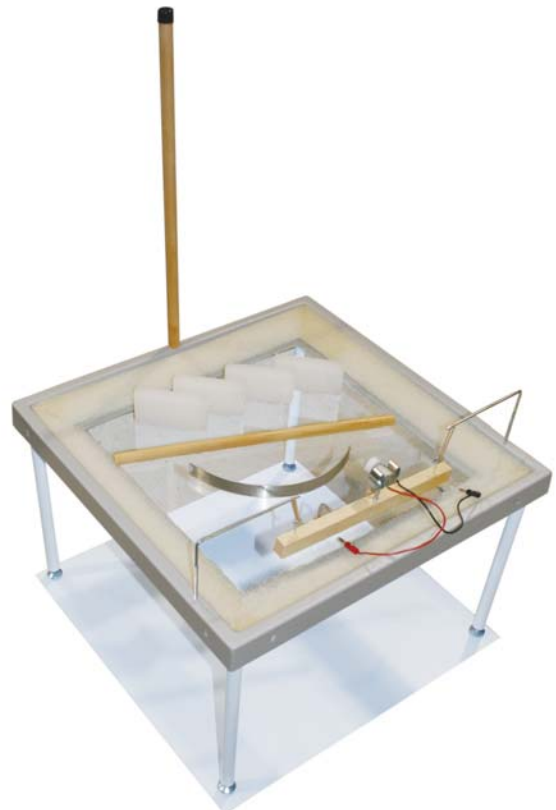
15415 Large Ripple Tank (Instructor Materials)



CONTENTS:

Included Accessories:

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 allows students 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, students 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

STANDARDS: The student will show evidence of the following criteria from the National Science Education Standards (NSES) for grades 5-12. Also, for more specific standards, consult the educational standards that apply to your state or province.

Grade 5-8 (Content Standard A) - *UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY*

Different kinds of questions suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms, or events; some involve collecting specimens; some involve experiments; some involve seeking more information; some involve discovery of new objects and phenomena; and some involve making models.

Addressed by all procedures. Students are asked to make observations and descriptions about the examples of wave phenomena created in the ripple tank. Experiments are performed with many different configurations of the ripple tank and accessories.

Grade 5-8 (Content Standard B) - *MOTIONS AND FORCES*

The motion of an object can be described by its position, direction of motion, and speed.

Addressed by all procedures. Students are asked to describe the speed, shape, etc. of waves as they travel through a medium. Although waves are not actually objects, mechanical waves and water waves consist of the motions of all the particles that make up the medium.

Grade 5-8 (Content Standard G) – *NATURE OF SCIENCE*

Scientists formulate and test their explanations of nature using observation, experiments, and theoretical and mathematical models. Although all scientific ideas are tentative and subject to change and improvement in principle, for most major ideas in science, there is much experimental and observational confirmation.

Addressed by all procedures. The water waves of the ripple tank are models for investigating and predicting the behaviors and properties of all types of waves. Configurations of the equipment are arranged to test predictions of wave behavior, results are observed, and conclusions are justified or used to modify predictions.

Grade 9-12 (Content Standard A) - *UNDERSTANDINGS ABOUT SCIENTIFIC INQUIRY*

Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results.

Addressed throughout the procedures listed below, but specifically addressed in Procedures C, D, and E. Students are asked to use mathematical equations, the wave equation and Snell's Law, to make predictions about the frequency, wavelength, wave speed and direction of motion of waves.

Grade 9-12 (Content Standard A) - *ABILITIES NECESSARY TO DO SCIENTIFIC INQUIRY*

Use technology and mathematics to improve investigations and communications. A variety of technologies, such as hand tools, measuring instruments, and calculators, should be an integral component of scientific investigations. The use of computers for the collection, analysis, and display of data is also a part of this standard. Mathematics plays an essential role in all aspects of an inquiry. For example, measurement is used for posing questions, formulas are used for developing explanations, and

charts and graphs are used for communicating results.
Addressed by all procedures. Measurement, formulas, charts and diagrams are used to make predictions, to organize data and observations, and to confirm results.

Grade 9-12 (Content Standard B) - *INTERACTIONS OF ENERGY AND MATTER*
Waves, including sound and seismic waves, waves on water, and light waves, have energy and can transfer energy when they interact with matter.
Addressed by all procedures. Water waves are used to model the behaviors of all types of waves, demonstrating a wide variety of wave properties and how energy is carried by waves.

Grade 9-12 (Content Standard E) – *UNDERSTANDINGS ABOUT SCIENCE AND TECHNOLOGY*
Creativity, imagination, and a good knowledge base are all required in the work of science and engineering.
Addressed by all procedures. Although wave properties are not extensively described in the NSES, an understanding of wave properties is essential for many kinds of work in science and engineering. Wave properties that should be recognized and understood include propagation, reflection, refraction, diffraction, interference, and Doppler Effect.

