chapter 4

Physical Properties: Glass and Soil

Key Terms

amorphous solid

atom

Becke line

birefringence

Celsius scale

chemical property

concentric fracture

crystalline solid

density

density-gradient tube

dispersion

Fahrenheit scale

intensive property

laminated glass

mass

mineral

physical property

radial fracture

refraction

refractive index

tempered glass

weight

Learning Objectives

After studying this chapter you should be able to:

- Define and distinguish the physical and chemical properties of matter
- Understand how to use the basic units of the metric system
- Define and understand the properties of density and refractive index
- Understand and explain the dispersion of light through a prism
- List and explain forensic methods for comparing glass fragments
- Understand how to examine glass fractures to determine the direction of impact for a projectile
- List the important forensic properties of soil
- **Describe the proper collection of glass and soil evidence**

Murder and the Horse Chestnut Tree

Roger Severs was the son of a wealthy English couple, Eileen and Derek Severs. The elder Serverses were reported missing in 1983. Police investigators were greeted at the Severs home by Roger, who at first explained that his parents had decided to spend some time in London. Suspicion of foul play quickly arose when investigators located traces of blood in the residence. More blood was found in Derek's car and signs of blood spatter were on the garage door. Curiously, a number of green fibers were located throughout the house, as well as in the trunk of Derek's car. A thorough geological examination of soil and vegetation caked onto Severs' car wheel rims seemed to indicate that the car had been in a location at the edge of a wooded area. Closer examination of the debris also revealed the presence of horse chestnut pollen. Horse chestnut is an exceptionally rare tree in the region of the Severs residence. Using land maps, a geologist was able to locate possible areas where horse chestnut pollen might be found. In one of the locations, investigators found a shallow grave that contained the bludgeoned bodies of the elder Severses. Not surprisingly, they were wrapped in a green blanket. A jury rejected Roger's defense of diminished capacity and found him guilty of murder.

The forensic scientist must constantly determine the properties that impart distinguishing characteristics to matter, giving it a unique identity. The continuing search for distinctive properties ends only when the scientist has completely individualized a substance to one correct source. Properties are the identifying characteristics of substances. In this and succeeding chapters, we will examine properties that are most useful for characterizing soil, glass, and other physical evidence. However, before we begin, we can simplify our understanding of the nature of properties by classifying them into two broad categories: physical and chemical.

Physical properties describe a substance without reference to any other substance. For example, weight, volume, color, boiling point, and melting point are typical physical properties that can be measured for a particular substance without altering the material's composition through a chemical reaction; they are associated only with the physical existence of that substance. **A chemical property describes the behavior of a substance when it reacts or combines with another substance.** For example, when wood burns, it chemically combines with oxygen in the air to form new substances; this transformation describes a chemical property of wood. In the crime laboratory, a routine procedure for determining the presence of heroin in a suspect specimen is to react it with a chemical reagent known as the Marquis reagent, which turns purple in the presence of heroin. This color transformation becomes a chemical property of heroin and provides a convenient test for its identification.

Which physical and chemical properties the forensic scientist ultimately chooses to observe and measure depends on the type of material that is being examined. Logic requires, however, that if the property can be assigned a numerical value, it must relate to a standard system of measurement accepted throughout the scientific community.

THE METRIC SYSTEM

Although scientists, including forensic scientists, throughout the world have been using the metric system of measurement for more than a century, the United States still uses the cumbersome "English system" to express length in inches, feet, or yards; weight in ounces or pounds; and volume in pints or quarts. The inherent difficulty of this system is that no simple numerical relationship exists between the various units of measurement. For example, to convert inches to feet one must know that 1 foot is equal to 12 inches; conversion of ounces to pounds requires the knowledge that 16 ounces is equivalent to 1 pound. In 1791, the French Academy of Science devised the simple system of measurement known as the metric system. This system uses a simple decimal relationship so that a unit of length, volume, or mass can be converted into a subunit by simply multiplying or dividing by a multiple of 10—for example, 10, 100, or 1,000.

Even though the United States has not yet adopted the metric system, its system of currency is decimal and, hence, is analogous to the metric system. The basic unit of currency is the dollar. A dollar is divided into 10 equal units called dimes, and each dime is further divided into 10 equal units of cents.

The metric system has basic units of measurement for length, mass, and volume: the meter, gram, and liter, respectively. These three basic units can be converted into subunits that are decimal multiples of the basic unit by simply attaching a prefix to the unit name. The following are common prefixes and their equivalent decimal value:

Prefix	**Equivalent Value**
deci-	1/10 or 0.1
centi-	1/100 or 0.01
milli-	1/1000 or 0.001
micro-	1/100,000 or 0.000001
nano-	1/1,000,000,000 or 0.000000001
kilo-	1,000
mega-	1,000,000

Hence, 1/10 or 0.1 gram (g) is the same as a decigram (dg), 1/100 or 0.01 meter is equal to a centimeter (cm), and 1/1,000 liter is a milliliter (mL). A metric conversion is carried out simply by moving the decimal point to the right or left and inserting the proper prefix to show the direction and number of places that the decimal point has been moved. For example, if the weight of a powder is 0.0165 gram, it may be more convenient to multiply this value by 100 and express it as 1.65 centigrams or by 1,000 to show it as its equivalent value of 16.5 milligrams. Similarly, an object that weighs 264,450 grams may be expressed as 264.45 kilograms simply by dividing it by 1,000. It is important to remember that in any of these conversions, the value of the measurement has not changed; 0.0165 gram is still equivalent to 1.65 centigrams, just as one dollar is still equal to 100 cents. We have simply adjusted the position of the decimal and shown the extent of the adjustment with a prefix.

One interesting aspect of the metric system is that volume can be defined in terms of length. A liter by definition is the volume of a cube with sides of length 10 centimeters. One liter is therefore equivalent to a volume of 10 cm × 10 cm × 10 cm, or 1,000 cubic centimeters (cc). Thus, 1/1,000 liter or 1 milliliter (mL) is equal to 1 cubic centimeter (cc) (see Figure 4–1). Scientists commonly use the subunits mL and cc interchangeably to express volume.

