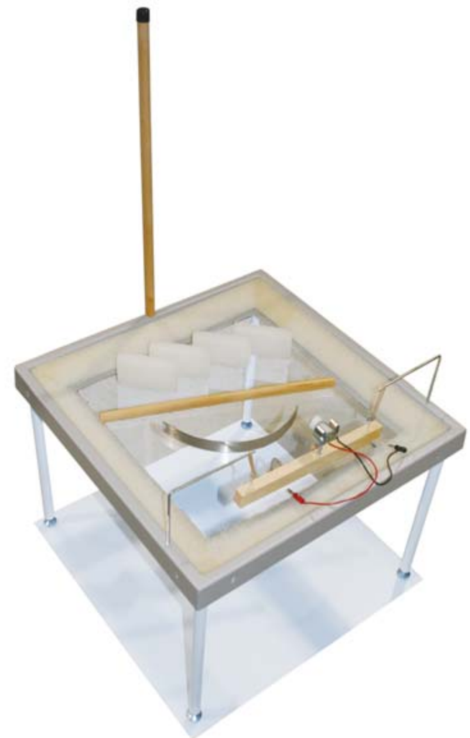
15415 Large Ripple Tank (Student Materials)
NAME:________________________________

CONTENTS:

Included Materials:

1- Ripple Tank
1- Glass Plate
1- Plastic Viewing Screen
4- Legs with levelers
1- Ripple Bar
2- Ripple Bar hangers
1- Light Support Bar
1- Rubber Stopper
4- Foam wave dampers
1- Parabolic reflector
4- Paraffin blocks
3- Spacers
2- Angled aluminum rods
2- Wood beads
2- Rubber Bands
1- Motor Assembly with leads
1- Dowel (for generating straight pulses)



Required Accessories:

1- High Power Light Source (TSS #14700)
1- Adjustable Hand Strobe (TSS #14502)
1- Variable Phase Wave Generator (TSS #15490)
1- Meter Stick
1- Stopwatch
1- Variable voltage power supply (0 to 3 VDC) (TSS #14720)
2- Pencils, pens, or small wooden dowels
Paper towels for drying hands, equipment, and tables
Utility knife (for cutting paraffin)

Optional Accessories:

Pipette or eye dropper (for optional method of creating circular waves)

Purpose:

This apparatus is used to investigate waves during propagation, reflection, refraction, interference, diffraction, and the Doppler effect by observing water waves projected onto a viewing screen. By using real water waves, we can better understand properties of electromagnetic, light, sound, and other types of waves.

OBJECTIVES:

To study the motion of waves through a medium
To study how waves react to barriers
To study how waves interact with each other
To study the Law of Superposition

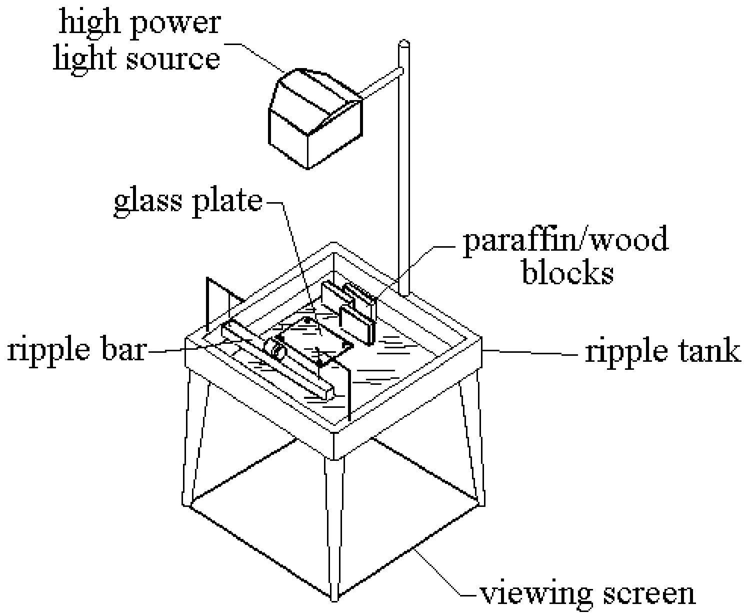
SAFETY:

Proper eye protection should be worn at all times.
The light source may become hot when left on for a period of time. Take care not to burn yourself on the lamp.
The glass plate and the bottom of the ripple tank are both made of glass. Be careful not to break either, as the glass is sharp and could cause injury.
The motor assembly, high power light source, and variable phase wave generator all require electricity. Electricity and water, when mixed, can cause electrocution. Take great care to keep all leads, wires, connectors, and power supplies away from water at all times.
The ripple tank apparatus contains metal parts that may be sharp. Be careful not to catch on any possible sharp edges.
The water in the ripple tank may splash or spill. Be careful not to spill water on the floor, as this causes a slipping hazard.
The rubber bands are not projectiles. *Do not* fling them across the room or at other students, as this may damage equipment, the rubber bands, or hurt someone.
Be careful with the utility knife when cutting the paraffin blocks to the desired shape to prevent damaging the surface or cutting yourself.

TIME REQUIREMENTS:

All time suggestions are approximate, and may vary depending upon the needs of the students, the number of students working together, the amount of explanation and facilitation necessary, and how much instruction on the material has already been done (or how much reading of the concepts and introduction the students have already done).

Assembly of the ripple tank should take 5-10 minutes.
Procedure A should take 5-15 minutes.
Procedure B should take 10-20 minutes.
Procedure C should take 10-20 minutes.
Procedure D should take 10-20 minutes.
Procedure E should take 5-15 minutes.
Procedure F should take 10-20 minutes.
Procedure G should take 5-15 minutes.



ASSEMBLY:

Prior to assembly, and each subsequent use of the ripple tank, clean both surfaces of the tank's glass bottom.

Adjust the levelers on each of the four legs so that all legs are the same length. Screw one leg into each corner of the underside of the ripple tank frame. Tighten firmly by hand. Spread the white plastic viewing screen on a smooth level surface (table top or floor). Set the ripple tank on this sheet. Thread the light source support rod into the center hole on the back edge of the ripple tank frame. Clamp a high power light source onto the support rod near the top. The light source should provide a point source for best results.

A 5 cm strip of ½ inch masking tape in the bottom of the tank serves as a convenient focusing reference for the light source. Adjust the height of the light source on the support rod to obtain the sharpest image of the focusing strip on the viewing screen. This adjustment will provide the sharpest image of the wave patterns generated with the ripple bar. The focusing strip also provides a handy guide for calculating the actual wavelength of the water waves:

$$\frac{\text{Actual Wavelength}}{\text{Measured wavelength (screen)}} = \frac{\text{Length of focusing strip}}{\text{Measured length of strip shadow (screen)}}$$

Calculate the fraction of actual length to measured length of the masking tape BEFORE adding water to the tank.

Place the stopper in the drainage hole. Level the tank by pouring approximately 5 to 7 mm of water into the bottom of the tank. Adjust the leveling screw on each leg until the water depth is constant at all locations in the tank. When the tank is level, lock the adjustable feet in position by tightening the hex nut on each foot. Insert the threaded end of a ripple bar hanger into the holes in each side of the ripple tank frame. Suspend the ripple bar from the hangers with rubber bands. Adjust the height of the hangers until the ripple bar (or wood beads) just touch the surface of the water. Fasten the hangers in place with wingnuts.

The “beaches” are built-in. They may be covered with wetted gauze if desired to reduce reflection.

