Teacher's Preparatory Guide

Lesson 1: Refraction Tank

Purpose: This lab will help students understand and measure the angle of incidence and the angle of refraction of a beam of light traveling through two mediums. This lab is part 1 of a series of 3 labs that will explore how light can be transmitted through a waveguide for communication purposes.

Level: Middle school or high school

Time required: One 45-minute class period

Materials for demonstrations
Phantom crystal demonstration:
- phantom crystals (8–9 crystals)
- medium-sized metal paper clip
- 100 ml glass beaker
- water

Internal reflection demonstration:
- 15-gallon rectangular aquarium, filled 2/3 of the way with water
- flashlight with a strong beam, such as a mini-Maglite
- 30 ml of 1% milk or powered milk
- 100 ml graduated cylinder
- blue tape or thin piece of colored paper and tape

Materials for lab activity for each group of 2 students
- refraction tank filled halfway with water
- laser pointer
- worksheet

Safety Information: The lasers can be removed from the refraction tank unit, thus the students should be given the rules for proper and safe behavior when working with lasers (or make sure the lasers are firmly attached to the tank). For example:
1. The laser should always remain on the refraction tank.
2. Students should never look into a laser pointer. Eye damage can occur.
3. The laser should never be pointed towards another person.

Advance Preparation
PREPARATION FOR THE PHANTOM CRYSTAL DEMONSTRATION

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Immerse 8–9 phantom crystals in water the night before class. In the morning, bend a medium-sized, metal paper clip to resemble a hook. Remove several phantom crystals from the water and hook several pieces the paper clip. Set the phantom crystals and hook back into the water. At first glance, the hook should appear to stand out of the water on its own. Below are some pictures of phantom crystals before immersing in water, after immersing in water, and then while immersed in water.

Above: phantom crystals before being soaked in water

Above: phantom crystals once they have absorbed water

Above: phantom crystals in water

2. PREPARATION FOR THE INTERNAL REFLECTION DEMONSTRATION
   Fill the aquarium two thirds full of water. Before your first class, add the milk. The amount of milk may depend on the size of tank you have available. The light scatters off the milk particles in the water so that the students can see the light beam. Test this demonstration before class in a darkened room with the flashlight to make sure the beam of light is visible. More milk may be added to increase scattering. Low-fat milk works better because of the smaller fat molecule size. Adding milk to the water creates a colloid solution in which solid particles (fat molecules) ranging in sizes between 1 – 100nm stay suspended in the solution and allow the scattering of light. On the backside of the aquarium, place a piece of blue tape vertically so as to split the tank in two. This tape will serve as a visual for the normal to the surface of the water.

3. DIM LIGHTS BEFORE LAB

Teacher Background: A cool fact about the speed of a beam of light in a vacuum is that, no matter how you look at it, it's always the same—about 3×10^8 m/s. Scientists noticed that if a light beam moves from a vacuum to a medium (like glass), the phase velocity of the light beam slows down by some amount that is always the same for that medium (in this example, glass).

speed of light (in vacuum) = speed of light in medium (like glass) × a number that is always the same for that medium (glass)

The "number" mentioned in the equation above is a measure of how much the speed of light is reduced in that medium when compared to the speed of light in a vacuum and this "number" is called the *index of refraction*. This is calculated as

