4.2 Physical Properties

Key Terms
physical property
viscosity
melting point
boiling point
solubility
density

How would you describe the work of art in **Figure 4.7**? What physical characteristics would you mention? You could mention the colours and the texture of the surface. You could also describe how shiny or dull the surface is.

You can use a similar approach when describing an element or compound. In chemistry, these physical characteristics are referred to as physical properties. A **physical property** is a characteristic of a substance that you can observe and measure without changing the identity of the substance. The physical properties of elements and compounds play a significant part in determining the practical uses of these substances. Certain characteristics are especially important when scientists observe and describe elements and compounds.

physical property a characteristic of a substance that can be observed and measured without changing the identity of the substance

Figure 4.7 This sculpture at the National Gallery in Ottawa has distinct physical characteristics that can be used to describe it.

Qualitative Physical Properties

A *qualitative* physical property can be observed and described without detailed measurement. Usually, qualitative physical properties are obvious and easy to observe. For example, colour is a qualitative physical property. The colour of the element aluminum is grey. The orange-brown colour of a roof is one clue that the roof is made from the element copper. A greenish-yellow gas could be a warning that chlorine gas is present. How a substance smells is another qualitative physical property. The compound hydrogen sulfide has a very characteristic odour, which resembles the smell of rotten eggs. Another qualitative physical property is the state of a substance. When you look at a sample, you can easily see if it is a solid, a liquid, or a gas. **Table 4.2** lists some of the qualitative physical properties that are often used to describe matter.

Table 4.2 Qualitative Physical Properties

Property	Examples
colour	colourless, red, black
odour	sweet, pungent, mouldy
state	solid, liquid, or gas
texture	rough, smooth, bumpy
lustre	shiny, dull
malleability	soft, pliable, hard

Activity 4-4

What's So Special about Paper Clips?

The metal paper clip was invented over 100 years ago, and it is still used today. How do the physical properties of this handy tool help it to carry out its functions?

Materials

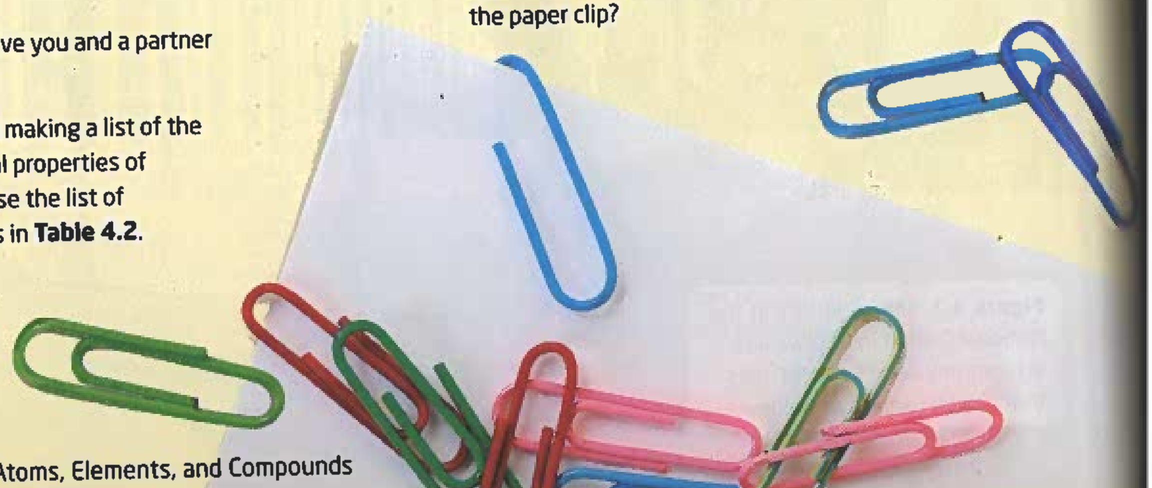
- 2 paper clips

Procedure

1. Your teacher will give you and a partner two paper clips.
2. Spend about 5 min making a list of the qualitative physical properties of your paper clips. Use the list of physical properties in **Table 4.2**.