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).

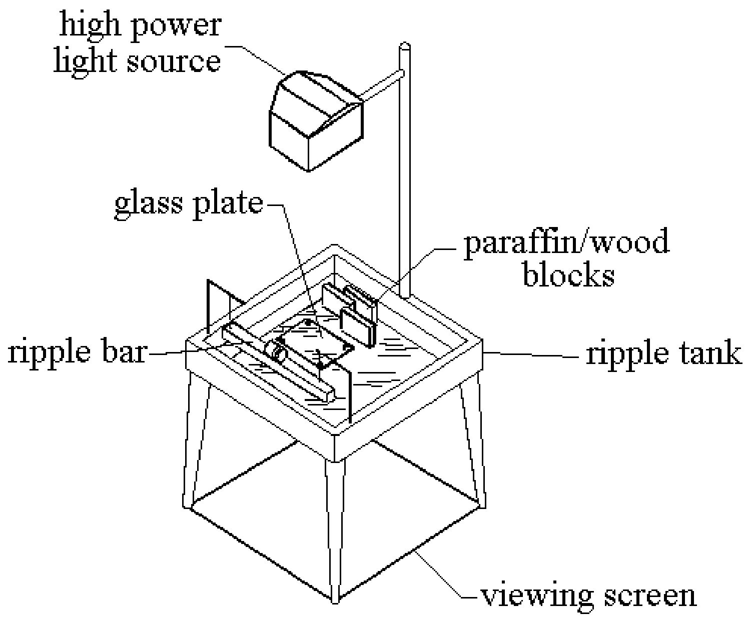
Assembly of the ripple tank should take 5-10 minutes.
Procedure A should take 5-15 minutes.
Procedure B should take 10-20 minutes.
Procedure C should take 10-20 minutes.
Procedure D should take 10-20 minutes.
Procedure E should take 5-15 minutes.
Procedure F should take 10-20 minutes.
Procedure G should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

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.

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 poppet beads) just touch the surface of the water. Fasten the hanger in place with wing nuts.*

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.

Suggestions:

If the High Powered Light Source suggested in the *Required Accessories* list is unavailable, a heat lamp or other similar light source with an oak-tag mask to serve as a point source light source.
This apparatus is best used in a semi-dark to dark room to allow optimum viewing of the projected waves.
If desired, the parabolic reflector can be used to generate parabolic waves (like the circular waves, only in a single direction) rather than using a finger in procedures B-F (when the parabolic reflector isn't needed as a barrier). Also, droplets of water from a pipette or eye dropper can be used to create the circular waves.

Brief description of procedures (Complete procedures found in Student Instructions)

Procedure A: Pulses

Procedure A is designed to introduce students to both the ripple tank and waves. By having students create both circular and plane waves with no interference, students can understand what these waves look like and how these waves move through the medium. This also gives students an opportunity to get a feel for the ripple tank and the creation of waves in the ripple tank.

Procedure B: Reflection

Procedure B is designed to introduce students to how waves reflect by using different shaped waves and barriers. This allows students to make generalizations about reflected waves, such as reflected shape, angle, and apparent source location. By allowing students to test different reflections, students can take this knowledge and apply it to reflections of other waves, such as electromagnetic waves.

Procedure C: Traveling waves

Procedure C is designed to allow students to discover how frequency and wavelength are related, how water waves change speed in different depths of water (analogous to different wave speeds in different media), and how wave speed changes with a difference in frequency or wavelength. This allows students to make generalizations about other types of waves, and how these waves travel through media depending upon their frequency, wavelength, and/or wave speed.

Procedure D: Refraction

Procedure D is designed to allow students to investigate the change in wave speed, shape, or angle when it enters a new medium (in this case, the new medium is shallower water). Students can then extrapolate from how water waves react when entering a new media to other types of waves (such as electromagnetic waves) traveling into new media (such as from air to water, for example).

Procedure E: Waves and obstacles

Procedure E allows students to observe how waves interact with an obstacle (object or slit) in their path. Students can see how wavelength, frequency, shape of the object, and size of the object all affect the "shadow" behind the obstacle, which can then be applied to shadows with electromagnetic waves, such as cell phone reception behind a hill. Students can also see how wave shape changes as waves pass through a slit, as well as how wave shape depends on the size of the slit and that wave speed does not change when waves travel through a slit.

Procedure F: Interference

Procedure F gives students the opportunity to create interference patterns with water waves, which they can then apply to interference of other types of waves, such as light interference. By using two circular sources and observing the interference pattern, students can simulate a double-slit interference pattern for light. Students also observe how the interference pattern changes as the frequency, distance between the sources, and phase change.

Procedure G: The Doppler effect

Procedure G gives students the ability to observe how perceived frequency can change if the source is moving towards or away from an observation point. These observations can then be applied to the shifting sound frequency of a moving object, such as a car or a jet.

