Inquiry Activity

Saturated and Unsaturated Solutions

The Question

How can you make saturated solutions?

Materials & Equipment

- graduated cylinder
- beaker
- balance
- paper to hold solutes
- spoon or scoopula
- water at room temperature
- powdered drink crystals
- sugar
- salt
- stir sticks

Figure 2.7 Step 2. Accurately measure 5 g of a substance.

Procedure

1. Use the graduated cylinder to measure 50 mL of water into a beaker.
2. Measure 5 g of one substance. Add this to the water.
3. Stir the mixture until the substance has dissolved. Record your observations in the table.
4. Keep adding more of the same substance to the water, 5 g at a time, until no more will dissolve.
5. Repeat steps 1 to 4 for each substance.

Collecting Data

6 Make a table like the one below in your notebook:

Substance	Mass Added	Volume of Water	Concentration in g/100 mL Water	Observations

7 Fill in the table for each substance you use.

Analyzing and Interpreting

8 Calculate the concentration of each solution in grams per 100 mL. Don't forget you used only 50 mL of water, so you will need to correct the differences in mass and volume.

9 How did you know when a solution was saturated?

Forming Conclusions

10 Describe how you made saturated solutions and calculated the concentration of each of your solutes.

Applying and Connecting

Many industrial processes depend on producing solutions of various concentrations. In some situations, the more concentrated the solution, the more useful the solution can be. An example of this is red dye for food colouring. In the 1970s, synthetic red dye was banned because of its potential carcinogenic effects. Industry needed a safe replacement. Scientists found it in an insect called the cochineal [kotch-e-neel] that lives in cacti in the Andes Mountains of South America. This bright red natural dye has been approved for use in cosmetics, drugs, and foods. Recently, two chemists from Simon Fraser University, Dr. Cam Oehlschlager and Dr. Eva Czyzewska, developed a method of improving the production process to make a more concentrated dye. The process is being used on the condition that the dye production remain close to the source of the insects. This is important because rural people are employed in collecting the insect.

Figure 2.8 Cochineal insects live on cacti. They are the source for a bright red dye.

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Insoluble Substances

Sometimes a substance won't dissolve in a solvent. That substance is insoluble in that solvent. Find out why some substances are insoluble.

Comparing Solubility of Common Substances

The solubility of a solute is the maximum amount of that solute that you can dissolve in a given amount of solvent at a given temperature. If you did the last Inquiry Activity, you noticed that different solutes have different solubilities. Solubility is a unique property for each substance. The table below shows the solubilities of some common substances in water at 0°C. You can see that 35.7 g of salt will dissolve in 100 mL of water at 0°C, and 180 g of sugar will dissolve in 100 mL of water at 0°C.

Solubility in g/100 mL of Water at 0°C

Compound	Solubility (g)
salt	35.7
baking soda	6.9
carbon dioxide	0.35
sugar	180
hydrogen	0.00019
oxygen	0.007
ammonia	92

Check and Reflect

1. What is the difference between a diluted solution and a concentrated solution?
2. If a solution has a concentration of 75 g per 100 mL, what does this mean?
3. Calculate the concentrations in grams per 100 mL for the following solutions:
   a) 10 g of chocolate in 50 mL of water
   b) 3 g of sugar in 300 mL of water
   c) 5 g of maple syrup in 25 mL of water
4. What is the difference between a saturated solution and an unsaturated solution?
5. What is the solute in a fruit punch drink?

2.3 Factors Affecting Solubility

In the last section, you learned about solubility. It is the maximum amount of solute you can dissolve in a given amount of solvent at a given temperature. Solubility depends on at least three factors: the type of solute, the type of solvent, and the temperature. First, let's consider the type of solute and the type of solvent.

Give it a TRY — **ACTIVITY**

DISSOLVING SOLUTES IN DIFFERENT SOLVENTS

TOOLBOX

Your teacher will give you these solutes: juice drink crystals, petroleum jelly, sugar, and salt. You will have two solvents: water and vegetable oil.

Which solutes will dissolve in water and which solutes will dissolve in vegetable oil?

Create a procedure that will allow you to collect data that will answer the above question. You will have to design a fair test to determine the answer to this question. (See Toolbox 2 for more information on how to design a fair test.)

TYPES OF SOLUTES AND SOLVENTS

The most common solvent is water. Water is sometimes referred to as the *universal solvent* because it can dissolve so many different substances. If you see the term **aqueous solution**, that means the solvent is water. (*Aqua* is the Latin word for water.)

It is important to remember that solutions do not have to be made up of only liquids. The table below contains examples of solutes and solvents in other states.

Examples of Common Solutions

Solute	Solvent	Solution
gas	gas	air (oxygen and other gases in nitrogen)
gas	liquid	soda water (carbon dioxide in water)
liquid	liquid	antifreeze (ethylene glycol in water)
liquid	solid	rubber cement (benzene in rubber)
solid	liquid	seawater (salt and other substances in water)
solid	solid	brass (zinc and copper)

Inquiry Activity

Temperature and Solubility

The Question

What effect does temperature have on the solubility of a substance? Hint: Recall that solubility is the maximum amount of solute (solid) that you can dissolve in a fixed volume of solvent (liquid) at a given temperature.

