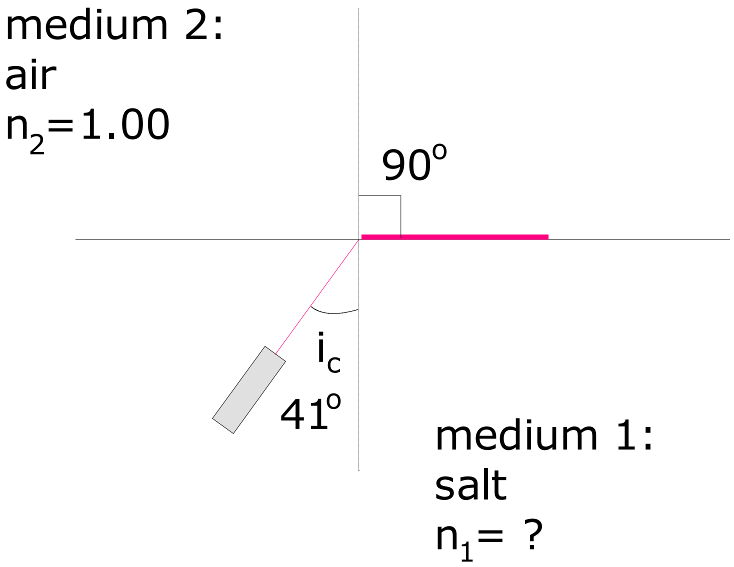
$$i_c = \sin^{-1} 0.671 = 42^o$$

The critical angle for honey is $42^o$.

# Example 2: A Very Sweet Problem in Reverse

The critical angle for salt is 41°. What is its index of refraction?

**Given:** Draw a picture:




**Solution:**

$$n_1 \sin i_c = n_2 \sin r$$

$$n_1 = \frac{n_2 \sin r}{\sin i_c} = \frac{1.00 \ x \ \sin 90}{\sin 41}$$

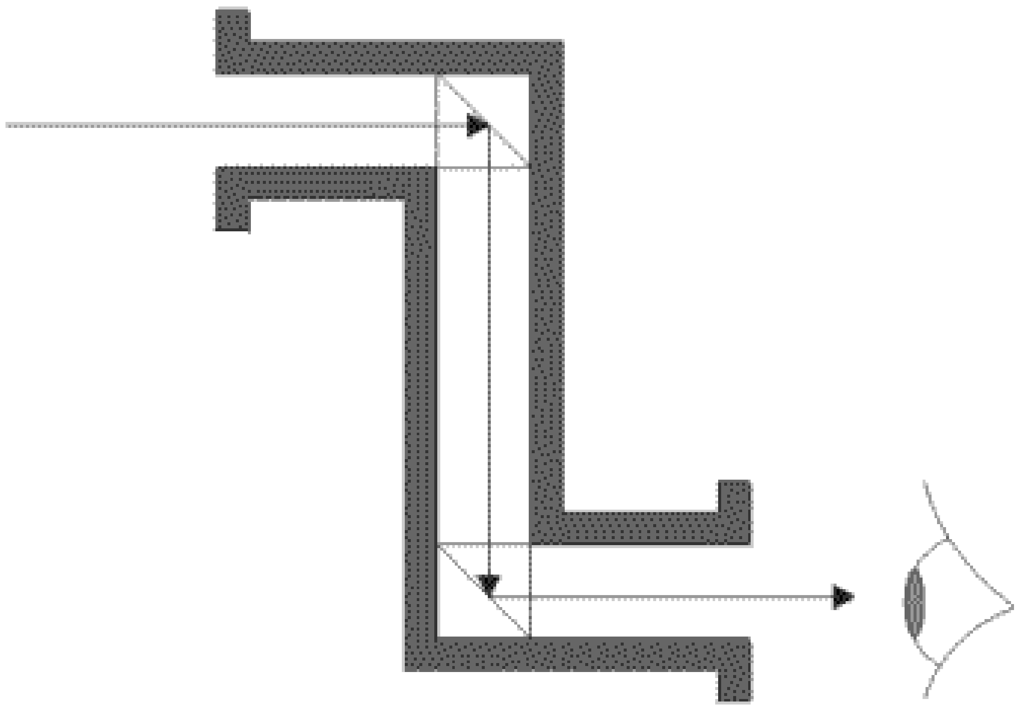
$$n_1 = \frac{1.00 \ x \ 1.000}{0.656}$$

$$n_1 = 1.52$$

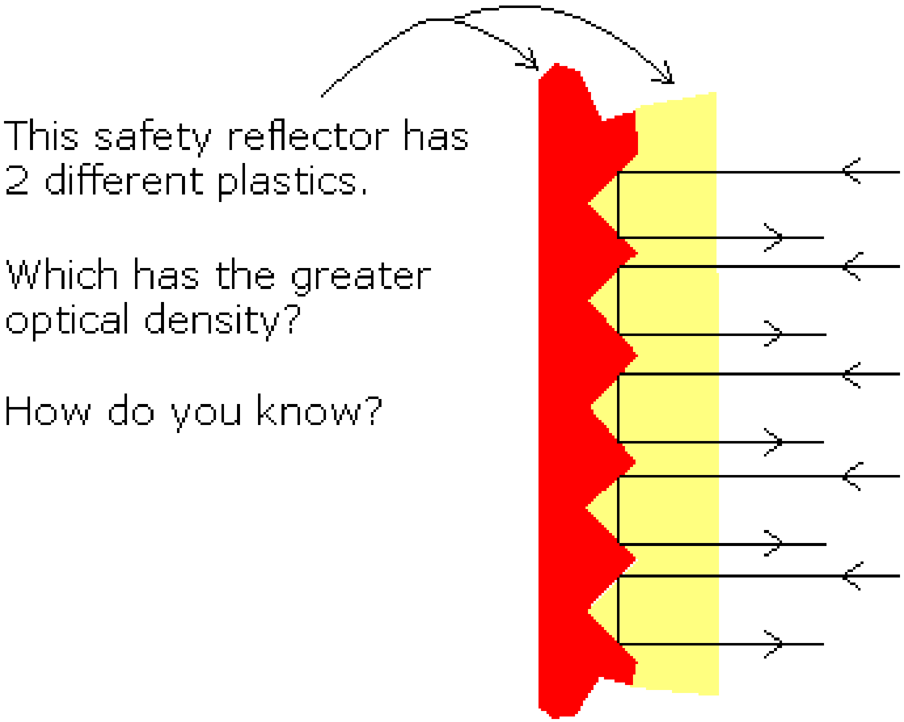
The index of refraction of salt is 1.52.

## Real life Total Internal Reflection

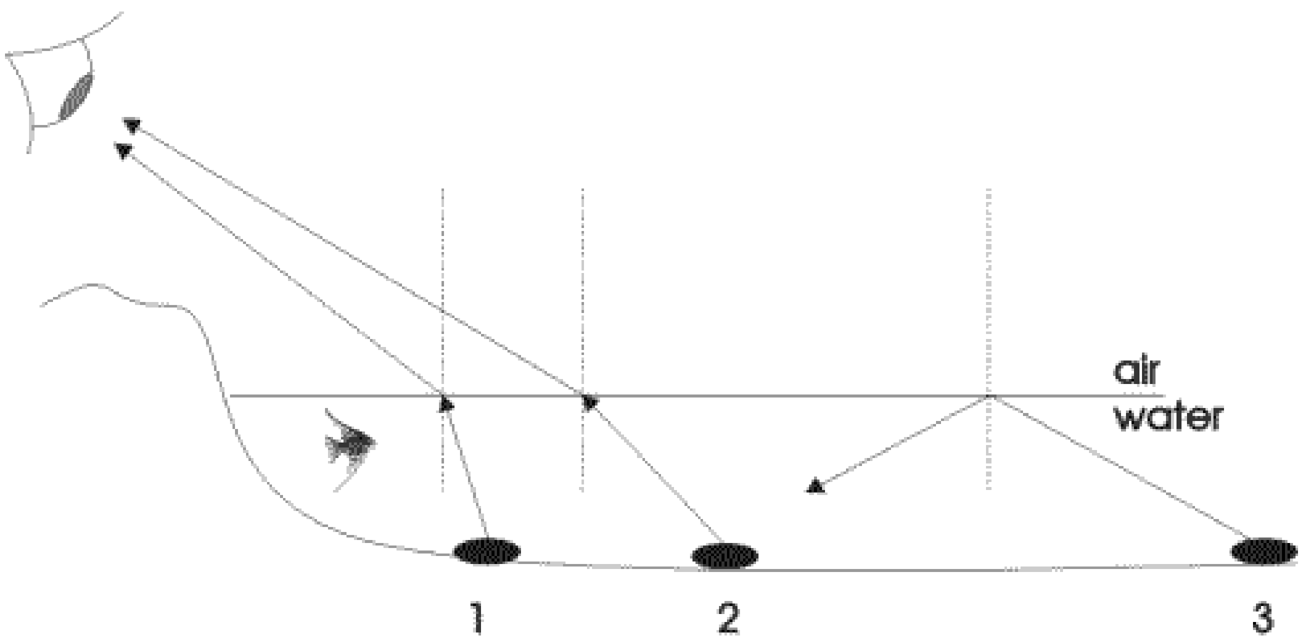
The periscope: The diagram above shows a ray of light being totally internally reflected in two glass prisms.



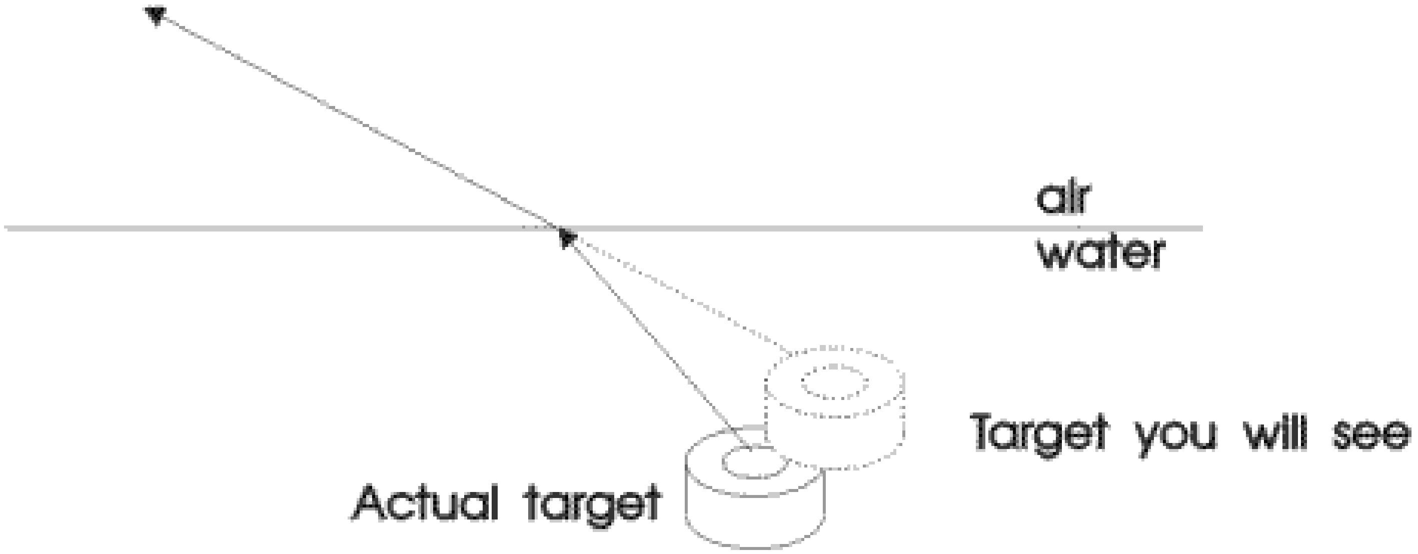
- Safety reflectors. Note that two different plastics are used. Ask yourself why.