PROCEDURES ANSWERS:

Procedure A: Pulses

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

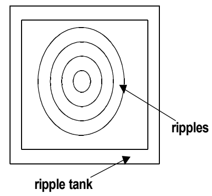
With no waves in the tank, there will be no projected image because there is nothing in the tank.

Q2. What happened when you touched the water?

Circular waves were created. The waves travel radially outward from the point of contact with the water.

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

The projected image looks like the situation in the ripple tank, only in two dimensions, with darker areas being the crests of waves.



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

The projected image looks the same as before, with circular waves moving radially outward from the point of contact with the water. (see picture in Q3)

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

The pattern is the same as in Q3.

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

The speed of the pulse is the same in both situations.

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

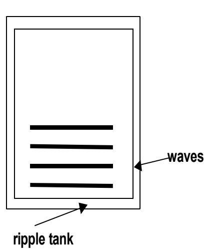
The speed of this pulse is the same as the last two pulses.

Q8. Does the speed of the wave pulse change depending upon how fast you touch the water?

No, the speed of the wave pulse does not change depending upon how fast you touch the water.

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

The projected image looks like flat waves that travel parallel to the dowel.



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

The two wave pulses traveled outward from their source, keeping the same pattern as the source. The waves traveled at the same speed. Both sets of waves were created by disturbing the water. The waves have different shapes and different sources.

Q11. How did this wave pattern compare to the last wave pattern?
Both patterns had the same shape.

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?
The speed of the wave pulses was the same in both cases. The speed of the plane waves was the same as the speed of the circular waves.

Q13. How does the amplitude of the wave pulse change as you create the pulses faster? How can you tell?
The amplitude of the wave pulses increased as the pulses were created faster. The higher amplitude waves create a darker line on the screen, making it easier to see the difference in amplitude.

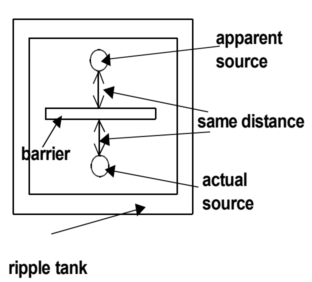
Procedure B: Reflection

Q1. Predict what will happen when a circular wave pulse reaches the barrier. Draw a picture.
Predictions and drawings will vary from student to student.

Q2. What happens when the wave pulse reaches the barrier? Was your prediction correct?
Answers will vary from student to student. When the wave pulse reaches the barrier, it will reflect back with the same shape as the waves before they reached the barrier. Whether the prediction is correct or not depends upon the answer to Q1.

Q3. What does the reflected wave pulse look like?
The reflected wave pulse looks like the incident wave pulse.

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?
The reflected wave pulse appears to come from behind the barrier, at a point equidistant from barrier as the source. The apparent source of the waves is a virtual source.



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)?
The angle of incidence is equal to the angle of reflection.

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

For each location, the reflected wave pulse appears to be coming from a virtual source equidistant from the barrier as the actual source.

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

Predictions and drawings will vary from student to student.

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)

The plane waves have the same speed as the circular waves did. The apparent source is a virtual source in both situations, both of them equidistant from the barrier. Both waves retain their shape after they reflect from the barrier.

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

Predictions and drawings will vary from student to student.

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

Answers will vary from student to student, and depend upon answers to Q9. When the wave pulse hits the barrier, it will reflect back, retaining its original shape, and appearing to come from a virtual source equidistant from the barrier as the actual source.

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

Predictions and drawings will vary from student to student.

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

Answers will vary from student to student, and depend upon answers to Q11. When the wave pulse hits the barrier, it will reflect back, retaining its original shape, and appearing to come from a virtual source equidistant from the barrier as the actual source.

Q13. Compare what was similar and what was different between the circular wave pulse and the plane wave pulse. How could you tell?

Both types of waves traveled at the same speed, both waves reflected the same way off of the barrier (created reflected waves with the same shape as the original wave pulse), and both appeared to come from virtual sources that were equidistant from the barrier as the actual sources (reflected waves appeared to start from the other side of the barrier, but looked identical to the waves that were originally created). The difference between the two wave pulses was the shape of the pulses.

Q14. How did the angle of incidence compare to the angle of reflection in the circular wave? The plane wave?

The angle of incidence was equal to the angle of reflection for both waves.

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

Predictions and drawings will vary from student to student.

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

Answers will vary from student to student, and depend upon answers to Q15. When the wave pulse hit the barrier, it reflected back in the shape of the parabolic reflector.

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

The angle of incidence is the equal 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?

The reflected waves appear to be created from a point equidistant from the barrier on the same side of the barrier as the actual source. The apparent source is a real source.

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

Predictions and drawings will vary from student to student.

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

Answers will vary from student to student, and depend upon answers to Q19. When the wave pulse hit the barrier, it reflected back in the shape of the parabolic reflector.