Materials & Equipment

- 2 beakers
- water
- thermometer
- hot plate or access to hot water
- solute and solvent
- spoon or scoopula
- graduated cylinder
- triple beam or electronic balance

The Hypothesis

Write a hypothesis about how the temperature of the solvent affects the amount of solute that can dissolve in it.

Procedure

1. Decide which materials you will need to test the hypothesis.
2. Plan your investigation.
   a) What variable(s) will change?
   b) What variable(s) will stay the same?
3. Write a procedure and show it to your teacher. Do not proceed any further until it is approved.
4. Carry out your investigation.

Caution!
If you spill liquid on your hands, wash it off with water right away. Wash your hands when you have completed the activity.

Collecting Data

5 Make sure you have recorded at least the following information: the hypothesis, your procedure, the temperature of the liquids used, and the mass of solute added.

Caution!
Always heat solvents in a water bath.

Figure 2.9 Carefully measure the mass of solute that you use.

Analyzing and Interpreting

6 Share and compare your results with your classmates. What variables did each group have to keep the same so that you could compare results?

Forming Conclusions

7 In a short paragraph, describe your results and how they compared with the hypothesis.

Extending

A *supersaturated* solution is one that contains more solute than it normally would be able to dissolve at a certain temperature. How do you think you could make a supersaturated solution with the solute and solvent combination you tested here? Find out how to do this and try it.

Solubility Changes with Temperature

For most common solid or liquid substances, solubility increases as the temperature of the solvent increases. For example, at 25°C, you can dissolve 36.2 g of salt in 100 mL of water, but at 100°C, you can dissolve 39.2 g. The reverse is true for a gas. As the temperature increases, the solubility of a gas in a liquid solvent decreases.

Thermal Pollution

This decrease in the solubility of gases can have a serious effect on the environment. Many industrial plants use water as a coolant in their processes. Usually this water is drawn from a lake or a river. Once the water is used, it is warmer than when it was taken into the plant. Before it can be returned to the lake or river, it must be stored in a cooling pond. What would happen if the warm water were poured directly back into the river or lake? This is commonly called *thermal pollution*.

All water contains various amounts of different gases, including oxygen. The oxygen is important for supporting life that lives in the water. If the temperature of the water increases, the concentration of oxygen decreases. This occurs because the solubility of a gas in a liquid solvent decreases as the temperature increases. So the solubility of the oxygen is less in the warmer water. What do you think will happen to the living organisms in the lake or river if the amount of oxygen in the water decreases greatly?

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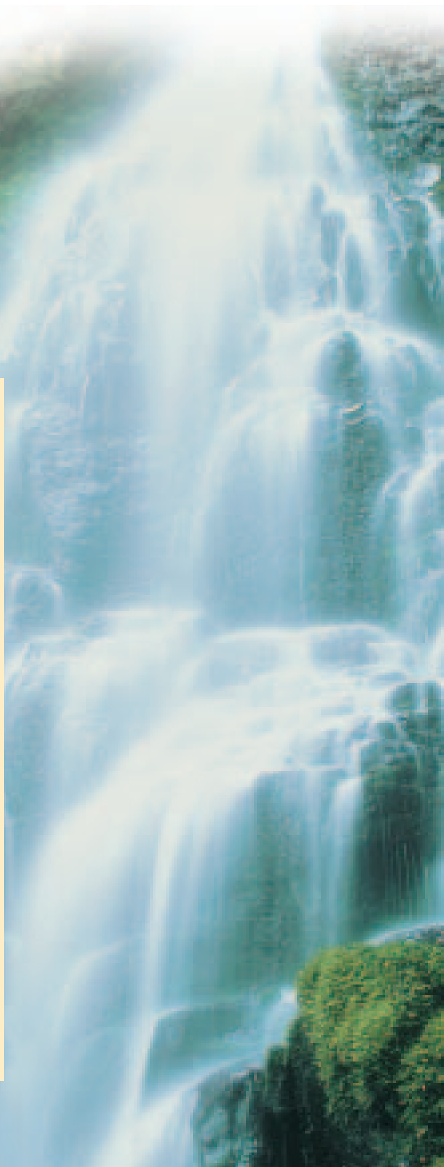
The Colour of Money

In 1857, Thomas Sterry Hunt, a professor at McGill University in Montreal, produced a green ink called chromium trioxide. This green ink is used to this day to print American money. Dr. Hunt's green ink cannot be dissolved or copied by photography.



Check and Reflect

1. Why is water called "the universal solvent"?
2. What factors affect the solubility of a solute?
3. For the substances in the chart below, answer the following questions.