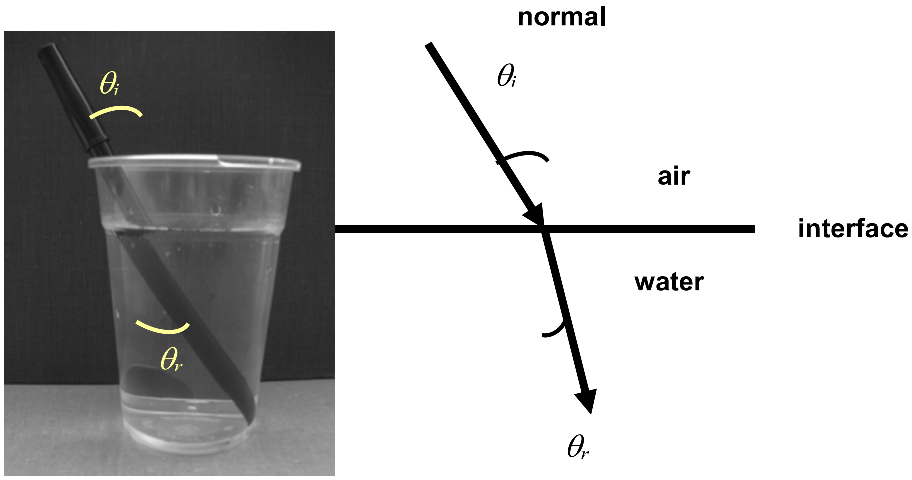
$$\mathbf{n} = \frac{\mathbf{c}}{\boldsymbol{v}}$$

where **n** is the index of refraction, **c** is the speed of light in a vacuum and ***v*** is the speed of light in the medium. Since light is slowed by the interaction with matter, the index of refraction of materials is always greater than one.

As a beam of light travels from one medium to another—as from air to water—its phase velocity will either speed up or slow down. This change in velocity causes the beam to bend as it crosses the interface between the two mediums. The effect of the light beam bending can be seen with a straw or pen in a glass of water. The light that is reflected off the immersed straw travels through the water then crosses the surface of the water out into the air then to the viewer. The change in mediums (water to air) causes the light to bend and thus gives the illusion that the object is bent as well.

It is important to note that solutions are mixtures that have particles that are smaller than one nanometer and colloids are mixtures that have particles that are between one and 100 nanometers. The milk solution is a colloid because of the size of the nanoparticles. Because of this small size they exhibit unique properties which are important in nanoscale science and engineering.

Images below: A pen in a cup of water appears bent because the light is bent as it crosses the interface between two mediums.

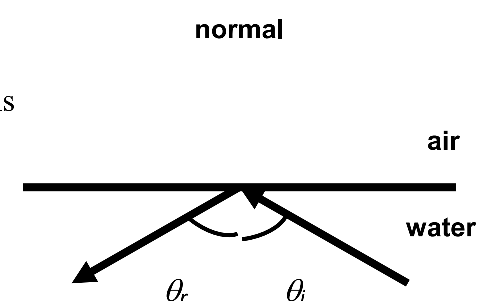


θ_i is the *angle of incidence* (light enters the interface)
θ_r is the *angle of refraction* (light bends as it leaves the interface)

The relationship between the angles of incidence and refraction involves the indices of refraction of the two mediums and can be calculated by Snell's Law, which is given by:

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

Total internal reflection occurs when light is bent past the interface *($\theta_r > 90°$)*. The light does not leave the medium in this case, but is instead reflected off the interface. When the two mediums have very different indices of refraction, this occurs readily (when the θ_i is small). In the case of water and air, the critical angle *(θ_i)* at which total internal reflection occurs is around 45°.



total internal reflection

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Resources You may wish to use these resources either as background or as a resource for students to use:

- aquarium demonstration: http://www.exploratorium.edu/snacks/critical_angle/index.html
- refraction tank instructions/lesson ideas: comes with refraction tank

Teaching Strategies To maximize student involvement, conduct this lab in groups of 2 students.

Instructional Procedure

Time	Activity	Goal
7 min	*Demonstration:* Phantom crystals. Students discuss and write explanation in notebook.	Review index of refraction.
8 min	*Demonstration:* Aquarium with flashlight. Students sketch demonstration and label the normal, angle of incidence and the angle of refraction.	Introduce the terms: *normal*, *angle of incidence,* and *angle of refraction.*
25 min	*Refraction Tank lab.* Students follow directions given on *Student Worksheets.*	Gather quantitative results and find a pattern that describes the results.

Procedure: Phantom Crystals Demonstration

(Note: Some background information and terminology, such as index of refraction and concepts such as light traveling in a straight line, have already been covered in a previous class.)