Questions

1. Describe six qualitative physical properties of your paper clip.
2. What provides your paper clip with many of the properties that you observed?
3. Think of what a paper clip is used for. How are the properties that you listed related to the function of the paper clip?



Quantitative Physical Properties

Although qualitative descriptions of a substance can provide some information, ultimately scientists rely on properties that can be measured. A *quantitative* physical property can be measured and assigned a particular value. For example, the melting point of a compound is a quantitative physical property. Quantitative physical properties are often distinctive, or unique, to a particular element or compound, and recorded values are available for reference. **Table 4.3** lists the quantitative physical properties that are most often studied. Try Activity 4-5 to gain some experience with a physical property called **viscosity**, which is a measure of how easily a fluid flows. The more viscous a fluid is, the slower it flows.

viscosity the measure of a substance's resistance to flow

Table 4.3 Quantitative Physical Properties

Property	Description
viscosity	resistance to flow
melting point	temperature of melting
boiling point	temperature of boiling
solubility	ability to dissolve in another substance
hardness	ability to scratch another material
conductivity	ability to conduct electricity or heat
density	ratio of mass to volume

Activity 4-5

Slow as Molasses

Have you ever heard the phrase "as slow as molasses"? You are about to see, firsthand, what is meant by this expression.

Materials

- 2 beakers of the same size
- 2 scoopulas
- water
- molasses
- medicine droppers
- stopwatch

Procedure

1. Work with a partner. You and your partner should each place your scoopula inside a beaker. Position the scoopula so the wider end is at the top and so it rests against the side of the beaker.
2. One partner adds a drop of water to the wide end of one scoopula. The other partner adds a drop of molasses to the wide end of the other scoopula.
3. At the same time, start the stopwatch. Make sure that you and your partner hold the scoopulas at the same angle. Observe and record the time that it takes for the water and the molasses to run to the bottom of each scoopula.

Questions

1. How long did it take for the water and molasses to run down the scoopulas?
2. What physical property of molasses does the expression "slow as molasses" refer to?
3. What is another way that you could measure the difference between the viscosities of water and molasses?

States of Matter

The specific temperature at which an element or a compound changes state is a characteristic physical property. **Figure 4.8** reviews the different changes of state that matter undergoes. *Melting* is the change of state from solid to liquid. The temperature at which a solid changes into a liquid is called the **melting point**. The melting points of compounds and elements have been used for numerous applications, such as the melting of gold for things like jewellery, shown in **Figure 4.9**. *Solidification* is the opposite of melting, when a substance changes from a liquid to a solid.

melting point
the temperature at which a solid turns into a liquid

boiling point
the temperature at which a liquid turns into a gas

Evaporation is the change of state from liquid to a gas. The temperature at which a liquid changes into a gas is called the **boiling point**. As you probably know, the boiling point of water is 100°C. In comparison, the boiling point of helium is –269°C. Because of its low boiling point, helium is used to keep things very cold. When liquid helium is introduced into a system and allowed to boil, it brings the temperature of the system down to its boiling point, which is very near absolute zero. Condensation is the opposite of evaporation and is the change in state from a gas to a liquid.

Some substances have the ability to change directly from a solid to a gas. This process is called *sublimation*. A well-known example of this is solid carbon dioxide—also called dry ice. As you can see in **Figure 4.10**, it is often used in live performances because it creates the effect of fog. When substances change from a gas to a solid, it is called *deposition*.

