Chapter Overview

People have been producing and improving upon glass for hundreds of years. Because glass is found throughout our homes, in vehicles, and even on ourselves, crime scenes often contain glass evidence. Most often the composition of glass is unique and therefore identifiable. Specific properties of glass, such as density, refractive index, and fracture patterns, give investigators clues to help link a suspect to a crime.

The Big Ideas

Melting together sand and a few other compounds at very high temperatures forms most glass. Some types of glass are made with specific characteristics, such as glass for cooking and laboratory use, that make the glass able to withstand a wide range of temperatures, and glass used in vehicle windshields that does not break apart when hit. Glass can be identified by the compounds used to make it, its density, and also by its refractive index. By analyzing the fracture patterns that form when glass is hit, forensic investigators can determine what object hit the glass and from which direction the object came.

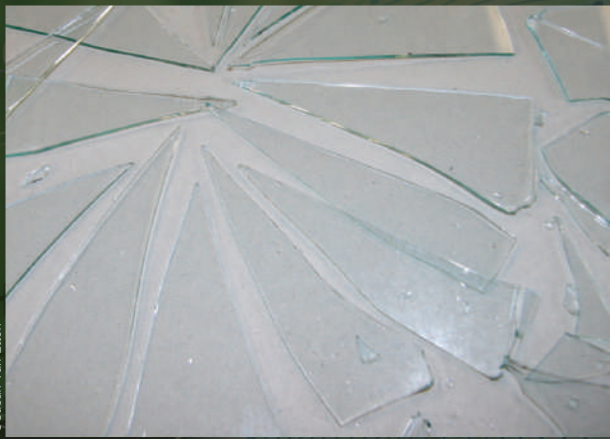
CHAPTER 14

Glass Evidence

IF YOU BREAK IT . . .

The boy quickly slipped the crystal glass vase into his jacket. He thought he could easily hide it and leave the store without getting caught. However, the vase slipped and fell to the floor, shattering into many small pieces. The boy quickly ran out of the store. A store clerk remembered seeing a young man looking at the vase just before the incident occurred. The clerk gave a detailed description to the police, who were able to find the youth in a nearby music store.

When questioned by the police, the boy claimed he had not been anywhere near the store where the incident happened. Upon further investigation, the police found evidence of broken glass wedged between the grooves of his sneakers. Was the glass in his sneakers the same as the glass from the broken vase? What type of testing could be done on the glass to try to match the glass in the sneaker with the broken crystal vase in the store?



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Glass evidence.

If the glass did match, is that enough evidence to convict the boy?

In this chapter, we will explore the formation, characteristics, history, and types of glass. Various methods of glass analysis used in forensics will follow in the activities at the end of the chapter.

SCENARIO

In groups of two, ask students to read the scenario and discuss the questions within the text. They should be prepared to share their thoughts with the class.

Objectives

By the end of this chapter you will be able to

14.1 Explain how glass is formed.

14.2 List some of the characteristics of glass.

14.3 Provide examples of different types of glass.

14.4 Calculate the density of glass.

14.5 Use the refractive index to identify different types of glass.

14.6 Describe how glass fractures.

14.7 Analyze glass fracture patterns to determine how glass was broken.

14.8 Explain how glass is used as evidence.

Vocabulary

amorphous without shape or form; applied to glass, it refers to having particles that are arranged randomly instead of in a definite pattern

Becke line line created as refracted light becomes concentrated around the edges of the glass fragment

density the ratio of the mass of an object to its volume, expressed by the equation: density = $\frac{\text{mass}}{\text{volume}}$

glass a hard, amorphous, transparent material made by heating a mixture of sand and other additives

leaded glass glass containing lead oxide

normal line a line drawn perpendicular to the interface of two different media

obsidian volcanic glass

refraction the change in the direction of light as it changes speed when moving from one substance into another

refractive index a measure of how light bends as it passes from one substance to another

silicon dioxide (SiO_2) the chemical name for silica

Key Science Concepts

Physics: reflection and refraction; why fracture patterns form in glass

Mathematics: calculation of density; solving equations for an unknown

Teaching Resources

- Instructor's Resource CD-ROM includes:
  - PowerPoint Presentation
  - Lesson Plan and extended Objective Sheets
  - Teacher Notes and Activities
  - Activity Forms
  - Rubric
- ExamView CD-ROM
- E-book on CD-ROM

Web site: school.cengage.com/forensicscience

Engage

After reading the Introduction, ask students to identify glass properties.

Explore

Explain to students that glass is considered class evidence, because it is mass-produced and a particular piece of glass is not unique. However, if pieces of glass from a suspect do reconstruct perfectly into a whole object, this is a match. For example, a broken headlight may be pieced together to form the original. For example, students can explore databases that specify the characteristics of windshield glass produced by a particular manufacturer for different years. Due to safety regulations, the amount of tinting in windshields varies and could help identify the year a particular windshield was produced.

Explore

Experienced glassmakers can mold and manipulate liquid glass as it cools and solidifies. A glassmaker may add several raw materials to obtain a desired effect, such as increasing the amount of sodium oxide to slow the solidification process, adding sodium to make the glass surface opaque, adding nitrate and arsenic to remove bubbles, or adding many different kinds of coloring agents.

Teaching Tip

Contact Corning Glass for a video on the making of glass, or check the Internet for online videos on how glass is made.

Teaching Tip

Obsidian is a naturally occurring glass formed as volcanic lava cools quickly. During the Stone Age, obsidian was shaped and used as arrowheads and blades for knives. Today, obsidian is still used to make blades for medical scalpels. These scalpels are sharper than steel and can be made extremely thin to reduce trauma to the area being cut.

INTRODUCTION

Glass evidence can be found at many crime scenes. Automobile accident sites may be littered with broken headlight or windshield glass. The site of a store break-in may contain shards of window glass with fibers or blood on them. If shots are fired into a window, the sequence and direction of the bullets can often be determined by examining the glass. Minute particles of glass may be transferred to a suspect's shoes or clothing and can provide a source of trace evidence linking a suspect to a crime scene.

Obj. 14.1

THE HISTORY OF GLASS

Long before humans began making **glass**, glass formed naturally. When certain types of rock are exposed to extremely high temperatures, such as lightning strikes or erupting volcanoes, glass can form. Humans have used and made glass for centuries.

- Prehistoric humans used **obsidian**, a type of glass formed by volcanoes, as a cutting tool.
- Pliny, a Roman historian, described how glass was first made by accident in ancient Syria. Blocks of rock containing a chemical compound made of nitrogen and oxygen, called nitrates, were used as cooking surfaces. When these blocks were placed on top of sand and heated, the sand and nitrates melted and fused together to form a type of glass.
- The earliest man-made glass objects (glass beads) were found in Egypt dating back to 2500 BC.
- Glass blowing began sometime during the first century BC.
- In 1291, one center of glass making was moved from the city of Venice, Italy, to the island of Murano, off the coast of Venice. This happened for two reasons. First, the high temperatures needed to make glass caused frequent fires that were a danger to the large population of Venice. Moving glass production to an island with a much smaller population reduced the danger. Second, the secrets of glass making could be more closely guarded on an isolated island than in a big city on the mainland.
- By the 14th century, the knowledge of glass making spread throughout Europe.
- The Industrial Revolution brought the mass production of many kinds of glass.

Did You Know?

In 1903, Mr. J. Karkowski of Herkimer, New York, was granted a patent for his method of sealing dead bodies in transparent blocks of glass. He claimed that this was an excellent way to preserve bodies, because no air or organisms could reach them and cause them to decay. It met with limited success because decomposition can still occur anaerobically.

WHAT IS GLASS?

Glass is a hard, **amorphous** material made by melting sand, lime—also called calcium oxide (CaO)—and sodium oxide (Na_2O) at very high temperatures. Its primary ingredient is **silicon dioxide** (SiO_2), also called silica. Sodium oxide is added to reduce the melting point of silica, or sand, and calcium oxide is added to prevent the glass from being soluble in water.

Differentiated Learning

Teaching At-Risk Students

Engage students by asking them to describe a two-car accident in which glass evidence is present. What kind of glass would be present as evidence? How would they collect and preserve it? How would they determine which car the glass came from?

Differentiated Learning

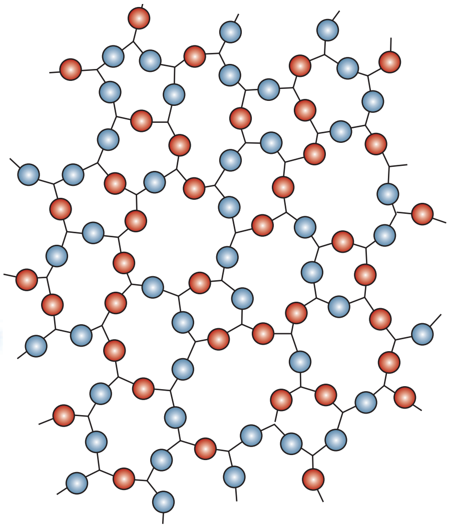
Teaching English-Language Learners

Some students may not know what glass blowing is. Bring in a video on glassmaking for them to watch. Afterward, ask students to describe what they saw and learned.

This type of glass is known as soda-lime glass because it contains sodium compounds and lime. Once it cools, the glass can be polished, ground, or cut for useful or decorative purposes. Glass blowers can form glass into many different shapes by blowing hot air through a long tube into the hot, molten, semi-liquid glass.

Glass is called an amorphous solid because its atoms are arranged in a random fashion (Figure 14-1). Because of its irregular atomic structure, when glass is broken, it produces a variety of fracture patterns.

Figure 14-1. *The arrangement of atoms in an amorphous solid.*



TYPES OF GLASS

Obj. 14.3

Because glass is a stable material that does not deteriorate over time, it has a variety of uses. The most common type of glass, soda-lime glass, is inexpensive, easy to melt and shape, and is reasonably strong. Manufacturers of most glass containers use the same basic soda-lime composition, making recycling easier.

Fine glassware and decorative art glass, called crystal or **leaded glass**, substitutes lead oxide (PbO) for calcium oxide. The addition of lead oxide makes the glass denser. As light passes through the more-dense glass, the light waves are bent, giving the glass a sparkling effect.

Ovenware and laboratory glassware is often sold as Pyrex® or Kimax® glass. These types of glass contain compounds that improve the ability of the glass to withstand a wide range of temperatures needed for cooling or heating glassware in a kitchen, laboratory, or in headlights. Adding certain metal oxides to the glass mixture produces different colors of glass. For example, nickel oxide produces colors ranging from yellow to purple, depending on the type of glass to which it is added. Cobalt oxide makes a purple-blue glass, whereas oxides of selenium make red glass.

Did You Know?

Some people say that glass is a liquid because it "flows" over time. They note that glass in very old church windows is thicker at the bottom of the pane than at the top, claiming that the glass has flowed to the bottom. In actuality, when placed into windows, the panes were installed with the heavier, thicker side at the bottom.

PROPERTIES OF GLASS

Obj. 14.2

Altering the compounds used to make glass changes the composition and produces different types of glass. The composition of a particular piece of glass may be unique and therefore identifiable. Because glass is made of a variety of compounds, it is possible to distinguish one type of glass from another by examining the different physical and chemical properties. We will examine some of the properties of glass, such as density, refractive index, and fracture patterns that are used in the forensic examination.

DENSITY

Obj. 14.4

Each type of glass has a **density** that is specific to that glass. One method of matching glass fragments is by a density comparison.

Teaching Tip

Good places to obtain glass samples include glass stores, junkyards, secondhand stores, garage sales, and construction sites.

Teaching Tip

Annealing is the process of heating glass and then slowly cooling it to relieve internal stress and make the glass more durable. If glass is not annealed, it will break or shatter with little stress or temperature change.

Explore

In 1894, Louis Tiffany created a type of glass that has an iridescent effect by combining different colors of glass together while the glass is still in its liquid state. This glass is known as favrile glass and is unique because of its bright colors. Tiffany lamps containing favrile glass are highly prized and quite expensive.

Explore

Most likely students have heard of and seen fiberglass. Fiberglass, as its name suggests, is made of very fine fibers of glass. The invention of fiberglass is typically credited to the Owens-Corning company in 1938 as an insulating material. Today it has many other uses, such as in making fiber optics for the telecommunications industry.

Teaching Tip

Glass is recyclable. However, glass bottles or jars used for food or beverages should not be mixed with other types of glass such as windshields, Pyrex®, frosted glass, ceramics, lightbulbs, or mirrors. Different types of glass have different melting points, so glass must be sorted before it can be recycled. Clear glass is the most valuable for recycling. Approximately 8 percent of all U.S. garbage comes from glass products.

Differentiated Learning

Teaching Gifted Students

Ask students to research the question: Is glass a solid or liquid? There may be no clear answer. Suggest they start by reading background information on glass from this Web site: http://math.ucr.edu/home/baez/physics/General/Glass/glass.html.

Differentiated Learning

Teaching Gifted Students

Ask students to research the Owens-Corning company and report back on the types of materials and products employees of this company have invented.