At times, it may be necessary to convert units from the metric system into the English system, or vice versa (see Figure 4–2). To accomplish this, we must consult references that list English units and their metric equivalents. Some of the more useful equivalents follow:

1 inch = 2.54 centimeters

1 meter = 39.37 inches

1 pound = 453.6 grams

1 liter = 1.06 quarts

1 kilogram = 2.2 pounds

The general mathematical procedures for converting from one system to another can be illustrated by converting 12 inches into centimeters. To change inches into centimeters, we need to know that there are 2.54 centimeters per inch. Hence, if we multiply 12 inches by 2.54 centimeters per inch (12 in. × 2.54 cm/in.), the unit of inches will cancel out, leaving the product 30.48 cm. Similarly, applying the conversion of grams to pounds, 227 grams is equivalent to 227 g × 1 lb/453.6 g or 0.5 lb.

PHYSICAL PROPERTIES

Temperature

Determining the physical properties of any material often requires measuring its temperature. For instance, the temperatures at which a substance melts or boils are readily determinable characteristics that will help identify it. Temperature is a measure of heat intensity, or the amount of heat in a substance. Temperature is usually measured by causing a thermometer to come into contact with a substance. The familiar mercury-in-glass thermometer functions because mercury expands more than glass when heated and contracts more than glass when cooled. Thus, the length of the mercury column in the glass tube provides a measure of the surrounding environment's temperature. The construction of a temperature scale requires two reference points and a choice of units. The reference points most conveniently chosen are the freezing point and boiling point of water. The two most common temperature scales used are the **Fahrenheit** and **Celsius** (formerly called *centigrade*) **scales**.

The Fahrenheit scale is based on the assignment of the value 32°F to the freezing point of water and 212°F to its boiling point. The difference between the two points is evenly divided into 180 units. Thus, a degree Fahrenheit is 1/180 of the temperature change between the freezing point and boiling point of water. The Celsius scale is derived by assigning the freezing point of water a value of 0°C and its boiling point a value of 100°C. A degree Celsius is thus 1⁄100 of the temperature change between the two reference points. Scientists in most countries use the Celsius scale to measure temperature. A comparison of the two scales is shown in Figure 4–3.

Weight and Mass

The force with which gravity attracts a body is called **weight**. If your weight is 180 pounds, this means that the earth's gravity is pulling you down with a force of 180 pounds; on the moon, where the force of gravity is one-sixth that of the earth, your weight would be 30 pounds.

Mass differs from weight because it refers to the amount of matter an object contains and is independent of its location on earth or any other place in the universe. The mathematical relationship between weight (w) and mass (m) is shown in Equation (4–1), where g is the acceleration imparted to a body by the force of gravity.

$$W=mg \qquad \textbf{(4–1)}$$

The weight of a body is directly proportional to its mass; hence, a large mass weighs more than a small mass.

In the metric system, the mass of an object is always specified, rather than its weight. The basic unit of mass is the gram. An object that has a mass of 40 grams on earth will have a mass of 40 grams anywhere else in this universe. Normally, however, the terms *mass* and *weight* are used interchangeably, and we often speak of the weight of an object when we really mean its mass.

The mass of an object is determined by comparing it against the known mass of standard objects. The comparison is confusingly called *weighing*, and the standard objects are called *weights* (*masses* would be a more correct term). The comparison is performed on a balance. The simplest type of balance for weighing is the equal-arm balance shown in Figure 4–4. The object to be weighed is placed on the left pan, and the standard weights are placed on the right pan; when the pointer between the two pans is at the center mark, the total mass on the right pan is equal to the mass of the object on the left pan.

The modern laboratory has progressed beyond the simple equal-arm balance, and either the top-loading balance or the single-pan analytical balance (see Figure 4–5) is now likely to be used. The choice depends on the accuracy required and the amount of material being weighed. Each works on the same counterbalancing principle as the simple equal-arm balance. Earlier versions of the single-pan balance had a second pan, the one on which the standard weights were placed. This pan was hidden from view within the balance's housing. Once the object whose weight was to be determined was placed on the visible pan, the operator selected the proper standard weights (also contained within the housing) by manually turning a set of knobs located on the front side of the balance. At the point of balance, the weights selected were automatically recorded on optical readout scales. Modern single-pan balances rely on an electromagnetic field to generate a current to balance the force pressing down on the pan from the sample being weighed. When the scale is properly calibrated, the amount of current needed to keep the pan balanced is used to determine the weight of the sample. The strength of the current is converted to a digitized signal for a readout. The top-loading balance can accurately weigh an object to the nearest 1 milligram or 0.001 gram; the analytical balance is even more accurate, weighing to the nearest tenth of a milligram or 0.0001 gram.

Density

A most important physical property of matter with respect to the analysis of certain kinds of physical evidence is **density**. **Density is defined as mass per unit volume** [see Equation (4–2)].

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \qquad \textbf{(4–2)}$$

Density is an **intensive property** of matter—that is, it is the same regardless of the size of a substance; thus, it is a characteristic property of a substance and can be used as an aid in identification. Solids tend to be more dense than liquids, and liquids more dense than gases. The densities of some common substances are shown in Table 4–1.

A simple procedure for determining the density of a solid is illustrated in Figure 4–6. First, the solid is weighed on a balance against known standard gram weights to determine its mass. The solid's volume is then determined from the volume of water it displaces. This is easily measured by filling a cylinder with a known volume of water (V_1), adding the object, and measuring the new water level (V_2). The difference $V_2 - V_1$ in milliliters is equal to the volume of the solid. Density can now be calculated from Equation (4–2) in grams per milliliter.

The volumes of gases and liquids vary considerably with temperature; hence, when determining density, it is important to control and record the temperature at which the measurements are made. For example, 1 gram of water occupies a volume of 1 milliliter at 4°C and thus has a density of 1.0 g/mL. However, as the temperature of water increases, its volume expands. Therefore, at 20°C (room temperature) one gram of water occupies a volume of 1.002 mL and will have a density of 0.998 g/mL.