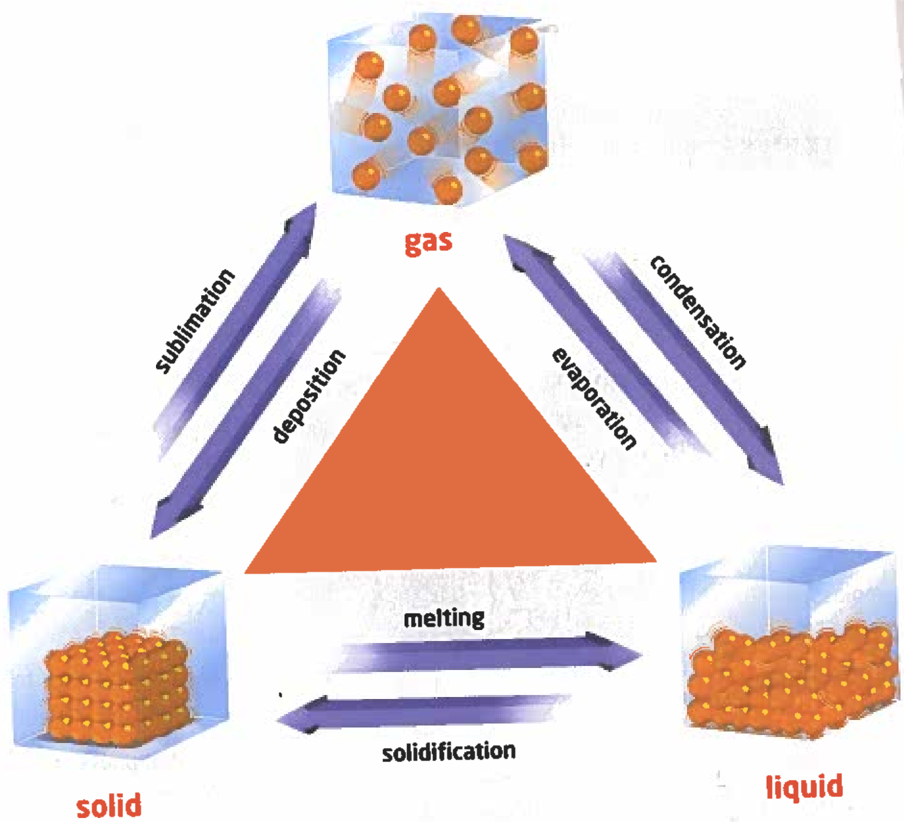


Figure 4.8 Matter can undergo different changes of state. The temperature at which a pure substance undergoes a change of state is an important physical property.

Figure 4.9 Gold is melted and used for products like jewellery.

Figure 4.10 The sublimation of dry ice is often used to mimic fog in stage performances.

Solubility

Another important physical property is **solubility**. The solubility of a substance is recorded as the maximum quantity of a substance that can dissolve in a given amount of solvent at a particular temperature and pressure. The solubility of a substance is expressed as a concentration. Typically, the units are mass of solute per mass of solvent, or mass of solute per volume of solvent. A substance is highly soluble if large amounts of the substance will dissolve in a given amount of solvent. For example, salt easily dissolves in water to produce a salt solution, as shown in **Figure 4.11**. The reported solubility of sodium chloride in water at 25°C and atmospheric pressure is 39.5 g/100 mL. This is a quantitative physical property of sodium chloride. A solution with water as a solvent is called an *aqueous solution*. One of the most important aqueous solutions is blood serum. The serum is the liquid component of blood, which blood cells are suspended in. Numerous chemicals that are essential for life are dissolved in aqueous-based blood serum and are transported throughout the body.

A substance that does not dissolve or has a very low solubility is sometimes described as being insoluble. For example, copper and iron are insoluble in water—which is good. Otherwise, every time it rained, many structures around you would dissolve!

solubility a measure of the ability of a substance to dissolve in another substance

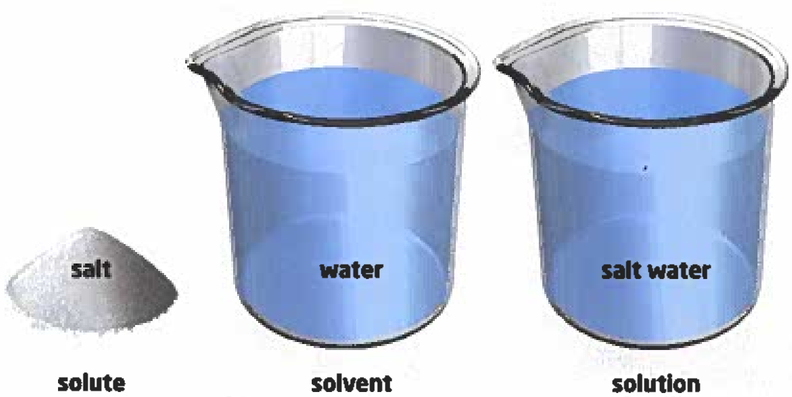


Figure 4.11 Salt is a solute that easily dissolves in the solvent water to produce a saltwater solution.