Science Mathematics

Density is a physical property. Density is calculated by determining the mass (m) per unit volume (V) of an object. Mass is the amount of matter in a particular object. Mass is typically measured in grams (g) when using the SI system. Volume is the amount of space an object takes up. The typical unit for volume is milliliters (mL). Volume can also be measured in cubic centimeters, since 1 milliliter is equal to 1 cubic centimeter. Pure water has a density of 1.0 g/mL, and therefore, anything with a density less than 1.0 g/mL will float in water, and anything with a density greater than 1.0 g/mL will sink in water.

Explore

Explain to students that Archimedes' principle states that a body immersed in a fluid is subject to an upward force equal to the weight of the fluid it displaces. This principle explains why it is possible to measure the density of glass by measuring the volume of water it displaces.

Teaching Tip

To demonstrate this, you may want to use displacement containers, cups with spouts in the sides (they can be made from water bottles and straws). Or, you may also want to try using an overflow can. It is better to use large pieces of glass, because volume differences in small pieces of glass are difficult to determine. This procedure can be simplified even further by using 50 mL BLUE MAX polypropylene conical tubes. The tube is calibrated, so you can just add water to a specific line, drop in weighed glass, and take a new reading. The difference in water height is the glass volume—no need for beakers or graduated cylinders!

Density (D) is calculated by dividing the mass (m) of a substance by its volume (V). The formula for calculating density can be written as $D = \frac{m}{V}$. Once you determine the mass of a fragment of glass and the volume of water it displaces, you can calculate the density. Some of the more common glass densities are shown Figure 14-2.

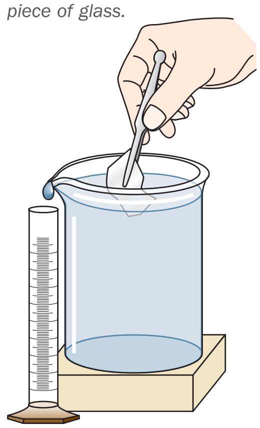
Figure 14.2. *Common glass densities.*

Type of Glass	Density (g/mL)
Bottle glass	2.50
Window glass	2.53
Lead crystal	2.98–3.01
Pyrex®	2.27
Tempered (auto)	2.98
Flint	3.70
Crown	2.50

Calculating the Density of a Piece of Glass

1. The mass of a piece of glass (in grams) can be found using a balance.
2. In order to determine the volume (in milliliters) of water displaced by a piece of glass, fill a beaker completely with water, so that adding a single drop will cause spillage.
3. Position a graduated cylinder under the spout of the beaker (Figure 14-3).
4. Carefully place the piece of glass into the beaker and collect the overflow water in the graduated cylinder.
5. Measure the volume of water displaced by the glass.
6. Divide the mass (g) by the volume displaced (mL) to find the density.

Figure 14-3. *Using a beaker and graduated cylinder to determine the volume of a piece of glass.*



Obj. 14.5

REFRACTIVE INDEX

Have you ever stood in a pool and looked down at your legs in the water? Did your legs appear to be where you expected them to be located? The distortion of your legs' position illustrates how a beam of light bends or refracts. When the beam of light moves from one medium (air) to another (water), its speed changes. The change in speed causes the beam to change direction, or bend. Another name for the bending of light is refraction. **Refraction** is the change in the direction of light as it speeds up or slows down when moving from one medium into another. The direction and amount the light bends varies with the densities of the two mediums.

The **refractive index** is a tool used to study how light bends as it passes through one substance and into another. Any substance through which light can pass has its own characteristic refractive index. The refractive index of a substance is calculated by dividing the speed of light in a vacuum—a space empty of all matter—by the speed of light through that particular substance.

Light in a vacuum travels at a speed of about 300,000 kilometers per second (km/s). The refractive index of a vacuum is 1 because the ratio of the speed of light in a vacuum divided by the speed of light in a vacuum is 300,000 km/s divided by 300,000 km/s equals 1.

When light travels through a vacuum, nothing interferes with the light to slow it down as it moves. When light travels through any other medium, the particles in that medium slow the light down. As the density of the medium increases, the speed of light passing through that material decreases.

The speed of light passing through air is slightly slower than the speed of light passing through a vacuum, because air is slightly denser than a vacuum. The refractive index of air is 1.0008 and is so close (for our purposes) to

Differentiated Learning

Teaching At-Risk Students

Ask students if they have ever tried diving into a pool to retrieve pennies. Ask them if they found the pennies exactly where they appeared to be when viewed from above the water? How deep did the pennies seem to be when viewed from standing outside the pool? Did they dive in one direction and then have to swim in another direction to grab the penny? Why?

Differentiated Learning

Teaching Gifted Students

Encourage interested students to research as a group whether the speed of light changes with changes in altitude. Does light travel faster through air that is less dense? Ask them to present their findings to the class on a poster.

that of the refractive index of a vacuum that we will use 1 as the refractive index for air as well.

As light passes through air, the light travels in a straight line at a speed slightly slower than 300,000 km/s. When that same beam of light enters water, it slows down to approximately 225,000 km/s. If the beam were to pass through a piece of window glass, it would slow down even more to a speed of approximately 200,000 km/s.

If the light travels from a less-dense medium to a denser medium, the beam of light will slow down and bend toward the normal, as shown in Figure 14-4. The **normal** is a line perpendicular to the surface where the two different mediums meet. The red line in the figure indicates the normal line. The incoming beam of light passing through the first medium is called the *incident ray*, and the beam of light as it passes through the second medium is called the *refracted ray*. The angle the incident ray in medium 1 forms with the normal is called the *angle of incidence*, labeled here as "Angle 1." The angle the refracted ray in medium 2 forms with the normal is called the *angle of refraction*, labeled here as "Angle 2."

If medium 1 is denser than medium 2, the light will bend away from the normal. You can see this in in Figure 14-5.

Scientists have found a way to slow down the speed of light from 186,000 miles per second to about 38 miles per hour, the speed of a car in rush-hour traffic.

Snell's Law

Snell's law describes the behavior of light as it travels from one medium into a different medium. Snell's law can be written as:

n_1 (sine angle 1) = n_2 (sine angle 2)

In this equation, n_1 is the refractive index of medium 1 and n_2 is the refractive index of medium 2. Angle 1 is the angle of incidence and angle 2 is the angle of refraction. The sine of an angle (abbreviated *sin*) is a trigonometric function. In this text, we will use a scientific calculator or a sine table to find the sine of an angle.

Figure 14-4. *Light travels through air and enters the glass of a windowpane. As it moves from a less-dense medium into a denser medium, the light slows down and changes direction.*

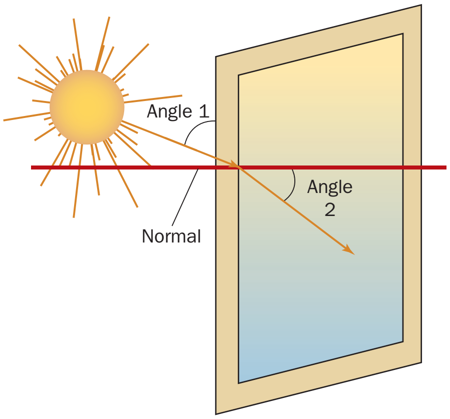
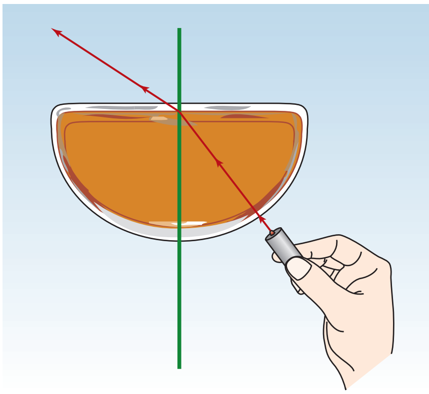


Figure 14-5. *As a beam of laser light travels from oil, medium 1, into air, medium 2, it speeds up and bends away from the normal.*



Evaluate

Ask students to identify the particles in a medium that interfere with light rays and slow them down. (The atoms and molecules of the substances that make up the medium.)

Teaching Tip

It may be helpful to demonstrate how to use a scientific calculator and also a sine table before teaching this section.

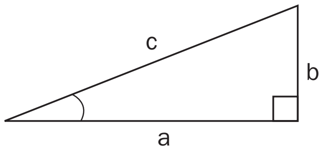
Teaching Tip

Some students may need help in understanding how to read mathematical expressions that contain the symbol ≈. For example, angle 2 = 28.1° ≈ 28° should be read, "Angle 2 is equal to 28.1 degrees, which is approximately equal to 28 degrees."

Science

Mathematics

The sine of an angle is one of the trigonometric ratios used to describe the relationship between two parts of a right triangle. For example, the sine of angle x is the length of the leg opposite angle b, divided by the length of the hypotenuse. The side opposite of an angle is not one of the sides of the triangle that forms the angle.



Teaching Tip

Another way to help students visualize refraction is to partially submerge a pencil into a beaker or glass of water. Students should view the pencil from the side, noting how the pencil appears to be split.

Science Mathematics
When using an equation such as the one representing Snell's law, students can use algebra to solve for one variable when they know the values of the other three.

Science Mathematics
Trigonometric ratios, such as sine, are usually expressed as decimals. They are found using a scientific calculator or a sine table. To find the sine using a scientific calculator, first enter the angle measure, then press the key labeled SIN. To find the sine using a sine table, find the angle measure in the first column, then look across the table to find the sine value given in decimal format.

CHAPTER 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Example 1: A beam of light travels in air (medium 1) and then passes through a piece of glass (medium 2). As the light passes from the air into the piece of glass, the light ray is bent (Figure 14-6). What is the angle of refraction measured from the normal?

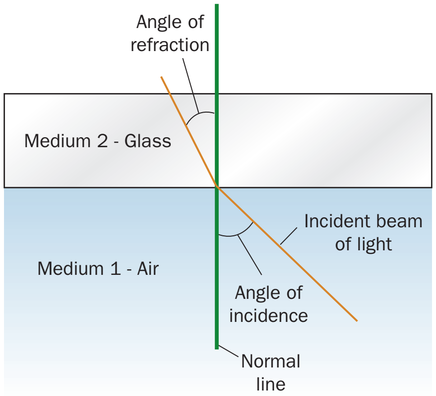


Figure 14-6. *Light refraction passing from air through glass.*

Here is what we know so far:

refractive index of air (medium 1) = 1.00

refractive index of glass (medium 2) = 1.50

angle 1 = 45°

angle 2 = ?

Using a scientific calculator to solve for the measure of angle 2

n_1 (sin of angle 1) = n_2 (sin of angle 2)
Substituting what we know into Snell's law:

1.00 (sin of 45°) = 1.50 (sin of angle 2)
To find the sine of an angle on most scientific calculators, enter the angle measurement, and then press the [sin] key.

The sine of 45° is 0.7071.

1.00 (0.7071) = 1.50 (sin of angle 2)

(0.7071)/1.50 = sin of angle 2

0.4714 = sin of angle 2
Now, you must find the measure of angle 2. On most scientific calculators, enter 0.4714, and then press the SHIFT key or the second function key, and then press the [sin–1] key.
angle 2 = 28.1° ≈ 28°

This answer makes sense because the light is moving from a less-dense substance in medium 1 (air) to a denser substance in medium 2 (glass). The light will slow down and bend toward the normal. Angle 1 is 45° and angle 2 is smaller at 28°, indicating that the light did bend toward the normal.

Using a sine table to solve for the measure of angle 2
It is possible to calculate the measure of an angle using a sine table (see Appendix A) if a scientific calculator is not available.

n_1 (sin angle 1) = n_2 (sin angle 2)
Substituting what we know into Snell's law:

1.00 (sin 45°) = 1.50 (sin angle 2)

Look up sine 45° in the sine table.

sin 45° = 0.7071

1.00 (0.7071) = 1.50 (sin angle 2)

0.7071/1.50 = sin angle 2

0.4714 = sin angle 2

Find the value closest to 0.4714 in the table. The sine value closest to 0.4714 in the table is 0.4695. According to the table, the angle measure with a sine value of 0.4695 is 28°.

So, sin 28° ≈ 0.470

angle 2 ≈ 28°

Angle 2 is smaller than angle 1. This means the beam of light will bend toward the normal. This makes sense because the glass is denser than the air and will slow down the light and bend it toward the normal.

Example 2: As light travels from water (medium 1) to air (medium 2), it bends (see Figure 14-7). Does it slow down or speed up as it passes from medium 1 through medium 2? Will the light bend toward the normal or away from the normal? Use Snell's Law to determine the size of angle 2.

Here is what we know so far:

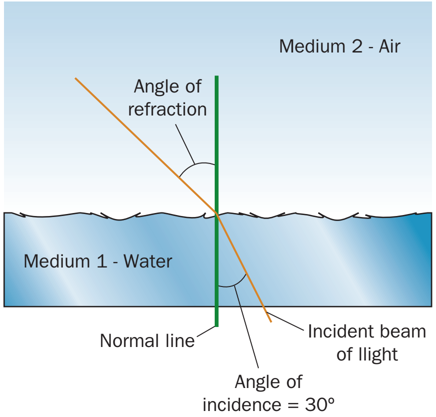
refractive index of water (medium 1) = 1.33

refractive index of air (medium 2) = 1.00

angle 1 = 30°

angle 2 = ?