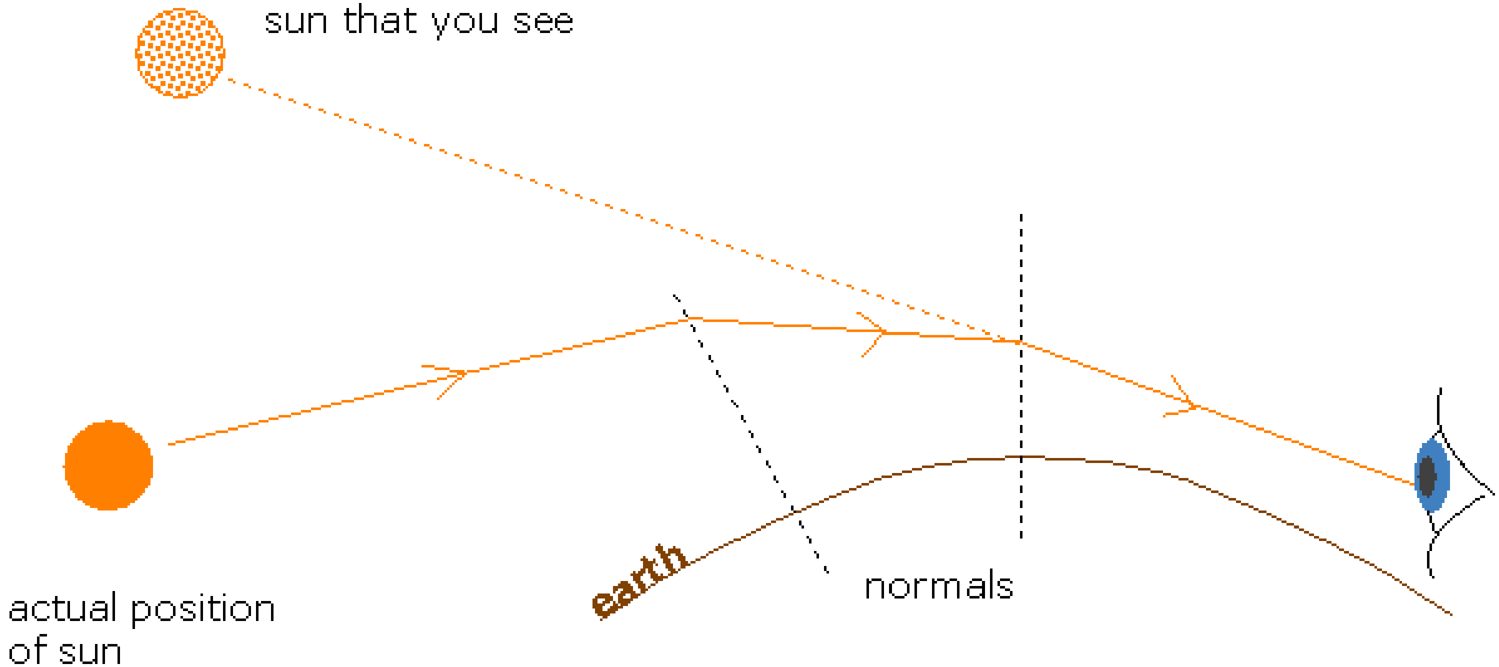
- When you are near a body of water notice you can see the bottom close to shore, but a few meters from shore it is impossible to do so.
- Below you will be able to see rock #1, and probably rock #2, but not #3. Any light ray heading your way from rock #3 will strike the water/air interface at an angle greater than the critical angle for water, and will therefore be totally internally reflected.



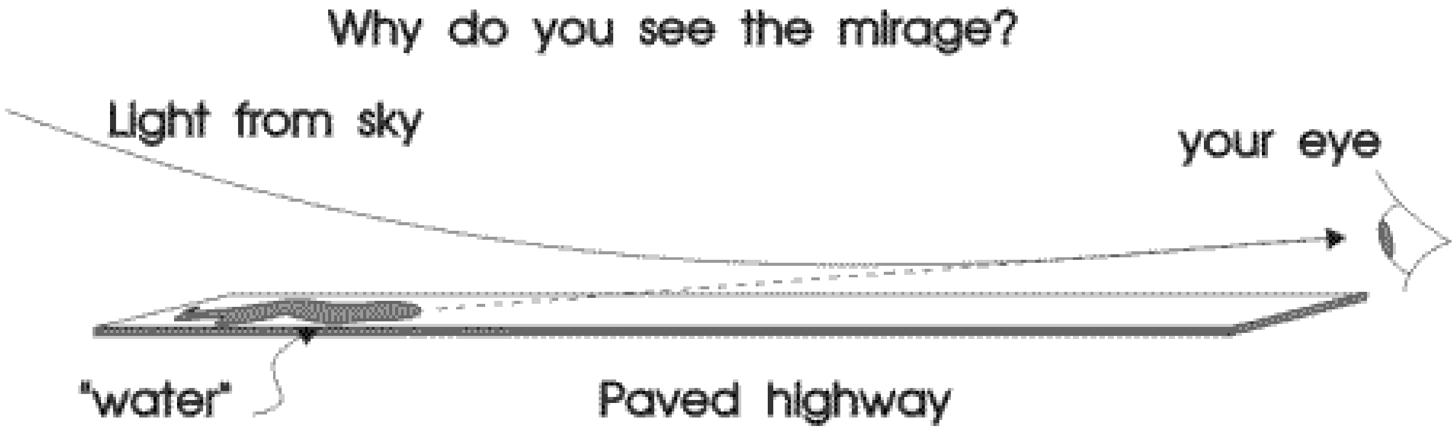
- Things under the water are not where they appear!



- The sun actually seems higher in the sky than it really is.



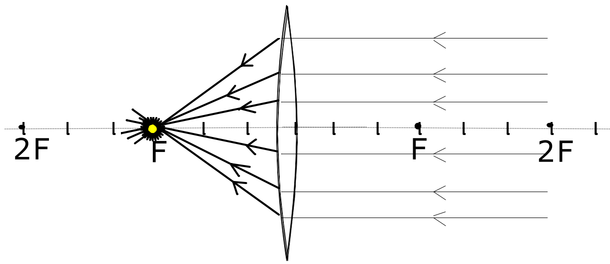
- Mirages are not figments of your imagination. They are real and can be photographed. The most common mirage is the "water" that you see a kilometre or so ahead of your car when you are driving on the highway on a summer day.



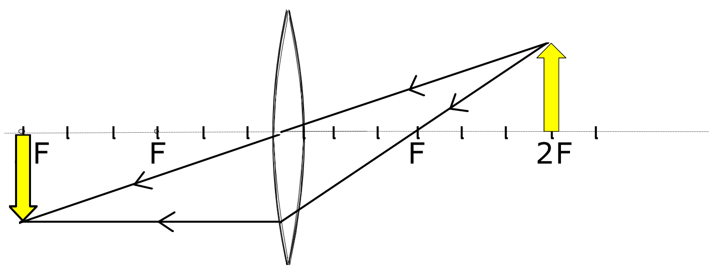

- As the light direction bends more and more, it is almost as if it is reflected from the pavement. This experience appears to be something like other situations where you have seen light reflected from a water surface. Therefore, for a moment you are willing to believe that there is water on the pavement ahead