The shaped wooden blocks are used as barriers and apertures in a number of experiments. Additional blocks may be cut from paraffin using a utility knife, if desired.

The included ripple bar can be used to create straight waves. To do this, remove the metal rods with poppet beads from the wooden bar or pivot them up and away from the water. To generate circular waves, insert the metal rods with poppet beads into the pre-drilled holes in the vertical face of the bar. Attach a rubber band to the screw hook in each end of the ripple bar, and suspend the unit by these rubber bands from hangers mounted on your ripple tank. Adjust the height of the ripple bar by raising or lowering the hanger supports until the bar just touches the surface of the water. (For circular waves, the poppet beads should just touch the surface of the water.)

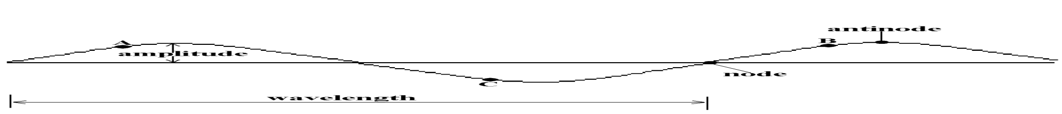
Connect the ripple bar motor to a variable DC power supply. The voltage controls the frequency of the waves (the higher the voltage, the higher the frequency) and the offset mass on the motor's flywheel controls the amplitude of the waves.

CONCEPTS:

There are many different types of waves. Water waves, electromagnetic waves (including radio, light, gamma rays, x-rays, etc.), and sound waves are a few examples. A mechanical wave is any kind of wave that displaces a material as it travels through it. The material that carries a mechanical wave is a *medium*. Two basic types of wave motion are transverse and longitudinal waves. Transverse waves displace the medium perpendicularly to the direction of propagation of the wave. Waves in a vibrating cord or cable are usually transverse waves, and water waves are similar to transverse waves. Longitudinal waves displace the medium parallel to the direction of propagation of the wave. Sound waves are similar to longitudinal waves, except that they usually radiate outward from the source of the sound, decreasing in amplitude as they travel. An electromagnetic wave acts similarly to a mechanical wave, but an electromagnetic wave does not require a medium to travel through (for example, light waves can travel through the vacuum of space, without air to travel through).

The movement of a wave through a medium is called *propagation*. The initial waves from the source are called *incident* waves. In this experiment, there are two different shaped waves: *plane* waves and *circular* waves. Plane waves are waves that stay parallel to the wave generator. Circular waves are waves that travel radially outward from the wave generator. A *pulse* is a brief disturbance of a medium (from its equilibrium point) that travels from one location to another.

All waves have particular quantities in common. These quantities are illustrated in the transverse wave sketched below, but apply to any kind of wave. The quantities are defined below the sketch.



Amplitude is the maximum displacement of the wave from the resting position of the medium.
A *node* is a location on the wave where the displacement from the undisturbed medium is zero.

An *antinode* is the location on a wave where maximum amplitude is reached.

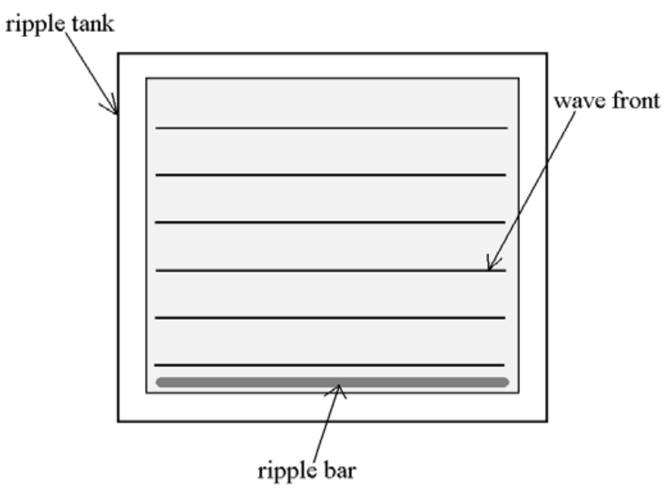
Each section of the wave that moves above or below the center line is sometimes called a *loop*. Note that *one wavelength* consists of two loops. In the SI unit system, wavelength is generally measured in meters (m). The wavelength of light is sometimes given in terms of nanometers (nm) or Pico meters (pm) because of how small the wavelength is. (A table of the prefixes used in this manual and their definition is included in the appendix.)

Frequency is the rate at which waves are produced, usually expressed in Hertz (Hz) or vibrations-per-second.

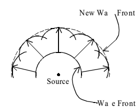
TYPE OF WAVE	LOWEST WAVELENGTH	HIGHEST WAVELENGTH	LOWEST FREQUENCY	HIGHEST FREQUENCY
Visible light	380 nm	740 nm	405 THz	790 THz
gamma rays	1.0 pm	10.0 pm	30 EHz	300 EHz
microwaves	1 mm	30 cm	300 GHz	3 GHz
X-rays	10.0 pm	10.0 nm	30 PHz	30 EHz

The human voice has a speaking frequency between 85 Hz and 255 Hz. The human ear can hear sounds in the approximate range of 20 Hz to 20 kHz.

The *phase* of a wave relates a point on the wave with the same point at another part of the wave (the corresponding points on a second wave can also be related and said to have the same or different phase). Points A and B are said to be *in phase* with each other, as they are at the same relative position at the same time. Points A and C are said to be *out of phase*, because they are at different relative positions at the same time. If there were two waves with points A, B, and C labeled as they are on both waves, point A on both waves would be in phase with each other, as would the two point Bs and the two point Cs.



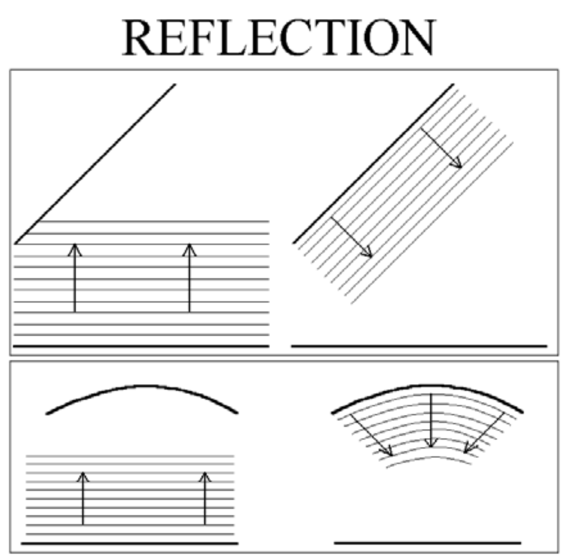
A *wave front* is a series of points on the same wave that all have the same phase. The movement of wave fronts can be predicted using Huygen's principle, which states that every point on a wave front is the source of a new wave front, and the new wave front is a sum of all the small wave fronts created by the points in the old wave front. (See picture below) Each point acts like a single source and creates a very small, curved wave around it. The number of points and their arrangement determine the shape of the new wave. In a plane wave, the single sources are lined up parallel to the original source, and so the very small waves create a line, just like the original one. In a circular wave, the original wave is circular, and the single sources within the wave continue to create a circular wave around it, but as the wave expands, the distance between the original sources gets larger and more sources fill in the space between. This causes the circular wave to appear to be a parallel wave as it gets further from the source. (This idea is very useful when thinking about diffraction a little later.)



