



By Brian Rohrig

**A** 23-year-old single female is awakened in the middle of the night by an intruder standing over her bed. She screams. The intruder flees in a panic, diving through a closed window. The police are notified immediately. They apprehend a suspect several blocks from the scene. He claims to be innocent, yet the police discover several shards of glass in the suspect's hair and clothing. When these samples are compared to the glass of the broken window, they are discovered to be the exact same type of glass. On the basis of this evidence, the intruder is eventually convicted and sent to jail.

Because acts of violence often involve broken glass, glass is one of the most commonly encountered forms of evidence found at crime scenes. However, many pieces of glass appear identical to the naked eye even though they can differ markedly in their chemical composition.

## How do forensic scientists match samples of glass?

Careful observation can reveal subtle but important differences between various types of glass. The forensic chemist may use several methods for determining whether two samples of glass originated from the same source. The first step is to visually examine the glass. Physical properties of the glass are then measured. Subsequent steps involve analysis of the chemical composition and differences in the way it was manufactured.

### Physical examination

Some important features to note are edge thickness, color, and the presence of any labels or imprints on the glass. A black-light lamp may be used to check for repairs as hairline cracks will glow under ultraviolet light. Modern paints will also glow under a blacklight.

### Thickness

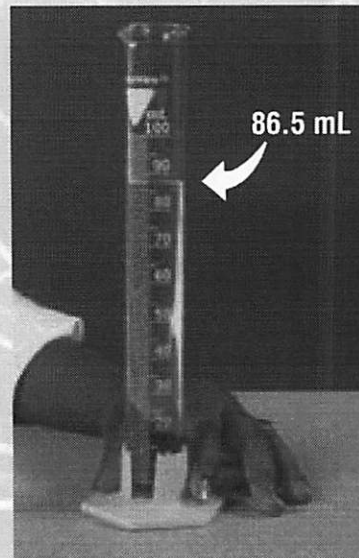
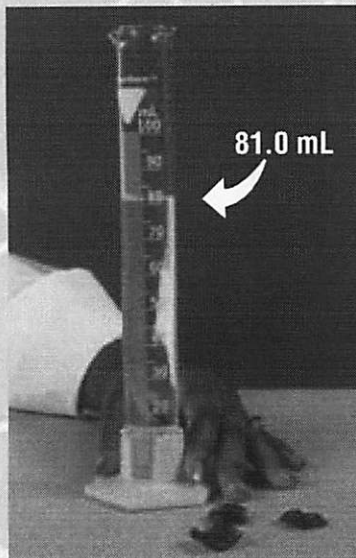
Glass thickness is generally a function of its application. Glass from a light bulb is going to be thinner than a pane of window

glass. The glass used in a picture frame is generally not subject to gusts of wind, so it will be thinner than glass used in a window. Glass used in a door is generally even thicker, to withstand the forces applied as a result of frequent opening and closing (and sometimes slamming!).

### Density

One of the most common methods for matching glass samples is the determination of density. The formula for density is mass/volume, and the density of two pieces of glass will always be the same if they come from the same source, regardless of the size of the two pieces. The formula method for determining density involves measuring the volume of a glass sample of known mass. The volume can be determined by displacing water in a volumetric flask.

Another more accurate method of comparing densities is the flotation method. A sample of glass is dropped into and sinks to the bottom of a liquid containing an exact volume of a dense liquid, such as bromobenzene ( $d = 1.52 \text{ g/mL}$ ). Then, a denser liquid, such as bromoform ( $d = 2.89 \text{ g/mL}$ ) is added dropwise until the piece of glass rises up from the bottom and attains neutral buoyancy. Neutral buoyancy occurs when an object has the exact



The formula method for determining density: After finding the mass of an object, measure its volume by water displacement.

same density as the surrounding fluid, and neither sinks nor floats but is suspended in one place beneath the surface of the fluid.