# (Optional) Ray diagrams to cover all cases of image formation in a converging lens.

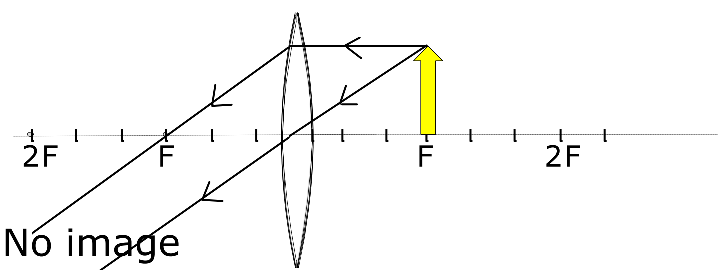
## Object at Infinity



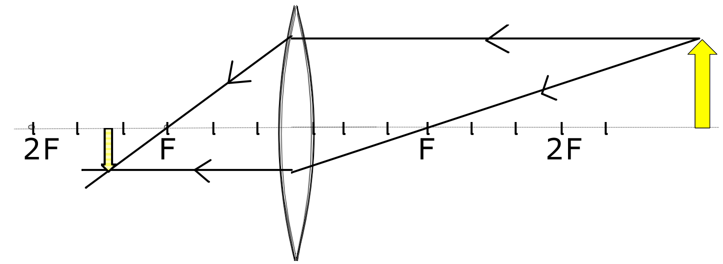

## Object at 2F



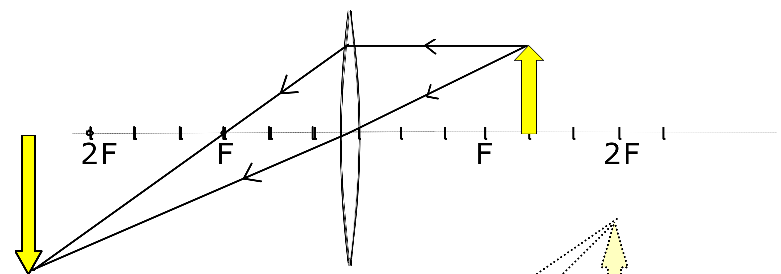

## Object at F



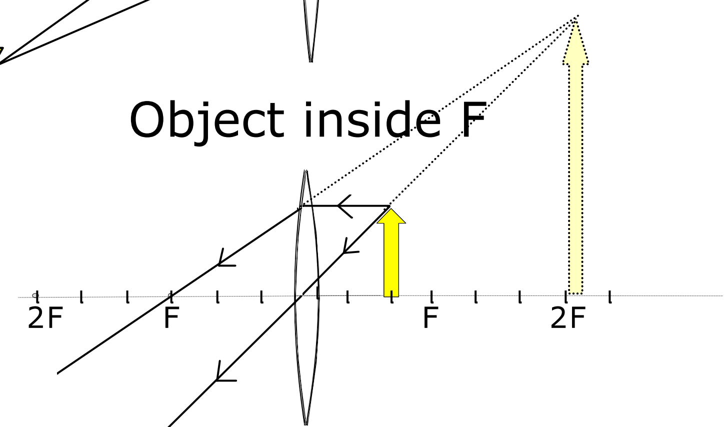

## Object outside 2F




## Object between 2F & F

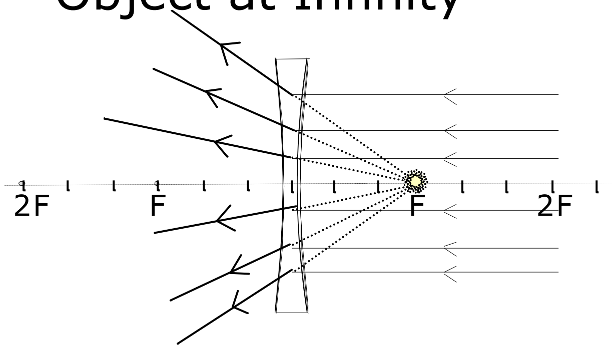



## Object inside F



# (Optional) Ray diagrams to show that a diverging lens has only one case.

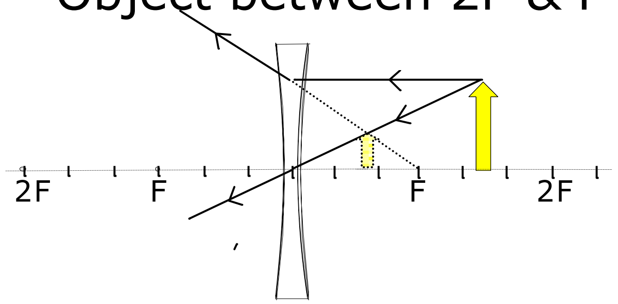
Object at Infinity




Object outside 2F

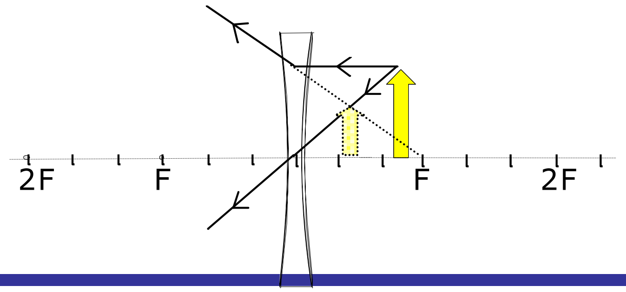
Object at 2F

Object between 2F & F




Object at F

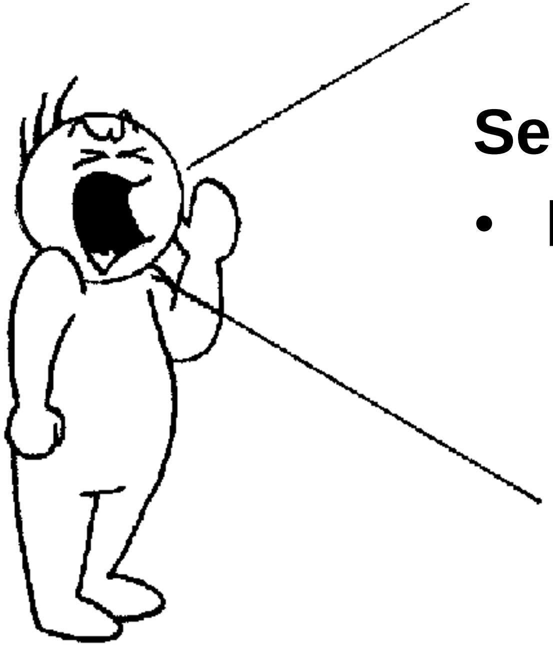
Object inside F



# Activity

- Worksheet: Refraction of Light

- Quiz



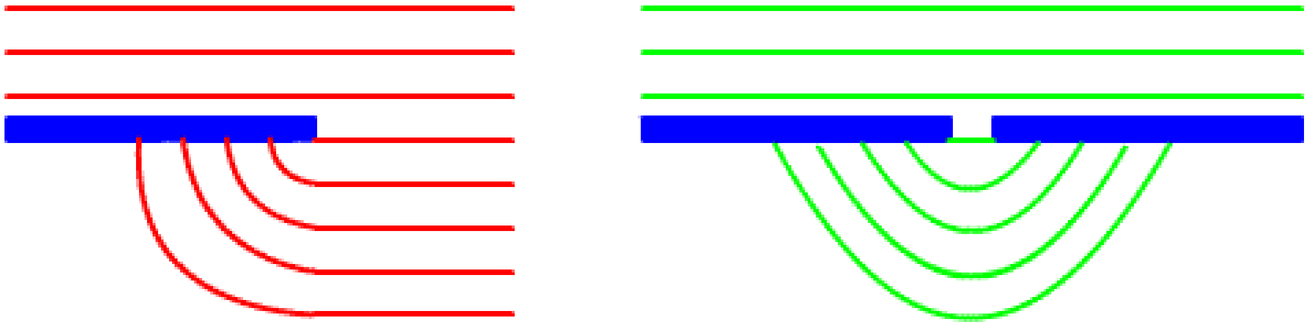
**Section 2 Topic 12**

- Diffraction and Poisson's Bright Spot

Text: Section

Remember Diffraction

- Diffraction is the bending of waves around a barrier or through a hole in the barrier.



- This is easily demonstrated with water waves or sound..On the other hand, it is not easy to show that light diffracts.

- Isaac Newton and his supporters said that since light does not show diffraction effects, it can't possibly travel in waves. This group of scientists proposed that light traveled in particles.

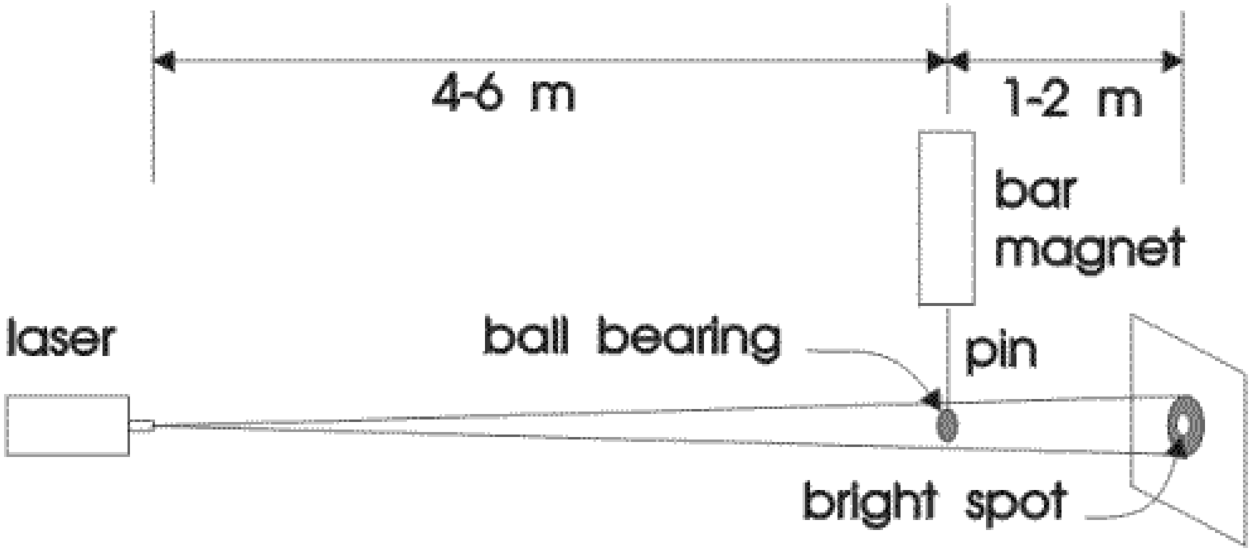
Nevertheless, other scientists (e.g., Grimaldi, Fresnel, and Arago) worked hard to find diffraction effects. Ask your teacher where you can read about the work of such scientists. Try a web search!

There are two reasons why the diffraction of light is difficult to demonstrate:

- light waves are extremely tiny, which means a very tiny opening or a very "sharp" barrier is needed to cause diffraction

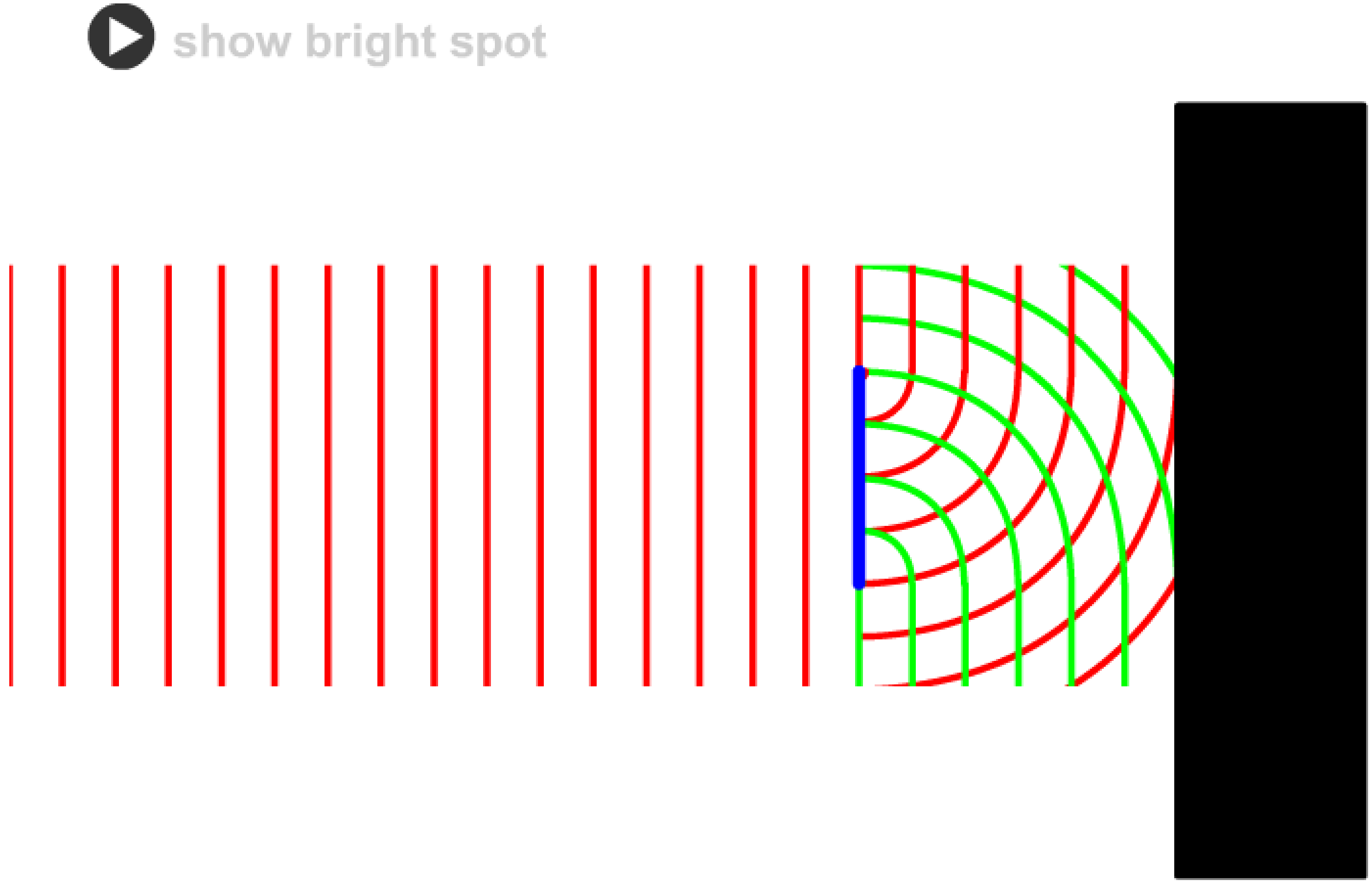
- ordinary light is composed of many colours, each with its own wavelength, all of which tends to contaminate efforts to show diffraction.