Solubility in g/100 mL of Water		
Substance	***at 0°C***	***at 100°C***
sodium chloride	*35*	*39*
sodium nitrate	*74*	*182*
sodium carbonate decahydrate	*21*	*421*

a) Which substance is the most soluble at 100°C?
b) Which substance is the most soluble at 0°C?
c) Which substance shows the most change in solubility as the temperature increases?

2.4 The Particle Model of Matter and the Behaviour of Mixtures

As you study the properties of mixtures, you may observe events that seem difficult to explain. For example, how would you explain the following situations involving mixtures?

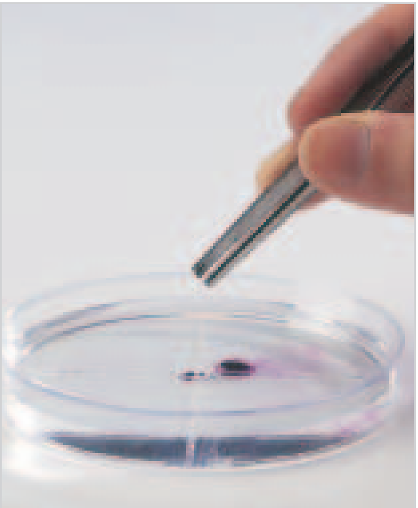


Figure 2.10a) The potassium permanganate has just been added to the water.

Figure 2.10b) What happened to the potassium permanganate after 5 min in the water?

Situation 1. Can something dissolve without stirring?

Figure 2.10a) shows a petri dish three-quarters full of water. A crystal of potassium permanganate was carefully added to the still water. The dish was left for 5 min without disturbing it. Figure 2.10b) shows the potassium permanganate after 5 min. What happened to it? Why do you think this happened?

Figure 2.11a) 20 mL of rubbing alcohol and 20 mL of water in separate 25-mL cylinders

Figure 2.11b) The two liquids combined in a 50-mL cylinder

Situation 2. Can you combine two liquids and have a volume less than the sum of the volumes when you started?

A lab technician carefully measured 20 mL of rubbing alcohol into one graduated cylinder and 20 mL of water into another. He then combined the two liquids. The combined liquid filled the graduated cylinder to a level of 39 mL. Did the technician make a mistake? Can you explain why this measurement resulted?

You may have developed explanations for these two situations, but you may not be completely sure of your answers. A model of matter would help explain these and other observations.

The Particle Model of Matter

Why did the potassium permanganate start to dissolve without being stirred? Why did the volumes not add up when the water and the rubbing alcohol were added together? The **particle model of matter** can help to explain these and other situations. The particle model has four main points that describe the structure of matter. Using this model, you will be better able to explain the properties of mechanical mixtures and solutions. As you look through the description of the particle model shown here, think about the situations described on the previous page.

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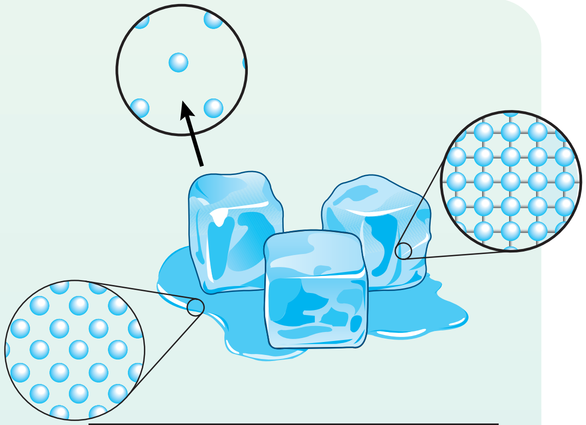
How Big Is a Particle?
There are about 10^{18} particles in a snowflake. That's the number 10 with 18 zeros after it.

1

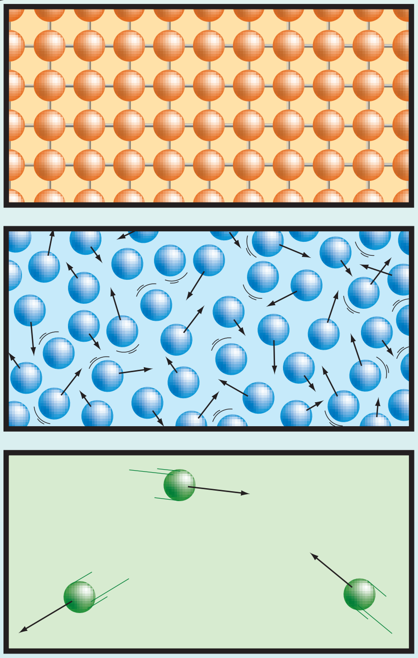
All matter is made up of tiny particles. Different substances are made up of different particles.

- This means every object in any state is made up of tiny particles too small to see.
- There are more particles in a given volume of solid than there are in the same volume of a liquid or a gas.



2

The tiny particles of matter are always moving and vibrating. For solids, this movement is like wiggling in one place. For liquids, the particles are sliding around and over each other. For gases, this movement means moving as far as the space they are in allows.



3

The particles in matter may be attracted to each other or bonded together.