Any periodic wave can be described with the following relationship

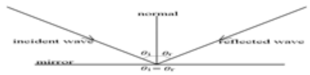
$$v = lf$$

where ‘v’ is the speed of the wave (in meters per second, m/s), ‘l’ (the Greek letter lambda) is the wavelength of the wave (in meters, m), and ‘f ’ is the frequency of the wave (in hertz, Hz). Ocean surface waves, while exhibiting similar behavior and described by the same equations as other waves, differ in that the motion of particles in the water is more complex and the speed of the wave varies with changing water depth.

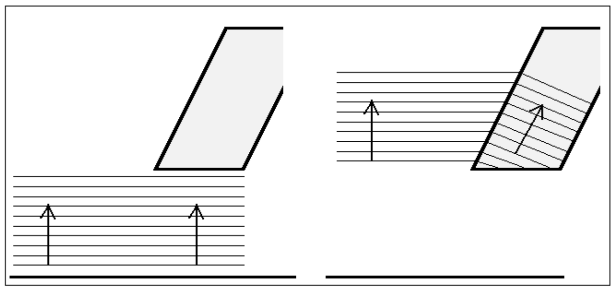


When a wave hits an obstruction and travels back through the medium where it came from, the wave is said to be *reflected*. This process is called *reflection*. When water waves bounce off the side of a sink and travel back through the water, that is a reflection of those waves. Electromagnetic waves, which don’t require a medium to travel through, can also reflect. When an incident wave reflects, the new wave is called the *reflected* wave.

The angle (relative to normal) that a reflected wave leaves the surface at is equal to the angle (relative to normal) the incident wave came in at. An example of reflection is when light waves are incident to a mirror, we see the light waves “bounce” off the surface of the mirror to our eyes. (see diagram).



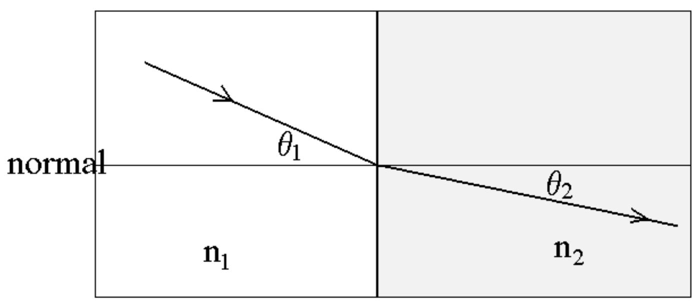
REFRACTION



When a wave hits a boundary and travels through into another medium, the wave is said to be *refracted*. This process is called *refraction*. Both mechanical and electromagnetic waves can be refracted. With water waves, how much they are refracted depends upon the depth of the water (water waves go faster in deep water than shallow water). With light waves, the angle of refraction is given by Snell's Law,

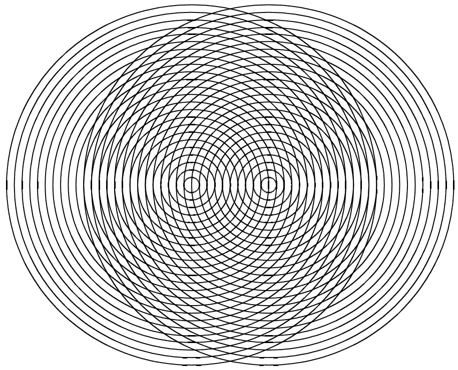
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where 'n' is the *index of refraction* (different for every material) and 'Θ' is the angle from normal the light is bent.

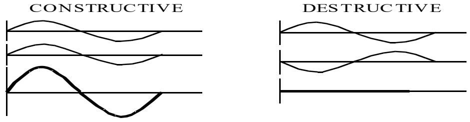


An example of refraction is a laser pointer pointed into a glass of water. The light from the laser pointer will bend, or *refract* when it enters the water. Refraction is also what causes rainbows- water droplets in the air cause sunlight to refract, breaking the sunlight (called "white light") into the individual colors (red through violet). Refraction is also responsible for mirages on a hot road. Hot air refracts light more than cooler air, so light comes in towards the road and is bent by the air warmed by the road, causing a mirage.

INTERFERENCE

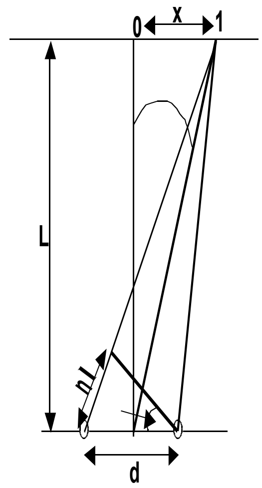


Interference is when two waves meet and create a new wave pattern. There are two types of interference: constructive and destructive. Constructive interference is when the two waves meet and “add together” to create a new, larger wave. Destructive interference is when two waves meet and “add together” to create a smaller wave (trough and crest). Completely constructive interference is when a trough of one wave and a trough of another wave (or a crest and a crest) meet to create a larger trough (or crest). Completely destructive interference is when a trough of one wave and a crest of another wave meet to cancel out and create a wave with zero amplitude.



This is called the Law of Linear Superposition; if more than one wave of the same type occupy the same space at the same time, the displacements add together at every point along the waves.

When performing Young’s Double Slit experiment, light passes through two slits and an interference pattern is observed on a screen. To determine the geometry of this interference pattern, we must know the distance from the slits the screen is, the wavelength of light, the distance from the center to the maxima in question, and the distance between the slits.



In this picture, the angle θ can be described in two ways:

$$\sin \theta = x/L$$

and

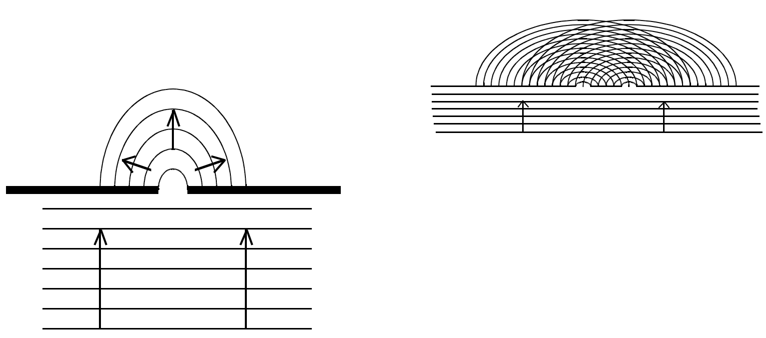
$$\sin \theta = nl/d$$

where ‘θ’ is the angle to the n^{th} maxima, ‘n’ is the maxima number beginning from the center of the pattern, ‘x’ is the distance from the center of the pattern to the n^{th} maxima, ‘L’ is the distance from the slits to the viewing screen, ‘l’ is the wavelength used, and ‘d’ is the distance between the two slits. Because the angle can be described using either equation, the two equations can be set equal to each other, yielding a geometric equation:

$$x/L = nl/d.$$

When using two separate point sources rather than two slits (the interference apparatus of the ripple tank), the distance ‘d’ becomes the distance between the two sources, and ‘L’ becomes the distance from the sources to the screen. If 4 of the 5 variables are known, the 5^{th} variable can be calculated by rearranging the equation to solve for the unknown.