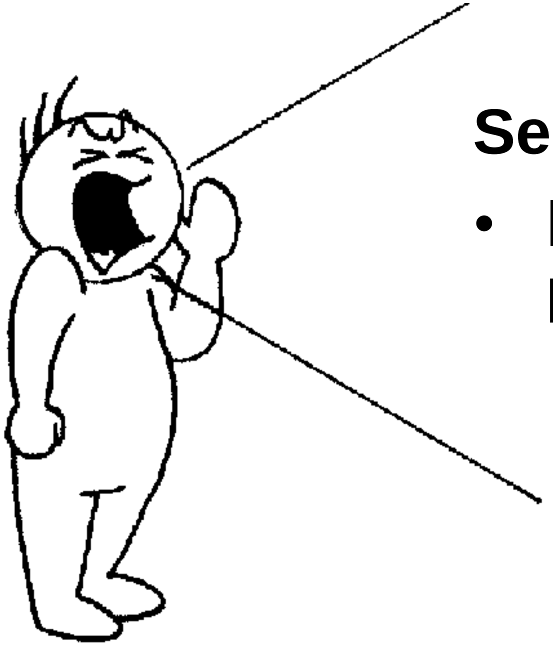
Scientist who believed in the particle theory: Their view was that if diffraction did exist, a set-up like the one shown below would result in a bright spot in the middle of the shadow on the screen. The bright spot would be caused by the waves interfering constructively after they bent around the obstacle. Since no one had ever seen a bright spot in the middle of a shadow, the whole idea seemed too absurd to talk about.




Today, using a laser this can be easily demonstrated!

- This Bright Spot is sometimes called Arago' s spot (after the person who first demonstrated it) or Poisson's spot (after the person who said it was an absurdity to look for it!).



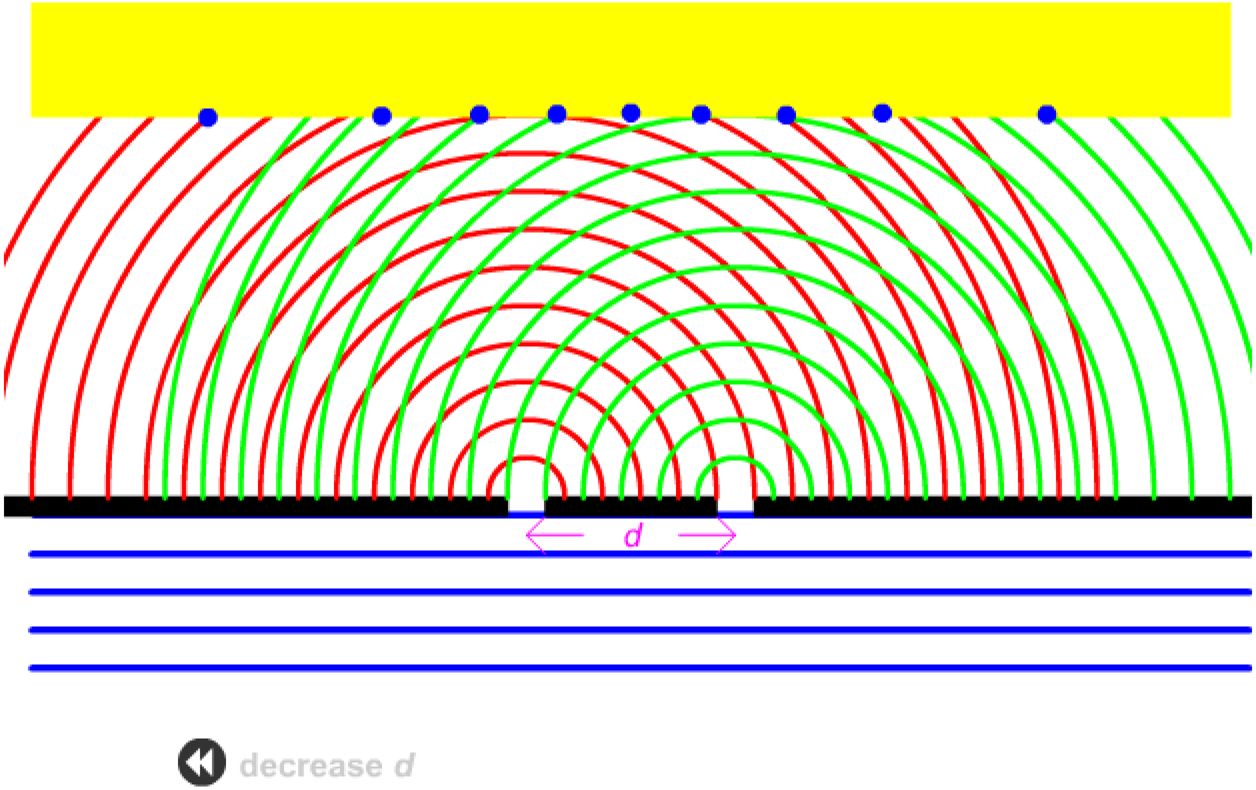


**Section 2 Topic 13**

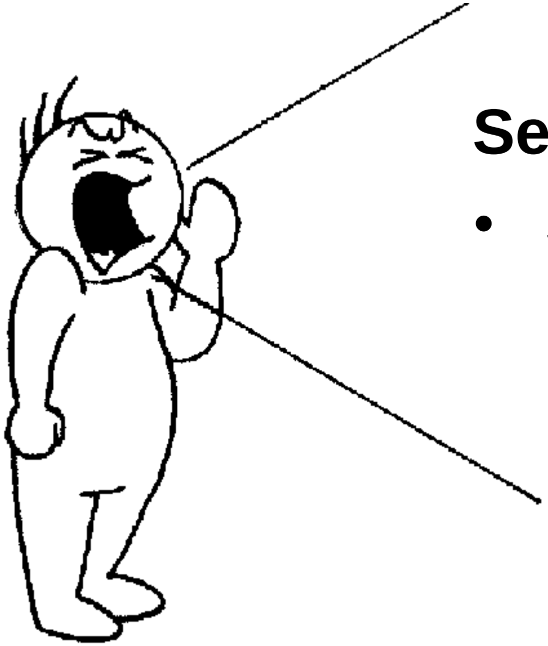
- Interference and Young's Double Slit Experiment

Text: Section

- Earlier we demonstrated the interference pattern in water waves that passed through two openings. To get the effect with light waves the openings must be so small that we call them slits.




This so-called "double-slit experiment" was first done by Thomas Young, a British physicist (1778-1829).

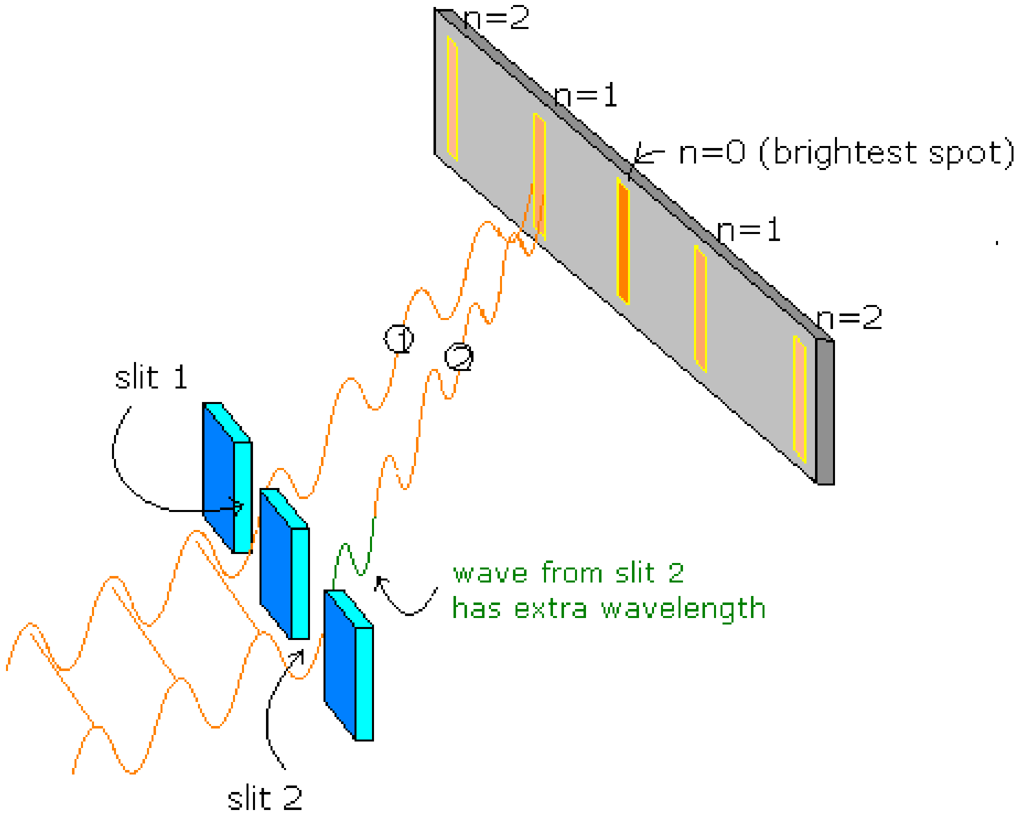


**Section 2 Topic 14**

- Solving Problems Involving Interference

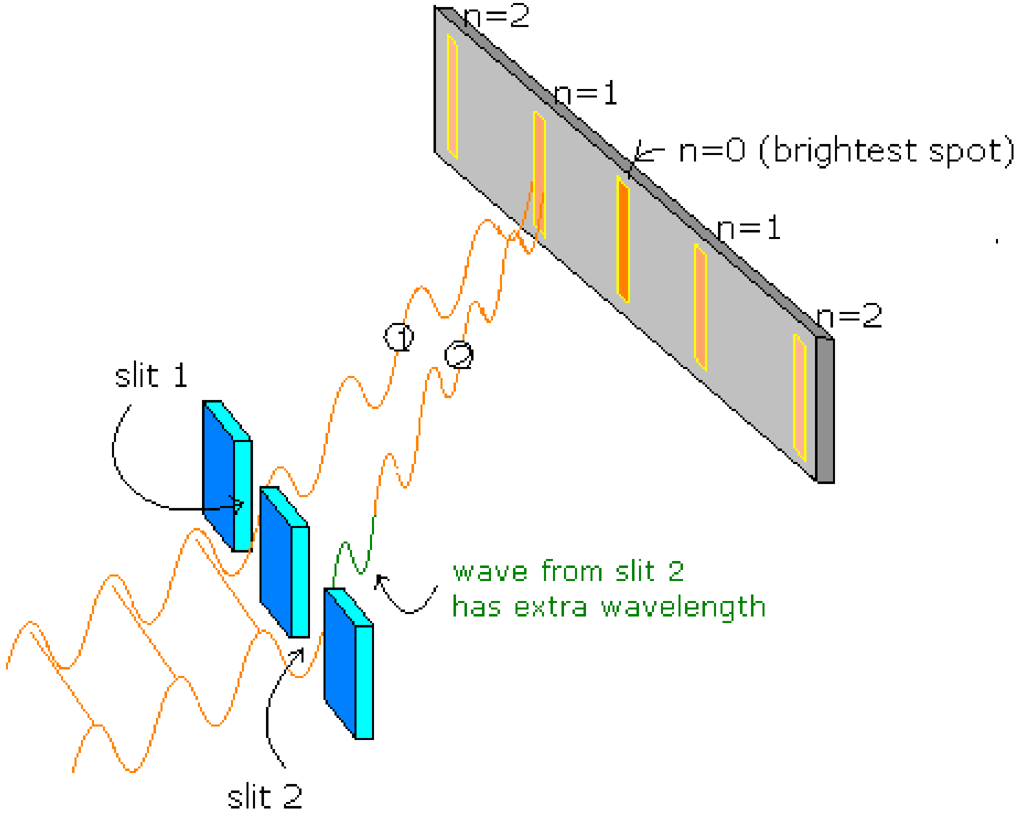
Text: Section

- When light passes through two openings we see is a series of bright bands or spots. This is show once again, but in a different way, below.