- Some particles, such as water, have more attraction for other particles, such as salt, than for each other.

4

The particles have spaces between them.

- Notice the difference in the amount of space between particles of a solid and a gas.

Give it a **TRY** ACTIVITY

USING THE PARTICLE MODEL OF MATTER

You have 50 mL of sand in one container and 250 mL of marbles in another container. When you mix the contents of the two containers, you will be modelling what happens when alcohol and water are mixed together.

What will be the total volume of the sand and marbles when they are mixed together?

Slowly pour the 50 mL of sand into the container of marbles. Record your observations.

Use the particle model to explain what happened when you mixed the sand and marbles together. Now use it to explain what happened when the technician mixed the alcohol and water earlier in this subsection.

HOW THE PARTICLE MODEL EXPLAINS MIXING SUBSTANCES

Figure 2.12 The marbles and sand represent two different substances made up of particles of two different sizes. Notice how the sand fills in the spaces between the marbles.

The alcohol and water that the technician mixed together earlier are two different substances. They are made of different particles, and these particles are different sizes. When the two substances are mixed together, the smaller particles of one substance fill in the spaces between the larger particles of the other. Figure 2.12 shows a model of this situation.

The particle model can also explain why substances dissolve. The particle model states that particles are attracted to each other. However, particles in some substances are more attracted to particles in other substances than to each other. For example, consider the situation in Figure 2.10 at the beginning of this subsection. When potassium permanganate is placed in water, its particles are attracted to the water particles. This is the process called *dissolving*. In a solution, the particles of the solute (potassium permanganate) are attracted to the particles of the solvent (water). The solute dissolves in the solvent. This is why a solute seems to disappear when mixed with a solvent.

FACTORS AFFECTING THE RATE OF DISSOLVING

In the subsection 2.3, you investigated different factors that affected the solubility of a substance. You found out that the kind of solute, the kind of solvent, and the temperature all had roles in solubility.

Another important consideration in dissolving solutes is the rate of dissolving. How fast will a solute dissolve in a solvent? How can you make a solute dissolve more quickly? Look at Figures 2.13a)–c). They show how the particle model can explain the factors that affect the rate at which a solute dissolves.

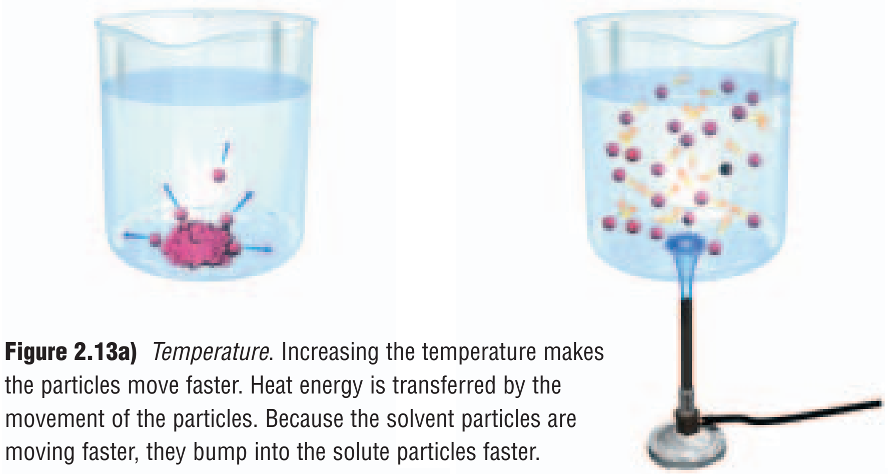


Figure 2.13a) *Temperature.* Increasing the temperature makes the particles move faster. Heat energy is transferred by the movement of the particles. Because the solvent particles are moving faster, they bump into the solute particles faster.

Figure 2.13b) *Size of Pieces.* Small pieces of solute dissolve more quickly than large pieces. All the smaller pieces together have more surface area among them for the solvent particles to bump into. Think of cooking a potato in water. If you put the whole potato in, it takes a long time to cook. If you cut the potato up into smaller pieces, the cooking time becomes much shorter.

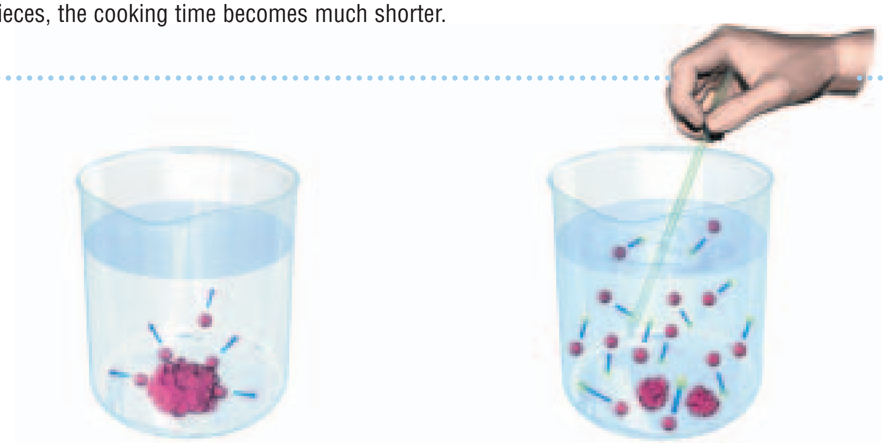


Figure 2.13c) *Stirring.* Stirring moves all the particles around, so the solvent particles bump into the solute particles.