DIFFRACTION



Diffraction is a type of interference characterized by the bending and spreading of waves when they meet an obstruction. Diffraction is different from refraction and reflection, and is a third way in which light is bent. Both electromagnetic and mechanical waves can be diffracted. Diffraction occurs when the size of the opening the waves are traveling through is small compared to the wavelength of the traveling wave. When plane waves are incident to a slit, a small portion of the wave front passes through the slit. This means that there are a smaller number of wave fronts, and the slit acts like a new source for waves. These waves are circular, and on this side of the slit, it would appear as if the waves were being created at the slit, rather than behind the slit. (See the pictures above)

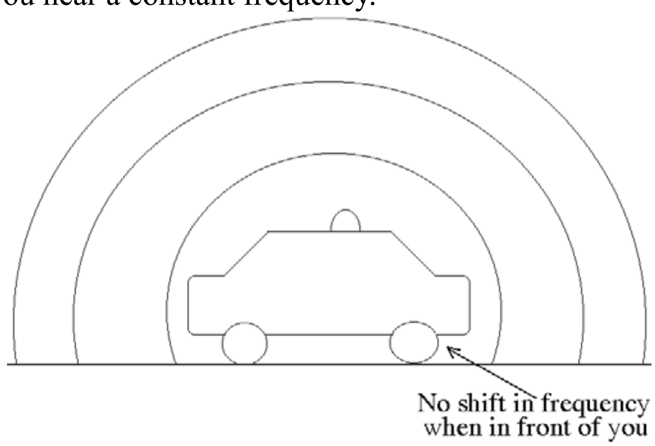
There are different types of diffraction. *Fraunhofer diffraction* is the diffraction of a wave when it is many wavelengths from the source. This is also known as *far-field* diffraction. It is the mathematically more simple diffraction, and is commonly observable in nature. *Fresnel diffraction*, also known as *near-field* diffraction, is the diffraction of a wave when it is very close to the source. It is more difficult mathematically, and as the wave moves further from the source before it is diffracted, the diffraction pattern approaches Fraunhofer diffraction. Both Fraunhofer and Fresnel diffraction are caused by an obstruction in the path of the light waves- in the laboratory, this obstruction is generally a slit or series of slits.

Diffraction can also occur with crystals as the obstruction, and this type of diffraction is known as *Bragg diffraction*. Bragg diffraction is sometimes called *X-ray diffraction*, because X–rays can be used to determine the identity of an unknown crystal by observing the diffraction pattern and identifying the peaks in the pattern. Bragg diffraction can be observed in the “every day world” when light is reflected from a compact disc. The white light diffracts off of the small tracks on the disc, and the different wavelengths that make up white light refract at different angles to create the white light spectrum.

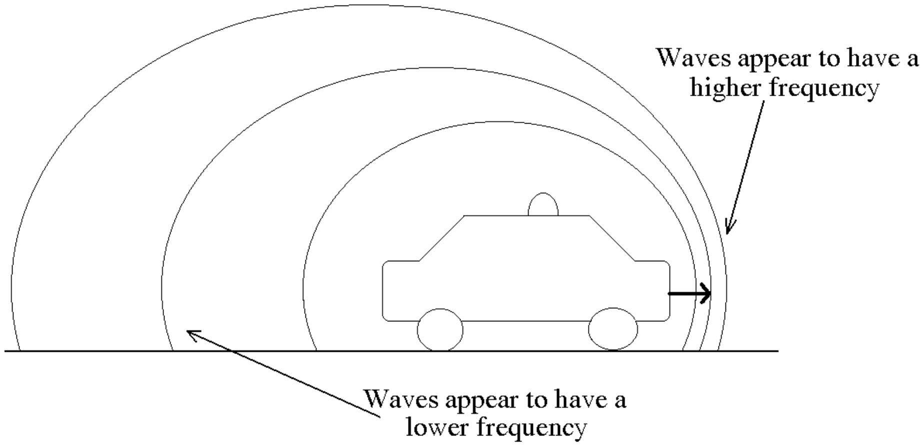
Diffraction can also occur from a circular slit, creating what is known as an *Airy disc* pattern. The diffraction pattern is similar to a radial (circular) diffraction from a single-slit (Fraunhofer). The ripple tank can give an accurate depiction of Fraunhofer and Fresnel diffraction, but Bragg diffraction and Airy disc patterns are difficult to achieve with water waves in the ripple tank.

THE DOPPLER EFFECT

The *Doppler effect* is the apparent change in frequency of a wave as it moves closer to or farther away from an observer. This is easily observed when standing in a driveway and a police car with a siren on drives by. If the siren is in front of you, you hear a constant frequency.



If the police car is driving past you, the frequency of sound waves created by the siren doesn’t change, but how the sound waves reach you does change.



As the car drives forward, the sound waves are compressed more because there is a velocity of the waves as well as a velocity of the source (the siren). This causes more waves to reach you in a given time, meaning the frequency seems higher. As the car drives away, the sound waves are stretched more because of the velocity of the source, causing less waves to reach you in the given time, meaning the frequency seems lower.

For a moving source and stationary observer, the equation for the Doppler effect is

$$f = f_0[v/(v-v_s)]$$

where 'f' is the detected frequency, 'f_0' is the actual frequency, 'v' is the speed of the wave, and 'v_s' is the speed of the source. For a moving observer and a stationary source, the equation for the Doppler effect is

$$f = f_0[1+(v_o/v)]$$

where 'v_o' is the velocity of the observer. These equations are valid for all mechanical waves. Electromagnetic waves, such as light, require what is known as the relativistic Doppler effect. The ripple tank can be used to observe the patterns created by a moving source/stationary observer and stationary source/moving observer situations.

INTRODUCTION:

There are many different phenomena concerning waves, and several of them can be observed with the ripple tank. These wave phenomena were discovered between the 16th and 19th centuries by many different and famous scientists. These scientists made leaps and bounds in their fields, dramatically increasing our knowledge of the world around us.

Christiaan Huygens was born in 1629 and died in 1695. Huygens studied mathematics in great detail when he was younger, and using this knowledge he developed better ways to grind lenses. With his better lenses, he discovered the first moon of Saturn, as well as the true shape of Saturn's rings (as well as some nebulae and a few double stars throughout the sky). Huygens also patented the first pendulum clock so that he could keep more accurate time while studying astronomy. Huygens also derived the law for centrifugal force in uniform circular motion, allowing for the derivation of the inverse-square law of gravitation. Huygens also was the first to experimentally prove that the momentum before a collision (in a fixed direction) is the same as the momentum after the collision (in the same fixed direction). Later in his life, he determined that light is a wave, and that each point on the wave acted like a source for a new wave of the same frequency and phase. At the end of his life, he wrote about the possibility of extraterrestrial life throughout the universe.

Rene Descartes was born in 1596 and died in 1650. Descartes was an accomplished mathematician and philosopher, developing several mathematical theories and constructs still in use today. Descartes invented what is now known as the Cartesian coordinate system, as well as laid the groundwork for modern geometry. Descartes was the first person to link algebra and geometry together. He believed that everything could be described using mathematics, and attempted to describe the world around him in this way. Descartes wrote about optics in an essay about philosophy in 1637, where he outlined his discovery of the Law of Reflection. In 1644, his *Principia Philosophiae* combined everything in the universe into a mathematical construct, which has since been proved incorrect.

Willebrord van Roijen Snell was born in 1580 and died in 1626. Snell did many careful calculations about how light bends when it enters a new medium, and in 1621, he discovered how the path of light changes as the index of refraction of the medium changes. The ratio became known as Snell's Law, even though many other scientists, including Newton, Kepler, and Descartes (as well as several lesser-known scientists such as Ibn Sahl in the 10^{th} century and Thomas Harriot in the 16^{th} century) had also discovered it. Descartes determined the ratio at approximately the same time, and no one is sure whether it was Snell or Descartes.