The same procedure is then performed with another piece of glass, and if the volume needed to attain neutral buoyancy is the same as for the first sample, then the densities of the two samples are equal. The exact density of each sample can be calculated by using the following formula:

$$d = \frac{X(2.89) + Y(1.52)}{X + Y}$$

X and Y refer to the volumes of the respective liquids, with the numbers in parentheses referring to the densities of each liquid. Any two liquids can be used, as long as they are miscible in one another and have appropriate densities. But when determining the density of glass, liquids with a relatively high density must be used, since glass is always denser than water. The density of a typical piece of single-pane window glass ranges from 2.47 to 2.56 g/mL. If the density of a 1.5-g sample of glass were 2.48 g/mL, what would you predict the density to be for a 3.0-g sample of the same glass? (Find the answer at the conclusion of this article.)

## Refractive index

Another very accurate method used to compare samples is to determine their index of refraction, or refractive index. Any object that transmits light has its own refractive index, which is a measure of how much the object slows the speed of light. When light passes through any medium, it is slowed down. The denser the medium, the slower the light travels. The refractive index of any substance is a ratio of the velocity of light in a vacuum to the velocity of light in that particular medium. For example, the refractive index for water is 1.33. This means that light travels 1.33 times faster in a vacuum than it does in water. And when light passes from one medium to another one with a different refractive index, refraction (or bending) of the light occurs. This is why objects appear bent or distorted under water.

Every liquid has its own refractive index. If a piece of glass is placed in a liquid with a different refractive index, an outline of the glass is clearly visible—known as the Becke line. However, if a piece of glass is placed in a liquid with the same refractive index, the Becke line will disappear and the glass will seem to disappear. This is because the glass bends light at the same angle as the liquid.

Glycerin has a refractive index of 1.473. If a piece of glass seems to disappear in glycerin, then it too has a refractive index of 1.473. If two samples of glass have the same refractive index, this does not necessarily prove they are from the same source. But if two samples have different refractive indexes, they are definitely not from the same source. The FBI has a database of refractive index values for approximately 2000 different types of glass, allowing forensic scientists the ability to identify samples. The most common value for the refractive index of glass is 1.5180.



The beaker on the left contains water and the one on the right, glycerin. Both beakers also contain a glass stirring rod. Because the glass rod and glycerin have the same refractive index, the glass rod in the beaker on the right seems to "disappear."



## Chemical composition

If both the density and refractive index of two samples of glass are the same, then the final test will involve sophisticated methods to determine their chemical composition. The difference between types of glass can be due to the chemical composition of the glass itself or differences in how the glass was manufactured. Most glass is made from silicon dioxide ( $\text{SiO}_2$ ), the primary ingredient in sand, which has been heated above its melting point of  $1600^\circ\text{C}$ . Various substances are then added, depending on what type of glass is desired.

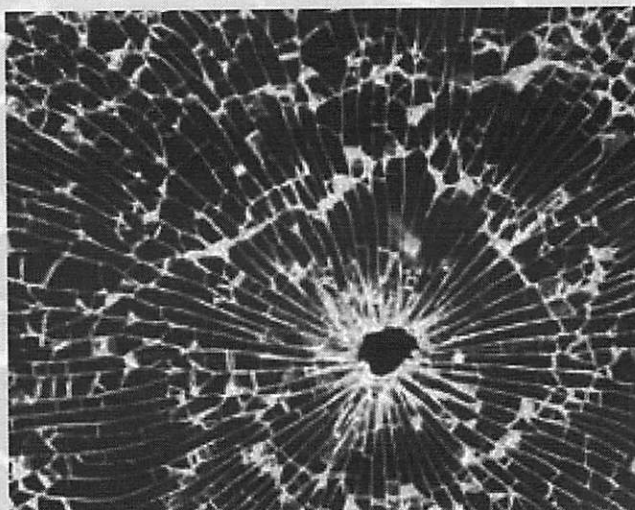
Different additives can impart different properties to the glass. Sodium carbonate or soda ( $\text{Na}_2\text{CO}_3$ ) is added to the silicon dioxide during glassmaking, lowering both its viscosity and melting point. The soda increases the water solubility of  $\text{SiO}_2$ , making it much easier to fashion into glass. Calcium oxide or lime ( $\text{CaO}$ ) is added next, restoring water insolubility to the mixture. As a result of these two additives, most glass used to make windows or bottles is known as soda-lime glass.