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Atomic Structure

The particle model is a simple way of describing matter and its behaviour. Atomic structure is another way. You have probably heard about atoms. How are atoms related to particles? Find out about atomic structure.

Check and Reflect

1. Make a particle sketch showing how instant coffee dissolves in hot water.
2. You've been asked to try out a new type of fruit drink flavouring that comes in the form of a cube that dissolves in water. You're in a hurry to try it so you want to dissolve it as quickly as possible. Name three ways of speeding up dissolving. Explain each one using the particle model.
3. Figure 2.14 shows a Web page about the particle model that is still under construction. The text hasn't been added yet.
   a) In your notebook, complete the Web page with information that explains the picture. Include one hyperlink topic in the text of your Web page.
   b) Write one other Web page that explains your hyperlink. The text on this page should use the words *solubility* and *factors affecting the rate of dissolving*.

Figure 2.14 Question 3. Web page under construction

4. Why did the potassium permanganate crystals start to dissolve in water without being stirred?

Assess Your Learning

1. Give an example of a pure substance. Why is it a pure substance?
2. Think about examples of solutions made by combining different states of matter. Make a chart like this one, and fill it in with an example of each combination.

Substance	Substance	Solution Made	Other Examples
solid	*liquid*	table syrup	
solid	*solid*	steel	
liquid	*liquid*	perfume	
liquid	*gas*	tap water	

   a) Which combination of substances was the most difficult to think of as a solution?
   b) Which combination was the easiest?
3. In paper chromatography, is the substance being tested the solute or the solvent? Explain your answer.
4. Use the particle model to explain what happens to the rate at which a solute dissolves when the temperature increases.
5. A bucket of paint spills on your classroom floor. How could you use your knowledge of dissolving to help clean up the paint?

Focus On SCIENCE AND TECHNOLOGY

Scientific knowledge may lead to the development of new technologies, and new technologies may lead to scientific discovery. Think back to the information on using paper chromatography to separate substances in a solution.

1. What do you need to know about pure substances and solutions in order to use paper chromatography technology?
2. Use the library or the Internet to find other applications of chromatography.
3. After finishing your research, consider the following statement. Then write a brief response to it. *Understanding the scientific principles of paper chromatography is more important than developing uses for it.*

3.0 The properties of gases and liquids can be explained by the particle model of matter.

Key Concepts

In this section, you will learn about the following key concepts:

- properties of fluids
- mass, volume, density
- viscosity and flow rate
- buoyancy

Learning Outcomes

When you have completed this section, you will be able to:

- define viscosity and describe how temperature affects it
- calculate and compare densities and relate them to the particle model of matter
- describe methods of altering density in fluids
- explain buoyancy
- describe pressure and examples of its use
- compare the compressibility of liquids and gases

Most people think of liquids when they hear the word "fluids." But gases are also fluids. A fluid is any matter that has no fixed shape—it takes the shape of its container. For example, the air in a bicycle tire takes the shape of the tire and water in a bottle takes the shape of the bottle.

Fluids have many properties that are useful. In this section, you will investigate the fluid properties of viscosity, density, buoyancy, and compressibility. Each of these plays a role in how a fluid may be used. For example, the Canadarm can move heavy objects using only gears while the space shuttle orbits Earth. On Earth's surface, hydraulics provide an advantage that makes it possible for one person to lift and move huge loads. An engineer designing a hydraulic arm must understand how forces are transmitted through a fluid and how fluids behave under pressure. You will have the scientific knowledge to design a hydraulic arm at the end of this section.

For Web links relating to 3.0, visit www.pearsoned.ca/scienceinaction

3.1 Viscosity and the Effects of Temperature

One property of fluids is how they move or flow. Think about the fluids you have used in the last couple of days. What would happen if they didn't flow the way they usually do? For example, what if soda pop was like a thick syrup or ketchup was like water? In both these situations, the properties of the fluids are very different. With your partner, identify three fluids that you have used, and describe what they would be like if they were thicker or thinner. Here is an example:

Fluid	Thicker	Thinner
shampoo	– hard to get out of bottle	– would probably use more to wash hair

How quickly fluids flow is a property called **viscosity**. It is determined by a fluid's internal resistance or friction that keeps it from flowing. Recall from the particle model that the particles in a liquid slide around and roll over each other. In a gas, the particles move around even more easily. The greater the friction or rubbing between particles in any fluid, the higher the viscosity. Fluids with high viscosity do not flow as easily as fluids with a low viscosity.