- Notice that the waves are in phase when they reach the n=1 spot.
- Look closely to see that wave form 2 has to travel further than wave form1.
- In fact, it travels exactly 1 wavelength further (shown by the green part).
- If we drew the waveforms to the n=2 band, it would be 2 wavelengths longer.

- CONCLUSION: bright spots will occur when the difference between the wave distances from slit 1 and slit 2 are 1λ, 2λ, 3λ, and so on. In other words, multiple whole wavelength differences are needed to create constructive interference.

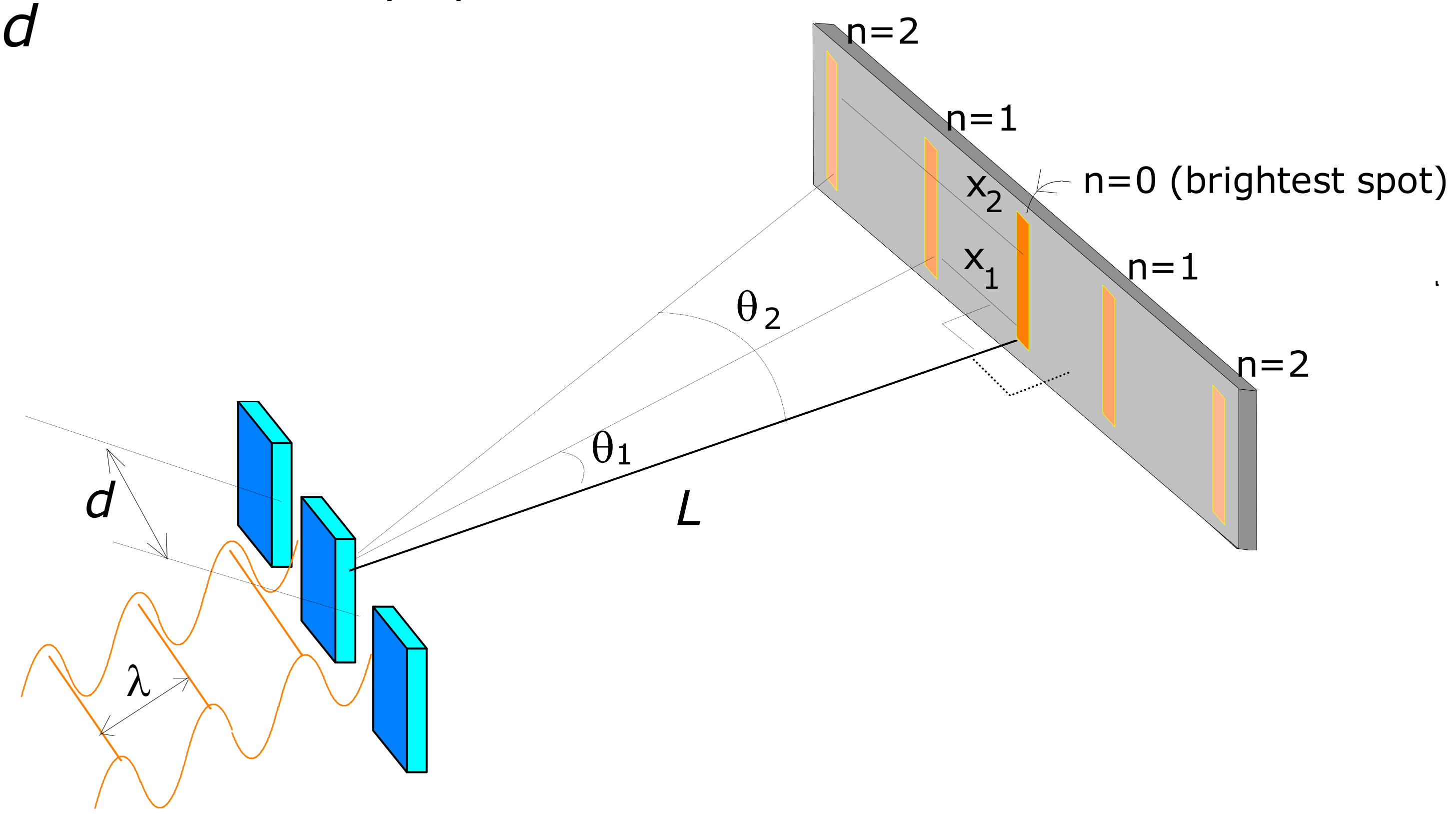


- Using the above information and the diagram below we can write equations for finding the distance between the bright spots.

$$\tan\theta_n = \frac{x_n}{L}$$

$$\sin\theta_n = \frac{n\lambda}{d}$$

*n* = the number of the bright spot to the right of the brightest spot
λ = the wavelength of the light
*d* = the distance between the slits (measured from slit centres)
$x_n$ = the distance from the *n*=0 spot to the *n*th spot
*L* = the perpendicular distance from the slits to the screen



# Example 1: Finding angular separation and distance between adjacent bright lines.

Light of wavelength 525 nm passes through two slits with separation 1.5 x $10^{-5}$ m. (a) Find the angular separation between the central bright line and the next line to it. (b) Find the distance between the two lines if the screen is 3.7 m from the slits.

Given:

$\lambda = 525 \times 10^{-9}$ m

$d = 1.5 \times 10^{-5}$ m

$n = 1$ $\quad L = 3.7$ m

(a) $\theta_1 = ?$ (b) $x_1 = ?$

Solution:

a) Find $\theta_1$ :

$$\sin \theta_n = \frac{n\lambda}{d}$$

$$\theta_1 = \sin^{-1} \frac{1 \times \lambda}{d}$$

$$= \sin^{-1} \frac{525 \times 10^{-9}}{1.5 \times 10^{-5}}$$

$$= \sin^{-1} 0.035 = 2.0^{o}$$

b) Find $x_1$ :

$$\tan \theta_n = \frac{x_n}{L} \Rightarrow \quad x_n = L \tan \theta_n$$

$$x_1 = L \tan \theta_1 = 3.7 \text{ m} \times \tan 2.0^{o}$$

$$= 3.7 \text{ m} \times 0.035 = 0.13 \text{ m}$$

# Example 2: Finding the wavelength of the impinging light.

When light passes through two slits with separation 1.5 x $10^{-5}$ m the distance between the brightest line and the line at n=2 is 21.0 cm. If the screen is 3.2 m from the slits, what is the wavelength of the light?

Given:

$d = 1.5 \text{ x } 10^{-5} \text{ m}$

$n = 2$

$x_2 = 21.0 \text{ cm} = 0.21 \text{ m}$

$L = 3.2 \text{ m}$

$\lambda = ?$

Solution: Step 1: Find $\theta_2$ :

$$\tan \theta_n = \frac{x_n}{L}$$

$$\theta_n = \tan^{-1} \frac{x_n}{L}$$

$$\theta_2 = \tan^{-1} \frac{x_2}{L} = \tan^{-1} \frac{0.21}{3.2}$$

$$\theta_2 = \tan^{-1} 0.0656 = 3.75^{o}$$

b) Find $\lambda$ :

$$\sin \theta_n = \frac{n\lambda}{d} \text{ which means } \lambda = \frac{d \sin \theta_n}{n} = \frac{d \sin \theta_2}{2}$$

$$\lambda = \frac{1.5 \text{x} 10^{-5} \text{ m x } \sin 3.75^{o}}{2}$$

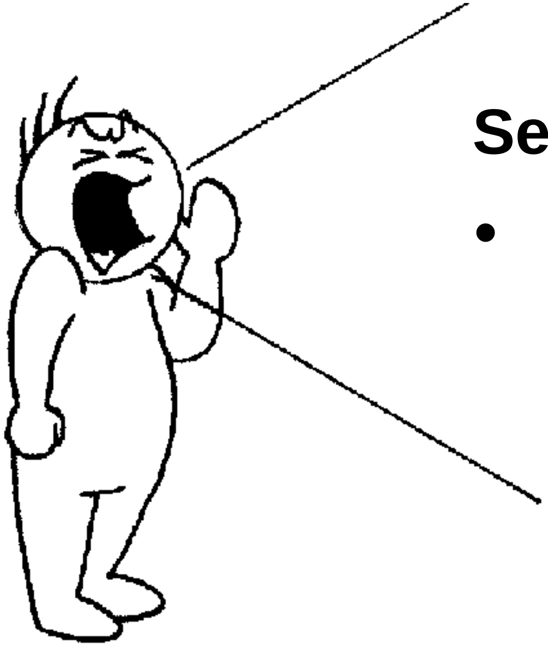
$$= \frac{1.5 \text{x} 10^{-5} \text{ m x } 0.065}{2}$$

$$= 4.88 \text{x} 10^{-7} \text{m} = 488 \text{x} 10^{-9} \text{ m} = 488 \text{nm}$$