Francesco Grimaldi was born in 1618 and died in 1663. He was the first person to make accurate observations of the diffraction of light. (Leonardo da Vinci (1452-1519) had made note of diffraction, but had not studied it or determined what caused it.) Grimaldi was the first person to use the term "diffraction" to describe the phenomena. He was also one of the first people to postulate that light was wavelike. His work inspired Isaac Newton to work on optics and he improved upon Grimaldi's experiment and made a deeper study into the colored bands around the shadow of the object.

Joseph Von Fraunhofer was born in 1787 and died in 1826. Fraunhofer was trained in glass-blowing and lens making, which gave him a solid background for the study of optics. While studying the solar spectrum, Fraunhofer noticed that there were dark lines throughout the spectrum, which he noted were not in the spectrum of a candle. He identified over 500 lines, and also found that other stars emit different spectra than the sun. He studied the emission spectra of many elements using the spectroscope (which he invented), and using this knowledge he worked to identify all the dark lines in the solar spectrum. The dark lines in the solar spectrum are sometimes referred to as *Fraunhofer lines* in reference to the work Fraunhofer did with them.

Augustin Fresnel was born in 1788 and died in 1827. Fresnel did a great deal of groundbreaking work on the wave nature of light, a theory which was not widely accepted at that time, by applying mathematics to the experimental results. Fresnel was able to convert many people to the wave theory of light from the corpuscular (discrete packets) theory through his extensive use of mathematics. (It should be noted that the current theory of light states that light is BOTH a wave and a particle (photon), not one or the other.) His early work was similar to the work of Thomas Young with double-slits years earlier, but Fresnel went further with the application of mathematical formulas to describe and predict the phenomena. He also worked with polarization, and was one of the first scientists to study the polarization of light.

Thomas Young was born in 1773 and died in 1829. Young is best known for his double-slit experiment, which proved the wave nature of light. He also discovered that light experiences a phase shift of 🚔 when it reflects from a higher density medium (low to high, phase shift 🚔; high to low, phase shift no). Both Young and Fresnel discovered that light is a transverse wave (rather than a longitudinal wave). Young also did work on the optics of the eye, including a description of an astigmatism and how the eye perceives color. He also did work on the motion of blood in the human body, as well as some deciphering of Egyptian hieroglyphics on the Rosetta Stone and developing a theory on the tides. Young was the first person to call the physics concept of energy by that name, and was the first person to find the relationship between energy (kinetic) and work.

Johann Christian Andreas Doppler was born in 1803 and died in 1853. He spent many years as a professor of mathematics at the Technical Secondary School in Prague, Czech Republic. In 1841, he published a paper that outlined the Doppler effect. He outlined this effect for light, but within four years of the paper being published, experimental results using sound were collected. He also published work on electricity and magnetism, optics, and astronomy, but none of his papers were as important as his paper outlining the Doppler effect.

PROCEDURE A: PULSES

Make sure there is at least 5-7 mm (about ¼ inch) of water in the ripple tank before beginning. Turn on the high-powered light.

When watching the waves you create, remember that there are sides to the ripple tank, and when the waves hit the sides they will bounce back into the middle and make viewing things more difficult. Try to view things during the early part of the wave to prevent problems with interference.

Q1. What does the projected image of the ripple tank look like?

Slowly and lightly touch the surface of the water in the middle of the tank. Touching the water briefly with a finger-tip will make a point-source wave pulse, similar to throwing a small stone into a still pond. If you find that your finger tends to make a series of waves, rather than a single wave front, try using an eye dropper to create the wave. Hold the eye dropper just one or two centimeters above the water, and squeeze out one drop. A single, circular wave pulse should result. If you use the dropper and keep slowly squeezing successive drops into the water, you can make a series of almost-periodic wave pulses.

Q2. What happened when you touched the water?

Q3. What does the projected image of the ripple tank look like? (Hint: Draw a picture)

Lightly touch the surface of the water in the middle of the tank again, this time faster than before.

Q4. What does the projected image of the ripple tank look like? (Hint: Draw a picture)

Q5. How does this pattern compare to the pattern from Q3?

Q6. How does the speed of the pulse compare to the slower touch pulse you just created?

Lightly touch the surface of the water again, this time faster than last time.

Q7. How does the speed of this pulse compare to the last two?

Q8. Does the speed of the wave pulse change depending upon how fast you touch the water?
Place the dowel in the water. Slowly and gently, roll the dowel forward a small amount (no more than a ¼ turn is necessary).

Q9. What does the projected image of the ripple tank look like? (Hint: Draw a picture)

Q10. How is this wave pulse the same as the one created when you touched the water? How is it different?

Gently roll the dowel forward again, this time faster than before.

Q11. How did this wave pattern compare to the last wave pattern?

Q12. How does the speed compare to the last wave pulse? How does it compare to the round pulses created when you touched the water?

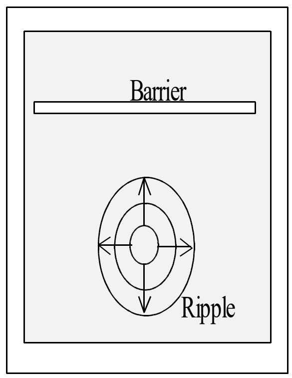
Q13. How does the amplitude of the wave pulse change as you create the pulses faster? How can you tell?

When a wave remains in the same medium, the speed does not change, no matter how fast the pulses are created or the shape of the pulse. Amplitude increases as the speed at which the wave is created increases, but speed remains constant.

PROCEDURE B: REFLECTION

Place a long flat barrier in the middle of the tank parallel to the edge of the ripple tank you are working from (see picture below). (This can be made by placing the wooden blocks next to each other to create a flat surface.)

When watching the waves you create, remember that there are sides to the ripple tank, and when the waves hit the sides they will bounce back into the middle and make viewing things more difficult. Try to view things during the early part of the wave to prevent problems with interference.



Q1. Predict what will happen when a circular wave pulse reaches the barrier. Draw a picture.

Make a round wave pulse by dipping in your finger as in Procedure A.

Q2. What happens when the wave pulse reaches the barrier? Was your prediction correct?

Q3. What does the reflected wave pulse look like?

Q4. Where does the reflected wave pulse appear to come from? Is this place a real source (from in front of the barrier) for the pulse or a virtual source (from behind the barrier) for the pulse?

Q5. How does the angle of incidence (the angle the wave comes in at) compare to the angle of reflection (the angle the wave comes off the barrier at)?

Move your finger to a different location and repeat the process.

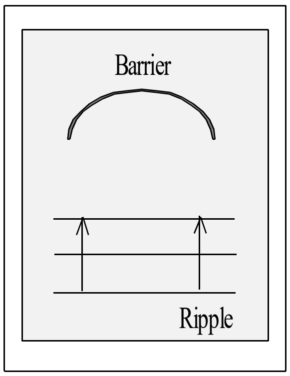
Q6. At each location you chose, where does the reflected wave pulse appear to be coming from? Is it real or virtual?