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

The angle of incidence is the equal to the angle of reflection.

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

The reflected waves appear to be created from a point equidistant from the barrier on the same side of the barrier as the actual source. The apparent source is 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?

The apparent source of the reflected waves is the same for both the plane waves and the circular waves. This point is known as the *focal point* of the parabolic reflector.

Procedure C: Traveling waves

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

Answers will vary from student to student.

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

The frequency of the adjustable hand strobe is the same as the frequency of the waves. The waves appear to stop when looking through the strobe, meaning that the waves are actually passing through the strobe at the same frequency as the strobe is going around.

Q3. How many waves fall between the two pencils?

Answers will vary depending upon the frequency of the wave generator.

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

Answers will vary depending upon the frequency of the wave generator.

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.)

Student should have calculated the projected size difference of the piece of tape before beginning the experiments.

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

Answers will vary depending upon the frequency and wavelength calculated for the wave tank. All students should calculate the same speed (within a reasonable degree of accuracy) as all students are doing the experiment in water. The equation they should use is located in the concepts section, and is v = lf.

Q7. What is the frequency of the waves at this increased motor speed?
Answers will vary depending upon the frequency of the wave generator.

Q8. How many waves fall between the two pencils?
Answers will vary depending upon the frequency of the wave generator.

Q9. What is the distance (in meters) between the two pencils?
Answers will vary depending upon the frequency of the wave generator.

Q10. What is the wave speed for the waves in the ripple tank?
Answers will vary depending upon the frequency and wavelength calculated.

Q11. How does this wave speed compare to the wave speed from the first run at a slower frequency?
The wave speeds should be the same for both runs.

Q12. Compare the wave speed from each of the runs. How do they compare?
The wave speeds should be the same for all runs.

Q13. What is the wave speed in the shallower water?
Answers will vary depending upon the frequency of the wave generator.

Q14. How does the shallower wave speed compare to the wave speeds from before?
The shallower water wave speed is slower than the wave speeds from before.

Q15. What is the wave speed in the deeper water?
Answers will vary depending upon the frequency of the wave generator.

Q16. How does the deeper wave speed compare to the shallow wave speed? The shallowest wave speed?
The deeper wave speed is faster than both of the shallower ripple tank wave speeds.

Q17. Did the wavelength of the water waves change as you changed the depth of the water?
The wavelength of the water waves increased as the water got deeper.

Q18. Did the frequency of the water waves change as you changed the depth of the water?
The frequency of the water waves did not change as the water depth changed. (Kept constant because of the motor.)

Procedure D: Refraction

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

frequency?
Answers will vary from student to student.
wavelength?
Answers will vary from student to student.
speed?

Answers will vary from student to student.

Q2. What happened to the wavelength of the plane wave when it went from deeper to shallower water?
The wavelength decreased when the plane wave went from deeper to shallower water.
Q3. What happened to the frequency of the plane wave when it went from deeper to shallower water?
The frequency of the plane wave remains the same when the waves go from deeper to shallower water.

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

Q5. Were your predictions correct? Explain why or why not.
Answers will vary from student to student, and depend upon answers to Q1.

Q6. Predict what will happen to a plane wave when it goes from the deeper to shallower water. What will happen to the:
frequency?
Answers will vary from student to student.
wavelength?
Answers will vary from student to student.
speed?
Answers will vary from student to student.

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.
Answers will vary from student to student.

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

Q9. What happened to the frequency of the plane wave when it went from deeper to shallower water?
The frequency of the plane wave remains the same when the waves go from deeper to shallower water.
Q10. What happened to the speed of the wave as it went from deeper to shallower water?
The speed of the wave decreased 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?
When the plane waves hit the boundary and traveled into the shallower water, they are refracted. Because the wave in the shallower water is traveling slower than the wave in the deeper water, the wave runs into the barrier between the different depths at different times. This causes the wave to bend.

Q12. Were your predictions correct? Explain why or why not.
Answers will vary from student to student, and depend upon answers to Q6 and Q7.

Q13. What is the angle of refraction for your setup?
Answers will vary from student to student, and depend upon the angle of the glass and the depth of the water.

Procedure E: Waves and Obstacles

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

Q2. What happens to the plane waves when they reach the block?
The waves reflect off of the flat surface parallel to the waves and they bend around the object.

Q3. What happens to the waves when they go beyond the block?
The waves begin to fill in the space behind the block, causing a "shadow" to form behind the block.

Q4. What happens to the plane waves when they reach the block?
The waves reflect off of the flat surface parallel to the waves and they bend around the object.

Q5. What happens to the waves when they go beyond the block?
The waves begin to fill in the space behind the block, causing a "shadow" to form behind the block.

Q6. What happens to the plane waves when they reach the block?
The waves reflect off of the flat surface parallel to the waves and they bend around the object.

Q7. What happens to the waves when they go beyond the block?
The waves begin to fill in the space behind the block, causing a "shadow" to form behind the block.