# Activity

- Worksheet: Solving Problems Involving Interference

- Quiz

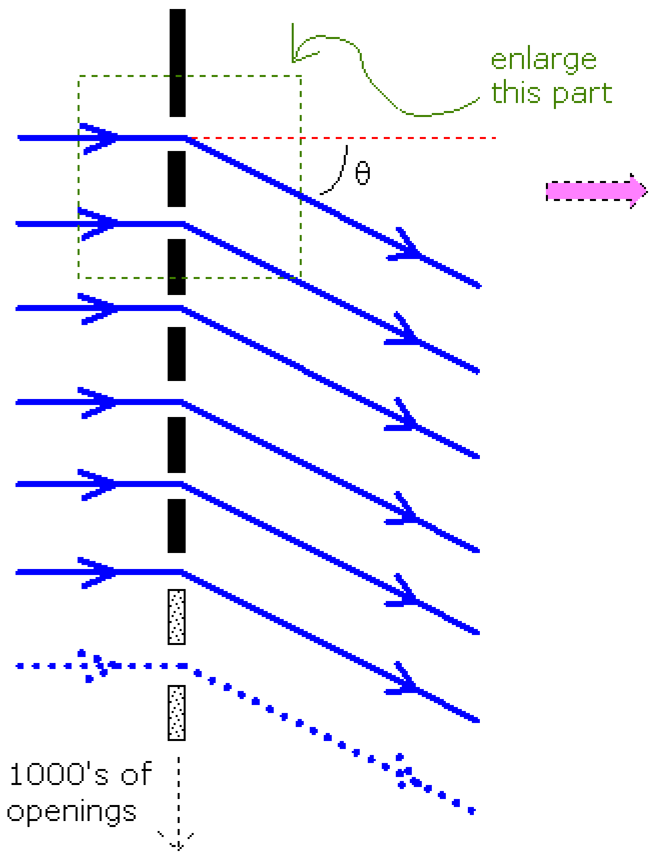


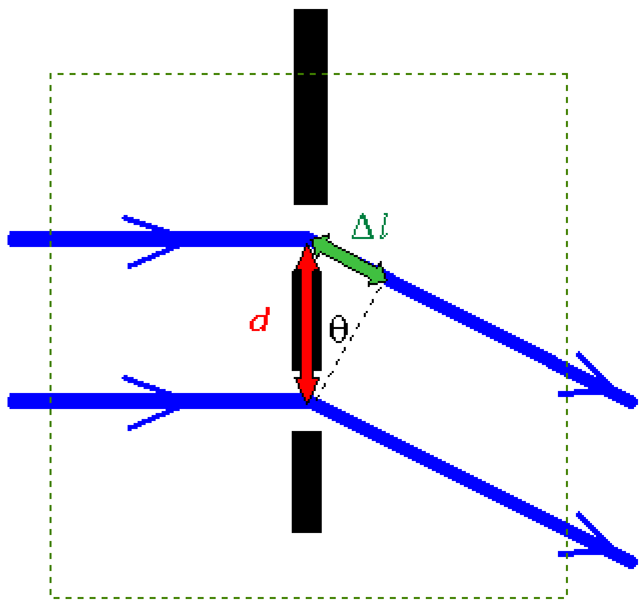
**Section 2 Topic 15**

- Interference With a Diffraction Grating

Text: Section

- Light is diffracted through each of the openings. Constructive interference, seen as bright spots, results when the difference in the distance is some multiple of l. That is, when the path difference (Δ l) is λ, or 2 λ, or 3 λ, etc--just like in the last lesson. We can say, therefore, that l = n λ, where n is an integer.




$$\sin\,\theta_n = \frac{\Delta l}{d} = \frac{n\lambda}{d} \quad \text{or} \quad d\sin\,\theta_n = n\lambda$$

## Sample exercise

Blue light with a wavelength of 400 nm is incident on a diffraction grating with 10 000 opening/cm. The resulting bright spots fall on a screen 3.00 m away from the grating. How far away from the central bright spot will the first bright spots be?

Given:

n = 1 (first bright spot),

# of openings = 10 000 openings/cm,

l = 400 x 10-9 m, x = ?

- Since there are 10 000 openings/cm there are 1 000 000 openings/m
- The distance between the openings is therefore $10^{-}6$ m. This is d.

Next….

Now we find the angle between the bright spots

$$\sin \theta_n = \frac{n\lambda}{d}$$

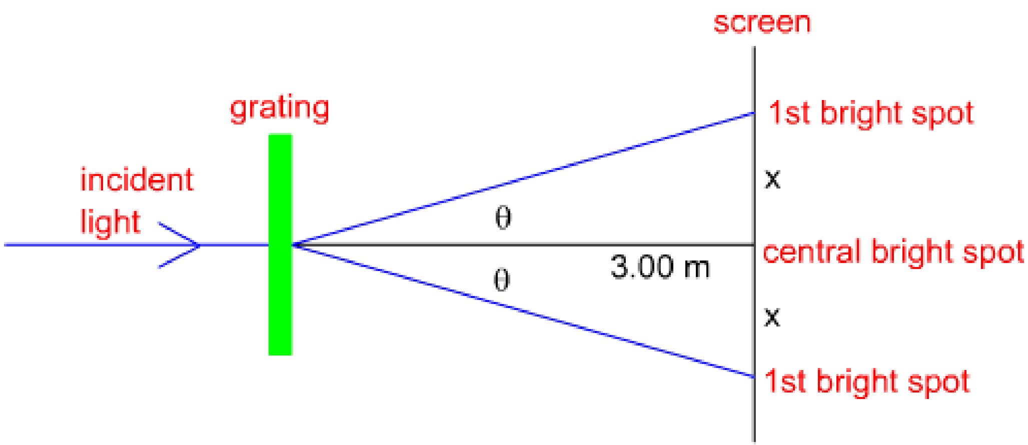
$$\sin \theta_1 = \frac{1 \times 400 \times 10^{-9}\ \text{m}}{10^{-6}\ \text{m}} = 0.400$$

$$\theta_1 = \sin^{-1}(0.400)$$

$$\theta_1 = 23.6^{\circ}$$

- The diagram below shows what happens. Notice that the angle θ can be used to find the distance x from the central bright spot to the 1st bright spot.

- The distance x, the distance (3.00 m) to the screen and the line to the 1st bright spot all form a right triangle. The value of x can be found using trigonometry.




$$\tan \theta = \frac{x}{3.00}$$

$$\tan 23.6^{\circ} = \frac{x}{3.00}$$

$$x = 3.00 \tan 23.6^{\circ} = 1.31\ \text{m}$$

Example 2: Finding the wavelength of the impinging light.

When light passes through a diffraction grating with 5000 openings per cm, the distance between brightest line (n=0) and the line at n=1 is 15.0 cm. If the screen is 55 cm from the grating, what is the wavelength of the light?

Solution: Step 1-- Find $\theta_1$ :

$$\tan\,\theta_n = \frac{x_n}{L}$$

$$\theta_1 = \tan^{-1}\frac{x_1}{L} = \tan^{-1}\frac{0.15}{0.55}$$

$$\theta_1 = \tan^{-1} 0.273 = 15^o$$

Given:

$d = 0.000002$ m

n = 1

$x_1 = 15.0$ cm = 0.15 m

$L = 55$ cm = 0.55 m

$\lambda = ?$

Step 2 - Find $\lambda$ :

$$\sin\,\theta_n = \frac{n\lambda}{d} \quad \text{which means } \lambda = \frac{d \sin\theta_n}{n} = \frac{d\sin\theta_1}{1}$$

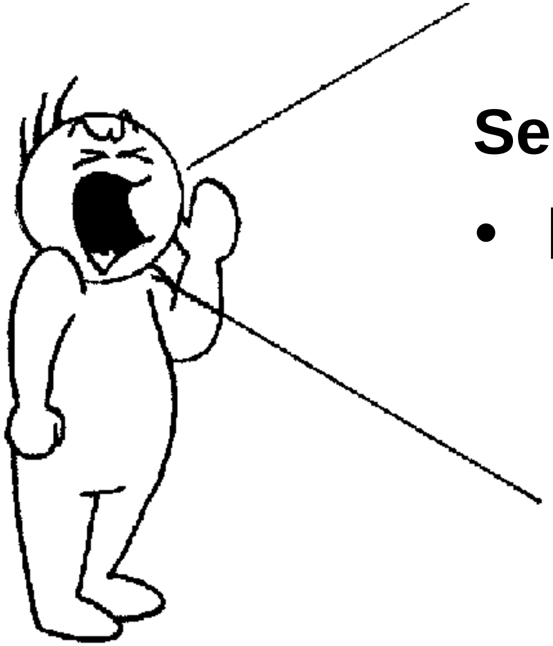
$$\lambda = 0.000002\,\text{m x } \sin 15^o$$