Table 4–1 Densities of Select Materials (at 20°C unless otherwise stated)

Substance	**Density (g/mL)**
Solids	
Silver	10.5
Lead	11.5
Iron	7.8
Aluminum	2.7
Window glass	2.47–2.54
Ice (0°C)	0.92
Liquids	
Mercury	13.6
Benzene	0.88
Ethyl alcohol	0.79
Gasoline	0.69
Water at 4°C	1.00
Water	0.998
Gases	
Air (0°C)	0.0013
Chlorine (0°C)	0.0032

Oxygen (0°C)	0.0014
Carbon dioxide (0°C)	0.0020

The observation that a solid object either sinks, floats, or remains suspended when immersed in a liquid can be accounted for by the property of density. For instance, if the density of a solid is greater than that of the liquid in which it is immersed, the object sinks; if the solid's density is less than that of the liquid, it floats; and when the solid and liquid have equal densities, the solid remains suspended in the liquid. As we will shortly see, these observations provide a convenient technique for comparing the densities of solid objects.

Refractive Index

Light, as we will learn in the next chapter, can have the property of a wave. Light waves travel in air at a constant velocity of nearly 300 million meters per second until they penetrate another medium, such as glass or water, at which point they are suddenly slowed, causing the rays to bend. The bending of a light wave because of a change in velocity is called **refraction**.

The phenomenon of refraction is apparent when we view an object that is immersed in a transparent medium; because we are accustomed to thinking that light travels in a straight line, we often forget to take refraction into account. For instance, suppose a ball is observed at the bottom of a pool of water; the light rays reflected from the ball travel through the water and into the air to reach the eye. As the rays leave the water and enter the air, their velocity suddenly increases, causing them to be refracted. However, because of our assumption that light travels in a straight line, our eyes deceive us and make us think we see an object lying at a higher point than is actually the case. This phenomenon is illustrated in Figure 4–7.

The ratio of the velocity of light in a vacuum to that in any medium determines the **refrac-**

tive index of that medium and is expressed as follows:

$$\text{Refractive index} = \frac{\text{velocity of light in vacuum}}{\text{velocity of light in medium}} \qquad \textbf{(4–3)}$$

For example, at 25°C the refractive index of water is 1.333. This means that light travels 1.333 times as fast in a vacuum as it does in water at this temperature.

Like density, the refractive index is an intensive physical property of matter and characterizes a substance. However, any procedure used to determine a substance's refractive index must be performed under carefully controlled temperature and lighting conditions, because the refractive index of a substance varies with its temperature and the wavelength of light passing through it. Nearly all tabulated refractive indices are determined at a standard wavelength, usually 589.3 nanometers; this is the predominant wavelength emitted by sodium light and is commonly known as the sodium D light.

When a transparent solid is immersed in a liquid with a similar refractive index, light is not refracted as it passes from the liquid into the solid. For this reason, the eye cannot distinguish the liquid–solid boundary, and the solid seems to disappear from view. This observation, as we will see, offers the forensic scientist a simple method for comparing the refractive indices of transparent solids.

Normally, we expect a solid or a liquid to exhibit only one refractive index value for each wavelength of light; however, many crystalline solids have two refractive indices whose values depend in part on the direction in which the light enters the crystal with respect to the crystal axis. **Crystalline solids have definite geometric forms because of the orderly arrangement of the fundamental particle of a solid, the atom**. In any type of crystal, the relative locations and distances between its atoms are repetitive throughout the solid. Figure 4–8 shows the crystalline structure of sodium chloride, or ordinary table salt. Sodium chloride is an example of a cubic crystal in which each sodium atom is surrounded by six chloride atoms and each chloride atom by six sodium atoms, except at the crystal surface. Not all solids are crystalline in nature; some, such as glass, have their atoms arranged randomly throughout the solid; these materials are known as **amorphous solids**.

Most crystals, excluding those that have cubic configurations, refract a beam of light into two different light-ray components. This phenomenon, known as *double refraction*, can be observed by studying the behavior of the crystal calcite. When the calcite is laid on a printed page, the observer sees not one but two images of each word covered. The two light rays that give rise to the double image are refracted at different angles, and each has a different refractive index value. The indices of refraction for calcite are 1.486 and 1.658, and subtracting the two values yields a difference of 0.172; this difference is known as **birefringence**. Thus, the optical properties of crystals provide points of identification that help characterize them.

Many of us have held a glass prism up toward the sunlight and watched it transform light into the colors of the rainbow. This observation demonstrates that visible "white light" is not homogeneous but is actually composed of many different colors. The process of separating light into its component colors is called **dispersion**. The ability of a prism to disperse light into its component colors is explained by the property of refraction. Each color component of light, on passing through the glass, is slowed to a speed slightly different from those of the others, causing each component to bend at a different angle as it emerges from the prism. As shown in Figure 4–9, the component colors of visible light extend from red to violet. We will learn in Chapter 5 that each color actually corresponds to a different range of wavelengths of light. Dispersion thus separates light into its component wavelengths and demonstrates that glass has a slightly different index of refraction for each wavelength of light passing through it.

Now that we have investigated various physical properties of objects, we are ready to apply such properties to the characterization of two substances—glass and soil—that commonly must be examined by the criminalist.

COMPARING GLASS FRAGMENTS

Glass that is broken and shattered into fragments and minute particles during the commission of a crime can be used to place a suspect at the crime scene. For example, chips of broken glass from a window may lodge in a suspect's shoes or garments during a burglary, or particles of headlight glass found at the scene of a hit-and-run accident may offer clues that can confirm the identity of a suspect vehicle. All of these possibilities require the comparison of glass fragments found on the suspect, whether a person or vehicle, with the shattered glass remaining at the crime scene.

Glass is a hard, brittle, amorphous substance composed of sand (silicon oxides) mixed with various metal oxides. When sand is mixed with other metal oxides, melted at high temperatures, and then cooled to a rigid condition without crystallization, the product is glass. Soda (sodium carbonate) is normally added to the sand to lower its melting point and make it easier to work with. Another necessary ingredient is lime (calcium oxide), needed to prevent the "soda lime" glass from dissolving in water. The forensic scientist is often asked to analyze soda-lime glass, which is used for manufacturing most window and bottle glass. Usually the molten glass is cooled on a bed of molten tin. This manufacturing process produces flat glass typically used for windows. This type of glass is called *float glass.*

In addition, a wide variety of special glasses can be made by substituting in whole or in part other metal oxides for the silica, sodium, and calcium oxides. For example, automobile headlights and heat-resistant glass, such as Pyrex, are manufactured by adding boron oxide to the oxide mix. These glasses are therefore known as *borosilicates.*

Another type of glass that the reader may be familiar with is **tempered glass**. This glass is made stronger than ordinary window glass by introducing stress through rapid heating and cooling of the glass surfaces. When tempered glass breaks, it does not shatter but rather fragments or "dices" into small squares with little splintering. Because of this safety feature, tempered glass is used in the side and rear windows of automobiles made in the United States, as well as in the windshields of some foreign-made cars. The windshields of all cars manufactured in the United States are constructed from **laminated glass**. This glass derives its strength by sandwiching one layer of plastic between two pieces of ordinary window glass.