Figure 3.1 Juice has a low viscosity. Ketchup has a high viscosity.

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What grade of motor oil is this?

Multi-grade Engine Oil

The Society of Automotive Engineers (SAE) assigns all motor oils a viscosity number between 5 and 50. The higher the number, the higher the viscosity. SAE 30 oil is suitable for summer use, while SAE 10 oil can be used for winter driving. Multi-grade motor oil, such as SAE 10W30, has compounds added to it that allow the oil to flow easily at cold temperatures, but prevent it from thinning out too much when the weather becomes hot.

The Effect of Temperature on Viscosity

Earlier in this section, you thought about different fluids and what would happen if their viscosity changed. What might cause a fluid's viscosity to change? Temperature is one factor that can have a big effect on viscosity. Look at Figures 3.2a)–d). What will happen to the viscosities of these fluids in the situations shown?

Figure 3.2a) Table syrup poured on hot pancakes

Figure 3.2b) Hot tar spread on a road

Figure 3.2c) Olive oil placed in a refrigerator

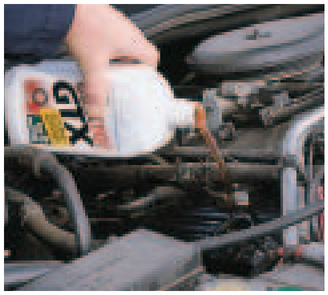

Figure 3.2d) Room temperature engine oil poured into a hot engine

Measuring Viscosity with the Ramp Method

The *ramp method* of testing viscosity involves pouring a fluid down a ramp and timing how long it takes to get to the bottom. By pouring the same amount of another fluid and timing it, you can compare the viscosities of different fluids. You can also investigate the effect of temperature on viscosity by testing the same fluid at different temperatures. First, you test it at room temperature. Then, you warm it in hot water or cool it in an ice bath, and test it again.

Give it a TRY — ACTIVITY

How Fast Can It Go?

You will use the ramp test to determine the effect of temperature on the viscosity of four fluids.

Design a fair test that will allow you to collect evidence to demonstrate the effect of temperature on viscosity. (See Toolbox 2 for more information on designing a fair test.)

Write a procedure and show it to your teacher for approval. Then carry out your tests.

When you have completed your tests, create a one-page summary poster of your results. Include one graphic illustrating your results.

Caution!
Handle hot water carefully. If you spill any on your skin, immediately run cold water over the area.

Materials & Equipment

- shampoo
- pancake or table syrup
- vegetable oil
- Teflon-coated cookie sheet
- thermometer
- hot water
- cold water
- beakers
- a stopwatch

Understanding Viscosity and Temperature

Recall that viscosity is a fluid's internal resistance or friction that keeps it from flowing. A fluid with a high viscosity has a large amount of internal resistance or friction. As the temperature of a liquid increases, its viscosity decreases. The opposite is also true. As the temperature of a liquid decreases, its viscosity increases. If you did the ramp method activity, your data will show that the warmer the fluid, the faster it flows.

The particle model of matter can help you understand why this change in viscosity happens. Recall that in the particle model, a liquid is made of particles that can slide and roll over each other. When energy or heat is added to the liquid, the particles slide and roll more quickly. As a result, the fluid flows more readily—its viscosity decreases. The reverse is also true. As the temperature of the liquid drops, the particles slow down. The result is that the viscosity increases—the fluid flows more slowly.

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Fluids from the Environment

In Alberta, Aboriginal peoples used to use the thick, viscous bitumen of the oil sands to seal their canoes. Aboriginal peoples all over North America also used tree sap to make a glue for building canoes. Find out how Aboriginal peoples made glue from tree sap. In what other ways did Aboriginal peoples use their knowledge of fluid characteristics?

Check and Reflect

1. Write a short paragraph to describe viscosity. Include at least two examples of fluids, and use the words *flow*, *fluid*, *particles*, and *viscosity* in your description.
2. Describe two substances that are useful because of their viscosity.
3. In a fair test, you have to keep all the variables the same except one. That way, you can see the effect of the one variable. If you had to do a ramp test for viscosity:
   a) What would you change during the tests?
   b) What things would you keep the same for each test?
4. You are given three samples of the same shampoo at three different temperatures: 35°C, 50°C, and 75°C. Which sample would have the highest viscosity? Which sample would have the lowest?
5. You are making cookies that call for 3 tablespoons of molasses. But you are having trouble measuring out the thick, syrupy liquid. What could you do to make it easier to pour and measure this fluid?

3.2 Density of Fluids

Figure 3.3
Why isn't this grape floating?

Recall that at the beginning of this unit, you had an opportunity to answer an e-mail from the president of GeeWHIZ Beverage Ltd., asking you to find out if a piece of fruit could be suspended in a fluid. Here is an example of some data that was collected in this activity. One student, Emma, used cranberry juice, tomato sauce, peach juice concentrate, and a grape in her research.