Solubility and the Environment

Solubility in fat is an especially important property for some chemicals, because of bioaccumulation and biomagnification. As discussed in Chapter 1, *bioaccumulation* involves the build-up of toxic substances in the tissues of animals over time. This can lead to *biomagnification*, which involves the accumulation of these toxic substances in progressively higher concentrations toward the top of food chains. Often, these toxic substances are highly soluble in fat and collect in fat deposits in animals.

Go to **scienceontario** to find out more

The chemical dichloro-diphenyl-trichloroethane (DDT) is an example of a fat-soluble substance that bioaccumulates and biomagnifies in mammals. DDT is a synthetic pesticide that was used extensively in the 1940s and 1950s to eliminate insect-carrying diseases and increase crop yields throughout the world. For many years, DDT was seen as a huge success. By the 1970s, over a billion kilograms of DDT had been introduced into the environment in North America alone. Since then, however, scientists have learned that DDT does not break down easily, and is stored in the fatty tissue of animals. This has a negative impact on mammals in Canada, such as Arctic polar bears and seals, as shown in **Figure 4.12**. DDT is carried to the Arctic by atmospheric transport and ocean currents. Phytoplankton, which take up the DDT water pollutant, are consumed by snails. Arctic cod thrive on snails and retain all the DDT from every snail they eat. A ringed seal, in turn, can consume large quantities of DDT-contaminated arctic cod. The ringed seal stores the DDT it has consumed. The DDT concentration in the seal can be several hundred times higher than in organisms lower on the food chain. Ultimately, the DTT from the ringed seal is passed to the polar bear that consumes the seal.

Figure 4.12 The concentration of DDT increases at each trophic level of this Arctic food chain. Since DDT is soluble in fat but not in water, organisms do not excrete it in significant amounts. Instead, they store DDT in the fat of their bodies.

Hardness

The *hardness* of a substance refers to its ability to be scratched. Harder substances can scratch softer substances, but softer substances cannot scratch harder substances. The hardness of a substance is often helpful for determining its practical use. Hardness is usually given as a number between 1 and 10 on a scale called the Mohs scale. For example, your fingernail has a hardness of around 2 on the Mohs scale. Diamond, which is the hardest natural material, has a hardness of 10.

Hardness is one of several properties that make diamonds useful in a variety of applications. High lustre, transparency, and their way of reflecting light make diamonds very valuable as gemstones. Nevertheless, the majority of diamonds are used in industry. Hardness, low reactivity with chemicals, low electrical conductivity, high thermal conductivity, and high density are just a few physical properties that make diamonds useful in industry. The most common industrial applications of diamonds are ones requiring a great deal of durability, such as drilling, cutting, and grinding. For example, drill bits for drills used in drilling oil wells contain diamonds. Each of the cutting tips in **Figure 4.13** has grains of diamond embedded into the end of it.

Figure 4.13 Diamonds have been embedded into the ends of these drill bits to make it easier for the drills to cut through rock.

Activity 4-6

Hard as Nails

The hardness of a material can play a big part in determining what the material is used for. How do some common substances, with very different uses, compare with each other in terms of hardness?

Materials

- piece of talc
- copper penny
- steel nail

Procedure

1. Examine the three materials that your teacher has given you. Rank them from least hard to hardest, by simply observing and touching them.
2. Make a table similar to the one on the right to record your results. List the materials that you are using to scratch in the vertical column and the materials being scratched as the horizontal headings.

   Perform scratch tests on each material, by systematically scratching each material with each of the other materials, as well as with a sample of itself.
3. Use a plus sign (+) to indicate ability to scratch, and use a minus sign (-) to indicate inability to scratch. One box has been filled in for you, indicating that talc cannot scratch a penny.

Scratch Tests

	Talc	Penny	Nail
Talc		(-)	
Penny			
Nail			

Questions

1. Based on your scratch tests, rank the three materials from least hard to hardest. What happened when you scratched two samples of the same material?
2. How did your initial hypothesis about the relative hardness of the materials compare with your experimentally determined rankings?
3. What does the fact that chalk is used to write on a chalkboard tell you about the relative hardness of chalk and chalkboard material?