For the forensic scientist, comparing glass consists of finding and measuring the properties that will associate one glass fragment with another while minimizing or eliminating the possible existence of other sources. Needless to say, considering the prevalence of glass in our society, it is easy to appreciate the magnitude of this analytical problem. Obviously, glass possesses its greatest evidential value when it can be individualized to one source. Such a determination, however, can be made only when the suspect and crime-scene fragments are assembled and physically fitted together. Comparisons of this type require piecing together irregular edges of broken glass as well as matching all irregularities and striations on the broken surfaces (see Figure 4–10). The possibility that two pieces of glass originating from different sources will fit together exactly is so unlikely as to exclude all other sources from practical consideration.

Unfortunately, most glass evidence is either too fragmentary or too minute to permit a comparison of this type. In such instances, the search for individual properties has proven fruitless. For example, the general chemical composition of various window glasses within the capability of current analytical methods has so far been found relatively uniform among various manufacturers and thus offers no basis for individualization. However, trace elements present in glass have been shown to be useful for narrowing the origin of a glass specimen. **The physical properties of density and refractive index are most widely used for characterizing glass particles.** However, these properties are class characteristics, which cannot provide the sole criteria for individualizing glass to a common source. They do, however, give the analyst sufficient data to evaluate the significance of a glass comparison, and the absence of comparable density and refractive index values will certainly exclude glass fragments that originate from different sources.

Recall that a solid particle will either float, sink, or remain suspended in a liquid, depending on its density relative to the liquid. This knowledge gives the criminalist a rather precise and rapid method for comparing densities of glass. In a method known as *flotation,* a standard/reference glass particle is immersed in a liquid; a mixture of bromoform and bromobenzene may be used. The composition of the liquid is carefully adjusted by the addition of small amounts of bromoform or bromobenzene until the glass chip remains suspended in the liquid medium. At this point, the standard/reference glass and liquid each have the same density. Glass chips of approximately the same size and shape as the standard/reference are now added to the liquid for comparison. If both the unknown and the standard/reference particles remain suspended in the liquid, their densities are equal to each other and to that of the liquid.[1] Particles of different densities either sink or float, depending on whether they are more or less dense than the liquid.

The density of a single sheet of window glass is not completely homogeneous throughout. It has a range of values that can differ by as much as 0.0003 g/mL. Therefore, in order to distinguish between the normal internal density variations of a single sheet of glass and those of glasses of different origins, it is advisable to let the comparative density approach but not exceed a sensitivity value of 0.0003 g/mL. The flotation method meets this requirement and can adequately distinguish glass particles that differ in density by 0.001 g/mL.

Once glass has been distinguished by a density determination, different origins are immediately concluded. Comparable density results, however, require the added comparison of refractive indices. This determination is best accomplished by the *immersion method.* For this, glass particles are immersed in a liquid medium whose refractive index is adjusted until it equals that of the glass particles. At this point, known as the *match point*, the observer notes the disappearance of the **Becke line** and minimum contrast between the glass and liquid medium. The Becke line is a bright halo that is observed near the border of a particle that is immersed in a liquid of a different refractive index. This halo disappears when the medium and fragment have similar refractive indices.

The refractive index of an immersion fluid is best adjusted by changing the temperature of the liquid. Temperature control is, of course, critical to the success of the procedure. One approach to this procedure is to heat the liquid in a special apparatus known as a *hot stage.* The glass is immersed in a boiling liquid, usually a silicone oil, and heated at the rate of 0.2°C per minute until the match point is reached. Increasing the temperature of the liquid has a negligible effect on the refractive index of glass, while the liquid's index decreases at the rate of approximately 0.0004 per degree Celsius. The hot stage, as shown in Figure 4–11, is designed to be used in conjunction with a microscope, through which the examiner can observe the disappearance of the Becke line on minute glass particles that are illuminated with sodium D light or other wavelengths of light. If all the glass fragments examined have similar match points, it can be concluded that they have comparable refractive indices (see Figure 4–12). Furthermore, the examiner can determine the refractive index value of the immersion fluid as it changes with temperature. With this information, the exact numerical value of the glass refractive index can be calculated at the match point temperature.[2]

An automated approach for measuring the refractive index of glass fragments by temperature control using the immersion method with a hot stage is with the instrument known as GRIM 3 (Glass Refractive Index Measurement) (see Figure 4–13). The GRIM 3 is a personal computer/video system designed to automate the measurements of the match temperature and refractive index for glass fragments. This instrument uses a video camera to view the glass fragments as they are being heated. As the immersion oil is heated or cooled, the contrast of the video image is measured continually until a minimum, the match point, is detected (see Figure 4–14). The match point temperature is then converted to a refractive index using stored calibration data.

As with density, glass fragments removed from a single sheet of plate glass may not have a uniform refractive index value; instead, their values may vary by as much as 0.0002. Hence, for comparison purposes, the difference in refractive index between a standard/reference and questioned glass must exceed this value. This allows the examiner to differentiate between the normal internal variations present in a sheet of glass and those present in glasses that originated from completely different sources.

A significant difference in either density or refractive index proves that the glasses examined do not have a common origin. But what if two pieces of glass exhibit comparable densities and comparable refractive indices? How certain can one be that they did, indeed, come from the same source? After all, there are untold millions of windows and other glass objects in this world. To provide a reasonable answer to this question, the FBI Laboratory has collected density and refractive index values from glass submitted to it for examination. What has emerged is a data bank correlating these values to their frequency of occurrence in the glass population of the United States. This collection is available to all forensic laboratories in the United States.