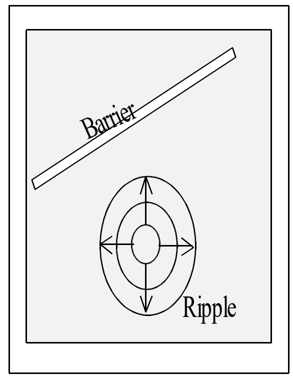
Place the wooden dowel in the ripple tank.

Q7. Predict what will happen when a plane wave pulse hits the barrier. Draw a picture.

Using the same barrier, try creating plane waves with the dowel.

Q8. How do the plane waves incident to the barrier compare to the circular waves? What is the same? What is different? (Apparent source, speed, reflected shape, etc)





Turn the barrier to create an angled barrier, as shown in the picture to the left. Remove the wooden dowel.

Q9. Predict what will happen when the circular wave pulse hits the barrier. Draw a picture.

Create a short circular wave pulse, and pay attention to what happens when the wave hits the barrier.

Q10. What happens when the wave pulse hits the barrier? Is it what you predicted?

Replace the wooden dowel.

Q11. Predict what will happen when the plane wave pulse hits the barrier. Draw a picture.

Create a short plane wave pulse, and pay attention to what happens when the wave hits the barrier.

Q12. What happened when the wave pulse hit the barrier? Is it what you predicted?

Q13. Compare what was similar and what was different between the circular wave pulse and the plane wave pulse. How could you tell?
Q14. How did the angle of incidence compare to the angle of reflection in the circular wave? The plane wave?
Remove the wooden barrier and place the parabolic reflector in the tank.

Q15. Predict what a plane wave pulse would look like when it reflects from the parabolic reflector. Draw a picture.

With the wooden dowel, create a short plane wave pulse

Q16. What happened when the wave pulse reached the barrier? Was your prediction correct?

Q17. How does the angle of incidence compare to the angle of reflection?

Q18. Where do the reflected waves appear to be created from? Is it a virtual source or a real source? How can you tell?

Remove the wooden dowel.

Q19. Predict what would happen to a circular wave pulse incident to the barrier. Draw a picture.

Create a short circular wave pulse.

Q20. What happened when the wave pulse reached the barrier? Was your prediction correct?

Q21. How does the angle of incidence compare to the angle of refraction?

Q22. Where do the reflected waves appear to be created at? Is it a virtual source or a real source?

Q23. Is the apparent source of the reflected waves the same for the plane waves and the circular waves? If so, what is the name of this location? If not, why would they have different apparent sources?

When plane waves and circular waves bounce off of the parabolic reflector, the reflected waves appear to come from a single real source. This apparent real source is called the *focal point* of the reflector. If the waves were light rays and the reflector were a parabolic mirror, the same effect would be seen. If all we could see were the reflected light rays, they would appear to be originating at the focal point, rather than the light source.

PROCEDURE C: Traveling waves

Make sure to determine the increase in size from projection between the ripple tank and the screen. The equation for calculating this is in the assembly section of the instruction sheet.

Insert the bent metal rods into their holes in the ripple tank sides. The straight wave generator consists of the small motor and the ripple bar with hooks. Place the motor in the holder, and hang the bar from the bent rods with the rubber bands. Adjust the height of the bent metal rods as necessary to make sure the ripple bar is lightly touching the top of the water. (There should be between 5 mm and 8 mm of water in the tank.) Connect the motor to a variable DC source. Turn on the motor and create slow waves in the tank.

Practice using the adjustable hand strobe to make the wave motion on the screen appear like a still photograph (make the motion “stop”, so to speak). If the adjustable hand strobe is set to 10 slots, and those 10 slots go by your eye in one second, then the frequency is 10 Hz. Adjust the adjustable hand strobe until the wave motion has stopped.

Q1. What frequency of the adjustable hand strobe is needed to apparently stop the wave motion?

Q2. How does this frequency compare to the frequency of the waves? How can you tell?

Once you have determined the frequency of the waves, place two pencils (or something similar) on the screen below the ripple tank marking two crests on the screen several wavelengths apart.

Q3. How many waves fall between the two pencils?

Q4. What is the distance (in meters) between the pencils?

Q5. What is the difference in scale between the screen and the actual waves in the tank? (Use the method in the assembly instructions to determine the scale.)

Q6. Using the equation for wave speed given in the concepts section, determine the wave speed of the waves in the ripple tank.

Once you have calculated the wave speed, increase the frequency of the motor.

Q7. What is the frequency of the waves at this increased motor speed?

Place two pencils on the screen as before, one each on a crest and several wavelengths apart.

Q8. How many waves fall between the two pencils?

Q9. What is the distance (in meters) between the two pencils?

Q10. What is the wave speed for the waves in the ripple tank?

Q11. How does this wave speed compare to the wave speed from the first run at a slower frequency?

Repeat the procedure again for a faster motor speed (higher frequency).

Q12. Compare the wave speed from each of the runs. How do they compare?

Remove some of the water from the tank to create a much shallower pool of water. Lower the ripple bar so that it once again just touches the top of the water. Repeat the procedure as before, using only the higher frequency at the end of the last run.

Q13. What is the wave speed in the shallower water?

Q14. How does the shallower wave speed compare to the wave speeds from before?

Add water to the tank so that there is between 8 mm and 12 mm of water in the tank. Adjust the ripple bar so that it once again just touches the top of the water. Repeat the procedure using the same frequency as before.

Q15. What is the wave speed in the deeper water?

Q16. How does the deeper wave speed compare to the shallow wave speed? The shallowest wave speed?

Q17. Did the wavelength of the water waves change as you changed the depth of the water?

Q18. Did the frequency of the water waves change as you changed the depth of the water?

PROCEDURE D: Refraction

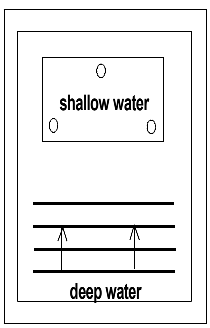
Place the spacers in the ripple tank toward the back of the tank. Place the glass plate on top of the spacers, making sure there are no air bubbles under the glass plate. Add water as necessary until there is no more than 2 mm of water covering the glass plate. Make sure the water is even across the plate, and level the apparatus as necessary. There should be enough room in the ripple tank to allow the viewing of the waves before they reach the plate, as well as while the waves are over the glass plate. There should also be enough room to create the wave with the wooden dowel or ripple bar (on a very slow frequency).

Align the glass plate so that it is parallel to the dowel or ripple bar.

Q1. Predict what will happen to a plane wave when it goes from the deeper to shallower water. What will happen to the:

frequency?
wavelength?
speed?

Using the wooden dowel or the ripple bar at a low frequency, send plane waves towards the glass plate.



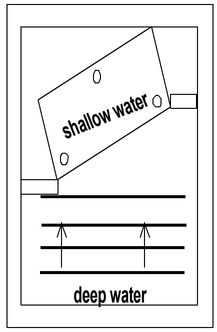
Q2. What happened to the wavelength of the plane wave when it went from deeper to shallower water?

Q3. What happened to the frequency of the plane wave when it went from deeper to shallower water?

Q4. What happened to the speed of the wave as it went from deeper to shallower water?

Q5. Were your predictions correct? Explain why or why not.

Now, turn the glass plate so that the waves will hit the glass plate at an angle. Two small blocks can be placed at the corners of the glass plate (as shown) to prevent the incident plane waves from interfering with the refracted plane waves.



Q6. Predict what will happen to a plane wave when it goes from the deeper to shallower water. What will happen to the:

frequency?
wavelength?
speed?