Learning Check

1. What is the difference between qualitative physical properties and quantitative physical properties?
2. What physical property of DDT contributes to its bioaccumulation in animals?
3. How could knowing the melting points of two pure substances that look alike help you tell the substances apart?
4. Why do people often check to see if a diamond is real by rubbing it against glass?

Sense of Value

Although copper and silver have very similar electrical conductivity properties, silver is over 100 times more expensive than copper. Therefore, it is more economical to use copper in things like wiring.

Conductivity

The ability of a substance to conduct electricity is another distinguishing physical property. You have probably learned that electrical wires are made from copper. Copper is used because it has a high electrical conductivity. In other words, it conducts electric current very well. Aluminum pans are useful for cooking food because aluminum has a high thermal conductivity—it transfers heat easily. The burner heats the bottom of the pan. The pan then transfers the energy to the food. In comparison, the handles on many pots and pans are made of plastic because plastic has a low thermal conductivity and helps to protect you from burning your hands while cooking.

density the ratio of the mass of a substance to the volume it occupies

Density

You have learned that matter is anything that has mass and volume. You can use the mass and volume of a sample to determine an important physical property called density. **Density** is defined as the mass of a substance that occupies a certain unit volume. In other words, for a particular mass of a substance, a certain volume is required.

Density is not just a property of solids. It is also a property of gases and liquids. Liquids that have different densities will separate into distinct layers when added to the same container. The liquid that is the most dense will be the bottom layer, while the liquid that is the least dense will be the top layer. Of course, this only occurs when neither of the liquids are soluble in each other. You may have heard about the *Exxon Valdez* oil spill, shown in **Figure 4.14**. An oil spill can have devastating consequences because oil is insoluble in water and less dense than water. As a result, it floats on the water. Ultimately, a great deal of the oil spreads on the water, until reaching a shoreline.

Figure 4.14 The 1989 *Exxon Valdez* oil spill, which occurred in Prince William Sound off the coast of Alaska, was one of the worst environmental disasters in history. It affected almost 4000 km of shoreline.

Determining Density

Density can be calculated using the formula

$$\text{density} = \frac{\text{mass}}{\text{volume}} \quad \text{or} \quad D = \frac{m}{V}$$

Density is often expressed as grams per cubic centimetre, represented as g/cm^3. When calculating density using these units, make sure that the mass is in grams and the volume is in cubic centimetres.

Sample Problem: Calculating Density

Problem

A sample of silver has a mass of 5.04 g and a volume of 0.480 cm^3. What is the density of silver?

Solution

This problem requires you to determine the density.

The values for mass and volume are given:

$m = 5.04$ g and $V = 0.480\ cm^3$

The equation for density is $D = \frac{m}{V}$

Substitute the given values into the equation, and solve:

$$D = \frac{5.04\ g}{0.480\ cm^3}$$

$D = 10.5\ g/cm^3$

The density of silver is 10.5 g/cm^3.

Check Your Solution

By rounding the mass to 5 g and the volume to 0.5 cm^3, you can see that the mass is about 10 times larger than the volume. An estimate of 10 g/cm^3 for the density is close to the calculated value of 10.5 g/cm^3.

Study Toolkit

Previewing Text Features

Notice how the sample problem is presented on this page. How do you think this text feature will help you to learn about calculating density?

GRASP

Go to **Science Skills Toolkit 9** to learn about an alternative problem solving method.

Practice Problems

1. A sample of an unknown metal has a mass of 21.6 g and a volume of 8.00 cm^3. Calculate the density of the unknown metal.
2. What is the density of a liquid if 95.5 cm^3 has a mass of 101 g?
3. A balloon contains 5470 cm^3 of gas and has a mass of 10.24 g. The mass of the empty balloon is 2.42 g. What is the density of the gas?
4. One side of a cube of an unknown metal measures 0.53 cm. If the mass of the cube is 0.92 g, what is the density of the cube?
5. A scientist has developed a new type of material that is supposed to float on water. This material has a mass of 2.0 g for every 3.0 cm^3 of volume. Will this material float on water (density = 1.0 g/cm^3)? Explain.