Figure 14-7. Light refraction passing from air through water.



Using a scientific calculator to solve for the measure of angle 2

n_1 (sin angle 1) = n_2 (sin angle 2)

1.33 (sin 30°) = 1.00 (sin angle 2)

To find the sine of an angle on most scientific calculators, enter the angle measure, and then press the [sin] key. The sin of 30° is 0.5.

1.33 (0.5) = 1.00 (sin angle 2)

0.665 = 1.00 (sin angle 2)

Now, you must determine the size of angle 2.
On most scientific calculators, enter 0.665, press the SHIFT key, and then press the [sin–1] key.

angle 2 = 41.6° ≈ 42°

Angle 2 is larger than angle 1. The beam of light will bend away from the normal. This makes sense because water is denser than air. When passing from water into air, light will speed up and bend away from the normal.

Using a sine table to solve for the measure of angle 2

n_1 (sin angle 1) = n_2 (sin angle 2)
Substituting what we know into Snell's law:

1.33 (sin 30°) = 1.00 (sin angle 2)
Look up sin 30° in the sine table.

sin 30° = 0.5000

1.33 (0.5000) = 1.00 (sin angle 2)

0.665 = sin angle 2

Find the value closest to 0.665 in the table. The sine value closest to 0.665 in the table is 0.6691. According to the table, the angle measure with a sine value of 0.6691 is 42°.

So, sin 42° ≈ 0.6691

angle 2 ≈ 42°

Science Mathematics

To use an equation to solve a mathematical problem, first write the equation that pertains to your topic. Then, write down the information given in the problem. Next, substitute that information into the equation to determine the one variable you do not know. This is the variable for which you must solve. Use inverse operations to get the unknown variable by itself on one side of the equation. Inverse operations undo each other. Addition and subtraction undo each other. Multiplication and division undo each other. For example, to get the variable x by itself on one side of the equation 2x – 5 = 3, first add 5 to both sides. This results in 2x – 5 + 5 = 3 + 5, or 2x = 8. Next, divide both sides of the equation by 2, resulting in (2x)/2 = 8/2, or x = 4. Remember, whatever you do to one side of an equation, you must also do to the other side.

Teaching Tip

Based on the refractive index alone, experts would not be able to prove a piece of glass matches glass found on a suspect's shoes. Typically, when using the refractive index, experts would say the glass was consistent with what was found on the suspect's shoes.

Explore

To demonstrate the submersion method, use two beakers, a 250-mL and a 500-mL, and place the smaller into the larger. Confirm that students can still see the smaller beaker. Add vegetable oil, which has approximately the same refractive index as Pyrex® glass, to the smaller beaker. Again confirm that students can still see both beakers. Then, fill the larger beaker with the same oil until the smaller is fully submerged. When submerged, the smaller beaker completely disappears.

This means the beam of light will bend away from the normal. This makes sense because water is denser than the air. When the light passes from water into air, it should speed up and bend away from the normal.

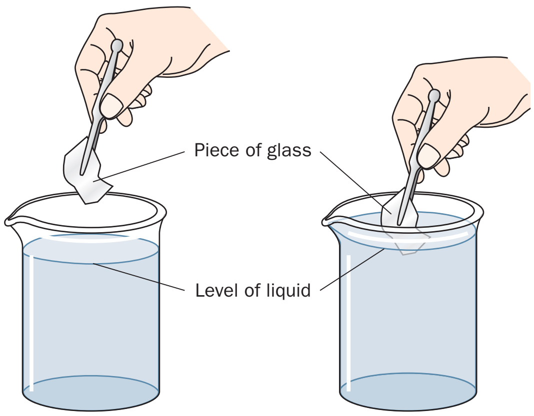
Obj. 14.8

APPLICATION OF REFRACTIVE INDEX TO FORENSICS

Glass fragments from car headlights or broken windows can link a suspect to a crime scene. Forensic scientists can use the refractive index of glass fragments and determine if the evidence at a crime scene is consistent or remove suspicion from a suspect. How is it possible to match glass from a crime scene to glass collected as evidence?

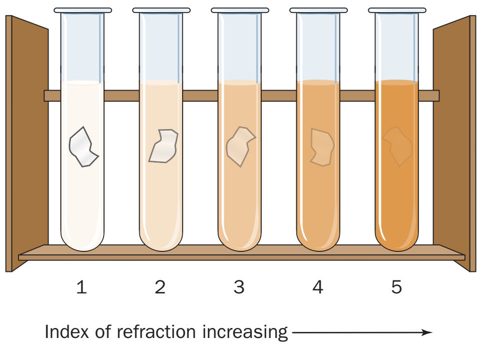
One method of determining if the evidence glass matches the glass from the crime scene is to compare the refractive index of the evidence glass to the refractive index of the glass from the crime scene. Car dealers and glass manufacturers have databases containing the refractive indexes of their products. However, the evidence glass obtained from the clothing or shoes of a suspect is often too small to easily check consistency. Therefore, the *submersion method* can be used (Figure 14-8). This method involves placing the glass fragment into different liquids of known refractive indexes. If a piece of glass and a liquid have the same refractive index, the glass fragment will seem to disappear when placed in the liquid.

Figure 14-8. *The submersion method of determining the refractive index of a piece of glass.*



If the refractive indexes of several different liquids are known, the submersion method can be used to estimate the refractive index of the glass. Notice in Figure 14-9 that the piece of glass is totally invisible in test tube 5. This means the glass fragment and the refractive index of the liquid in test tube 5 are very similar.

Figure 14-9. *Comparing the known refractive indexes of different liquids to an unknown refractive index of a piece of glass.*



The refractive indexes of some of the more common liquids used in determining the refractive index of glass are listed in Figure 14-10. The second half of the table lists examples of different types of glass and their refractive indexes.

In which liquid would headlight glass seem to disappear? Which liquid would you select to determine if the evidence glass was quartz glass?

BECKE LINES

You have learned that a piece of glass will seem to disappear when submerged in a transparent liquid that has the same

Differentiated Learning

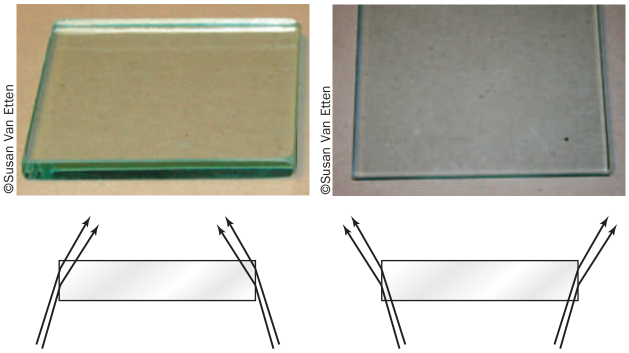
Teaching At-Risk Students

Arrange for students to visit the local car dealership or auto parts store and inquire about the refractive index of their products. Or, invite a representative to come and talk to the class.

refractive index. Another technique involves submerging a fragment of glass in a liquid and then viewing it under a low power using a compound microscope. If the refractive index (n) of the liquid medium is different from the refractive index of the piece of glass, a halo-like ring appears around the edge of the glass. This halo-like effect is called a **Becke line**. It appears because the refracted light becomes concentrated around the edges of the glass fragment. A Becke line is visible under a microscope when the glass and liquid have different refractive indexes. The position of the Becke line surrounding the glass fragment is significant. The Becke line is located in the medium that has the higher refractive index.

If the Becke line is located inside the perimeter of the glass fragment, then the refractive index of the glass is higher than the refractive index of the surrounding liquid. If the Becke line is located on the outside of the perimeter of the glass fragment, then the refractive index of the surrounding medium is higher than the refractive index of the glass. Look at Figure 14-11. The arrow shows the position of the Becke line in each photograph.

Figure 14-11. *The position of the Becke line indicates whether the refractive index of the glass sample is higher or lower than the liquid in which it is placed.*



- Glass has higher refractive index
- Becke line seen inside
- Rays converge

- Glass has lower refractive index
- Becke line seen outside
- Rays converge

Figure 14-10. *Refractive indexes of liquids and glasses.*

Liquid	Refractive Index
Methanol	1.33
Water	1.33
Isopropyl alcohol	1.37
Olive oil	1.47
Glycerin	1.47
Castor oil	1.48
Clove oil	1.54
Cinnamon oil	1.62

Type of Glass	Refractive Index
Pyrex	1.47
Automotive headlight glass	1.47–1.49
Television glass	1.49–1.51
Pane window glass	1.49–1.51
Bottle glass	1.51–1.52
Eyeglass lenses	1.52–1.53
Quartz glass	1.54–1.55
Lead glass	1.56–1.61

Estimating the Refractive Index of Glass Using a Microscope and Becke Lines

The refractive index of glass collected as evidence can be compared to the refractive index of glass collected at the crime scene. This is accomplished by following these steps:

1. Place the glass on a slide surrounded by a liquid medium of known refractive index.
2. Place the slide on the microscope stage and focus the lens on the glass.
   - If the glass seems to disappear when focused, the glass and the surrounding medium have the same refractive index.

Teaching Tip

Tell students that *Becke* is pronounced like the name Becky.

Teaching Tip

Instead of using a microscope slide and compound light microscope to estimate the refractive index of a glass fragment, try using a porcelain dish of water on a dissecting (stereo) microscope.

Teaching Tip

Point out to students that when equipment is too expensive (or used too infrequently to justify the cost) for a small forensic lab, the lab can often have the evidence processed by a larger regional or state lab, for a fee.

Differentiated Learning

Teaching English-Language Learners

Students may not know what a halo is, and therefore will not be able to envision the halo effect of the Becke lines. Use pictures or illustrations to describe halos to the class before students read this section.

Digging Deeper

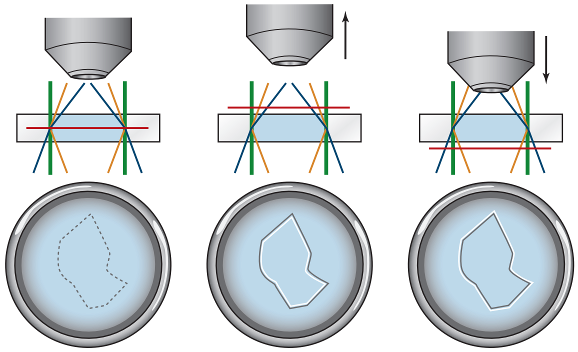
As previous chapters have stated, ensuring that a crime scene is not contaminated is of utmost importance. *Teleforensics*, the use of a video camera mounted with a wireless transmitter, can help investigators do just that. The crime scene and its evidence can be viewed from a remote location in real time. Teleforensics can help limit the number of people physically present at a crime scene, while still allowing all who need access to the crime scene to study it.

- If the glass did not disappear, the surrounding medium and the glass have different refractive indexes. In the next step, you will use the position of Becke lines to estimate which medium, the glass or the surrounding liquid, has the higher refractive index.

3. Increase the distance between the stage and the lens. Look for the appearance of a Becke line.
   - If a Becke line appears inside the perimeter of the glass, then the glass has a higher refractive index than the surrounding liquid.
   - If a Becke line appears outside the perimeter of the glass, then the surrounding liquid has a higher refractive index than the glass.

By using several different types of liquids with different refractive indexes, it is possible to arrive at a good estimate of the refractive index of the glass fragment (Figure 14-12).

Figure 14-12. *Estimating the refractive index of a glass sample using a compound microscope and Becke lines.*



Match Point	Moved up	Moved down
No Becke line.	Becke line moves towards higher refractive index.	Becke line moves towards lower refractive index.
Glass and liquid refractive indices match.	Glass piece has a higher refractive index than the liquid.	Glass piece has a lower refractive index than the liquid.
Glass seems to disappear.		

There are automated instruments, such as the GRIM 2 (Glass Refractive Index Measurement), that measure the refractive index of glass. However, these instruments are too expensive for most forensic laboratories to own.

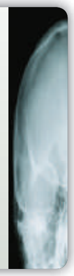
THICKNESS OF GLASS

Not all glass is the same thickness, and this difference provides another clue for identifying glass. Picture frame glass is 1/8 inch thick, while window glass must be 3/32 inch to 1/8 inch thick to resist wind gusts without breaking. Door glass will vary in thickness from 3/16 inch to 1/4 inch thickness and can also be reinforced with wire threads running through it.

Glass as a Source of Trace Evidence

The trained examiner will be able to determine the composition, type, and perhaps the manufacturer from a sample of glass found on a victim, suspect, or at a crime scene. By determining the thickness, refractive index, and density of the glass collected, glass fragments can be matched assuming a large enough piece can be recovered.