Once a criminalist has completed a comparison of glass fragments, he or she can correlate their density and refractive index values to their frequency of occurrence and assess probability that the fragments came from the same source. Figure 4–15 shows the distribution of refractive index values (measured with sodium D light) for approximately two thousand glasses analyzed by the FBI. The wide distribution of values clearly demonstrates that the refractive index is a highly distinctive property of glass and is thus useful for defining its frequency of occurrence and hence its evidential value. For example, a glass fragment with a refractive index value of 1.5290 is found in approximately only 1 out of 2,000 specimens, while glass with a value of 1.5180 occurs approximately in 22 glasses out of 2,000.

The distinction between tempered and nontempered glass particles can be made by slowly heating and then cooling the glass (a process known as *annealing*). The change in the refractive index value for tempered glass upon annealing is significantly greater when compared to non-tempered glass and thus serves as a point of distinction.[3]

GLASS FRACTURES

Glass bends in response to any force exerted on any one of its surfaces; when the limit of its elasticity is reached, the glass fractures. Frequently, fractured window glass reveals information that can be related to the force and direction of an impact; such knowledge may be useful for reconstructing events at a crime-scene investigation.

The penetration of ordinary window glass by a projectile, whether a bullet or a stone, produces a familiar fracture pattern in which cracks both radiate outward and encircle the hole, as shown in Figure 4–16. The radiating lines are appropriately known as **radial fractures**, and the circular lines are termed **concentric fractures**.

Often it is difficult to determine just from the size and shape of a hole in glass whether it was made by a bullet or by some other projectile. For instance, a small stone thrown at a comparatively high speed against a pane of glass often produces a hole very similar to that produced by a bullet. On the other hand, a large stone can completely shatter a pane of glass in a manner closely resembling the result of a close-range shot. However, in the latter instance, the presence of gunpowder deposits on the shattered glass fragments points to damage caused by a firearm.

When it penetrates glass, a high-velocity projectile such as a bullet often leaves a round, crater-shaped hole surrounded by a nearly symmetrical pattern of radial and concentric cracks. The hole is inevitably wider on the exit side (see Figure 4–17), and hence examining it is an important step in determining the direction of impact. However, as the velocity of the penetrating projectile decreases, the irregularity of the shape of the hole and of its surrounding cracks increases, so that at some point the hole shape will not help determine the direction of impact. At this time, examining the radial and concentric fracture lines may help determine the direction of impact.

When a force pushes on one side of a pane of glass, the elasticity of the glass permits it to bend in the direction of the force applied. Once the elastic limit is exceeded, the glass begins to crack. As shown in Figure 4–18, the first fractures form on the surface opposite that of the penetrating force and develop into radial lines. The continued motion of the force places tension on the front surface of the glass, resulting in the formation of concentric cracks. An examination of the edges of the radial and concentric cracks frequently reveals stress markings *(Wallner lines)* whose shape can be related to the side on which the window first cracked.

Stress marks, shown in Figure 4–19, are shaped like arches that are perpendicular to one glass surface and curved nearly parallel to the opposite surface. The importance of stress marks stems from the observation that the perpendicular edge always faces the surface on which the crack originated. Thus, in examining the stress marks on the edge of a radial crack near the point of impact, the perpendicular end is always found opposite the side from which the force of impact was applied. For a concentric fracture, the perpendicular end always faces the surface on which the force originated. A convenient way for remembering these observations is the 3R rule—***R*adial cracks form a *R*ight angle on the *R*everse side of the force.** These facts enable the examiner to determine the side on which a window was broken. Unfortunately, the absence of radial or concentric fracture lines prevents these observations from being applied to broken tempered glass.

When there have been successive penetrations of glass, it is frequently possible to determine the sequence of impact by observing the existing fracture lines and their points of termination. **A fracture always terminates at an existing line of fracture.** In Figure 4–20, the fracture on the left preceded that on the right; we know this because the latter's radial fracture lines terminate at the cracks of the former.

COLLECTION AND PRESERVATION OF GLASS EVIDENCE

The gathering of glass evidence at the crime scene and from the suspect must be thorough if the examiner is to have any chance to individualize the fragments to a common source. If even the remotest possibility exists that fragments may be pieced together, every effort must be made to collect all the glass found. For example, evidence collection at hit-and-run scenes must include all the broken parts of the headlight and reflector lenses. This evidence may ultimately prove invaluable in placing a suspect vehicle at the accident scene by matching the fragments with glass remaining in the headlight or reflector shell of the suspect vehicle. In addition, examining the headlight's filaments may reveal whether an automobile's headlights were on or off before the impact (see Figure 4–21).

When an individual fit is improbable, the evidence collector must submit all glass evidence found in the possession of the suspect along with a sample of broken glass remaining at the crime scene. This standard/reference glass should always be taken from any remaining glass in the window or door frames, as close as possible to the point of breakage. About one square inch of sample is usually adequate for this purpose. The glass fragments should be packaged in solid containers to avoid further breakage. If the suspect's shoes and/or clothing are to be examined for the presence of glass fragments, they should be individually wrapped in paper and transmitted to the laboratory. The field investigator should avoid removing such evidence from garments unless absolutely necessary for its preservation.

When a determination of the direction of impact is desired, all broken glass must be recovered and submitted for analysis. Wherever possible, the exterior and interior surfaces of the glass must be indicated. When this is not immediately apparent, the presence of dirt, paint, grease, or putty may indicate the exterior surface of the glass.

FORENSIC CHARACTERISTICS OF SOIL

There are many definitions for the term *soil;* however, for forensic purposes, soil may be thought of as any disintegrated surface material, natural or artificial, that lies on or near the earth's surface. Therefore, the forensic examination of soil not only is concerned with the analysis of naturally occurring rocks, minerals, vegetation, and animal matter—it also encompasses the detection of such manufactured objects as glass, paint chips, asphalt, brick fragments, and cinders, whose presence may impart soil with characteristics that will make it unique to a particular location. When this material is collected accidentally or deliberately in a manner that will associate it with a crime under investigation, it becomes valuable physical evidence.[4]

The value of soil as evidence rests with its prevalence at crime scenes and its transferability between the scene and the criminal. Thus, soil or dried mud found adhering to a suspect's clothing or shoes, or to an automobile, when compared to soil samples collected at the crime site, may provide associative evidence that can link a suspect or object to the crime scene. As with most types of physical evidence, forensic soil analysis is comparative in nature; soil found in the possession of the suspect must be carefully collected to be compared to soil samplings from the crime scene and the surrounding vicinity. However, one should not rule out the value of soil even if the site of the crime has not been ascertained. For instance, small amounts of soil may be found on a person or object far from the actual site of a crime. A geologist who knows the local geology may be able to use geological maps to direct police to the general vicinity where the soil was originally picked up and the crime committed.