Q8. What is the same in the three situations? What is different?
The waves bend around the shape in all situations. The difference is the size and sharpness of the shadow

Q9. How does the shadow (the fuzzy area behind the block) change with frequency?
As the frequency of the wave increases, the shadow behind the block increases.

Q10. Predict what will happen to the plane waves incident to the slit when they pass through the slit. (Hint: draw a picture)
Predictions and drawings will vary from student to student.

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

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

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

Q14. What happens to the shape of the waves as they pass through the slit?
The waves become less planar and more circular 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?
They are less circular than the shape of the waves from the smaller slit.

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

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

Q18. What is different in the pattern created by the increase in frequency? What is the same?
There are more nodal lines (fuzzy lines) in the increased frequency pattern. All frequencies created a pattern with light, dark, and fuzzy lines.

Procedure F: Interference

Q1. Predict what the pattern created by the two point sources will look like. (Hint: Draw a picture.)
Predictions and drawings will vary from student to student.

Q2. What does the pattern created by the interfering waves look like? Was your prediction correct?
The pattern created looks like a single circular wave pulse with lines outward from the center of the two sources where the displacement of the water is zero. Whether the student prediction was correct or not depends upon their answer to Q1.

Q3. Using the geometry equation in the Interference section of the Concepts, calculate the wavelength of the waves.
Answers will vary from student to student depending upon the distance to the screen, the wavelength of waves, and the distance between the sources. Students should use the equation from the concepts section: $x/L = nl/d$.

Q4. What is the measured wavelength of the waves?
Answers will vary depending upon the frequency the motor is set at.

Q5. How does the calculated wavelength compare to the measured wavelength?
The two wavelengths are equal to each other.

Q6. What happened to the interference pattern you observed when the frequency changed?
There were more fuzzy lines (nodal lines) of interference than at the lower frequency.

Q7. What happened to the interference pattern you observed when the frequency increased?
There were more fuzzy lines (nodal lines) of interference than at the lower two frequencies.

Q8. What happens to the nodal lines as the frequency changes? Do they move closer together or further apart?
The nodal lines increase in number as frequency increases. The higher the frequency, the closer together the nodal lines.

Q9. What happens to the interference pattern when the sources are closer together?
The distance between nodal lines gets smaller.

Q10. How does this interference pattern compare to the interference pattern created with the larger source separation?
Both interference patterns have nodal lines and maxima, and both sets of nodal lines appear to start at a point half-way between the two sources.

Q11. Predict what will happen to the interference pattern with different source phases.
Answers will vary from student to student.

Q12. What does the interference pattern look like?

The interference pattern looks like the previous two-source interference patterns.

Q13. What does the interference pattern look like?
The interference pattern looks like the patterns from sources of the same phase. Nodal lines are shifted some, but the general pattern is the same.

Q14. How do the two interference patterns compare? What is the same? What is different?
The nodal lines shift when the sources do not have the same phase. In the same phase situation, the center of the pattern is a maxima. In the situation of completely out of phase (one at crest, the other at trough), the center of the pattern is a minima.

Q15. What happens to the nodal lines in the out-of-phase interference pattern?
The nodal lines shift, but do not disappear.

Procedure G: The Doppler effect

Q1. If there was a bug sitting in the ripple tank at location A, what would he feel?
At location A, a bug would feel himself move up and down with the waves with a constant motion.

Q2. If there was a bug sitting in the ripple tank at location B, what would he feel?
At location B, a bug would feel himself move up and down with the waves with a constant motion.

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?
At both A and B, the wavelength and frequency of the waves is the same.

Q4. Predict how this pattern of circular waves would change if the poppet bead was moving.
Answers will vary from student to student.

Q5. Describe the pattern projected on the screen.
The circular waves appear to be closer together at one side (the side of the bead closer to you) and farther apart at the other side (the side of bead farther away from you).

Q6. Was your prediction correct?
Answers will vary and depend upon students' answer to Q4.

Q7. If there was a bug sitting in the ripple tank at location A, what would he feel?
At location A, a bug would feel himself move up and down with the waves with a constant motion.

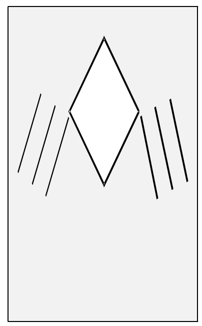
Q8. If there was a bug sitting in the ripple tank at location B, what would he feel?
At location B, a bug would feel himself move up and down with the waves with a constant motion.

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?
At location A, the bug would feel himself move up and down at a higher frequency than at location B. While the source is producing waves at the same frequency at all times, because the source is moving there is an apparent shift in frequency at different locations.