Digging Deeper
with Forensic Science e-Collection



How can recent technological developments help investigators detect trace evidence? Go to the Gale Forensic Science eCollection at school.cengage.com/forensicscience and enter the search terms "trace evidence." Click on "Magazines" and read about remote information-sharing techniques. Write a short report on the new field of teleforensics. What is teleforensics? How is it helping investigators? What do you think are the advantages and disadvantages of this technology?

Differentiated Learning

Teaching Gifted Students

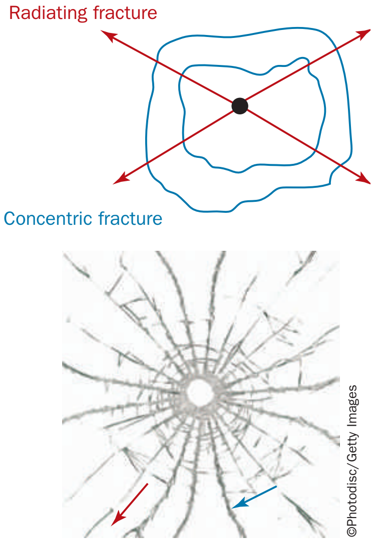
If students have access to a remote learning lab at your school, ask them to discuss the advantages and disadvantages of learning in this type of educational environment, and how these advantages and disadvantages may be translated to crime solving using teleforensics.

FRACTURE PATTERNS IN BROKEN GLASS Obj. 14.6 and 14.7

Glass has some flexibility. When glass is hit, it can stretch slightly. However, when the glass is forced to stretch too far, fracture lines appear and the glass may break. Recall that glass is an amorphous solid. Its atoms are not arranged in a pattern, but have a random structure. Therefore, glass will break into fragments, not into regular pieces with straight lines at the edges. The fracture patterns formed on broken glass can provide clues about the direction and rate of impact.

When glass breaks, fracture patterns form on the surface. Breaks, called *primary radial fractures*, are produced. These fractures start at the point of impact and radiate, or move outward, from there. Radial fractures form on the side opposite the point of impact. Secondary fractures may also form. These fractures take the form of concentric circles around the point of impact. *Concentric circles* are circles that have the same center. Concentric circle fractures form on the same side of the glass as the point of impact. By examining these glass fracture patterns, it is possible to determine which side of the glass was hit (Figure 14-13).

Figure 14-13. *Glass after an impact shows radial fractures (red) and concentric circle fractures (blue).*

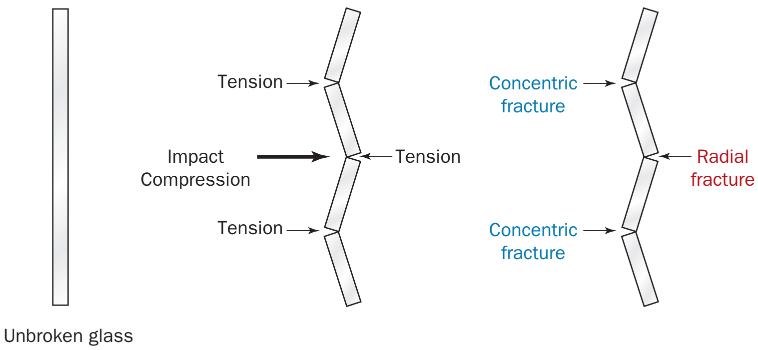


Why Radial and Concentric Fractures Form

When an object such as a bullet or rock hits glass, the glass stretches. On the side where the impact takes place, the glass surface is compressed, or squeezed together. The opposite side of the glass (the side away from the impact) stretches and is under tension. Glass is weaker under tension than under compression. It will break first on the weaker side, the side opposite the strike, producing radial fractures. The radial fracture lines will start at the center of the spot where the object hit the glass and move outward.

After the primary radial fractures form, the secondary or concentric fractures form. These are in the shape of concentric circles. They are formed on the same side as the impact or force on the glass. Knowing how and where glass fractures form, it is possible to determine where the force came from that broke the glass. Figures 14-14 and 14-15 (on next page) compare radial and concentric glass fractures.

Figure 14-14. *How radial and concentric circle fractures form when glass is hit.*



Explore

Allow students to watch one of the several videos online at Google or YouTube that show a bullet going through glass at ultra-slow speed. Point out that if they look carefully, for a split second they should be able to see the glass stretching.

Teaching Tip

Because glass fractures, early humans were able to chip obsidian into shapes that fit their needs, mostly as knives and arrow points. Show students a close-up image of an obsidian spear point and show them the conchoidal fracture patterns (fracture patterns that occur when materials break without following any natural planes of separation).

Evaluate

Ask students how fracture patterns might be different if the hit impacted the glass on the edge.

Teaching Tip

Glass under tension is being stretched, whereas glass under compression is being pushed together. When a material is stretched, it is weaker than when it is compressed, and it is the weaker, stretched side that will break first.

Teaching Tip

Currently, the strength of the glass products we use is engineered at 10,000 psi (pounds per square inch). Over time, scientists have found ways to strengthen glass. Thermal tempering allows glass to be strengthened up to three times that of normal glass. Another type of engineered strengthening is called *ion exchange* or *chemical strengthening*, which can enhance the strength of glass by a factor of 10. The scientific community has been trying to develop other ways to boost the strength of glass even further.

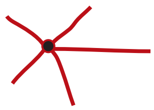
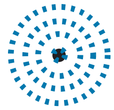
Explore

Show students the *MythBusters* episode from the Discovery Channel titled, "Breaking Glass," episode 31, which premiered on May 8, 2005 (available online at http://www.shopping.discovery.com). This episode answers the question, "Can a singer really break glass with just his or her voice?"

Explore

If possible, ask an automobile glass shop that replaces windshields to donate one to you. Contact a law enforcement officer and ask him or her to shoot the windshield for you to bring into class (or ask if they have a windshield that already has bullet holes in it). Have the officer recover any bullets (if possible) or casings used. Put duct tape around the entire edge of the windshield to help keep the glass in place. Ask students to analyze the order of the shots (ask the officer to keep track of this just to be sure), caliber, fracture patterns, angle of impact, and/or identification of the entry side and the exit side.

Figure 14-15. *Comparison of radial and concentric fractures in glass.*

	Radial Fracture	Concentric Fracture
When formed?	First (primary)	Second (secondary)
On which side of the glass?	Opposite the side of force or impact	Same side as force or impact
Description	Lines originating from point of impact and extending to edge of glass (like spokes in a bicycle tire)	Series of circles one inside the other sharing the same center
Diagram		

Bullet Fractures

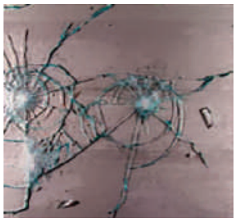
The direction of a single bullet fired through glass can be easily determined (Figure 14-16). As the bullet passes through the glass, it pushes some glass ahead of it, causing a cone-shaped piece of glass to exit along with the bullet. This cone of glass makes the exit hole larger than the entrance hole of the bullet.

If several shots are fired through the glass, the order in which the shots were fired can be determined if enough of the glass is available or can be reconstructed. The first shot produces the first set of fracture lines. These lines set the boundaries for further *fracturing by following shots*. Radiating fracture lines from a second shot stop at the edge of fracture lines already present in the glass. Notice in Figure 14-17 that the fracture pattern on the right occurred before the fracture pattern on the left. The first shot made fracture lines that blocked the fracture lines made by the second shot. The second shot produced radiating fractures that stopped when they reached the first set of fractures.

Figure 14-16. *A bullet passing through glass.*

©Digital Vision/Getty Images

Figure 14-17. *Three bullet holes and the fracture patterns they produced in glass.*



©Cengage Learning

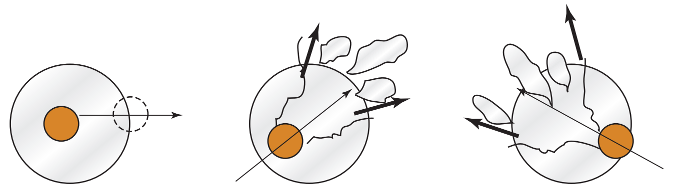
Path of a Bullet Passing through Window Glass

The angle at which a bullet enters a piece of window glass can help locate the position of the shooter (Figure 14-18). If the bullet was fired perpendicular to the windowpane, the entry hole of the bullet will be round. If the bullet was fired into the window at an angle, fracture patterns in the glass left by the bullet can be used to help locate the shooter's position.

If the shooter was firing at an angle coming from the left, glass pieces will be forced out to the right. The bullet's exit hole will form an irregular oval as it exits to the right. If the shot originated at an angle coming from the right, glass pieces will be forced out to the left, leaving an irregular oval hole to the left.

Ammunition type may be determined from the size and characteristics of the bullet hole. The distance from the shooter to the window can be estimated based on knowledge of the type of ammunition and its effect on the window. However, a high-speed bullet fired from a great distance will often exhibit characteristics of a slower-speed bullet fired from a closer range.

Figure 14-18. *The glass pattern left by a bullet can help determine the position of the shooter.*



Differentiated Learning

Teaching Gifted Students

Ask students to research and report on the following questions:

- What does the fracture pattern look like if a bullet does not successfully penetrate the glass?
- What does the pattern of a BB or pellet gun projectile look like?
- What is bullet wipe residue? Can it be detected on glass?

Bulletproof Glass

Bulletproof glass is a combination of two or more types of glass, one hard and one soft. The softer layer makes the glass more elastic, so it can flex instead of shatter (Figure 14-19). The index of refraction for both of the glasses used in the bulletproof layers must be almost the same to keep the glass transparent and allow a clear view through the glass. Bulletproof glass varies in thickness from three-quarter inch to three inches.

Tempered Glass

The point of impact is more difficult to determine on windshield glass. Safety glass, also known as tempered glass, used in windshields is composed of two layers of glass bonded together by a layer of plastic in the middle. When hit, tempered glass is supposed to crack, but not break apart (Figure 14-20). Tempered glass is designed to protect passengers in the vehicle from being showered with broken pieces of glass following an impact. Tempered glass tends to produce a pattern of large pieces with fewer concentric circle fractures than other types of glass. Additionally, the pieces break into small, nearly cubic pieces, so they do not cut deeply.

Figure 14-19. *A bullet hole in bulletproof glass.*

©AFP/Getty Images

Figure 14-20. *Fracture patterns on tempered glass.*

©Getty Images News

Backscatter

When a window breaks, most of the fragments will be carried forward. However, some of the fragments, known as *backscatter*, can be projected backward because as the glass shatters, fragments collide and tumble in various directions. Backscatter is a form of trace evidence that may link a suspect to the crime scene.

Heat Fractures

During a fire, glass may break as a result of heat fracturing. Heat fracturing produces breakage patterns on glass that are

Digging Deeper
with Forensic Science e-Collection

Not all bulletproof glass will stop bullets. Go to the Gale Forensic Science eCollection eCollection at school.cengage.com/forensic science and research safety glass. Prepare a short presentation on what you find. Include these topics in your presentation: What is the rating system used to determine the level of protection given by each material? What other materials besides glass are used to protect people and property?

Digging Deeper

Underwriters Laboratories, Inc. (UL) is a product safety testing and certification company first established in 1894 by William Merrill. UL is one of several companies that develop standards and test procedures for bulletproof materials. UL does not recommend products, companies, or materials, but instead evaluates products for compliance with specific standards, and offers product certificates to carry the UL label as long as standards are upheld.

Explore

Show students the *MythBusters* episode from the Discovery Channel titled, “What Is Bulletproof?” This is episode 16, which premiered on September 29, 2004, and is available online at http://www.shopping.discovery.com. It answers the question: “Will a bulletproof shield really stop a direct hit from a bullet?” Afterward, discuss the findings as a class.

Teaching Tip

Bulletproof glass can be as thick as 100 millimeters and is usually made of several layers of tempered or toughened glass with a Perspex, or tough plastic panel, between each layer. Mention to students that bulletproof glass is not totally bulletproof; it is more bullet resistant.

Explore

Ask students to think of the places you would find bulletproof glass. Create a class list (e.g., windows of banks, jewelry stores, and similar businesses; the limousine used by the president, pope, and other leaders).

Teaching Tip

Laminated glass is the type of glass used in vehicle windshields. When broken, laminated glass produces a spider-web breaking pattern, and the glass holds together instead of shattering. Laminated glass is a type of safety glass. It is used not only in windshields but in other products where there tends to be a lot of human contact, such as telephone booths and in gas masks used during World War II. In the production of laminated glass, two or more layers of glass are held together by PVB (polyvinyl butyral). PVB not only keeps the layers of glass together in the event of breakage, but also blocks 99 percent of UV rays from the sun. Manufacturers sometimes apply color to PVB to make tinted films for windshields.

Teaching Tip

Contact your local fire department and ask if they have any glass that has been in a fire that they could donate to you for students to view.