Most soils can be differentiated and distinguished by their gross appearance. A side-by-side visual comparison of the color and texture of soil specimens is easy to perform and provides a sensitive property for distinguishing soils that originate from different locations. Soil is darker when it is wet; therefore, color comparisons must always be made when all the samples are dried under identical laboratory conditions. It is estimated that there are nearly 1,100 distinguishable soil colors; hence, the comparison of color offers a logical first step in a forensic soil comparison.

Low-power microscopic examination of soil reveals the presence of plant and animal materials as well as of artificial debris. Further high-power microscopic examination will help characterize minerals and rocks present in earth materials. Although this approach to forensic soil identification requires the expertise of an investigator trained in geology, it can provide the most varied and significant points of comparison between soil samples. Only by carefully examining and comparing the minerals and rocks naturally present in soil can one take advantage of the large number of variations between soils and thus add to the evidential value of a positive comparison.[5] A **mineral** is a naturally occurring crystal, and like any other crystal, its physical properties—for example, color, geometric shape, density, and refractive index or birefringence—are most useful for identification. More than 2,200 minerals exist; however, most are so rare that forensic geologists usually encounter only about twenty of the more common ones. Rocks are composed of a combination of minerals and therefore exist in thousands of varieties on the earth’s surface. Their identification is usually made by characterizing their mineral content and grain size.

Considering the vast variety of minerals and rocks and the possible presence of artificial debris in soil, the forensic geologist is presented with many points of comparison between two or more specimens. The number of comparative points and their frequency of occurrence must all be considered before similarity between specimens can be concluded and the probability of common origin judged.

Rocks and minerals not only are present in earth materials but also are used to manufacture a wide variety of industrial and commercial products. For example, the tools and garments of an individual suspected of breaking into a safe often contain traces of safe insulation. Safe insulation may be made from a wide combination of mineral mixtures that can provide significant points of identification. Similarly, building materials, such as brick, plaster, and concrete blocks, are combinations of minerals and rocks that can easily be recognized and compared microscopically to similar minerals found on a breaking-and-entering suspect.

Some forensic laboratories currently rely on the **density-gradient tube** technique to compare soil specimens. Typically, glass tubes 6 to 10 millimeters in diameter and from 25 to 40 centimeters in length are filled with layers of two liquids mixed in varying proportions so that each layer has a different density value. For example, tetrabromoethane (density 2.96 g/mL) and ethanol (density 0.789 g/mL) may be mixed so that each successive layer has a lower density than the preceding one, from the bottom to the top of the tube. The simplest gradient tube may have from six to ten layers, in which the bottom layer is pure tetrabromoethane and the top layer is pure ethanol, with corresponding variations of concentration in the layers between these two extremes. When soil is added to the density-gradient tube, its particles sink to the portion of the tube that has a density of equal value; the particles remain suspended in the liquid at this point. In this way, a density distribution pattern of soil particles can be obtained and compared to other specimens treated in a similar manner (see Figure 4–22). Many crime laboratories use this procedure to compare soil evidence. However, there is evidence that this test is far from definitive, because many soils collected from different locations yield similar density distribution patterns.[6] At best, the density-gradient test is useful for comparing soils when it is used in combination with other tests.

The ultimate forensic value of soil evidence depends on its variation at the crime scene. If, for example, soil is indistinguishable for miles surrounding the location of a crime according to the methods used in the examination, it will have limited value in associating soil found on the suspect with that particular site. Significant conclusions relating the suspect to a particular crime-scene location through a soil comparison may be made when variations in soil composition occur every 10 to 100 yards from the crime site. However, even when such variations do exist, the forensic geologist usually cannot individualize soil to any one location unless an unusual combination of rare minerals, rocks, or artificial debris can be located. No statistically valid forensic studies have examined the variability of soil evidence. A pilot study recently conducted in southern Ontario, Canada, seems to indicate that soil in that part of Canada shows extensive diversity; it found that the probability is smaller than 1 in 50 of finding two soils that are indistinguishable in both color and mineral properties but that originate in two different locations separated by a distance on the order of 1,000 feet. Based on these preliminary results, similar diversity may be expected in the northern United States, Canada, northern Europe, and eastern Europe. However, such probability values can only generally indicate the variation of soil within these geographical areas. Each crime scene must be evaluated separately to establish its own soil variation probabilities.

COLLECTION AND PRESERVATION OF SOIL EVIDENCE

Establishing soil variation at the crime scene must be given primary consideration when the evidence collector gathers soil specimens. For this reason, standard/reference soils are to be collected at various intervals within a 100-yard radius of the crime scene, as well as at the site of the crime, for comparison to the questioned soil. Additionally, soil specimens should also be collected at all possible alibi locations that the suspect may claim. It is important that the specimens be representative of the soil that was removed by the suspect. In most cases, only the top layer of soil is picked up during the commission of a crime. Thus, standard/reference specimens must be removed from the surface without digging too deeply into the unrepresentative subsurface layers. A quantity of soil equal to approximately a tablespoon or two is all the laboratory needs for a thorough comparative analysis. All specimens collected should be packaged in individual containers, such as plastic vials. Each vial should be marked to indicate the location at which the sampling was made.

Soil found on a suspect must be carefully preserved for analysis. If it is found adhering to an object, as in the case of soil on a shoe, the investigator must not remove it. Instead, each object should be individually wrapped in paper, with the soil intact, and transmitted to the laboratory. Similarly, no effort should be made to remove loose soil adhering to garments; these items should be carefully and individually wrapped in paper bags and sent to the laboratory for analysis. Care must be taken that all particles that may accidentally fall off the garment during transportation will remain within the paper bag.