Assessment Answers:

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?*



The reflected wave pulses would look like the shape of the obstacle, because the angle of incidence is equal to the angle of reflection. The portions of the wave that hit the obstacle first will be reflected back at the same angle, and as the entire wave hits the obstacle, the wave will bounce back in succession, creating a wave in the shape of the obstacle.

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?

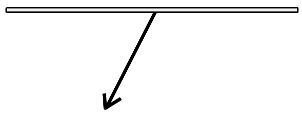
The original shape of the wave is impossible to tell. Reflected waves appear to be generated from a source, in this case the edge of the obstacle. The waves bounce off this surface and create new waves of the shape of the obstacle, and therefore the shape of the incident waves prior to reflection cannot be determined.

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?

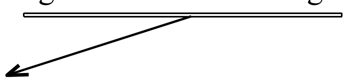
When the waves reflect, they will appear to be coming from a virtual source at the focal point of the parabolic reflector. The reflected waves will be parabolic shaped, like the reflector.

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.

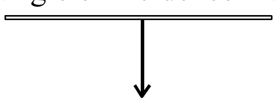
a) angle of incidence = angle of reflection



b) angle of incidence = angle of reflection



c) angle of incidence = angle of reflection



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?

Using the equation from the assembly instructions:

$$\frac{\text{Actual wavelength}}{\textbf{Measured wavelength}} = \frac{1}{\mathbf{3}}$$

(3)*(Actual wavelength) = (1)*(Measured wavelength)
Actual wavelength = (Measured wavelength)/3
Actual wavelength = (1.25 cm)/3

Actual wavelength = 0.4167 cm = 0.004167 m = 4.167 mm = 0.164 in

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

$$v = lf$$
$$(3.0 \times 10^{8}\ \text{m/s}) = (575\ \text{THz})\cdot l$$
$$3.0 \times 10^{8}\ \text{m/s} = (575 \times 10^{12}\ \text{Hz})\cdot l$$
$$(3.0 \times 10^{8}\ \text{m/s})/(575 \times 10^{12}\ \text{Hz}) = l$$
$$(3.0 \times 10^{8}\ \text{m/s})/(5.75 \times 10^{14}\text{Hz}) = l$$

$$l = .522 \times 10^{-6}\ \text{m} = 522 \times 10^{-9}\ \text{m} = 522\ \text{nm}.$$

This wavelength corresponds to a green color light.

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

$$v = lf$$

$$3.0 \times 10^8 \text{ m/s} = (500 \times 10^{-12} \text{ m})\cdot f$$

$$f = (3.0 \times 10^8 \text{ m/s})/(500 \times 10^{-12} \text{ m})$$

$$f = (300 \times 10^6 \text{ m/s})/(500 \times 10^{-12} \text{ m})$$

$$f = 0.6 \times 10^{18} \text{ Hz} = 6 \times 10^{17} \text{ Hz} = 600 \text{ THz}$$

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

$$v = lf$$

$$v = (20 \text{ m})\cdot(10 \text{ Hz})$$

$$v = 200 \text{ m}*\text{Hz} = 200 \text{ m/s}$$

Refraction

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

When the waves enter the deeper water, the wavelength will increase and the wave speed will increase. We know this from the observations made about how waves from deep water decrease speed when entering shallow water.

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

Just after the wave leaves the plane generator, it will be a plane wave

b) when half of the wave has been refracted

Half of the wave will be traveling slower than the other half. Half of the wave will still be parallel to the generator, and half of the wave will be bent at an angle

c) when the entire wave has entered the new medium (shallower water)

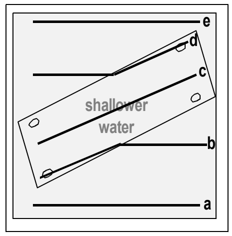
The wave will be bent at an angle from normal, but will all be traveling at the same speed and direction.

d) when half of the wave has left the new medium

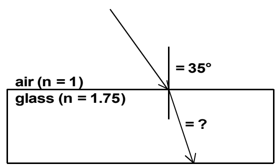
The half that left the medium will once again be parallel to the generator, traveling at the speed it was originally traveling at

e) when the entire wave has left the new medium

The wave will once again be parallel to the generator, and traveling at the original speed.



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)

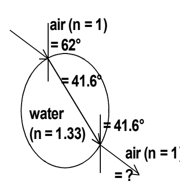


$$n_1 \cdot \sin\ {}_1 = n_2 \cdot \sin\ {}_2$$
$$(1) \cdot \sin(35°) = (1.75) \cdot (\sin\ {}_2)$$
$$(0.5736)/(1.75) = \sin\ {}_2$$
$$0.3278 = \sin\ {}_2$$

$${}_2 = \sin^{-1}(0.3278) = 19.13°$$

The angle of the light rays inside the glass is 19.13° from normal.