For a Guided Activity or Independent Inquiry Activity:
Hold up a glass of water with some phantom crystals in it. Hook a paper clip through several phantom crystals to keep them together. The students should clearly see the paper clip in the water but will have difficulty seeing the crystals themselves. Then dramatically lift the paper clip and the crystals should now be easily seen by the students. Ask the students to explain why the crystals can be seen in air but not seen so easily in water. Have the students discuss answers in table groups for one minute then ask for volunteers to give answers. *The crystals have absorbed so much water so that their index of refraction is similar to that of water, making it difficult to distinguish between the crystals and water when the crystals are immersed. However, when the crystals are lifted out of the water, the index of refraction is greater than air and light is bent as it travels through the crystal causing it to be easily distinguished from the surrounding air.* Have the students describe the demonstration and explanation in their notebooks.

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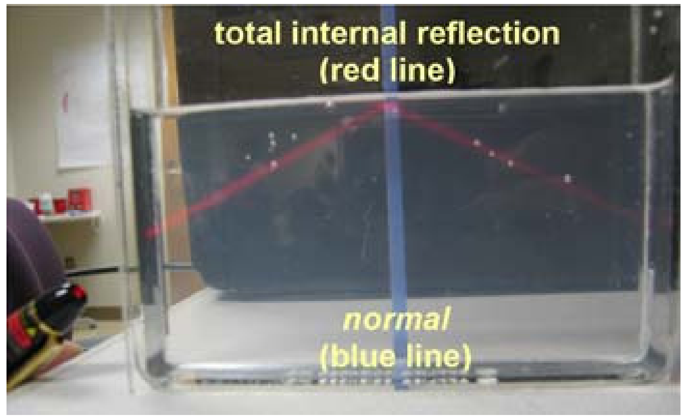
Procedure: Aquarium with Flashlight Demonstration

<u>For a Guided Activity:</u>

Add about 30 ml of low fat milk to the aquarium filled about 2/3 with water. Mix well. The light scatters off the nano-sized fat molecules in the milk, allowing the beam to be seen. In a dim room, shine the flashlight so that the beam enters the tank from the side and travels upward into the air above the water. Use this demonstration to introduce the terms of *normal, angle of incidence, angle of refraction* and to introduce the idea of *total internal reflection.*



For an independent Inquiry Activity:

More time can be devoted to creating a student-generated list of terms. For example, as the teacher shines the flashlight into the aquarium, the students can generate vocabulary that describes the incident beam, the reflected beam, and the refracted beam. The teacher can then gently guide the students to the appropriate terminology while gaining class consensus.

Guided Dialog Before beginning the lab, review the meaning of these terms:

Normal *The line perpendicular to the interface at the point of incidence.*
Interface *The surface between two mediums.*
Angle of Incidence *The angle between the incident light beam and the normal.*
Angle of Refraction *The angle between the refracted light beam and the normal.*

Directions for the activity

Name:______________________________Date:______________Class:_______________

Student Worksheet

Refraction Tank: Guided Inquiry

Safety
Never shine a laser into anyone's eyes. It can cause permanent blindness.

Introduction

To further investigate the bending of light through different mediums, we will be using a new scientific measurement tool called the refraction tank. Using this tool, you will be able to measure the *angle of incidence* and the *angle of refraction* of a beam of light as it travels through two mediums. Your goal will be to establish a general rule describing the bending of light as it travels from <u>water to air</u> and as the light travels from <u>air into water</u>.

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Materials

- refraction tank
- water
- laser pointer

Question

What happens to a beam of light as it crosses from one medium to another?

Make a Prediction:

Light will bend towards the normal as it enters water from air because light travels slower in water.