Q7. Predict what a plane wave would look like after half of it is in the shallow water and the other half is in the deeper water.

Using the wooden dowel or the ripple bar at a low frequency, send plane waves towards the glass plate.

Q8. What happened to the wavelength of the plane wave when it went from deeper to shallower water?

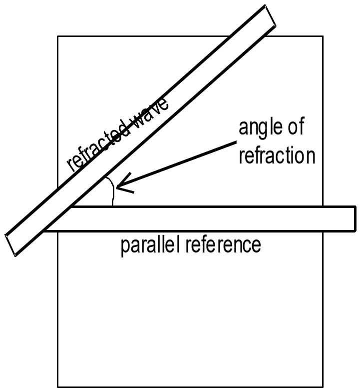
Q9. What happened to the frequency of the plane wave when it went from deeper to shallower water?

Q10. What happened to the speed of the wave as it went from deeper to shallower water?

Q11. What happened to the plane waves as they hit the boundary and traveled into the shallower water?

Q12. Were your predictions correct? Explain why or why not.

Use a straight edge (such as a ruler or piece of paper) as a parallel reference on the screen, and another straight edge as the refracted wave front. Place the parallel reference on the screen at the boundary between the glass plate and the deeper water, and place the other straight edge parallel to the refracted wave front.



Q13. What is the angle of refraction for your setup?

The change in depth of the water changes the speed of the waves. When the speed changes, the amplitude and wavelength also change. The refraction of the waves as they go from deeper to shallower water is very similar to the refraction of light waves when they go from one medium to another medium with a different index of refraction, such as from air to glass.

V = wave velocity (speed)

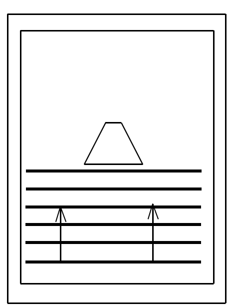
f = Frequency

λ = wavelength

$$V = f * \lambda$$

PROCEDURE E: Waves and Obstacles

Place a small wood or paraffin block in the middle of the ripple tank.



Q1. Predict what will happen to plane waves incident to the block. What path will they take?

Using either the straight wave generator or the wooden dowel, create plane waves at a constant frequency.

Q2. What happens to the plane waves when they reach the block?

Q3. What happens to the waves when they go beyond the block?

Decrease the frequency of the waves to half of the original frequency.

Q4. What happens to the plane waves when they reach the block?

Q5. What happens to the waves when they go beyond the block?

Increase the frequency of the waves to twice the original frequency.

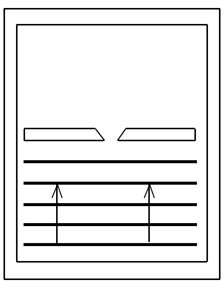
Q6. What happens to the plane waves when they reach the block?

Q7. What happens to the waves when they go beyond the block?

Q8. What is the same in the three situations? What is different?

Q9. How does the shadow (the fuzzy area behind the block) change with frequency?

Remove the block and replace it with an open slit made from two blocks of wood or paraffin with a space between the blocks.



Q10. Predict what will happen to the plane waves incident to the slit when they pass through the slit. (Hint: draw a picture)

Using either the wooden dowel or the straight wave generator, create plane waves at a constant frequency.

Q11. What happens to the shape of the waves as they pass through the slit?

Q12. What happens to the frequency of the waves as they pass through the slit?

Q13. What happens to the wavelength of the waves as they pass through the slit?

Increase the width of the opening.

Q14. What happens to the shape of the waves as they pass through the slit?

Q15. How does the shape of these waves compare to the shape of the waves from the original slit?

Q16. What happens to the frequency and wavelength of the waves as they pass through the slit?

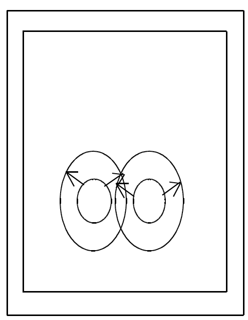
Increase the frequency of the waves.

Q17. What happens to the shape of the waves as they pass through the slit?

Q18. What is different in the pattern created by the increase in frequency? What is the same?

PROCEDURE F: Interference

Remove all objects from the ripple tank. Replace the straight wave generator with the point source generator. (The ripple bar has holes in the front of it, and there are 2 poppet beads attached to metal bends designed to create point source waves.) Adjust the height of the ripple bar until the poppet beads are just touching the top of the water. (Removing some water may also help reach the correct height.)



Q1. Predict what the pattern created by the two point sources will look like. (Hint: Draw a picture.)

Turn on the motor to a low frequency.

Q2. What does the pattern created by the interfering waves look like? Was your prediction correct?

Use the parallel reference from the Refraction procedure as a marker for the viewing screen on the projection of the ripple tank. Measure the distance between the sources (the poppet beads), the distance from the sources to the viewing screen (parallel reference), and the distance to the desired maxima.

Q3. Using the geometry equation in the Interference section of the Concepts, calculate the wavelength of the waves.

Using the adjustable hand strobe method from the Traveling Waves procedure (procedure C), determine the wavelength of the waves.

Q4. What is the measured wavelength of the waves?

Q5. How does the calculated wavelength compare to the measured wavelength?

Leaving the poppet beads in their present location, increase the frequency of the waves.

Q6. What happened to the interference pattern you observed when the frequency changed?

Increase the frequency of the waves again.

Q7. What happened to the interference pattern you observed when the frequency increased?

In the concepts, we defined *node* as a part of a medium where the displacement of the medium is zero. A *nodal line* is a line in an interference pattern where the displacement of the medium is zero due to destructive interference. In the ripple tank, these lines appear fuzzy, and are radially outward from the sources.

Q8. What happens to the nodal lines as the frequency changes? Do they move closer together or further apart?

Keeping the frequency of the waves the same, change the spacing between the two sources.

Q9. What happens to the interference pattern when the sources are closer together?

Q10. How does this interference pattern compare to the interference pattern created with the larger source separation?

Remove the ripple bar and replace it with a variable phase wave generator.

Q11. Predict what will happen to the interference pattern with different source phases.

Start the variable phase wave generator with the sources in phase with each other.

Q12. What does the interference pattern look like?

With the generator running, change the phase of one of the sources.

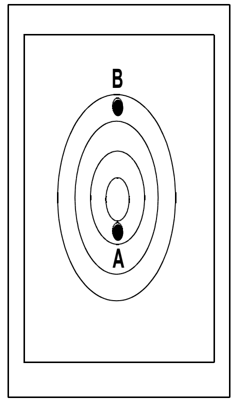
Q13. What does the interference pattern look like?

Q14. How do the two interference patterns compare? What is the same? What is different?

Q15. What happens to the nodal lines in the out-of-phase interference pattern?

PROCEDURE G: The Doppler effect

Remove one of the wood beads from the ripple bar. Holding it in your fingers, place it in the middle of the ripple tank and bounce it up and down slowly, creating circular waves at a constant frequency.



Q1. If there was a bug sitting in the ripple tank at location A, what would he feel?

Q2. If there was a bug sitting in the ripple tank at location B, what would he feel?

Q3. How does the movement of the bug at A compare to the movement of the bug at B? What is the same? What is different?

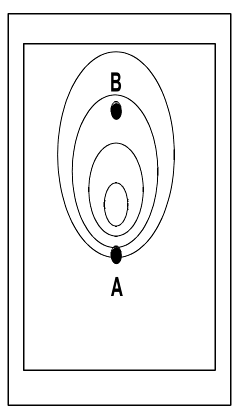
Q4. Predict how this pattern of circular waves would change if the poppet bead was moving.