When a lump of soil is found, it should be collected and preserved intact. For example, an automobile tends to collect and build up layers of soil under the fenders, body, and so on. The impact of an automobile with another object may jar some of this soil loose. Once the suspect car has been apprehended, a comparison of the soil left at the scene with soil remaining on the automobile may help establish that the car was present at the accident scene. In these situations, separate samples are collected from under all the fender and frame areas of the vehicle; care is taken to remove the soil in lump form in order to preserve the order in which the soil adhered to the car. Undoubtedly, during the normal use of an automobile, soil will be picked up from numerous locations over a period of months and years. This layering effect may impart soil with greater variation, and hence greater evidential value, than that which is normally associated with loose soil.

The prevalence of glass and soil in our environment makes them common types of physical evidence at crime scenes. Their proper collection and preservation by the criminal investigator will help ensure that a proper scientific examination can support investigative conclusions placing a suspect or object at the crime scene. Equally important is that glass and soil, like other types of physical evidence, when properly collected and examined may exonerate the innocent from involvement in a crime.

Chapter Summary

The forensic scientist must constantly determine the properties that impart distinguishing characteristics to matter, giving it a unique identity. Physical properties such as weight, volume, color, boiling point, and melting point describe a substance without reference to any other substance. A chemical property describes the behavior of a substance when it reacts or combines with another substance. Scientists throughout the world use the metric system of measurement. The metric system has basic units of measurement for length, mass, and volume: the meter, gram, and liter, respectively. Temperature is a measure of heat intensity, or the amount of heat in a substance. In science, the most commonly used temperature scale is the Celsius scale. This scale is derived by assigning the freezing point of water a value of 0°C and its boiling point a value of 100°C.

To compare glass fragments, a forensic scientist evaluates two important physical properties: density and refractive index. Density is defined as the mass per unit volume. Refractive index is the ratio of the velocity of light in a vacuum to that in the medium under examination. Crystalline solids have definite geometric forms because of the orderly arrangement of their atoms. These solids refract a beam of light in two different light-ray components. This results in double refraction. Birefringence is the numerical difference between these two refractive indices. Not all solids are crystalline in nature. For example, glass has a random arrangement of atoms to form an amorphous or noncrystalline solid.

The flotation and immersion methods are best used to determine a glass fragment's density and refractive index, respectively. In the flotation method, a glass particle is immersed in a liquid. The density of the liquid is carefully adjusted by the addition of small amounts of an appropriate liquid until the glass chip remains suspended in the liquid medium. At this point, the glass will have the same density as the liquid medium and can be compared to other relevant pieces of glass. The immersion method involves immersing a glass particle in a liquid medium whose refractive index is varied until it is equal to that of the glass particle. At this point, known as the match point, minimum contrast between liquid and particle is observed.

By analyzing the radial and concentric fracture patterns in glass, the forensic scientist can determine the direction of impact. This can be accomplished by applying the 3R Rule: *R*adial cracks form a *R*ight angle on the *R*everse side of the force.

The value of soil as evidence rests with its prevalence at crime scenes and its transferability between the scene and the criminal. Most soils can be differentiated by their gross appearance. A side-by-side visual comparison of the color and texture of soil specimens is easy to perform and provides a sensitive property for distinguishing soils that originate from different locations. In many forensic laboratories, forensic geologists characterize and compare the mineral content of soils. Some crime laboratories use density-gradient tubes to compare soils. These tubes are typically filled with layers of liquids that have different density values.

Review Questions

1. A(n) ___________ property describes the behavior of a substance without reference to any other substance.
2. A(n) ___________ property describes the behavior of a substance when it reacts or combines with another substance.
3. The ___________ system of measurement was devised by the French Academy of Science in 1791.
4. The basic units of measurement for length, mass, and volume in the metric system are the ___________, ___________, and ___________, respectively.
5. A centigram is equivalent to ___________ gram(s).
6. A milliliter is equivalent to ___________ liter(s).
7. 0.2 gram is equivalent to ___________ milligram(s).
8. One cubic centimeter (cc) is equivalent to one ___________.
9. True or False: One meter is slightly longer than a yard. ___________
10. The equivalent of 1 pound in grams is ___________.
11. True or False: A liter is slightly larger than a quart. ___________
12. ___________ is a measure of a substance's heat intensity.
13. There are ___________ degrees Fahrenheit between the freezing and boiling points of water.
14. There are ___________ degrees Celsius between the freezing and boiling points of water.
15. The amount of matter an object contains determines its ___________.
16. The simplest type of balance for weighing is the ___________.

17. Mass per unit volume defines the property of ____________.

18. If an object is immersed in a liquid of greater density, it will (sink, float).

19. The bending of a light wave because of a change in velocity is called ____________.

20. The physical property of ____________ is determined by the ratio of the velocity of light in a vacuum to light's velocity in a substance.

21. True or False: Solids having an orderly arrangement of their constituent atoms are crystalline. ____________

22. Solids that have their atoms randomly arranged are said to be ____________.

23. The crystal calcite has two indices of refraction. The difference between these two values is known as ____________.

24. The process of separating light into its component colors or frequencies is known as ____________.

25. A hard, brittle, amorphous substance composed mainly of silicon oxides is ____________.

26. Glass that can be physically pieced together has ____________ characteristics.

27. The two most useful physical properties of glass for forensic comparisons are ____________ and ____________.

28. Comparing the relative densities of glass fragments is readily accomplished by a method known as ____________.

29. When glass is immersed in a liquid of similar refractive index, its ____________ disappears and minimum contrast between the glass and liquid is observed.

30. The exact numerical density and refractive indices of glass can be correlated to ___________ in order to assess the evidential value of the comparison.

31. The fracture lines radiating outward from a crack in glass are known as ___________ fractures.

32. A crater-shaped hole in glass is (narrower, wider) on the side where the projectile entered the glass.

33. True or False: It is easy to determine from the size and shape of a hole in glass whether it was made by a bullet or some other projectile. ___________

34. True or False: Stress marks on the edge of a radial crack are always perpendicular to the edge of the surface on which the impact force originated. ___________

35. A fracture line (will, will not) terminate at an existing line fracture.

36. True or False: Most soils have indistinguishable color and texture. ___________

37. Naturally occurring crystals commonly found in soils are ___________.

38. A comparison of the density of soil particles is readily accomplished through the use of ___________ tubes.

39. True or False: The ultimate value of soil as evidence depends on its variation at the crime scene. ___________

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Physical Property

Describes the behavior of a substance without having to alter the substance's composition through a chemical reaction.