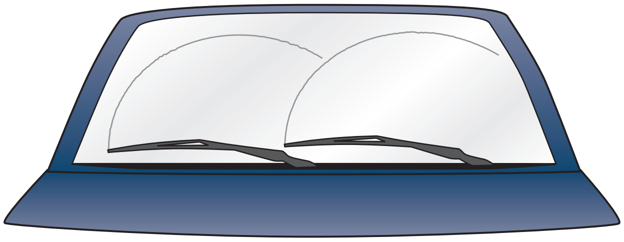
Explore

Fire-resistant glass has a special glaze applied to achieve specific levels of protection from a fire. Fire-resistant glass receives ratings that depend on the amount of time it can withstand a certain heat and temperature, as well as if the glass allows the heat to transfer from one side of the glass to another. Many products, such as ovens and woodburning stoves, require fire-resistant glass.

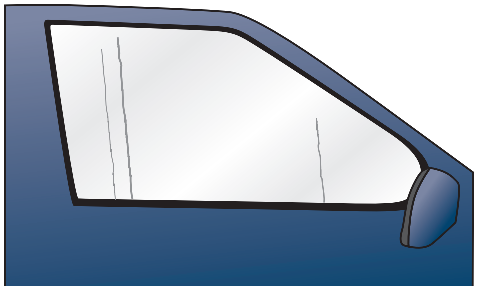
Teaching Tip

Tell students that glass evidence is always packaged in a paper container, never plastic. If the glass evidence is small, it should be collected in an envelope or paper bindle. Make sure to stipulate it cannot be a regular mailing envelope, because they often have gaps in the corners. If the glass evidence is large, it should be collected in a cardboard box, sealed, and labeled.

Figure 14-21. *(a) Wiper marks in a windshield.*



(b) Scratch marks on a car window



different from breakage patterns caused by an impact. Wavy fracture lines develop in glass that has been exposed to high heat. Also, glass will tend to break toward the region of higher temperature. If the glass was not broken before the fire, there will be no radial or concentric circle fracture patterns in glass broken by high heat.

Other Scratch Patterns

Patterns or scratches other than those already mentioned may be found on evidence glass. For example, windshield wipers may leave marks on the windshield (Figure 14-21a).

Any dirt or other particles embedded in the rubber insulation of a car window may leave scratch marks when the window is opened or closed (Figure 14-21b).

The speed of an object when it hits a piece of glass influences the number of concentric circles in the fracture pattern. An object moving at a high rate of speed at impact, such as a bullet striking the glass, produces fewer concentric circles. An object moving at a slower rate of speed at impact, such as a rock thrown at a window, produces a greater number of circles.

HANDLING OF CRIME-SCENE GLASS SAMPLES

When collecting glass evidence, it is important to follow the correct evidence collection procedures to avoid the loss or contamination of any evidence samples. Here are some general rules to follow when collecting glass evidence.

- Identify and photograph any glass samples before moving them.
- Collect the largest fragments that can be reasonably collected.
- Identify the outside and inside surfaces of any glass.
- If multiple window panes are involved, indicate their relative position in a diagram.
- Note any other trace evidence found on or embedded in the glass, such as skin, hair, blood, or fibers.
- Properly package all materials collected to maintain the proper chain of custody.

Glass collected by crime-scene investigators should be initially separated by physical properties, such as size, color, and texture. Samples should be carefully catalogued and kept separate to avoid contamination between two different sources.

Once in the lab, other trace evidence (e.g., hair, fibers, blood) can be separated from glass fragments. Any clothing related to the crime scene should be examined for glass fragments and other trace evidence. Any objects that might have been used to break the glass should also be collected and examined for glass fragments.

CLEANING AND PREPARING THE GLASS FRAGMENTS

After glass fragments have been documented and examined, they should be cleaned. Any surface debris (e.g., grease, soil particles), which might serve as additional evidence, should be noted and collected before cleaning. Cleaning solvents may be used as well as ultrasound cleaners to clean the glass.

It is important to avoid destroying any glass samples collected as evidence, if possible. If glass fragments are needed for further analysis, nondestructive methods, such as examination under a compound microscope, should be considered first. However, sometimes techniques must be used that do destroy the evidence sample during analysis. If this is the case, it is important to try to avoid using all of the evidence in the testing procedures. Additional material may be needed for duplicate lab tests.

SUMMARY

- Humans have been making glass for centuries. Glass is also produced by natural forces, such as volcanoes and lightning.
- Glass is an amorphous solid usually made from silica, calcium oxide, and sodium oxide.
- Glass fragments can be identified by their density, thickness, and refractive index.
- The density of an object is calculated by dividing its mass (usually in grams) by its volume (usually in milliliters).
- The refractive index of a material is a measure of how much light bends, or refracts, as it travels through that material.
- Snell's law can be used to calculate the refractive index of a piece of glass.
- The submersion method is a laboratory method used to estimate the refractive index of a glass sample.
- The position of a Becke line is another laboratory method used to estimate the refractive index of a piece of glass.
- When glass is hit, it first stretches, then breaks, forming radial fracture and concentric fracture patterns. Radial fracture patterns occur on the side of the glass opposite the point of impact. Concentric fracture patterns occur on the same side as the point of impact.
- When a bullet is shot through glass, the exit hole is larger than the entry hole.
- The angle of entrance of a bullet into glass can be determined by the pattern of glass left by the bullet's entry and exit.

Teaching Tip

Explain to students that the collection of the filaments from headlights or taillights of vehicles is important. The filaments can be analyzed to determine if these lights were on or off at the time of the accident or crime. (The filaments of lights that were on are reduced to white ash, while filaments of lights not turned on during an accident are intact, or broken with no ash.)

Explore

Point out to students there are specialty products that help preserve broken glass at a crime scene. One such product is spray foam. This product is portable and can be sprayed on any piece of glass evidence. The foam is sticky and hardens quickly, allowing investigators to "freeze" the evidence in the state in which it was found.

Teaching Tip

Discuss with students that even though finding and matching twenty-two elements seems like a powerful corroboration, there are lots of other cars with the same windshield glass containing the same elements. Emphasize that this kind of analysis cannot individualize the glass to one car.

Teaching Tip

The chemical composition of glass can be determined by neutron activation analysis.

Close

Write the key vocabulary terms on the board: density, refraction. Organize the class into groups and assign each group one of the words. Have groups explain the term and how it figures in the forensic analysis of glass.

- When glass breaks from exposure to a fire, the fracture pattern formed is different from the fracture pattern caused by an impact. In a fire, glass tends to break toward the area of higher temperature.

CASE STUDY

Susan Nutt (1987)

At 9:30 P.M. on a cloudy, dark night in February, 19-year-old Craig Elliott Kalani went for a walk in his neighborhood in northwest Oregon but never returned home. A hit-and-run driver killed him. Crime-scene investigators collected pieces of glass embedded in Craig's jacket and other glass fragments found on the ground near his body.

Police searched for a vehicle that had damages consistent with a hit-and-run accident. They found a car with those types of damages that belonged to a woman named Susan Nutt. In order to connect Ms. Nutt and her car with the crime, the police had to match the glass from the crime scene to the glass in her car. Researchers at Oregon State University's Radiation Center compared the glass from both sources. The scientists found that windshield glass from the crime scene contained the same 22 chemical elements as those used to make the glass in Ms. Nutt's car. The scientists considered both samples of glass to be a definite match.

The glass evidence helped convict Susan Nutt of failure to perform the duties of a driver for an injured person. She was sentenced to up to five years in prison and five years' probation.

©Nonstock/Jupiter Images

Think Critically Describe a scenario in which glass evidence is important in solving a crime.

CAREERS IN FORENSICS

Neutron Activation Analyst

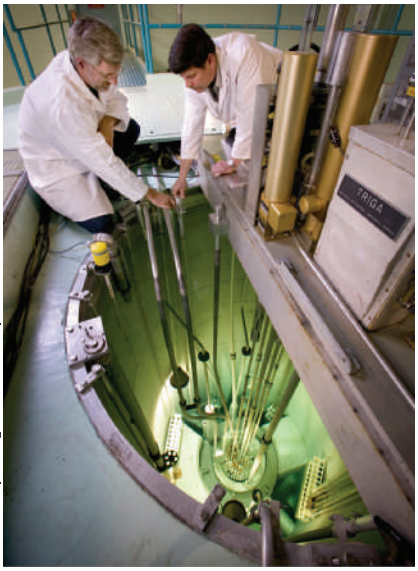


Photo courtesy of Oregon State University Radiation Center

A neutron activation analyst applies techniques that can be used in many different fields, such as medicine, geology, engineering, and forensics. Given a sample of trace evidence, a nuclear activation analyst bombards the sample with neutrons produced by a nuclear reactor. Some atoms in the sample may absorb one of these neutrons and become radioactive.

The radioactive sample gives off radiation of different wavelengths, which the analyst measures to determine the elements contained in the sample. Each chemical element gives off radiation of a specific wavelength. The amount of radiation at a certain wavelength can indicate the amount of the element in the sample. Instrumental neutron activation analysis is a very sensitive technique that can detect chemicals that other methods cannot. In addition to being very sensitive, neutron activity analysis requires a very small sample, does not destroy the sample, and is very expensive.

Although neutron activation analysis is a powerful technique that would be useful in helping to solve many crimes, most laboratories cannot perform this type of analysis, because it requires a nuclear reactor. One laboratory that does have the facilities to perform neutron activation analysis is the Radiation Center at Oregon State University. Police departments have called on analysts there to help solve crimes by analyzing trace evidence, such as glass fragments.

Neutron activation analysis does not work as well on human hair, because hair is porous and can absorb contaminants from the environment. Besides glass evidence, this analysis also works well on bullets. A neutron activation analyst can use this technique to match a bullet found at a crime scene to a bullet found in a suspect's possession, even when the police have not found a gun connected to the crime. Like paint chips, the material used to make bullets contains varying amounts of several elements, such as arsenic, copper, silver, tin, mercury, or gold. The exact chemical composition of a bullet made in one batch is different from that of a bullet made in a different batch. According to one analyst there is only one out of 10,000 chance that a bullet from one batch will match a bullet from a different batch of bullets.

An analyst from the Radiation Center at Oregon State University was able to determine the exact chemical composition of bullets found at the scene of a murder and link the bullets to bullets found at a suspect's home. These findings helped convict the suspect on three counts of aggravated murder. The suspect was sentenced to life in prison without parole.

Learn More About It

To learn more about a career as a neutron activation analyst, go to school.cengage.com/forensicscience.

CAREERS

Ask students to think of other uses for the neutron activation analysis (NAA) technique. (NAA is a nondestructive process that determines the elemental concentrations in material. Therefore, it can be used to test water and food for contamination, to test urine and blood for illegal drugs, and to test for the purity of gems, metals, or oil.)

Chapter 14 Review

True or False

1. False
2. True
3. True
4. True
5. True
6. True
7. False

Multiple Choice

8. a
9. c
10. b
11. d
12. a

CHAPTER 14 REVIEW

True or False

1. Obsidian is a type of glass-like sedimentary rock formed in the ground under great pressure. *Obj. 14.1*
2. One of the earliest forms of man-made glass was accidentally produced in Syria during food preparation. *Obj. 14.1*
3. Metal oxides added to glass produce glass of different colors. *Obj. 14.3*
4. Safety glass is made so it will not crack and not break apart into pieces upon impact. *Obj. 14.6*
5. When it is hit, glass bends and stretches before breaking. *Obj. 14.6*
6. Secondary fracture lines radiate out from the center of impact as glass shatters. *Obj. 14.7*
7. If glass is located near a fire within a building, it will tend to shatter outward. *Obj. 14.6*

Multiple Choice

8. The refractive index refers to the ability of a substance to *Obj. 14.5*
   a) bend light
   b) reflect light
   c) absorb light
   d) convert light to heat energy

9. The substance added to glass that makes crystal glasses seem to sparkle is *Obj. 14.3*
   a) copper
   b) silver
   c) lead
   d) aluminum

10. The speed of light in a vacuum is approximately *Obj. 14.5*
    a) 30,000 kilometers/hour
    b) 300,000 kilometers/hour
    c) 30,000 miles/hour
    d) 300,000 meters/hour

11. Which refractive index would indicate the densest material? *Obj. 14.5*
    a) 1.2
    b) 1.3
    c) 1.4
    d) 1.5

12. As the density of a medium increases, the refractive index should *Obj. 14.5*
    a) increase
    b) decrease
    c) stay the same

13. The normal is the line that is *Obj. 14.5*
   a) parallel to the surface where two different mediums meet
   b) moving in the same direction as the beam of light through the first medium
   c) perpendicular to the surface where two different mediums meet
   d) the line of light passing through a vacuum

14. What are the correct units when measuring density? *Obj. 14.4*
   a) milliliters/gram
   b) cubic centimeters/milliliter
   c) grams/milliliter
   d) millimeters/second

Short Answer

15. Describe how to use the submersion method to determine the refractive index of a piece of glass found at a crime scene. *Obj. 14.5 and 14.8*

____

____

____

16. In order to determine the refractive index of a small piece of glass, the glass is submerged in different liquids and viewed under a compound microscope. The appearance of a Becke line is used to determine the refractive index. *Obj. 14.5 and 14.8*
   a) What is a Becke line?