While bouncing the wood bead up and down, slowly move the bead toward you.

Q5. Describe the pattern projected on the screen.

Q6. Was your prediction correct?

The following picture is an approximation of what the ripples looked like in the ripple tank with the wood bead moving.



Q7. If there was a bug sitting in the ripple tank at location A, what would he feel?

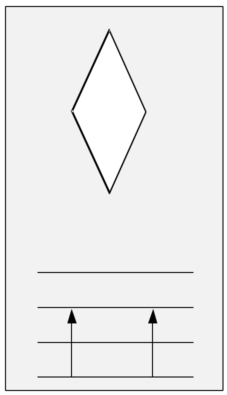
Q8. If there was a bug sitting in the ripple tank at location B, what would he feel?

Q9. How does the movement of the bug at A compare to the movement of the bug at B? What is the same? What is different?

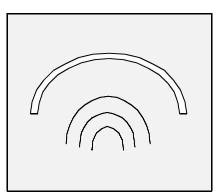
ASSESSMENT:

Reflection

1. A plane wave pulse is headed towards an obstacle, shown in the picture below. What will the reflected wave pulse look like? How can you tell?

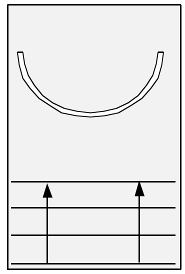


2. The picture below is a snapshot of a ripple tank after some waves were reflected. What might have been the wave shape before they were reflected? How can you tell?



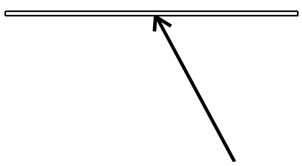
3. If the waves below are incident to the barrier, where will the reflected waves appear to be coming from, and

what will their shape be when they reflect?

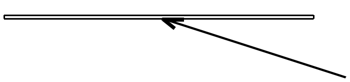


4. Light rays are incident to a mirror, as shown below. Draw the reflected rays in their correct locations. Show all work needed to determine the correct locations.

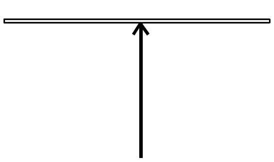
a)



b)

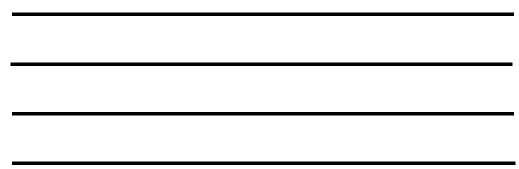


c)



Traveling waves

1. If the picture below is a picture of the screen of a ripple tank, and the ratio of projection is 1/3, what is the actual wavelength of this wave in the ripple tank?



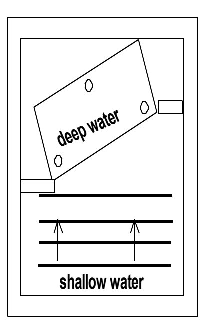
2. If light waves have a frequency of 575 THz, what is their wavelength? What color light is this?

3. If an EM wave has a wavelength of 500 pm, and a wave speed of 3×10^8 m/s, what is its frequency?

4. If a water wave has a wavelength of 20 m and a frequency of 10 Hz, what is the wave speed?

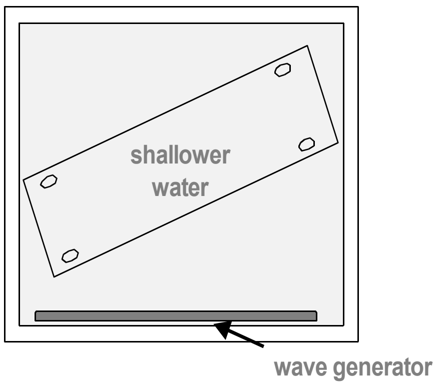
Refraction

1.What will happen to the plane waves when they enter the deep water? How do you know?

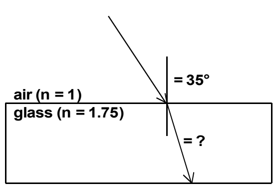


2. Draw and describe what the wave in the following diagram would look like at each of the following locations:

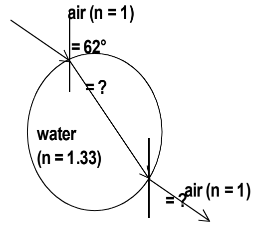
a) just after it leaves the plane generator
b) when half of the wave has been refracted
c) when the entire wave has entered the new medium (shallower water)
d) when half of the wave has left the new medium
e) when the entire wave has left the new medium



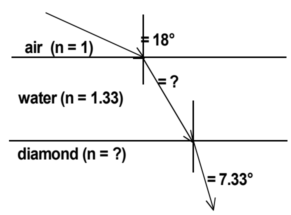
3. If light rays are incident to a thick piece of glass, and enter the glass at an angle of 35°, what angle will the light rays be at inside the glass? Show all your work. (Assume $n_{glass} = 1.75$, $n_{air} = 1.00$)



4. When light travels through a rain droplet, it is refracted. If light is incident to the rain droplet at 62°, what angle will it come out of the rain droplet at? (Assume $n_{water} = 1.33$)



5. Light is incident to a wet diamond with an angle of 18°. If the angle the light is refracted at when it is inside the diamond is 7.33°, what is the index of refraction for a diamond? What is the angle of refraction in the water?



Interference

1. Derive an equation relating the size of the interference pattern to the frequency of the waves.

2. An interference pattern from a double-slit apparatus looks like the picture below. If the slits are 0.75 meters away from the screen and 8 millimeters apart, and the third maxima is 6 centimeters from the center, what is the wavelength? Where on the spectrum is this wavelength?

3. Light with a wavelength of 400 nm is sent through a double slit. The screen is 50 cm away from the slits, and the second maxima is 2 cm from the center. What is the separation between the slits?

4. Light with a frequency of 515 THz is sent through a double slit with a slit separation of 250µm. The seventy-

fifth maxima appears on the screen 5 cm from the center of the pattern. How far away from the slits is the screen?

Doppler Effect

1. On a float in a parade, a young child is blowing a whistle. The actual frequency of the whistle is 975 Hz. If the speed of the sound waves from the whistle is 330 m/s, what frequency do you hear the whistle at

a. when it's moving toward you at 2.5 m/s?

b. when it's moving away from you at 2.5 m/s?

2. A very large speaker is putting out a constant frequency of 472 Hz. If the speed of sound is 330 m/s7, what frequency would you hear the sound at if:

a. you are walking toward it 1 m/s?

b. you are running toward it at 2.5 m/s?

c. you are driving slowly toward it at 9 m/s?

d. you are driving fast toward it at 29 m/s?

e. you are Wile E. Coyote trying to catch Road Runner with a rocket strapped to your back, traveling toward it at 447 m/s?

3. You are standing on the sidewalk when you hear a police siren. The police siren has an actual frequency of 1100 Hz, but you hear the siren at 1250 Hz. If the speed of sound is 331 m/s, how fast is the police car going?

4. You hear a sound as you walk through the woods. You note that at one point, it has a frequency of 1322 Hz. When you reach the source, you find that the frequency is really 1232 Hz. If you were traveling at 2 m/s, what speed were the waves traveling at?