$$= 2\,x\,10^{-6}\text{ m x } 0.259$$

$$= 517\,\text{x}\,10^{-9}\text{ m} = 520\,\text{nm}$$

# Activity

- Worksheet: Interference With a Diffraction Grating
- Quiz

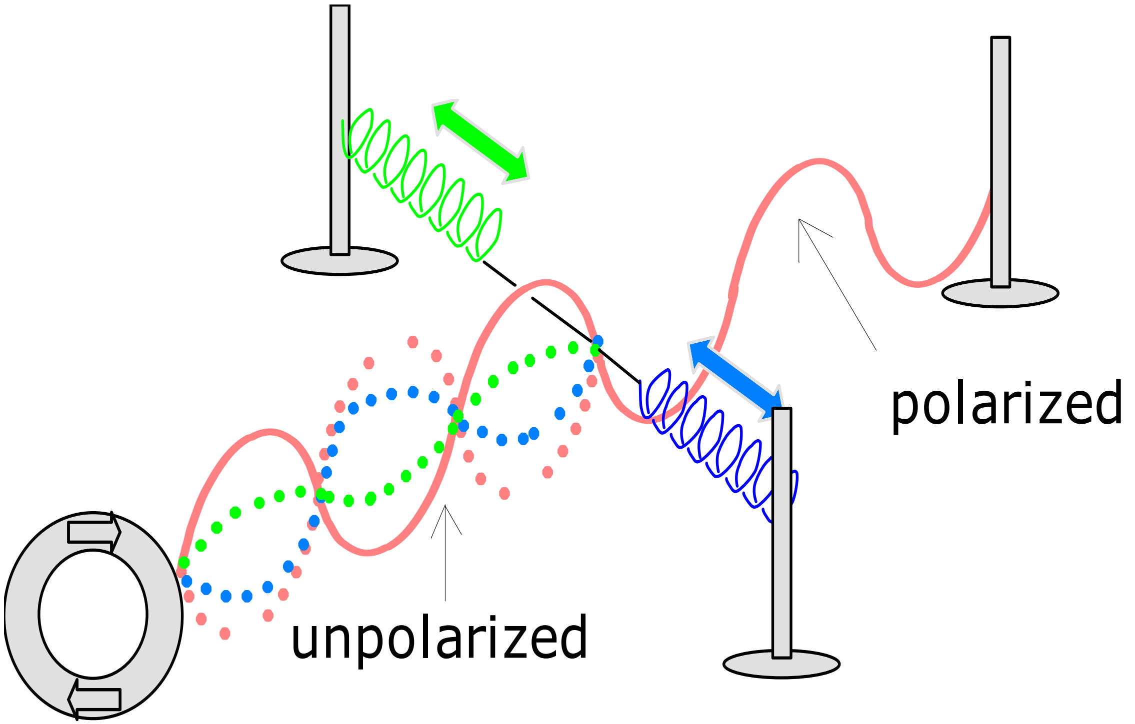


**Section 2 Topic 16**

- Polarizing Light

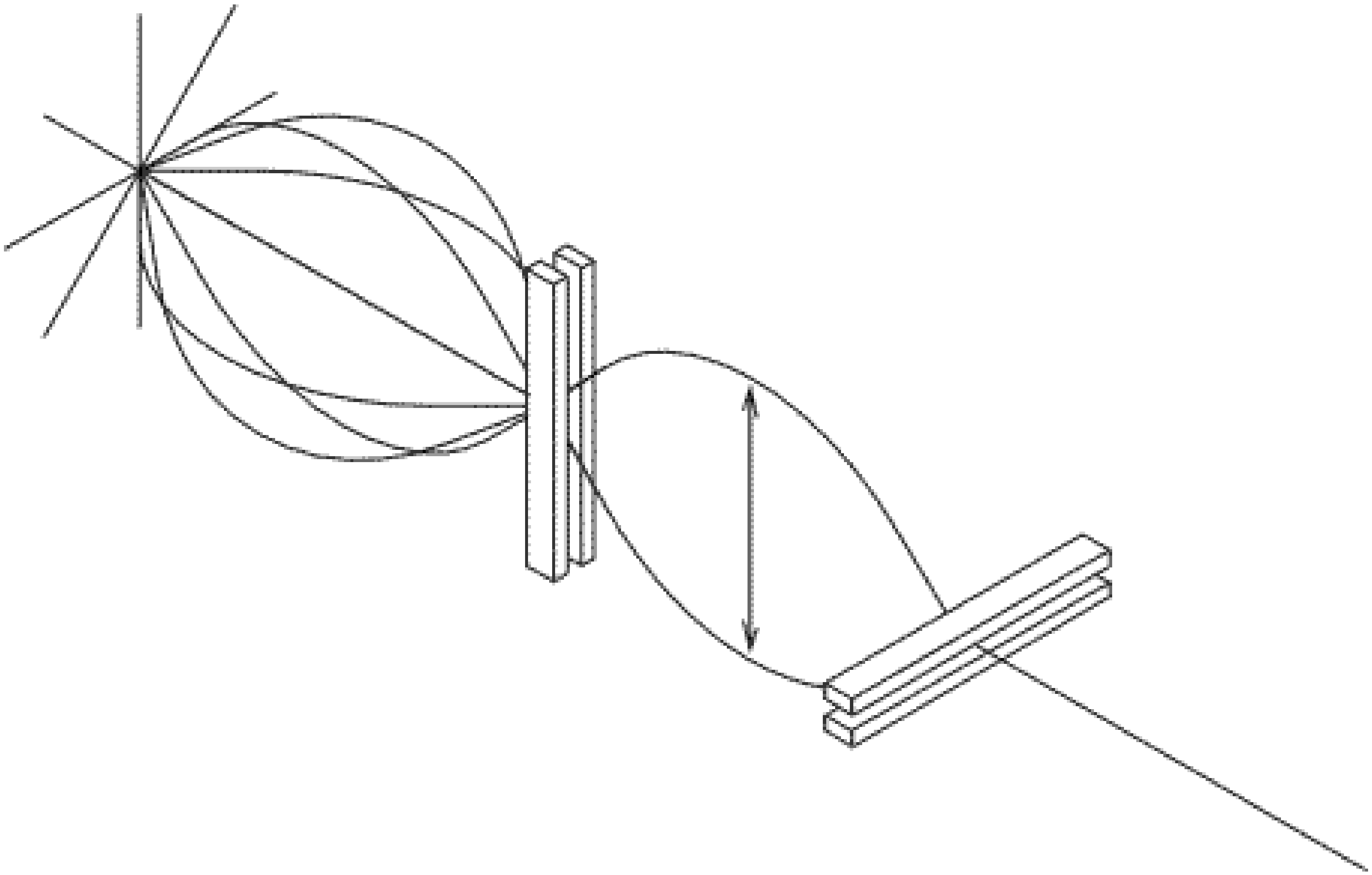
Text: Section

- Polarization: a wave is polarized when it is vibrating in one plane only.  Conversely, unpolarized wave energy vibrates in many planes.




- Polarization can be demonstrated using meter sticks and rope, or two polarizing lenses.

- Rope and a meter stick



## Polarizing lenses

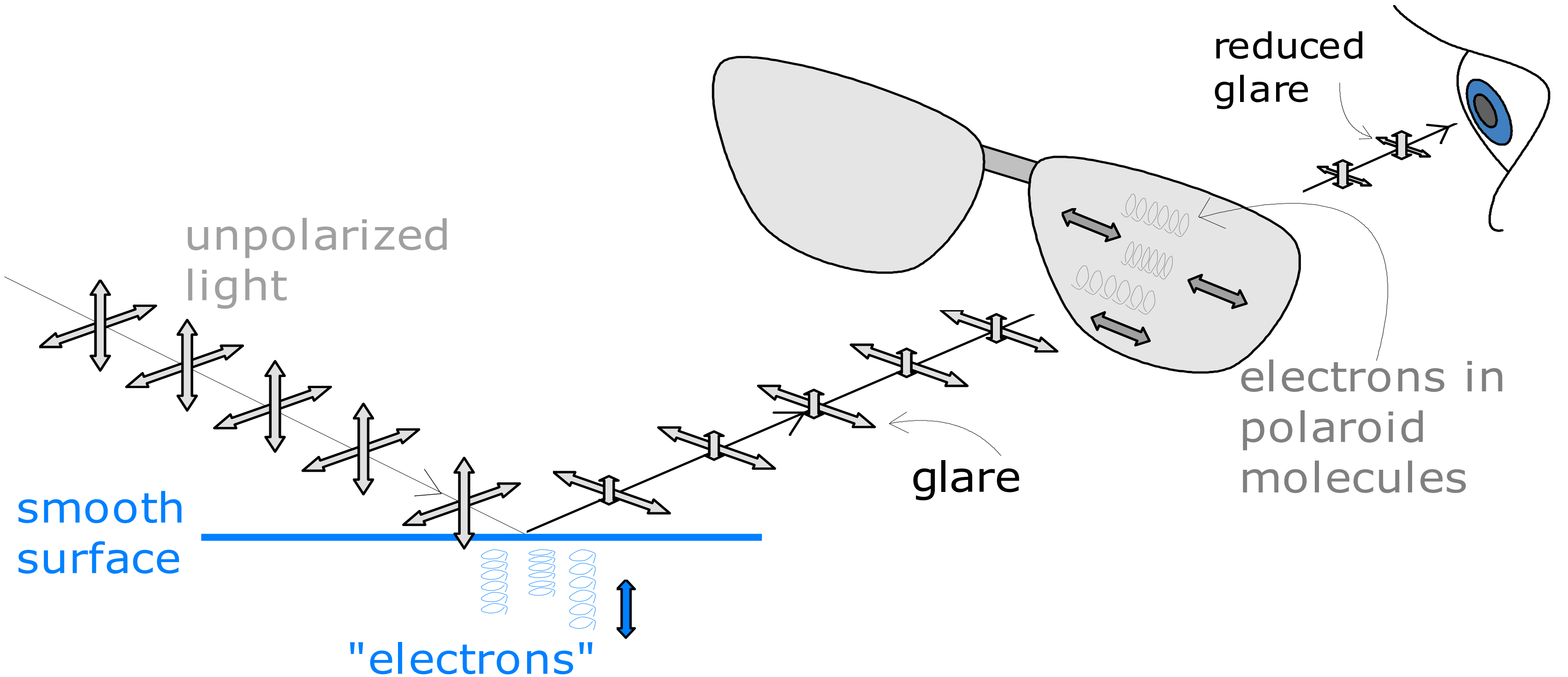
Polarizing lenses actually work oppositely to polarizing rope!

A sheet of polaroid material is made by heating and stretching a special type of plastic. The stretching causes the molecules of the plastic to form molecular "chains" in the direction of the stretch. Some "free" electrons can vibrate up and down along the chains.

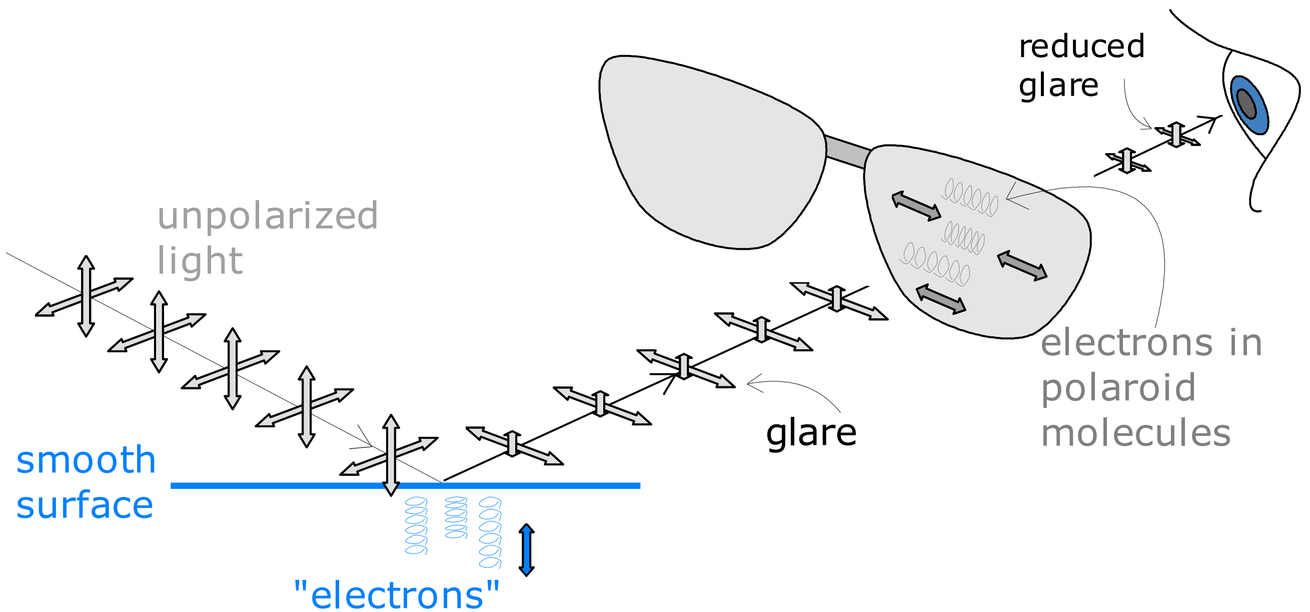
A ray of unpolarized light strikes the polaroid sheet (that was stretched horizontally). The unpolarized light has energy components in all directions. The horizontal components of this energy will make the free electrons in the sheet vibrate back and forth in the molecular chains. The electrons will "rob" or absorb the these energy components and only allow verticle components to pass through!

In this example the incident light has been polarized vertically.

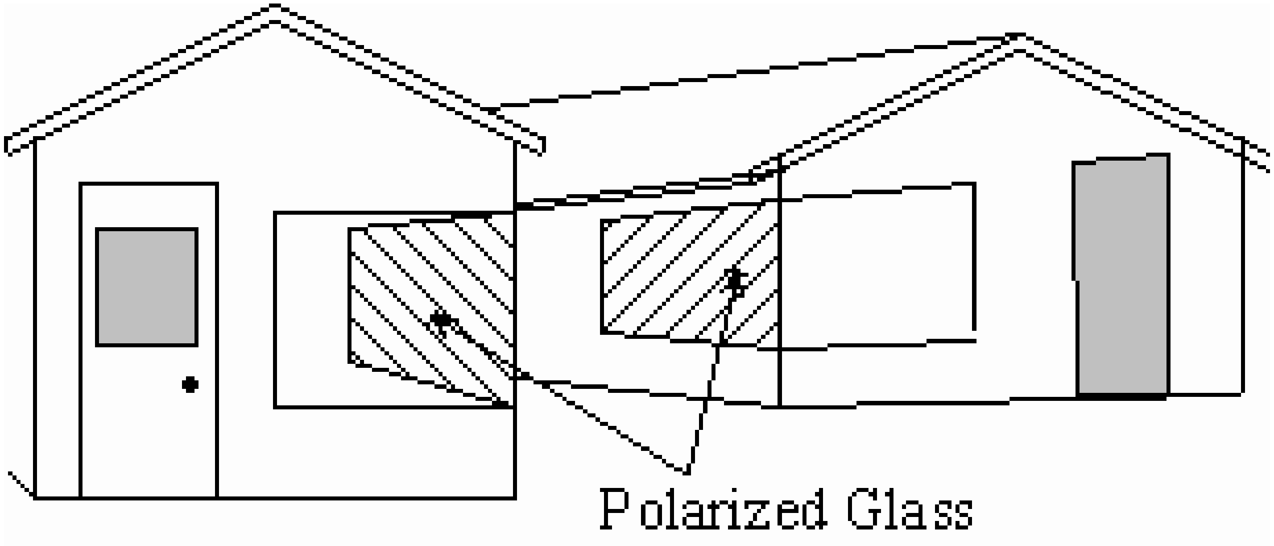
- Why do polarized sun glasses work?



