



# Refraction and Total Internal Reflection

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## Topic

Refraction and internal reflection



## Time

1½ hours



## Safety

Please click on the safety icon to view the safety precautions.

## Material

chewing gum  
penny  
Styrofoam™ cup  
water

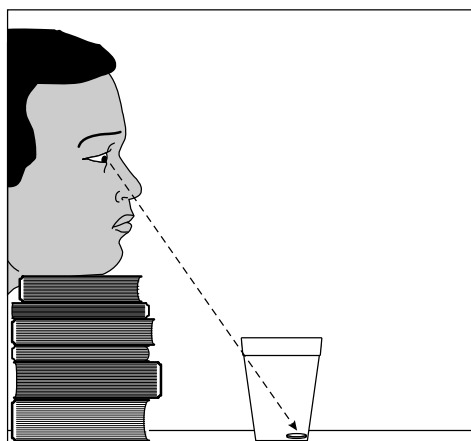
stack of books about 15 cm high  
quarter  
large, clear drinking glass

## Procedure

### PART A: REFRACTION

1. For this part of the experiment, you will need the help of a partner. First, chew a small piece of gum until it is soft. Stick the penny to the gum, and then use the gum to stick the penny to the inside bottom of the Styrofoam™ cup. The edge of the penny should be right next to the side of the cup (figure 1).
2. Set the cup on the table with the penny side farthest away from you. Rest your chin on some books about 15 cm high, and move the cup away from you until the penny is just out of sight. (The edge of the cup nearest you should be just blocking your view of the penny on the bottom, figure 1.)

Figure 1



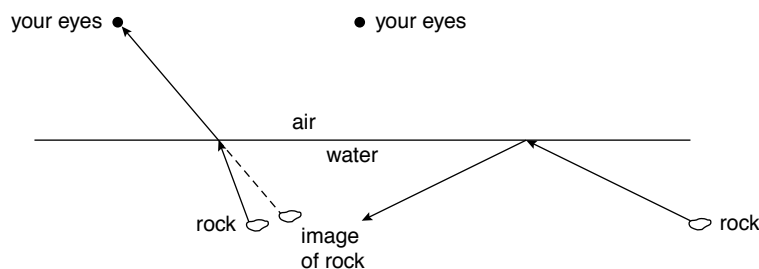
- Hold your head perfectly still, and have your partner slowly pour water into the cup. As the cup is filling, carefully observe what happens to the image of the penny.

### PART B: TOTAL INTERNAL REFLECTION

- Set the quarter on the table.
- Set a large clear glass on top of the coin. Observe the coin through the side of the glass. Is the coin visible?
- While you watch the coin through the side of the glass, fill the glass with water. What happens to the image of the coin?
- Look over the top of the glass. Do not look at the actual coin, which should now be visible through the bottom of the glass. Instead, look at the opposite, interior side of the glass. Record your observations.

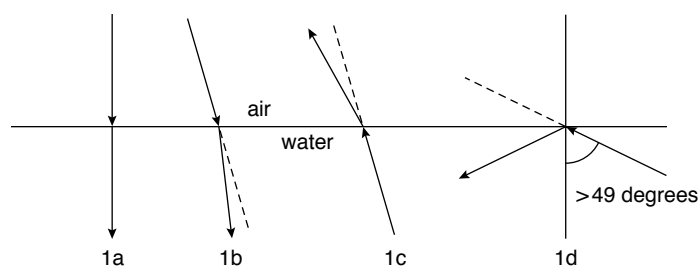
Objects are visible when light bounces off their surfaces and enters your eyes. Our brains assume that the light from the objects travels in a straight path to our eyes. Thus, we can be fooled by refraction and total internal reflection because an object appears in a certain place—or does not appear at all—only because the light rays coming from that object have been bent. For example, when you reach for a rock you see at the bottom of a shallow pond, you may come up empty handed unless you take refraction into account. You automatically extend the light rays that reach your eyes in a straight line to the place on the bottom of the pond where the rock appears to be. But as figure 3 shows, that is not where the rock actually is. If you were farther off to the side of the rock so that your eyes were at a great enough angle to it, you would not see the rock at all because of total internal reflection.

Figure 2



- Describe what happened when the Styrofoam™ cup was filled with water. Try to construct a diagram to explain what you saw.
- Describe what you saw from the side and from the top of the clear glass when it was filled with water. Try to draw a diagram to explain what you saw. (Hint: The glass-air boundary is important here (figure 3). The speed of light is fastest in air, much slower in water, and slowest in glass. Refraction also plays a part.)