   ____

   ____

   ____

   b) Why does a Becke line form?

   ____

   ____

   ____

   c) What does the location of the Becke line tell you about the refractive index of the piece of glass and the surrounding liquid in which it is placed?

   ____

   ____

   ____

13. c
14. c

Short Answer

15. Submerge your crime scene glass in a range of liquids with increasing refractive indices. The liquid sample that makes the glass "disappear" will be closest to the refractive index of the glass sample.

16. a. A Becke line is a halo (edge) around the piece of glass when viewed under the microscope.
    b. The Becke line forms because of the bending of light as it passes from one medium (the glass) to another (the liquid in which it is submerged).
    c. If the Becke line appears within the edge of the submerged glass, the glass has a higher refractive index than the liquid. If the Becke Line appears outside the edge of the glass, the glass has a lower refractive index than the liquid.

17. a. Choose a liquid with the closest refractive index to the blanket glass sample. This liquid should make the glass "disappear." Next, submerge the headlight glass in the same liquid and see if the headlight glass also "disappears."

b. Sample answer: Place the glass fragment into different liquids of known refractive indexes, and if the piece of glass and a liquid have the same refractive index, the glass fragment will seem to disappear when placed in that liquid.

c. Sample answer: Glass with the same refractive index can be identified as to type, and then as to use (application).

18. Use Snell's Law, n_1 (sine angle 1) = n_2 (sine angle 2) and a scientific calculator or sine chart to calculate your answer.

$1.00 (\sin 33°) = n_2 (\sin 48°)$

$0.545 = n_2 (0.743)$

$n_2 = 0.734$

19. Sample answer: When an object, such as a bullet or a rock, hits glass, the glass stretches. On the side where the impact takes place, the glass surface is compressed, or squeezed together. The opposite side of the glass (the side away from the impact) stretches and is under tension. Glass is weaker under tension than under compression. It will break first on the weaker side, the side opposite the strike, producing radial fractures. The radial fracture lines will start at the center of the spot where the object hit the glass and move outward. After the primary radial fractures form, the secondary or concentric fractures form. These are in the shape of concentric circles. They are formed on the same side as the impact or force on the glass. Knowing how and where glass fractures form, it is possible to determine the direction of the force that broke the glass.

Refer to Figure 14-10 on page 403 to answer question 17.

17. You are testifying as an expert in glass evidence. You want to demonstrate that the evidence glass found embedded in a blanket came from a broken headlight of a vehicle suspected to be the vehicle involved in a hit-and-run accident. *Obj. 14.3, 14.5, 14.6, and 14.8*

a. What liquid would you use to demonstrate that the glass fragment was obtained from a broken car headlight?

____

____

b. Describe the demonstration that you would show the jury.

____

____

c. What explanation would you provide to the jury to convince them that the glass evidence has to come from a glass like the glass found in a car headlight?

____

____

18. A beam of light passes through air into a second medium. Angle 1 (angle of incidence) is 33°. Angle 2 (angle of refraction) is 48°. Calculate the refractive index. Show all your work. *Obj. 14.5*

____

____

19. Compare and contrast radial and concentric glass fractures. Include in your answer: *Obj. 14.6*

a. Description of each type of fracture

____

____

b. On which side of the glass will they form

____

____

c. Which type of fracture will form first and why

____

____

20. A window is broken. The group of vandals who were standing behind the broken window run away. If the broken glass projected inward, how is it possible that a small amount of trace broken glass evidence was found on their clothes? *Obj. 14.6 and 14.8*

21. List characteristics of glass that can be used to compare suspect glass samples to glass found at a crime scene. *Obj. 14.2 and 14.8*

22. Using a light source and a protractor, explain how to calculate the refractive index of a liquid. *Obj. 14.5*

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http://www.haines.com.au/Gee_Store/Scripts/prodList.asp?idCategory=1136

20. Backscatter
21. Color, density, thickness, refractive index, and fracture patterns.
22. Sample answer: Using a light source, shine it through the first medium and into the second medium. Use a protractor to find both the angle of incidence and the angle of refraction. Then use Snell's law to calculate the refractive index of the liquid.

ACTIVITY 14-1

Background

In this activity, students examine glass fracture patterns to determine the sequence of breaks in the glass.

Safety Precautions

1. This activity involves paper exercises only. If you choose to include additional hands-on work with fractured glass, students must wear gloves and goggles while handling glass.
2. Spread newspaper or construction paper in your work area.
3. Tell students how they should dispose of all materials.

Procedures

Make sure students read all directions *before* beginning the activity.

Teaching Tips

1. If you choose to use actual glass, you may want to contact a windshield replacement shop or local law enforcement agency and ask them for some windshield and/or headlight glass.
2. Good places to get glass samples include glass stores, junkyards, secondhand stores, garage sales, and construction sites. You may want to document (manufacturer and type of glass) these samples to create a teaching collection.
3. Place the glass to be broken in a cardboard box so that the pieces will not scatter. The back of the glass should be taped to hold fragments in place.

ACTIVITY 14-1 *Ch. Obj. 14.6 and 14.7*

GLASS FRACTURE PATTERNS

Objectives:

By the end of this activity, you will be able to:

1. Use glass fracture patterns to explain how to sequence events that occurred to form the broken glass.
2. Analyze glass fracture patterns and determine the order of the breaks in the glass.
3. Distinguish the differences between fractures formed in tempered or safety glass and the fractures formed in window glass.

Time Required to Complete Activity: 45 minutes

Materials:

(per group of two students)
diagrams included with lab
pencil
ruler
piece of broken window glass (demonstration table)
piece of broken tempered glass or safety glass (demonstration table)

Safety Precautions:

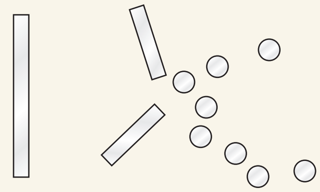
This activity involves paper exercises only. If your teacher chooses to include additional hands-on work with fractured glass, wear gloves and goggles while handling glass. Spread newspaper or construction paper in your work area. Dispose of all materials as directed by your teacher.

Background:

Forensic examiners need to be able to look at evidence left at a crime scene and try to determine what happened. If witnesses or suspects are at the crime scene, they may describe their version of what happened. Evidence can either corroborate their story or present a new version of what actually occurred. In this activity, you will examine glass fracture patterns to determine the sequence of events that lead to the breaking of the glass. The fracture patterns may also indicate where force was applied to break the window, and if there are a series of impacts, which impact occurred first.

Procedure:

1. Examine the diagrams to the right, which show a side view of a window both before and after impact. Determine the point of impact and direction of force.



side view of window before impact   *side view of window after impact*

2. Draw an arrow showing the direction in which the force was applied to the window. Explain your answer using the terms *tension* and *compression*.
3. Tempered glass is also known as safety glass. One of the main uses of this type of glass is for car windshields. When impacted, safety glass fractures differently than window glass. Analyze the pictures of safety and window glass. (If you have actual pieces of broken safety glass and window glass, refer to them.)
   a. Record some of the differences you observed between the two types of glass.
   b. Explain how safety glass is better suited for windshield glass than window glass.

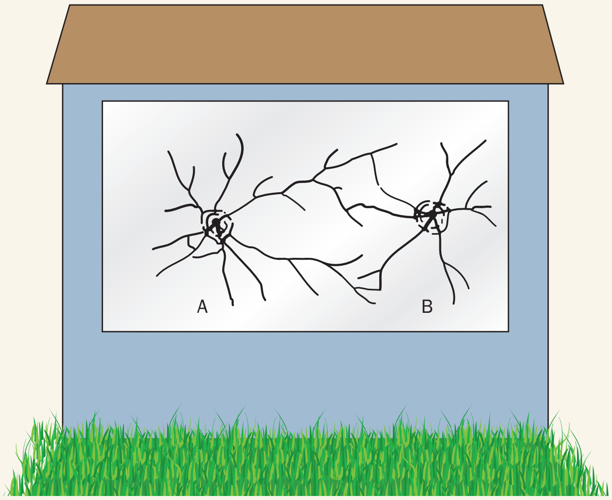

©imageshop/Jupiter Images

(a) Safety glass


©Stock4B/Jupiter Images

(b) Window glass

4. Police responded to an incident involving gunshots. When they arrived at the scene, they found two men arguing. One man named Henry was inside the home, and the other man, Ralph, was outside near a shed. Two bullets went through the large living-room window. The police did not recover the bullets. Henry claimed that he was firing in self-defense and that Ralph had fired the first shot noted by A in the diagram. In self-defense, Henry shot the second bullet from inside the house, noted by letter B in the diagram. Ralph claimed that he did not fire any guns and that the man in the house fired both bullets at him. You have been called in as a glass expert to analyze the glass. Based on the glass fracture patterns, can you determine if either of the two men is telling the truth or if both men are lying.



   a. On diagram B, label the primary and secondary fracture lines. Explain your answer.
   b. Based on the fracture lines, which impact, A or B, occurred first? Explain your answer.

Answers

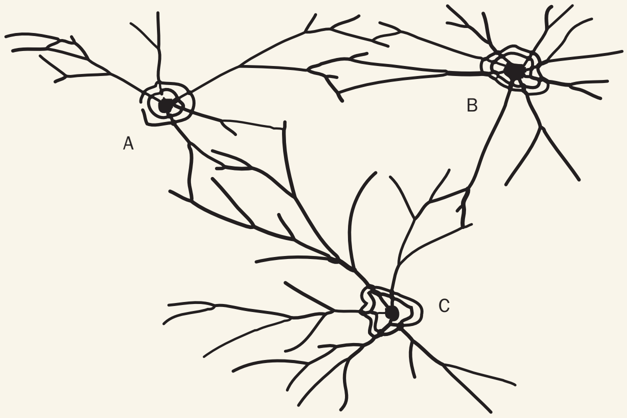
Collect all activity pages and grade students on accuracy and completeness.

1. Check student's diagrams.
2. When glass is struck by a projectile, it is compressed on the side where the projectile strikes. The opposite side of the glass will be under tension. At first the glass under tension will stretch and then the glass will break.
3. a. Safety glass has no radial or concentric fractures, the pieces are small and square; the window glass is a mixture of large and small and possibly sharp pieces.
   b. Safety glass is better suited for windshields because it will shatter into small pieces that are less likely to cut the driver, whereas window glass might produce large shards of glass capable of serious injury to a driver or passenger in the car.
4. a. Check student's diagrams.
   b. A

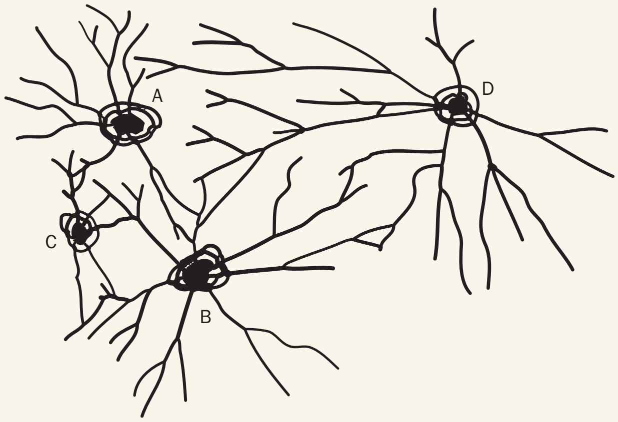
c. As a glass expert, you told the police that if you could examine the actual broken glass, it would be possible for you to determine the direction in which the bullets were fired. You explain that it is possible to determine if they were fired from inside the house or from the outside. Explain two different methods you could use to determine the direction of the bullets based on glass analysis.

d. If you examined the actual glass, could you determine who was telling the truth: Henry or Ralph? Explain your answer.

5. Examine the diagram of the glass fracture patterns. Three different impacts resulted in the breaking of the glass. Which impact occurred first, second, and third? Justify your answer in writing and by labeling the diagram using words like “boundary” and “radial fracture.”



6. Review the diagram showing four different impacts from four different rocks striking glass.
   a. What is the sequence?
   b. Justify your answer.



c. Answers will vary, but should include the shape of the impact hole (smaller on the impact side), and examine the fractures (radial fractures form on the side opposite the impact; concentric fractures form on the side of the impact).

d. If you could actually examine the glass, yes, it could be determined who was telling the truth based on the size of the holes and the location of the concentric and radial fractures.

5. C, A, B; Radial fracture lines from C stop the radial fractures of A and B, so C must have been first. The radial fractures of B are stopped by A, meaning A formed before B.

6. a. D, B, A, C

   b. Radial fractures of D halt formation of fractures of all the others, therefore, D was first. B fractures stop fractures of A and C, making it the second to form. The fracture lines for C appear to be stopped by A, making A third and C last to form. This last relationship is uncertain.

Further Research and Extensions

Allow students to actually perform the two tests they think they will need to gather more information about the glass. Provide materials and equipment for them to perform their experiments.