# Example: Explaining "Glare"



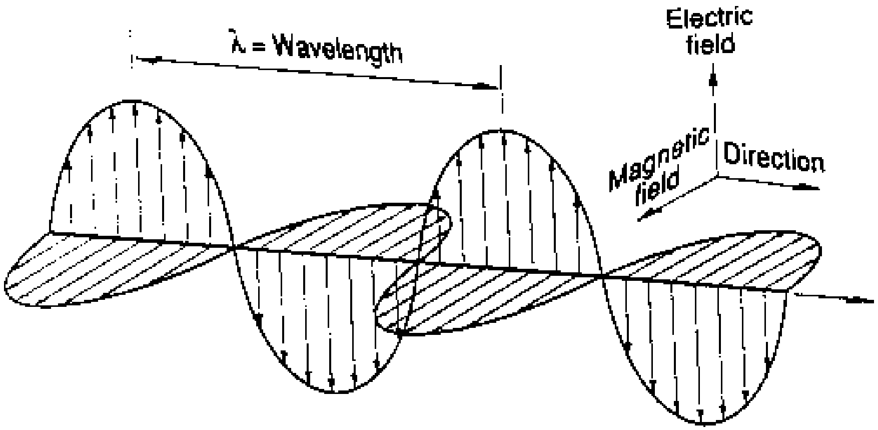
- Privacy windows



A final note:

**Electromagnetic waves don't need a medium to travel in!**

- If you study Physics 3204, you will learn that a moving electric charge creates a continually changing magnetic field around it. In turn, the changing magnetic field creates an electric field which creates another magnetic field which creates another electric field, and so on, and so on. These fields "push" each other along as they keep on creating each other at the speed of light.



- Electromagnetic spectrum

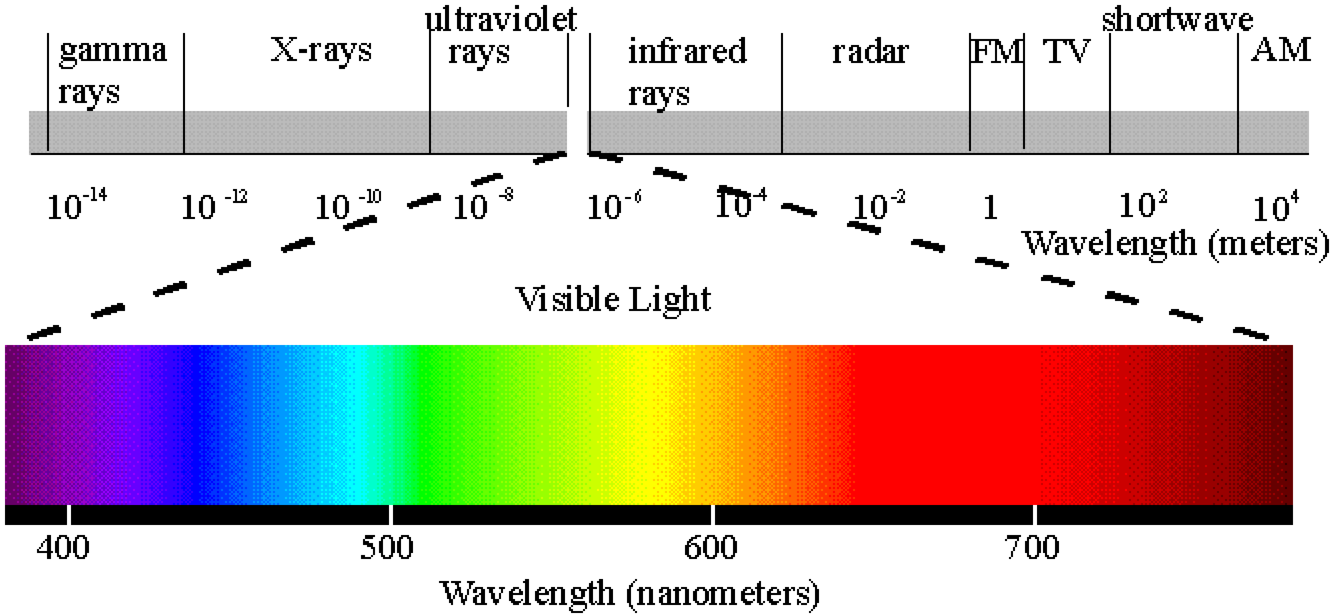
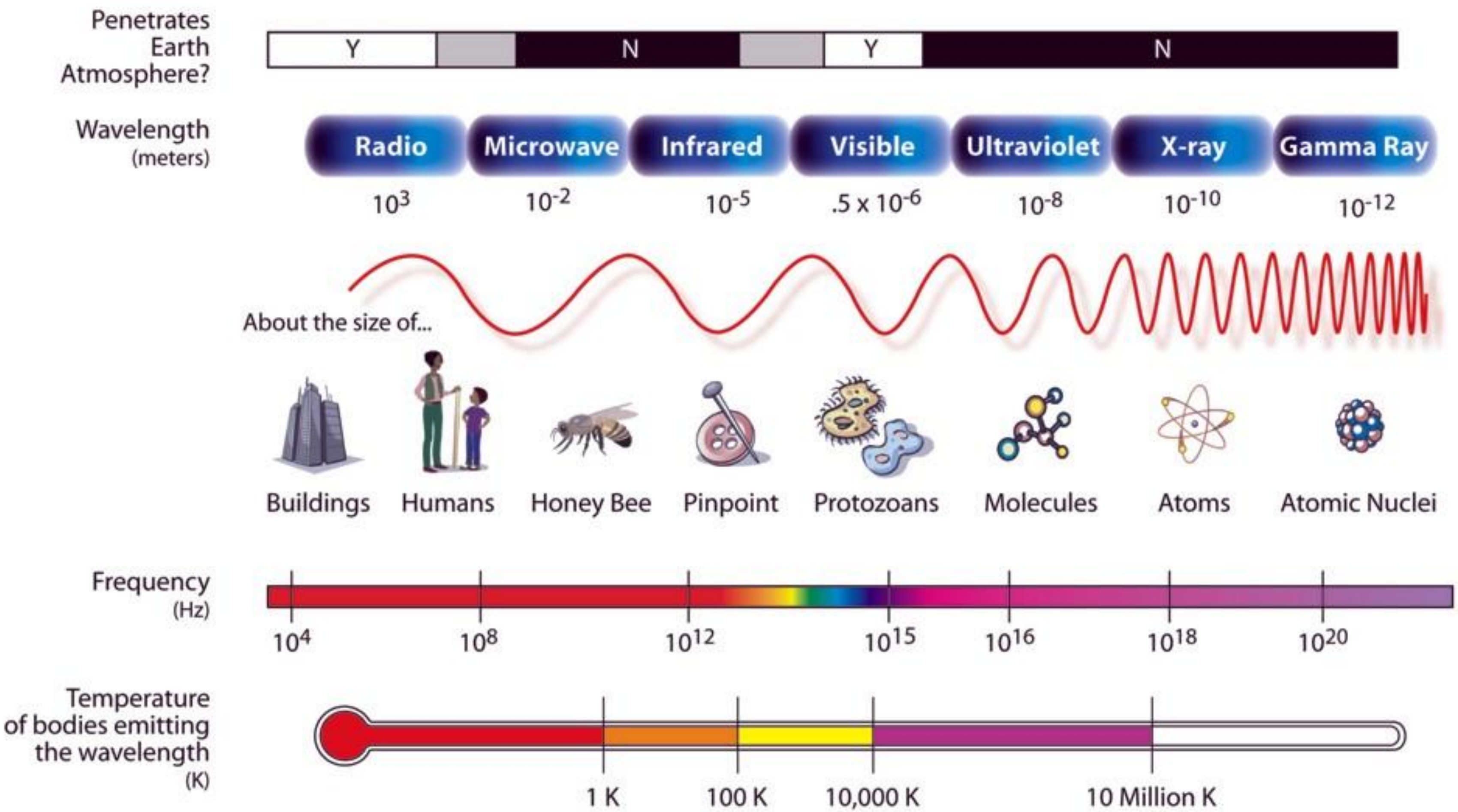
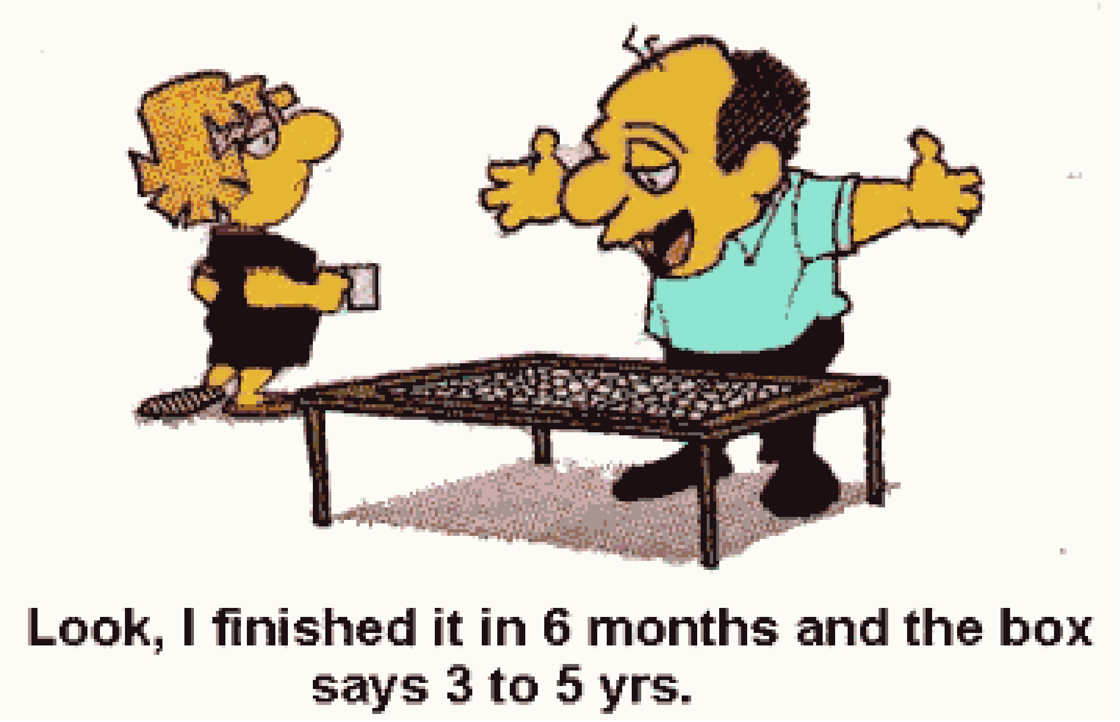



Table of Contents    Visual Stimulus

# THE ELECTROMAGNETIC SPECTRUM



## Congratulations…you are finished Physics 2204!



# Activity

- Worksheet: Polarization of Light
- Quiz
- The Nature of Light - A Final Assignment
- Technology Project

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