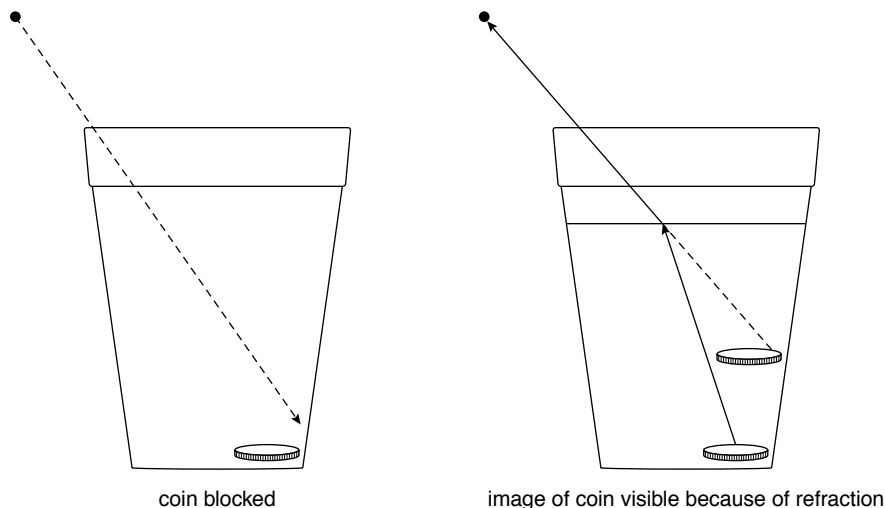
Figure 3



**What's Going On**

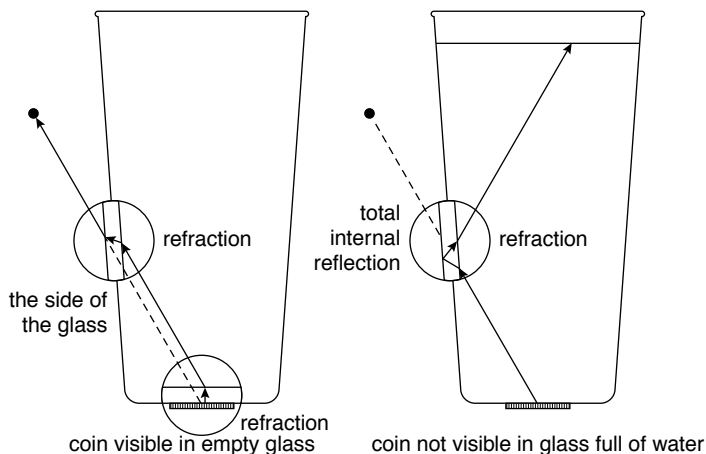
The penny is visible once the Styrofoam™ cup is filled with water (figure 4). Light rays coming from the coin were refracted toward your eyes at the water-air boundary (compare figure 4 with figure 3c). An image of the coin was therefore visible. As your brain assumes that the light rays followed a straight path, the coin appears *higher* in the cup than it actually is.

Figure 4



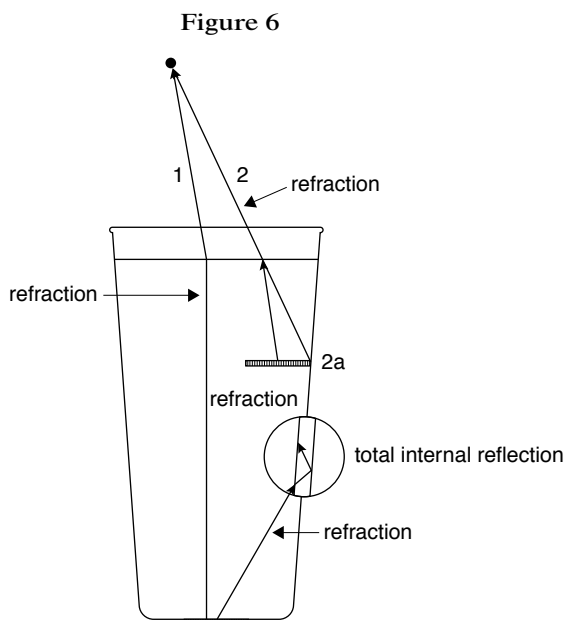
The coin is clearly visible through the side of the “empty” (air-filled) glass, and it appears at the place where it actually lies—despite refraction at air-glass and glass-air boundaries (figure 5). There is air both inside and outside the glass, so the light is bent first toward the perpendicular and then away from it. Since the glass is so thin—and this occurs both at the bottom of the glass and at the side—the light is only

Figure 5



slightly deviated from its original path, and you see the coin very close to its actual position. (The dashed line in figure 5 represents your apparent line of vision.) The coin disappears when the glass is filled with water (figure 3b). The light rays that

travel from the coin through the water are first refracted at the water-glass (faster-to-slower) boundary. At the glass-air (slower-to-faster) boundary on the side of the glass, total internal reflection takes place. Thus, no light from the coin reaches your eyes at this angle, and the coin is invisible. Looking over the top of the glass, you should be able to see the actual coin at the bottom and a reflected image of the coin appearing on the opposite interior side of the glass. Light rays from the coin were totally reflected at the glass-air boundary on the opposite side of the glass and then refracted toward the eyes at the water-air boundary. An image of the coin was therefore visible.