Boron oxide ( $\text{B}_2\text{O}_3$ ) is used to make Pyrex glassware. The beakers and test tubes you use in chemistry lab are most likely made from Pyrex, as is the glass used to make auto headlights. Glass made with boron oxide expands and contracts very little when heated and cooled, which is why Pyrex glassware can be heated and then cooled without breaking.

To make eyeglasses, a very sturdy glass is desired, so the additive potassium oxide ( $\text{K}_2\text{O}$ ) may be used. This imparts hardness to the glass. Other metallic oxides can give glass a specific color. Copper and cobalt oxides are used to make glass blue, manganese oxides give glass a purple color, and lead-antimony oxide imparts an opaque yellow.

## Who fired first?

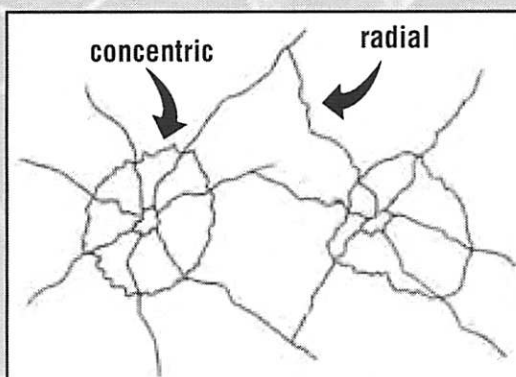
When a bullet strikes a pane of ordinary window glass, careful observation can reveal several crucial details. First of all, glass has a certain degree of elasticity and will break when this elastic limit is exceeded. This elasticity produces the familiar pattern of concentric and radial fractures that accompany penetration of glass by a projectile. The radial fractures are produced first and always form on the side of the glass opposite to where the



A bullet hole in window glass.

impact originated. Radial fractures look like spider webs that spread outward from the impact hole. Concentric fractures form next, and these lines encircle the bullet hole. Concentric fractures always start on the same side as that of the destructive force.

A radial fracture will always terminate into an existing fracture (see illustration). If there is a second bullet hole in a piece of glass, its radial fractures will always terminate into the cracks from the first bullet hole. The radial cracks from a third bullet will terminate into the radial fractures from the second bullet, and so forth. The sequence of numerous bullet holes can be determined by this method. If the glass is shattered, it may be



The sequence of shots can be determined: the radial fractures of the second hole terminate in those from the first hole.

necessary to reconstruct the broken pieces first. There has been more than one case of a shootout ensuing through the windshield of a car between a police officer and a suspect. By examining the termination lines of the radial fractures from each bullet hole and by com-

paring the size of the exit and entrance holes of each bullet, it can be determined who fired first.

The direction from which a bullet was fired can be determined by comparing the size of the entrance hole to that of the exit hole. Exit holes are always larger, regardless of the type of material through which a bullet penetrated.

Because glass is elastic and bows

outward when struck by a bullet, a larger piece of glass will be knocked out on the surface where the bullet is leaving as opposed to the very small hole the bullet makes when it enters.

Because of its elasticity, glass always blows back in the direction the impact originated. Because of the violent tendency of glass to snap back after being stressed, it can blow back glass several meters in the direction from which the shot originated. If a bullet strikes a window from the outside and shatters it, most of the glass will be on the outside. This piece of information can be extremely valuable in determining from which direction a shot was fired.

## Was the light on or off?

Here's a bit of information that can be valuable in crime scenes involving a broken incandescent bulb, especially among vehicle collisions. It is easy for someone to drive at night with their lights off while driving down a well-lit street. But suppose you're cruising down the road one night, and bam! You get into an accident with a motorist who did not have his lights on. If it could be proven that the other motorist failed to turn on his headlights, this would be a big boost to your case. But suppose it is his word against yours. By examining the broken filament of a light bulb, it can easily be determined whether the bulb was on or off when it was broken.

Light bulbs do not actually burn, but rather, glow as the tungsten filament becomes very hot due to the resistance that the elec-

trons encounter as they pass through the very narrow wire filament. The definition of incandescence is the property of emitting light as a result of being heated, but not actually burning. The electrons in the filament material absorb energy and jump to higher atomic orbitals (excited state). They then release a photon as they fall back to their original ground state orbital. In a properly functioning light bulb, the glowing filament is inside of the bulb filled with a noble gas such as argon.