ACTIVITY 14-2 *Ch. Obj. 14.4 and 14.8*

GLASS DENSITY

Objectives:

By the end of this activity, you will be able to:

1. Describe how density is determined using a water displacement method.
2. Calculate the density of various samples of glass.
3. Determine if any of the glass evidence obtained from the four suspects has the same density as the glass found at the crime scene.
4. Maintain the proper chain of evidence when collecting and examining glass evidence.

Time Required to Complete Activity: 45 minutes

Materials:

(per group of three students)
evidence bags containing glass labeled Suspects 1, 2, 3, and 4
evidence bag containing crime-scene evidence labeled CS
displacement containers *or* 10 mL graduated cylinders
beaker (250 mL)
water
dropper bottle of water containing 50 mL of water
balance (accurate to at least .01 gram)
forceps
newspaper or construction paper
labeling tape
permanent marker pen

Safety Precautions:

Wear gloves and goggles while handling glass. Spread newspaper or construction paper in your work area. Dispose of all materials as directed by your teacher. Immediately report any accidents with glass to the teacher.

Background:

The density of glass fragments found at a crime scene can be compared to the glass fragments found on suspects. Keep in mind that if the densities do match, this does not prove that the suspect is guilty, because glass would be considered class evidence.

Glass fragments from a crime scene need to be matched with any glass fragments associated with the four suspects.

In this activity, you will be asked to determine the density of glass fragments found at the crime scene and the densities of glass fragments found on any of the suspects. If the densities do not match, you may be able to disqualify a suspect. If you find that the densities do match, then you will need to collect further evidence to help prove that a particular suspect was at the crime scene.

ACTIVITY 14-2

Background

In this activity, students determine the density of glass fragments found at the crime scene and the densities of glass fragments found on the suspects. From the densities, they will attempt to match glass fragments from the crime scene to those found on one of the suspects.

Safety Precautions

1. Students should always wear gloves and goggles while handling glass.
2. Spread newspaper or construction paper in the work area.
3. Tell students how they should dispose of all materials.
4. Emphasize that students should report any accidents immediately.

Procedures

1. Print, copy, and distribute Activity Sheet 14-2 from the IRCD.
2. Make sure students read all directions *before* beginning the activity.

Teaching Tips

1. Make sure students know that the glass must be totally submerged.
2. Tell students not to drop the glass into the beaker since it may be difficult to retrieve.
3. Cross contamination of glass pieces is a big issue. It can be difficult to identify the glass types by visual comparison if the lab materials get accidentally mixed up. One way to prevent this is to take four different colors of Sharpie® markers and lightly mark the edges of the glass. This should not be done, however, if the same glass pieces will also be used for either refractive index or Becke line analysis.
4. Another method for density analysis by displacement is to use a graduated cylinder only. All you have to do is make sure the pieces will fit into the opening of the cylinder. Record the volume before and after adding the glass to the cylinder.
5. With the beaker filled to its maximum volume, it is important to tell students not to immerse forceps or fingers into the water, because they will also displace water and cause an inaccurate measurement.
6. Use large samples of glass if using a beaker and overflow can.
7. Make sure to tell students the type of scale they should use to measure mass and the expected accuracy (to nearest .01).

Procedure:

1. Obtain the evidence envelopes labeled:
   Suspect 1
   Suspect 2
   Suspect 3
   Suspect 4
   Crime Scene
2. Using Suspect #1 evidence bag, record your name, date, and time on the Chain of Possession form.
3. Open the envelope labeled Suspect #1. Do not disturb the signatures on the evidence envelope. Open it from a different side.
4. Remove two pieces of glass fragments from suspect's evidence bag #1. Using a balance, determine the combined mass of both pieces. Record the mass on Table 1. Leave the two pieces of glass on the balance for further testing.
5. Reseal the evidence bag. Place a piece of tape over the opened edge. Write your signature or initials across the interface of the tape and the bag to maintain chain of custody. At this point, there should be two taped areas on the bag, both containing signatures or initials on top of the tape. Refer to proper chain of command described in Chapter 2.
6. Set up a 250 mL beaker of water filled to overflowing. You may need to add the last few drops with a dropper.
7. Position a clean, dry, 10 mL graduated cylinder to receive overflow water. Several books may have to be placed under the beaker to adjust the height of the beaker.
8. Slowly add your two glass fragments of glass Sample 1 into the beaker one at a time. Water will spill over into your graduated cylinder.
9. Measure the volume of water displaced by the addition of the two glass fragments. This is determined by reading the amount of water that has overflowed into the graduated cylinder.
10. Record the combined volume for the two glass fragments in Data Table 1.
11. Calculate the density of the glass fragments from Suspect 1 evidence bag and record your answer on the data table.
12. Remove the two glass fragments from the beaker and handle as described by your teacher.
13. Refill the beaker to just overflowing.
14. Repeat the process with glass from (Suspect) 2. Be sure to properly open and reseal the evidence bag. Record your name, date, and time on the Chain of Possession form. Record all information for Suspect 2 in the Data Table.
15. Repeat the process until you have recorded all the information for the glass found on suspects 3 and 4, and the crime-scene evidence envelope.

Data Table: Density of Glass Samples

Sample	Combined Mass of Two Fragments (mass)	Combined Volume of Two Fragments (milliliters)	Density (M/V) (grams/ml)
Suspect 1			
Suspect 2			
Suspect 3			
Suspect 4			
Crime Scene			

Questions:

1. Did the density of the glass found on any of the four suspects match the density of the glass found at the crime scene? Explain your answer.
2. Check your results with your classmates. How did your results compare to those of the rest of the class?
3. Describe how you could improve your experiment to have more reliable results.
4. Based on your results, are you able to link any of the suspects to the crime scene based on your glass analysis?
5. Explain why glass is considered to be a form of class evidence.
6. If you did find that the glass density of fragments found at the crime scene matched those found on one or more of the suspects, what other additional tests could be done on the glass evidence to further link the suspect(s) to the crime scene?
7. In checking the density of the glass fragments, why did you use only two fragments of glass and not all of the glass fragments found in the evidence bag?

Answers

Check students' data tables.

Questions

1. Answers will vary.
2. Answers will vary.
3. Answers will vary, but might include: double-check calculations for math errors, be more accurate with measurements, being more consistent with amounts of water in overflow beaker.
4. Answers will vary.
5. Glass is considered class evidence because it is common and there is little variation among the types of glass. The only time glass evidence is individualized is if it can be pieced back together like a puzzle.
6. Other tests might include determining refractive index, and examining for trace evidence on the glass.
7. Use only two fragments so that you do not destroy the integrity of all the glass fragment evidence, which may be needed for future testing or comparison.

Further Research and Extensions

Ask students how they would change the procedure if they only had one piece of glass from the suspect about the size of a dime.

ACTIVITY 14-3

Background

In this activity, students will use Snell's law to determine the refractive index of three liquids.

Safety Precautions

Laser pointers are dangerous if aimed directly into the eye. Students love to play with laser pointers. It takes some strict teaching to prevent students from giving into the temptation.

ACTIVITY 14-3 *Ch. Obj. 14.5*

DETERMINING THE REFRACTIVE INDEX OF LIQUIDS USING SNELL'S LAW

Objectives:

By the end of this activity, you will be able to:
Determine the refractive index of three liquids.

Time Required to Complete Activity: 45 minutes

Materials:

(per group of two to three students)
laser pointer (that can be turned on without having to keep pressing down on a button)
paper (8 × 11)
protractor
calculator with sine function or Sine Table
three different liquids (Samples 1, 2, and 3)
ruler (mm or inches)
three semicircle plastic dishes
pencil

Safety Precautions:

Students should not look directly at the laser light.
Students should be careful when handling glass to avoid being cut. Immediately report any injuries to the teacher.

Background:

Light travels through different mediums at different velocities. There is a relationship between the density of a medium and the speed of light: the higher the density of the medium, the slower the velocity of light through that medium. When light passes between two different mediums of different densities, the velocity of the light will be altered. The change in the velocity of light results in a bending of the light wave as it passes through this medium. This bending is known as *refraction*.

As a means of comparison, a ratio of the speed of light through a vacuum (186,000 mi/sec or 300,000 km/sec) is compared to the speed of light through a different medium. This ratio is referred to as a *refraction index* (RI). For example:

Refraction index for water
speed of light in a vacuum = 186,000 mi/sec (300,000 km/sec)
speed of light through water = 140,000 mi/sec (225,800 km/sec)

$$= \frac{186{,}000 \text{ mi/sec}}{140{,}000 \text{ mi/sec}}$$

$$= 1.33$$

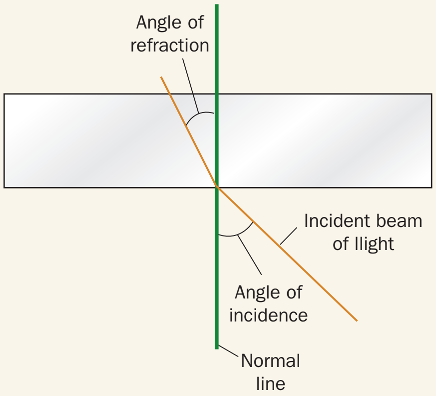
Snell's Law:
Mathematically, the relationship between the refractive indices and the angle of incidence and angle of refraction is expressed as Snell's Law.

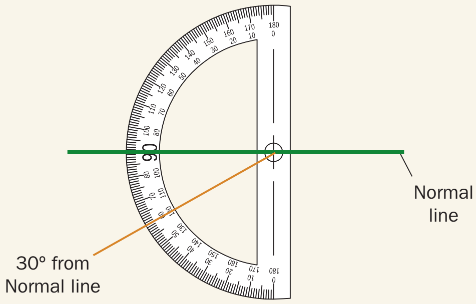
n_1 (sine angle of incidence) = n_2 (sine angle of refraction)

n_1 = refractive index of medium 1

n_2 = refractive index of medium 2

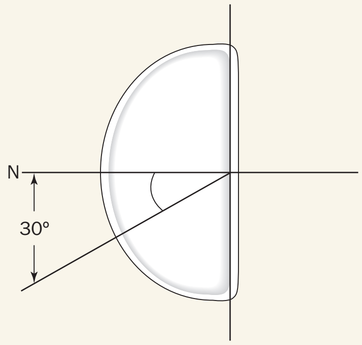
Comparison of Angle of Incidence and Angle of Refraction as light passes between two different mediums.

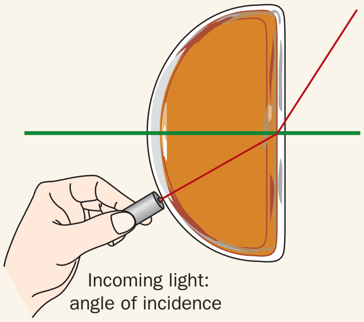


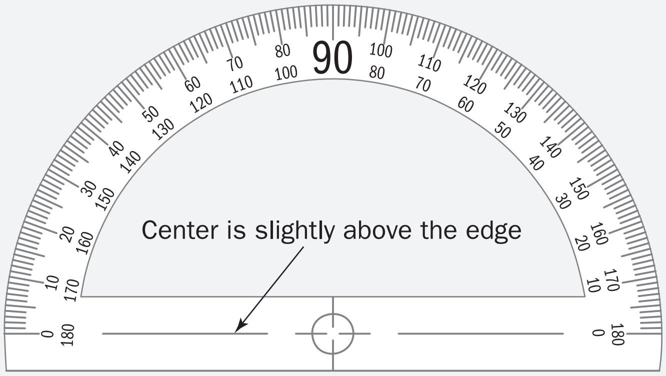


Procedure:

1. Place a piece of white paper on the table and draw a straight line down the center of the paper. Draw a second line that is perpendicular (90°) to the first line. This second line is called a normal (N).
2. Using a protractor, draw a line on the paper at 30° from the normal as shown in the diagram. This line will also be at a 60° angle from the first line you drew.
3. Obtain a semicircular plastic dish filled with Sample 1 and arrange the dish as pictured in the diagram. Position the center of the protractor at the point where the normal and 30° line meet.





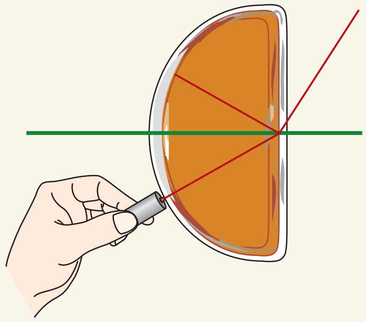


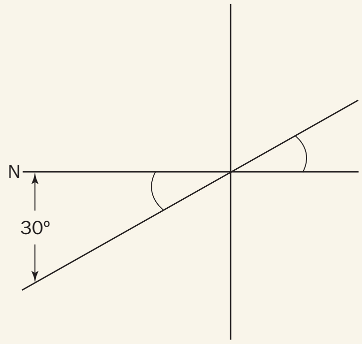
Procedures

1, Print, copy, and distribute Activity Sheet 14-3 from the IRCD.
2. Make sure students read all directions *before* beginning the activity.