Fluid	*Grape Sank*	*Grape Floated on Top*	*Grape Floated in Middle*
cranberry juice	✓		
tomato sauce			✓
peach juice concentrate		✓	

Why did the grape sink in some liquids and not in others? The reason for the difference is a property of fluids called density. **Density** is the amount of matter in a given volume. Think about density as you examine the results of Emma's investigation above.

Give it a TRY — ACTIVITY

DENSE AND DENSER

You have six identical jars full of different materials in front of you.

Make a list, ranking them in order of highest density to lowest density. You may use any method you like to determine this ranking, but you cannot open the jars.

The list here tells you what is in each jar. If a substance has been changed, your teacher will tell you.

Contents of Jars
1 water
2 sand
3 corn syrup
4 aquarium stones
5 shampoo
6 wood chips

What ranking did you choose? Be prepared to explain your reasons for the order of your ranking. Keep your ranking handy because you will be testing these substances later. You will be able to compare your ranking with your test results.

Understanding Density

As you probably realize, not all substances have the same density. Recall that the particle model of matter states that all matter is made of tiny particles. It also states that different substances are made of different particles. So the particles in each fluid are different from the particles in every other fluid. The density of a fluid or any other kind of substance depends on the particles it is made of.

Think about Emma's results again on page 42. If the density of the grape was *greater* than the density of the fluid, the *grape sank*. If the density of the grape was *less* than the density of the fluid, the *grape floated*. Look at the graph of the densities of some common materials in Figure 3.4. You'll notice that some solids are less dense than some liquids. That's why wood floats on water. It's the kind of particles in a substance that are important in determining a substance's density.

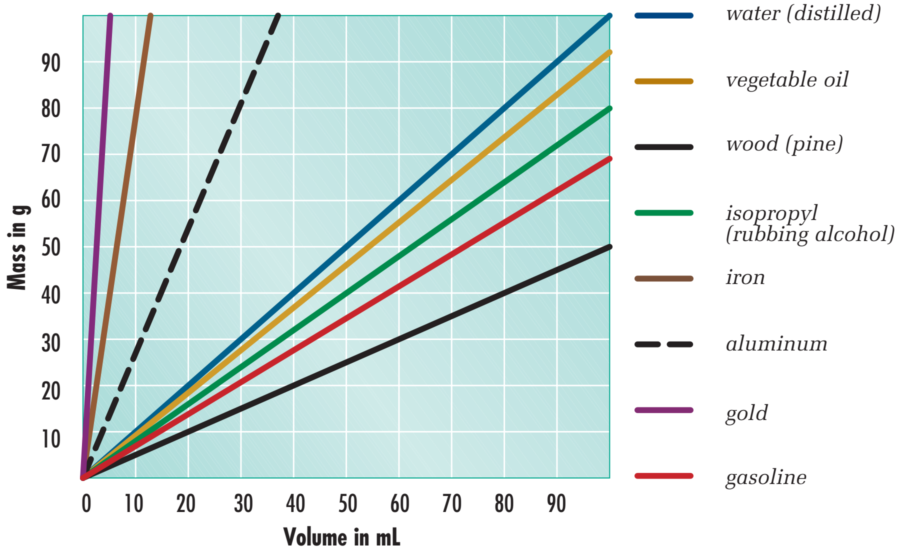

Figure 3.4 Densities of some common substances at 20°

Calculating Density

Density is the mass per unit of volume, which can be measured in mL or cm^3. Density is calculated by dividing the mass of a substance by its volume.

$$\text{Density } (d) = \frac{\text{Mass } (m)}{\text{Volume } (V)}$$

The units for the density of liquids and gases are usually grams per millilitre (g/mL) or kilograms per litre (kg/L). The units for the density of solids are usually grams per cubic centimetre (g/cm^3).

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Now That's Dense!

Mercury, like water, is a liquid at room temperature. Water's density at this temperature is 1.00 g/mL. Mercury's density at this same temperature is 13.55 g/mL!

*re*SEARCH

What's the Difference?

A can of diet soda pop will float in water, but a can of regular pop will not. Find out why.

Inquiry Activity

CALCULATING MASS/VOLUME RATIO

The Question

How can you calculate the density of a variety of solids and liquids?

The Hypothesis

Write a hypothesis about how to calculate density of solids and liquids.

Hint: Recall that density is the mass of a substance in a given volume.

Materials & Equipment

- 250-mL beaker
- graduated cylinder
- triple beam or electronic balance
- water, sand, corn syrup, aquarium stones, shampoo, wood chips
- graph paper

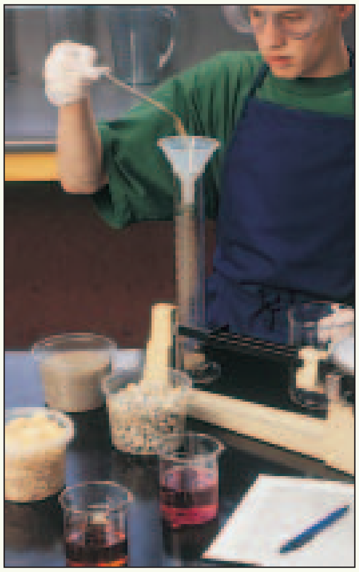

Figure 3.5 Step 2. Pour 50 mL of one substance into the beaker and record the volume in the table.