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)



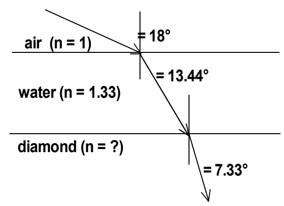
$$n_1 \cdot \sin\ {}_1 = n_2 \cdot \sin\ {}_2$$
$$(1) \cdot (\sin 62°) = (1.33) \cdot \sin\ {}_2$$
$$(0.8829)/(1.33) = \sin\ {}_2$$
$${}_2 = \sin^{-1}(0.6639)$$
$${}_2 = 41.6°$$

$$n_2 \cdot \sin\ _2 = n_3 \cdot \sin\ _3$$
$$(1.33) \cdot (\sin 41.6°) = (1) \cdot \sin\ _3$$
$$0.883 = \sin\ _3$$
$$_3 = \sin^{-1}(0.883)$$

$_3 = 62°$

The light will come out of the rain droplet at the same angle it went in at- 62°.

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?



$$n_1 \cdot \sin\ _1 = n_2 \cdot \sin\ _2$$

$(1) \cdot (\sin 18°) = (1.33) \cdot (\sin\ _2)$
$(\sin 18°)/(1.33) = \sin\ _2$
$_2 = \sin^{-1}(.232) = 13.44°$

$$n_2 \cdot \sin\ _2 = n_3 \cdot \sin\ _3$$

$(1.33) \cdot (\sin 13.44°) = n_3 \cdot (\sin 7.33°)$
$n_3 = (1.33) \cdot (\sin 13.44°)/(\sin 7.33°)$
$n_3 = 2.42$

Interference

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

The two equations that should be used to derive this equation are
v = fl
and x/L = nl/d.
Solve v = fl for l, yielding l = v/f. Plug this into the geometry equation;
x/L = n(v/f)/d, which simplifies to x/L = nv/fd.

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?

x = 0.06 m, L = 0.75 m, d = 0.008 m, n = 3

x/L = nl/d

$$l = xd/nL$$
$$l = [(0.06\ m) \cdot (0.008\ m)] / [(3) \cdot (0.75)]$$
$$l = (0.00048\ m^2)/(2.25\ m)$$
$$l = 2.13 \times 10^{-4}\ m = 213 \times 10^{-6}\ m = 213 \mu m$$

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?

$$l = 400 \times 10^{-9} \text{ m}, x = 0.02 \text{ m}, L = 0.5 \text{ m}, n = 2$$
$$x/L = nl/d$$
$$d = nlL/x$$
$$d = [(2)\cdot(400 \times 10^{-9} \text{ m})\cdot(0.5 \text{ m})] / (0.02 \text{ m})$$
$$d = 0.00002 \text{ m} = 200 \text{ µm}$$

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?

$x = 0.05$ m, $n = 75$, $d = .00025$ m, $f = 5.15 \times 10^{14}$ Hz, $v = 3.0 \times 10^8$ m/s

Option 1:
$x/L = nv/fd$
$L = fdx/nv$
$L = [(5.15 \times 10^{14} \text{ Hz})\cdot(0.00025 \text{ m})\cdot(0.05 \text{ m})] / [(75)\cdot (3.0 \times 10^8 \text{ m/s})]$
$L = (0.0000437 \text{ m}^2\cdot\text{Hz}) / (0.0000125 \text{ m/s})$

$L = 0.286$ m

Option 2:
$v = lf$
$l = v/f$
$l = (3.0 \times 108 \text{ m/s}) / (5.15 \times 1014 \text{ Hz})$
$l = 582$ nm

$x/L = nl/d$
$L = xd/nl$
$L = [(0.05 \text{ m})\cdot(0.00025 \text{ m})] / [(75)\cdot(582 \times 10\text{-}9 \text{ m})]$
$L = (0.0000125 \text{ m2}) / (0.00004365 \text{ m})$

$L = 0.286$ m

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?

$$f_0 = 975 \text{ Hz}, v = 330 \text{ m/s}, v_s = 2.5 \text{ m/s}$$
$$f = f_0[v/(v\text{-}v_s)]$$
$$f = (975 \text{ Hz})[(330 \text{ m/s})/(330 \text{ m/s} – 2.5 \text{ m/s})]$$
$$f = (975 \text{ Hz})[(330 \text{ m/s})/(327.5 \text{ m/s})]$$
$$f = 982 \text{ Hz}$$

b. when it's moving away from you at 2.5 m/s?
$f_0 = 975$ Hz, $v = 330$ m/s, $v_s = -2.5$ m/s
$f = f_0[v/(v\text{-}v_s)]$
$$f = (975 \text{ Hz})[(330 \text{ m/s})/(330 \text{ m/s} + 2.5 \text{ m/s})]$$
$$f = (975 \text{ Hz})[(330 \text{ m/s})/(332.5 \text{ m/s})]$$
$f = 967$ Hz