But if the filament is glowing when the bulb is broken, it will immediately react with oxygen in the air and break in half. This will form a thick layer of yellowish-white tungsten oxide on the filament due to the reaction of the tungsten with oxygen. If the presence of tungsten oxide on the filament is found, then it can be proven that the bulb was on when the accident occurred. The absence of tungsten oxide on the filament reveals that the bulb was probably off when it was broken.

## Solving the crime

Sometimes, a bit of deductive reasoning is all it takes to solve a crime. In 1988, there were dozens of claims by consumers that they had found shards of glass in jars of Gerber baby food. After forensic investigators examined these contaminated jars, they discovered many different types of glass—glass from mirrors, bulbs, and car headlights were all found. If the glass came from the manufacturing plant due to an accident such as a light bulb breaking over the production line, then you would expect to find only one type of glass in the jars, not several. It was therefore concluded that the glass found in the jars of baby food was a result of deliberate tampering.

The field of forensic science provides a fascinating glimpse into how science can be used to solve crimes. A well-trained forensic scientist uses aspects of biology, chemistry, physics, and mathematics to reconstruct what may have happened at a crime scene. Criminals may break society's laws, but they cannot break the laws of nature.

## Answer to question:

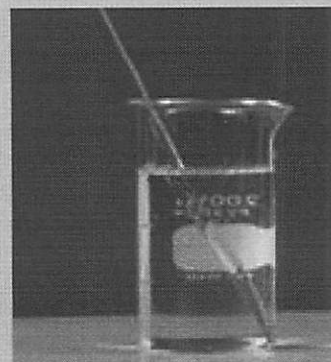
The 3.0-g sample of glass has the same density as the 1.5-g sample. It might be twice as massive, but then it has twice the volume. Since density is  $M/V$ , the density of both pieces would be identical. Remember, density does not depend on the size of the sample! ▲

# Disappearing Glass

*Here is another cool activity involving glass.*

## Materials

approved protective eyewear  
paper towels  
(2) 10-mL graduated cylinders  
1 glass stirring rod  
glycerol (about 10 mL)  
water (about 10 mL)



*Wear your safety goggles during this activity, and do not taste any of the liquids used.*

1. Obtain a glass stirring rod from your teacher.
2. Place about 8 mL of glycerol in a 10-mL graduated cylinder and 8 mL of water in another 10-mL graduated cylinder.
3. Put the stirring rod into the graduated cylinder with the water in it.
4. Record your observations.
5. Remove the stirring rod and dry it off with a paper towel.
6. Now place the rod in the graduated cylinder containing the glycerol. What happens?
7. Record your observations.

After discussing this activity with your small group, devise an explanation for what you observed. Be prepared to share this with the class.

## REFERENCES

Ellis, W. S., *Glass*. Avon Books: New York, 1998.  
Fisher, D. *Hard Evidence*. Dell: New York, 1995.  
Saferstein, R. *Criminalistics: An Introduction to Forensic Science*. Pearson Prentice Hall: Upper Saddle River, NJ, 2004.

## INTERNET RESOURCES

Automobile Window Glass—A Design Defect That Should Not Be Overlooked, <http://www.auto-law.com/CM/PracticeAreaDescriptions/PracticeAreaDescriptions58.asp>.  
Bullets Out, None In, <http://www.discover.com/issues/nov-03/rd/bullets-out-none-in/>.  
Different Types of Glass, <http://www.diydata.com/materials/glass/glass.htm>.  
Glass, <http://en.wikipedia.org/wiki/Glass>.  
How does safety glass work?, <http://computer.howstuffworks.com/questions508.htm>.  
Tempered Glass Breakage, <http://alumaxbath.com/tech/tgb.htm>.  
What makes glass transparent?, <http://science.howstuffworks.com/question404.htm>.  
What's That Stuff? Glass, <http://pubs.acs.org/cen/whatstuff/stuff/8147glass.html>.

*Brian Rohrig* teaches at Jonathan Alder High School in Plain City, OH. His most recent *ChemMatters* article, "The Chemistry of Digital Photography and Printing", appeared in the February 2006 issue.