____

Procedure: Part I

1. Make sure the water level reaches horizontal line (90°) on the refraction tank and turn on the laser.
2. Adjust the laser so that the beam enters the tank at 20° below the surface of the water. This is your *angle of incidence*.
3. Record the corresponding *angle of refraction* on the table below.
4. Increase your angle of incidence by 10° and continue to measure angles of refraction until you have reached an angle of incidence of 90°.
5. Does your light beam ever obtain *total internal reflection*? If so, at which angle does it start? ___40°–50°___________

refraction tank

Observations

Data Table: Angles of incidence and refraction as light travels from water into air

Angle of Incidence	Angle of Refraction
20°	*35°*
30°	*45°*
40°	*55°*

Analyze the Results

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1. Does the beam behave consistently at all angles of incidence? If not, explain.

   Between incidence angles of 40° and 50° the beam appears to bounce off the bottom of the water/air interface and instead of leaving the water, it reflects back into the water. This is called total internal reflection.

2. Develop a general rule describing the relationship between the angle of incidence and the angle of refraction as the beam travels from water into air.

   The angle of refraction is always larger than the angle of incidence until the angle of refraction reaches 90°, at which point total internal reflection occurs.

Procedure: Part II

Light traveling from air into water: Now investigate the bending properties of light as it travels from air into water. Set up a data table similar to the one you just completed and write a simple procedure to accompany your measurements.

Procedure:	**Data Table:**

Analyze the Results

1. Does the beam behave consistently at all angles of incidence? Develop a general rule describing the relationship between the angle of incidence and the angle of refraction as the beam travels from air into water.

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Yes, in each case the angle of refraction is less than the angle of incidence.

2. Does total internal reflection occur in this situation? Why or why not?

   Since the angle of refraction is always less than the angle of incidence, it never reaches 90° and is therefore not reflected.

3. How would the critical angle of total internal reflection change if a liquid other than water were used?

   If we used a liquid that slowed down light even more than the water, then critical angle of total internal reflection would be less.

Cleanup Water can be poured down a sink. Phantom crystals can be dried and reused, or can be disposed in the trash.

Enhancing Understanding Cover this section *after* the activity.
For advanced 8th graders and for high school students, Snell's Law can be introduced at this point in the form of a homework assignment that uses the data taken during the lab to find the index of refraction of water.

Assessment
Students should be able to identify and describe the angles of incidence and refraction and the normal of a beam of light at an interface. Students should understand that certain mediums slow light down and when this happens, the beam of light is bent towards the normal. Students should be able to find the critical angle at which total internal reflection occurs.

Resources
Refraction tanks can be purchased through many different science catalogs. Materials for this lab were purchased from:

Cynmar Corporation http://www.cynmar.com	**Arbor Scientific** http://www.arborsci.com
water refraction tank with laser, catalog number 095-28697	phantom crystals, catalog number P6-2800

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National Science Education Standards (Grades 5–8)
Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry

Content Standard B: Physical Science
- Transfer of energy

National Science Education Standards (Grades 9–12)
Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry

Content Standard B: Physical Science
- Interactions of energy and matter

California Science Education Standards (Grades 7–8)
Grade 7, Content Standard 6: Physical Principles in Living Systems (Physical Sciences)
c. Students know light travels in straight lines if the medium it travels through does not change.
f. Students know light can be reflected, refracted, transmitted, and absorbed by matter.

Grade 7, Content Standard 7: Investigation and Experimentation
a. Select and use appropriate tools and technology to perform tests, collect data, and display data.

Grade 8, Content Standard 9: Investigation and Experimentation
f. Apply simple mathematic relationships to determine a missing quantity in a mathematic expression, given the two remaining terms.

California Science Education Standards (Grades 9–12)
Investigation and Experimentation, Content Standard 1
a. Select and use appropriate tools and technology to perform tests, collect data, analyze relationships, and display data.
c. Formulate explanations by using logic and evidence.
g. Recognize the usefulness and limitations of models and theories as scientific representations of reality.

Physics, Content Standard 4: Waves
f. Students know how to identify the characteristic properties of waves: interference (beats), diffraction, refraction, Doppler effect, and polarization.

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