Teaching Tips

1. Try to use laser pointers that can be turned on without having to keep pressing down on a button. Otherwise, you have to place a piece of tape to hold down the button. Decent laser pointers are expensive, but are worth the cost in the long run.
2. Place the laser pointer very close to the plastic dish when obtaining your angle of incidence.
3. Darken the room and demonstrate how the laser must be accurately positioned to focus at the interface, as pictured in the illustration. Point out that the laser pointer must be positioned against the edge of the dish for greatest accuracy.
4. With the laser pointer in place, draw a line on the paper indicating the angle of refraction.
5. Make sure that students measure the angle of incidence and angle of refraction from the normal line.
6. Use a sharp pencil to draw the angle of refraction.
7. Be sure that your protractor is aligned correctly. Some protractors use the bottom edge of the protractor to align the protractor. Other protractors will have the center slightly above the edge of the protractor.
8. Fill the plastic dishes with oil. If you do not have enough oil in the plastic dish, it is more difficult to obtain accurate readings.
9. This activity might be done as a demonstration if your school or district has a policy against student use of laser pointers.





4. Position the laser pointer so that its beam lies on top of the 30° line you just drew.
5. All angles are measured from the normal line. It is called the *angle of incidence.* This is the angle of the incoming beam of light and is equal to 30°. Record 30 degrees as your angle of incidence on your data table. Use a calculator to determine the sine value of 30 degrees and record the sine on your data table.
6. Notice how the beam of light is bent as it passes through the container or liquid and then through the second medium of air. Note where the light shines on the paper on the other side of the liquid. Using a pencil and a dotted line, trace the line of refracted projected light as it exits the plastic dish and passes through the air. Label the line Sample 1.
7. Using this dotted line and the normal line and a protractor, determine R, the *angle of refraction*. Record the angle of refraction on your data table.
8. Using a calculator, determine the sine value of your angle of refraction. Alternatively, a sine table can be used and is found in the appendix at the back of your textbook.
9. Calculate the refractive index for Sample 1 using Snell's Law. Note: the angle of refraction was determined after the laser light was shown through the plastic dish.

   n_1 (sine of angle of incidence) = n_2 (sine of angle of refraction)
   angle of incidence = 30 degrees for all samples
   n_2 = 1 (recall that the refractive index of air is approximately 1)
   n_1 is unknown
   n_1 (sine of angle of incidence) = n_2 (sine of angle of refraction)
   n_1 (sine of 30 degrees) = 1 (sine of angle of refraction)
   n_1 (0.5000) = (sine of angle of refraction)
   n_1 = (sine of angle of refraction)/(0.5000)

Another way to look at this relationship is:

n_1 (sine of angle of incidence) = n_2 (sine of angle of refraction)
n_1 = n_2 (sine of angle of refraction)/(sine or angle of incidence)

10. Label two new sheets of paper, Sample 2 and Sample 3. Repeat this procedure for each of the Samples 2 and 3. Use 30 degrees as your angle of impact for each sample, and calculate the refractive index of each of the liquids. Record all information in the data table.

Refractive Index of Three Liquid Samples

Liquid Sample	Angle of Incidence (I)	Sine of Angle I	Angle of Refraction	Sine of Angle R	Refractive Index of Liquid
1	30°				
2	30°				
3	30°				

1. Compare the refractive indices of each of the three liquids. Which liquid had the highest refractive index and which one had the lowest refractive index?
2. Describe any visual correlation you can make about the refractive index and the appearance of the three different liquids.
3. Suppose you set your angle of impact at 45 degrees instead of at 30 degrees. Would you have obtained a different refractive index using the 45-degree angle of incidence instead of the 30-degree angle of incidence? Explain your answer.
4. Your two different mediums through which light passed in this experiment were the liquids and the air. In terms of density, air is less dense than any of the liquids. Would you expect the velocity of light to be faster or slower moving through the liquids than the air? Explain your answer.
5. If we assume that air is less dense than the liquids, did the angle of refraction move toward the normal, or did it move away from the normal as the light traveled from the liquid (more dense) through the air (less dense)? Support your answer with data from your table.
6. Suggest other liquids to test for refractive index that you think might give you a higher refractive index than any of the liquids selected in this experiment.
7. As the thickness of the liquid increases, what effect might that have on the bending of light? Will the bending become more pronounced or less pronounced? Explain.

Answers

Check students' diagrams, calculations, and data tables.

Questions

1. Answers will vary.
2. Answers will vary.
3. Refractive index is a physical property and will not change based on angle of impact. RI is a constant, just like density. (However, it can vary slightly with temperature and wavelength of light used.)
4. Light travels faster in the less-dense air and more slowly through the denser liquids.
5. The angle of refraction moves away from the normal as the light traveled from the liquid through the air.
6. Answers will vary.
7. The thicker (more dense) the liquid, the slower the beam of light will travel, making a more pronounced bend as thickness increases.

Further Research and Extensions

If all of the liquids you are testing are similar in color, after completing this activity, give students an unknown liquid and have them identify which of the three liquids it is.

ACTIVITY 14-4

Background

In this activity, students try to match the glass found in the sneakers on the two suspects to the glass found in the broken display case by determining the refractive indexes of the glass samples. Then, they will use the refractive indexes to try to match glass from one of the suspects to the crime-scene glass.

Safety Precautions

1. Spread newspaper or construction paper in the work area to capture small fragments of glass.
2. Remind students to always handle glass with forceps.
3. Stress that both methanol and isopropyl alcohol are highly flammable, and the fumes are volatile.
4. Have a designated area to dispose of any broken glass.
5. Use a vent or hood when using cinnamon oil due to the strong odor.

ACTIVITY 14-4 *Ch. Obj. 14.5 and 14.8*

DETERMINING REFRACTIVE INDEX OF GLASS USING LIQUID COMPARISONS IN A SUBMERSION TEST

Objectives:

By the end of this activity, you will be able to:

1. Perform a submersion test on glass fragments to estimate the refractive index of the glass fragment.
2. Explain how to do a submersion test on glass fragments.
3. Compare the refractive indices of the evidence glass pieces to the refractive index of the crime-scene glass.
4. Determine if the suspects can be linked to the crime scene based on the refractive indices of the evidence glass and the refractive index of the crime-scene glass.

Time Required to Complete Activity: 45 minutes

Materials

(per group of four students)
3 samples of glass fragments contained in evidence bags labeled Crime Scene, Suspect #1, Suspect #2
1 pair forceps
1 beaker of 250 mL detergent solution
250 mL of tap water
permanent marker
1 test tube rack
labeling tape
paper toweling
set of 7 small test tubes half filled with
- methanol
- water
- isopropyl alcohol
- olive oil
- cinnamon oil*
- castor oil
- clove oil*

*Because of expense and odor, these two tubes may be set up by your teacher as a demonstration for the entire class to use.

Safety Precautions:

Spread newspaper or construction paper in the work area to capture small fragments of glass. Handle glass with forceps.

Scenario:

Students at a local high school decided to steal the basketball trophy in the locked display case near the gym. They planned to steal the trophy after 7 p.m., when only a few janitors would be in the building. Once the glass case was broken, they thought they could easily run out of the back door by the gym. What they didn't plan on was that the coach came back to his office just as he heard the glass breaking and saw the two boys running out of the gym.

The coach thought he recognized one of the boys by his coat that held numerous old snowboard lift tickets from the past four years. He reported the incident and gave a description to the police, who quickly located both boys at the pizza place across the street from the school.

Did they break into the display case and steal the trophy? The police brought the boys to the police station, where they examined the bottom of their sneakers. As expected, small particles of glass were embedded in the soles of their sneakers. Did the glass in their sneakers match the glass found in the display window where the trophy case was removed? What type of testing can be used to match the glass in their sneakers to the glass found in the display case?

Background:

In this activity, we will try to match the glass found in the sneakers on the two suspects to the glass found in the broken display case. Refractive indices of the glass found in their sneakers will be compared to the refractive index of the glass in the display case.

Liquids of known refractive indices can be used to visually estimate the refractive index of glass samples. In order to estimate the refractive index of a piece of glass, submerge individual pieces of the glass in a series of different liquids. If the glass appears to disappear when submerged, then the glass has a refractive index similar to the solution. If the refractive index of the glass differs from the refractive index of the solution in which it is immersed, you will be able to see an outline of the glass. This is known as a submersion test for refractive index.

After testing the evidence glass from the sneakers and determining the refractive indices of the glass, you will test the crime-scene glass for its refractive index. If the glass from the crime scene has the same refractive index as the glass from the suspects' sneakers, it can place the suspects at the crime scene.

Procedure:

1. Obtain a test tube rack with five test tubes. Label the tops of the five test tubes in the following order:
   - methanol
   - water
   - isopropyl alcohol
   - olive oil
   - castor oil
2. Half fill each test tube with the five different liquids as numbered in the table. They are arranged in increasing order of refractive index. The table provides the refractive index of each liquid.

Procedures

1. Print, copy, and distribute Activity Sheet 14-4 from the IRCD.
2. Make sure students read all directions *before* beginning the activity.
3. Because there will inevitably be some accidental dropping of glass pieces into the test tubes, plan ahead of time how you will have students retrieve them from the tube.

Teaching Tip

Remind students to hold the piece of glass securely during the submersion tests. The same piece should be used for each liquid. It should be washed, blotted, and then submerged in each consecutive liquid.

Data Table 1: Refractive Indices of Liquids

Liquid	Refractive Index
1. Methanol	1.33
2. Water	1.33
3. Isopropyl alcohol	1.37
4. Olive oil	1.47
5. Castor oil	1.48
6. Clove oil (teacher display)	1.54
7. Cinnamon oil (teacher display)	1.62

3. You need to maintain proper chain of custody when opening and resealing each of the evidence envelopes. Remember to:
   a. Cut open the bag in an area that does not disrupt the signature of the person who had the evidence bag before you.
   b. Sign and date the Chain of Possession form on the front of the evidence bag.
   c. When resealing the bag, tape each bag and sign your name or initials across the interface of the tape and the package.
4. Starting with the crime-scene glass, submerge a fragment of the glass into test tube 1. Hold the glass fragment with a forceps. Do not let go of the glass fragment.
5. View the submerged glass at eye level. Is the glass invisible, or can you see the glass fragment? Record your results on Table 2. Remember: If the glass and the liquid have the same refractive index, the glass will seem to disappear in the solution. The test tube containing the liquid that results in the disappearance of the glass fragment best approximates the refractive index of the glass.
6. Remove the piece of glass from test tube 1 using the forceps. Wash the glass and forceps in the soap solution, rinse the glass and forceps in a beaker of water, and dry them on the paper towel.
7. Submerge the *same piece* or a new piece of glass in test tube 2 and observe. Is the glass visible, slightly visible, or invisible? Record the information on Data Table 2.
8. Rinse the glass piece and forceps in the soapy water followed by tap water and dry before continuing with the same procedure until you have tested the crime-scene glass on all seven solutions (your five solutions and the two solutions set up by your teacher).
9. Repeat the procedure for the submersion test on a glass fragment found on Suspect #1 and Suspect #2 and record your results in Data Table 2.

Data Table 2: Submersion Test Results

Test Tube #	Refractive Index of Liquid	Visibility: Visible / Slightly visible / Invisible		
		Crime Scene	Suspect 1	Suspect 2
1. Methanol	1.33			
2. Water	1.33			
3. Isopropyl alcohol	1.37			
4. Olive oil	1.47			
5. Castor oil	1.48			
6. Clove oil (teacher display)	1.54			
7. Cinnamon oil (teacher display)	1.62			

Questions:

1. Based on the results of your submersion test, record the estimated refractive indices for each of the glass fragments.
   The Refractive Index (RI) of the Crime Scene glass = ________
   The Refractive Index (RI) of the glass from Suspect #1 = ________
   The Refractive Index (RI) of the glass from Suspect #2 = ________
2. What would you consider to be the experimental errors in using this technique?
3. What could you do to improve the reliability of this experiment?
4. Is your match conclusive? Why or why not?
5. Why would the match of glass from a crime scene and a suspect be considered to be class evidence?
6. Explain refraction of light. Include in your answer the following:
   - two different mediums
   - light velocity
   - density
7. A refractive index of olive oil is equal to 1.47. It is calculated as a ratio between what two numbers?

Answers

Check students' data tables and calculations.

Questions

1. Answers will vary.
2. Answers will vary. Some answers might include not having a large enough piece of glass or not thoroughly cleaning and drying glass prior to new submersion.
3. Repeat the test using another glass sample, have your partner repeat the sampling, and compare results.
4. Answers will vary.
5. A match between glass from a suspect and crime scene is class evidence, because glass is common with little variation.
6. Refraction of light is the bending of a beam of light as it passes between two mediums of different densities. The velocity of the light slows as it moves from a lower-density medium to a higher-density medium.
7. The RI of olive oil (or any medium) is a ratio of the speed of light in a vacuum and the speed of light through the medium; in this case, olive oil.

Further Research and Extensions

Have several additional liquids available for students who complete the activity early, or who are interested in further investigation.