The coin is visible from the top of the glass (path 1, figure 6). An image of the coin in the opposite side is also visible (2a) because of the effects of refraction and total internal reflection (path 2).

### Connections

When a light ray strikes a slower-to-faster boundary at an angle to the perpendicular greater than a certain value (for water to air about 49 degrees), instead of normal refraction, a related optic phenomenon occurs: *total internal reflection*. The light ray is completely reflected off the boundary (see figure 3d), and none of the light passes through. In this procedure, you observed some of the effects of refraction and total internal reflection.

# Safety Precautions

READ AND COPY BEFORE STARTING ANY EXPERIMENT

Experimental science can be dangerous. Events can happen very quickly while you are performing an experiment. Things can spill, break, even catch fire. Basic safety procedures help prevent serious accidents. Be sure to follow additional safety precautions and adult supervision requirements for each experiment. If you are working in a lab or in the field, do not work alone.

This book assumes that you will read the safety precautions that follow, as well as those at the start of each experiment you perform, and that you will *remember* them. These precautions will not always be repeated in the instructions for the procedures. It is up to you to use good judgment and pay attention when performing potentially dangerous procedures. Just because the book does not always say “be careful with hot liquids” or “don’t cut yourself with the knife” does not mean that you should be careless when simmering water or stripping an electrical wire. It *does* mean that when you see a special note to be careful, it is extremely important that you pay attention to it. If you ever have a question about whether a procedure or material is dangerous, stop to find out for sure that it is safe before continuing the experiment. To avoid accidents, always pay close attention to your work, take your time, and practice the general safety procedures listed below.

## PREPARE

- Clear all surfaces before beginning work.
- Read through the whole experiment before you start.
- Identify hazardous procedures and anticipate dangers.

## PROTECT YOURSELF

- Follow all directions step by step; do only one procedure at a time.
- Locate exits, fire blanket and extinguisher, master gas and electricity shut-offs, eyewash, and first-aid kit.
- Make sure that there is adequate ventilation.
- Do not horseplay.
- Wear an apron and goggles.
- Do not wear contact lenses, open shoes, and loose clothing; do not wear your hair loose.
- Keep floor and work space neat, clean, and dry.
- Clean up spills immediately.
- Never eat, drink, or smoke in the laboratory or near the work space.
- Do not taste any substances tested unless expressly permitted to do so by a science teacher in charge.

## USE EQUIPMENT WITH CARE

- Set up apparatus far from the edge of the desk.
- Use knives and other sharp or pointed instruments with caution; always cut away from yourself and others.
- Pull plugs, not cords, when inserting and removing electrical plugs.
- Don’t use your mouth to pipette; use a suction bulb.
- Clean glassware before and after use.
- Check glassware for scratches, cracks, and sharp edges.
- Clean up broken glassware immediately.

- Do not use reflected sunlight to illuminate your microscope.
- Do not touch metal conductors.
- Use only low-voltage and low-current materials.
- Be careful when using stepstools, chairs, and ladders.

**USING CHEMICALS**

- Never taste or inhale chemicals.
- Label all bottles and apparatus containing chemicals.
- Read all labels carefully.
- Avoid chemical contact with skin and eyes (wear goggles, apron, and gloves).
- Do not touch chemical solutions.
- Wash hands before and after using solutions.
- Wipe up spills thoroughly.

**HEATING INSTRUCTIONS**

- Use goggles, apron, and gloves when boiling liquids.
- Keep your face away from test tubes and beakers.
- Never leave heating apparatus unattended.
- Use safety tongs and heat-resistant mittens.
- Turn off hot plates, bunsen burners, and gas when you are done.
- Keep flammable substances away from heat.
- Have a fire extinguisher on hand.

**WORKING WITH MICROORGANISMS**

- Assume that all microorganisms are infectious; handle them with care.
- Sterilize all equipment being used to handle microorganisms.

**GOING ON FIELD TRIPS**

- Do not go on a field trip by yourself.
- Tell a responsible adult where you are going, and maintain that route.
- Know the area and its potential hazards, such as poisonous plants, deep water, and rapids.
- Dress for terrain and weather conditions (prepare for exposure to sun as well as to cold).
- Bring along a first-aid kit.
- Do not drink water or eat plants found in the wild.
- Use the buddy system; do not experiment outdoors alone.

**FINISHING UP**

- Thoroughly clean your work area and glassware.
- Be careful not to return chemicals or contaminated reagents to the wrong containers.
- Don't dispose of materials in the sink unless instructed to do so.
- Wash your hands thoroughly.
- Clean up all residue, and containerize it for proper disposal.
- Dispose of all chemicals according to local, state, and federal laws.

BE SAFETY-CONSCIOUS AT ALL TIMES