Chemical Property

Describes the behavior of a substance when it reacts or combines with another substance.

Fahrenheit Scale

The temperature scale using the melting point of ice as 32° and the boiling point of water as 212°, with 180 equal divisions or degrees between.

Celsius Scale

The temperature scale using the melting point of ice as 0° and the boiling point of water as 100°, with 100 equal divisions or degrees between.

Weight

A property of matter that depends on both the mass of a substance and the effects of gravity on that mass.

Mass

A constant property of matter that reflects the amount of material present.

Density

A physical property of matter that is equivalent to the mass per unit volume of a substance.

Intensive Property

A property that is not dependent on the size of an object.

Refraction

The bending of a light wave as it passes from one medium to another.

Refractive Index

The ratio of the speed of light in a vacuum to its speed in a given substance.

Crystalline Solid

A solid in which the constituent atoms have a regular arrangement.

Atom

The smallest unit of an element; not divisible by ordinary chemical means. Atoms are made up of electrons, protons, and neutrons plus other subatomic particles.

Amorphous Solid

A solid in which the constituent atoms or molecules are arranged in random or disordered positions. There is no regular order in amorphous solids.

Birefringence

A difference in the two indices of refraction exhibited by most crystalline materials.

Dispersion

The separation of light into its component wavelengths.

Tempered Glass

Glass that is strengthened by introducing stress through rapid heating and cooling of the glass surfaces.

Laminated Glass

Two sheets of ordinary glass bonded together with a plastic film.

Becke Line

A bright halo that is observed near the border of a particle immersed in a liquid of a different refractive index.

Radial Fracture

A crack in a glass that extends outward like the spoke of a wheel from the point at which the glass was struck.

Concentric Fracture

A crack in a glass that forms a rough circle around the point of impact.

Mineral

A naturally occurring crystalline solid.

Density-Gradient Tube

A glass tube filled from bottom to top with liquids of successively lighter densities; used to determine the density distribution of soil.

Figure 4–1 Volume equivalencies in the metric system.

Figure 4–2 Comparison of the metric and English systems of length measurement; 2.54 centimeters = 1 inch.

Figure 4–3 Comparison of the Celsius and Fahrenheit temperature scales.

Figure 4–4 The measurement of mass.

Figure 4–5 (a) Top-loading balance. (b) Singlepan analytical balance. *(a) Courtesy Sirchie Finger Print Laboratories, Inc., Youngsville, N.C., www.sirchie.com; (b) Courtesy Scientech, Inc., Boulder, Colo., www.scientech-inc.com*

Figure 4–6 A simple procedure for determining the density of a solid is to first weigh it and then measure its volume by noting the volume of water it displaces.

Figure 4–7 Light is refracted when it travels obliquely from one medium to another.

Figure 4–8 Diagram of a sodium chloride crystal. Sodium is represented by the darker spheres, chlorine by the lighter spheres.

Figure 4–9 Representation of the dispersion of light by a glass prism.

Figure 4–10 Match of broken glass. Note the physical fit of the edges. *Courtesy Sirchie Finger Print Laboratories, Inc., Youngsville, N.C., www.sirchie.com*

Figure 4–11 Hot-stage microscope. *Courtesy Chris Palenik, Ph.D.*

Figure 4–12 Determination of the refractive index of glass. (a) Glass particles are immersed in a liquid of a much higher refractive index at a temperature of 77°C. (b) At 87°C the liquid still has a higher refractive index than the glass. (c) The refractive index of the liquid is closest to that of the glass at 97°C, as shown by the disappearance of the glass and the Becke lines. (d) At the higher temperature of 117°C, the liquid has a much lower index than the glass, and the glass is plainly visible. *Courtesy Walter C. McCrone*

Figure 4–13 An automated system for glass fragment identification. *Courtesy Foster & Freeman Limited, Worcestershire, U.K., www.fosterfreeman.co.uk*

Figure 4–14 GRIM 3 identifies the refraction match point by monitoring a video image of four different areas of the glass fragment immersed in an oil. As the immersion oil is heated or cooled, the contrast of the image is measured continuously until a minimum, the match point, is detected. *Courtesy Foster & Freeman Limited, Worcestershire, U.K., www.fosterfreeman.co.uk*

Figure 4–15 Frequency of occurrence of refractive index values (measured with sodium D light) for approximately two thousand flat glass specimens received by the FBI Laboratory. *Courtesy FBI Laboratory, Washington, D.C.*

Figure 4–16 Radial and concentric fracture lines in a sheet of glass. *Courtesy Sirchie Finger Print Laboratories, Inc., Youngsville, N.C., www.sirchie.com*

Figure 4–17 Crater-shaped hole made by a pellet passing through glass. The upper surface is the exit side of the projectile. *Courtesy New Jersey State Police*

Figure 4–18 Production of radial and concentric fractures in glass. (a) Radial cracks are

formed first, commencing on the side of the glass opposite to the destructive force. (b) Concentric cracks occur afterward, starting on the same side as the force.

Figure 4–19 Stress marks on the edge of a radial glass fracture. Arrow indicates direction of force. *Courtesy New Jersey State Police*

Figure 4–20 Two bullet holes in a piece of glass. The left hole preceded the right hole.

Figure 4–21 Presence of black tungsten oxide on the upper filament indicates that the filament was on when it was exposed to air. The lower filament was off, but its surface was coated with a yellow/white tungsten oxide, which was vaporized from the upper ("on") filament and condensed onto the lower filament. *Courtesy New Jersey State Police*

Figure 4–22 A soil comparison by density-gradient tubes. *Courtesy Philadelphia Police Department Laboratory*

[1] As an added step, the analyst can determine the exact numerical density value of the particles of glass by transferring the liquid to a density meter, which will electrically measure and calculate the liquid's density. See A. P. Beveridge and C. Semen, "Glass Density Measurement Using a Calculating Digital Density Meter," *Canadian Society of Forensic Science Journal* 12 (1979): 113.

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