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

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

f_0 = 472 Hz, v = 330 m/s, v_0 = 1 m/s
$f = f_0[1+ (v_0/v)]$
f = (472 Hz)[1 + ((1 m/s)/(330 m/s))]

f = 473.4 Hz

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

f_0 = 472 Hz, v = 330 m/s, v_0 = 2.5 m/s
$f = f_0[1+ (v_0/v)]$
f = (472 Hz)[1 + ((2.5 m/s)/(330 m/s))]

f = 475.6 Hz

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

f_0 = 472 Hz, v = 330 m/s, v_0 = 9 m/s
$f = f_0[1+ (v_0/v)]$
f = (472 Hz)[1 + ((9 m/s)/(330 m/s))]

f = 484.9 Hz

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

f_0 = 472 Hz, v = 330 m/s, v_0 = 29 m/s
$f = f_0[1+ (v_0/v)]$
f = (472 Hz)[1 + ((29 m/s)/(330 m/s))]

f = 513.5 Hz

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?

f_0 = 472 Hz, v = 330 m/s, v_0 = 447 m/s
$f = f_0[1+ (v_0/v)]$
f = (472 Hz)[1 + ((447 m/s)/(330 m/s))]

f = 1111 Hz

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?

f_0 = 1100 Hz, f = 1250 Hz, v = 331 m/s
$f = f_0[v/(v-v_s)]$
1250 Hz = (1100 Hz)[(331 m/s)/(331 m/s – v_s)]
[1250 Hz / 1100 Hz] = (331 m/s)/(331 m/s – v_s)
[(331 m/s)(1100 Hz)] / 1250 Hz = 331 m/s – v_s
331 m/s – [(331 m/s)(1100 Hz)/1250 Hz] = v_s
331 m/s – 291.28 m/s = v_s

v_s = 39.72 m/s = 88.85 mph

The police car is traveling at 39.72 m/s, or 88.85 mph.

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?*

$f = 1322$ Hz, $f_0 = 1232$ Hz, $v_0 = 2$ m/s

$f = f_0[1 + (v_0/v)]$

1322 Hz = 1232 Hz [1 + ((2 m/s)/v)]

(1322 Hz)/(1232 Hz) = 1 + (2 m/s)/v

[(1322 Hz)/(1232 Hz)] – 1 = (2 m/s)/v

v = (2 m/s)/[[(1322 Hz)/(1232 Hz)] – 1]

v = 28.6 m/s

The waves were traveling at a speed of 28.6 m/s.

SUGGESTIONS FOR FURTHER STUDY:

Please share this information with your students. These applets are designed to be a reinforcement tool for students and are not intended to replace the actual experiments. The physics department at the National Taiwan Normal University created a Java applet for light traveling between two different media, and how the angle of incidence depends upon the angle of reflection. Students can move the flashlight up and down, and change the angle to see how the reflected and refracted light changes. Students have the option of observing the refraction from water to air or from air to water. http://www.phy.ntnu.edu.tw/ntnujava/viewtopic.php?t=66

An independent website, www.falstad.com/ripple, has many Java applets available, including one for a ripple tank. Students have multiple scenarios they can play with, including mirrors, lenses, temperature gradients, multiple sources, obstacles, the Doppler effect, and a sonic boom, to name a few. Students have control over many of the variables, including frequency, wavelength, spacing, and color of the simulation.

A person in the physics department at Appleby College in Canada created a website filled with applets about pendulums, waves, lenses, mirrors, AC power, and DC power. These are quite user-friendly, and allow students to observe the phenomena with some control over the variables.
http://www.geocities.com/CapeCanaveral/Hall/6645/

The physics department at the University of Virginia also has a large list of applets (Macromedia and Java) for a wide range of phenomena, from waves to planetary orbits, and many more. Students can observe different phenomena and have control over some of the variables involved.
http://galileo.phys.virginia.edu/classes/109N/more_stuff/flashlets/home.htm

Safety and disposal:

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.

To dispose of the water in the ripple tank, remove the rubber stopper from the hole and drain the water out into a container or the sink. Water should be disposed of down the drain and not consumed after it has been in the tank. Use paper towels or a cloth towel to remove any remaining water from the ripple tank. Allow the ripple tank to air dry before packing away. To pack, disassemble the ripple tank by removing the legs, light source support rod, and angled aluminum rods, and store carefully in a dry place. Take care not to break the glass during storage.

APPENDIX A

The following table contains the values for the prefixes within the instruction sheet and assessment.

prefix	*symbol*	*10^n*	*scale*
exa	E	10^{18}	Quintillion
peta	P	10^{15}	Quadrillion
tera	T	10^{12}	Trillion
giga	G	10^{9}	Billion
kilo	k	10^{3}	Thousand
(none)	(none)	10^{0}	One
centi	c	10^{-2}	Hundredth
milli	m	10^{-3}	Thousandth
micro	µ	10^{-6}	Millionth
nano	n	10^{-9}	Billionth
pico	p	10^{-12}	Trillionth