Procedure

1. Measure the mass of the beaker and record it in your table. (See Toolbox 5 for information on measuring mass.)
2. Pour 50 mL of one substance into the beaker and record the volume in the table. (See Toolbox 5 for information on measuring volume.)
3. Place the beaker containing the substance on the balance and measure the mass. Record the mass in your table.
4. Repeat steps 2 and 3 for the same substance with volumes of 100 mL, 150 mL, 200 mL, and 250 mL.
5. Repeat this procedure for each of the other substances.
6. Clean and return your equipment to the proper location.

Collecting Data

7 In your notebook, make a table like the one shown below to record your data. Use a table like this for each substance.

Substance	Volume of Substance (mL)	Mass of Beaker (g)	Mass of Beaker and Substance (g)	Mass of Substance Only (g)	Mass/ Volume Ratio

Analyzing and Interpreting

8 When you have finished taking your measurements, enter your data into a spreadsheet program.

9 Find the mass of each substance by subtracting the mass of the beaker from the total mass of the beaker and substance together.

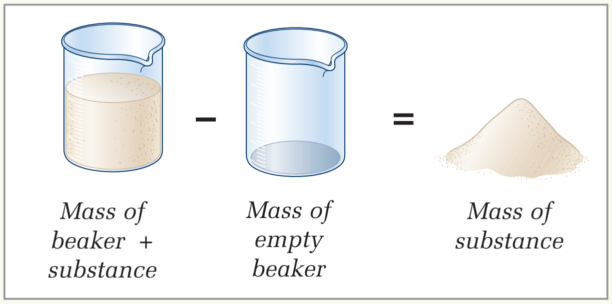

Figure 3.6 How to calculate the mass of the substance

10 Set up a line graph with mass on the vertical axis and volume on the horizontal axis. Plot your results for the first substance. Draw a straight line through or close to the points on the graph.

11 Plot your results for the other substances on the same graph. Label each line.

12 Compare the slopes of the lines. Which slope is the steepest? Which slope is the shallowest?

13 Find the ratio of the mass to the volume by dividing the mass of the substance by the volume for each volume measured. What is the average ratio for each substance? This ratio is the density of each substance.

For example:

- 200 mL of a substance has a mass of 400 g
- the mass to volume ratio is $\dfrac{400\text{ g (mass)}}{200\text{ mL (volume)}}$
- Density = $\dfrac{400\text{ g}}{200\text{ mL}} = \dfrac{2.00\text{ g}}{1\text{ mL}}$

14 Can you see any relationship between the average ratio for each substance and the slope of each line on your graph?

15 Compare your calculated densities for the substances with the predictions you made when you did the Give It a Try Activity at the beginning of this subsection. Was the order of the densities you predicted the same or was there a difference? Suggest reasons for any differences.

16 Use your graph to determine the answers to the following questions:

a) What would be the mass in grams of 150 mL of corn syrup?

b) What would be the volume in millilitres of 225 g of sand?

c) What would be the mass in grams of 300 mL of shampoo?

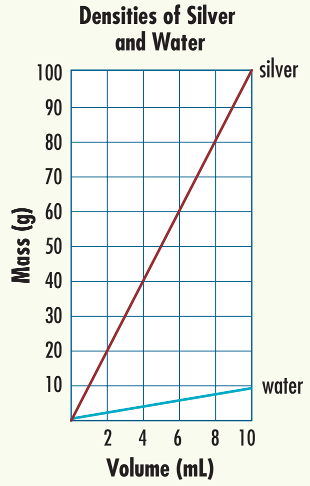

Figure 3.7 Step 10. How will you determine what scale you will use for each axis?

Forming Conclusions

17 Write a summary paragraph that explains how you calculated the density of the substances used in this investigation. Your summary should include the words *substance*, *volume*, *mass*, *graph*, *slope*, *ratio*, and *density*. Include your graph with your summary.

Applying and Connecting

If a boat is heavier than water, why does it float on water? The answer is in the concept of average density. Each of the materials that make up the boat might sink in water, but the average density of the whole boat is less than the average density of the water. The average density of the boat includes the boat's total volume, which not only contains the solid parts of the boat, but also the air in the cabins, the hold, and other spaces.

Check and Reflect

1. The table below shows mass and volume data for baby oil. What happens to the mass of the baby oil as the volume changes?

Mass (g)	Volume (mL)
0.8	1.0
1.6	2.0
2.4	3.0
3.2	4.0

2. a) What is the density of the baby oil?
   b) What happens to the density as the mass and volume change?
3. Suppose you were to graph the baby oil data on a graph with mass on the vertical axis and volume on the horizontal axis. Would the slope of the line for the baby oil be shallower or steeper than one for water? (The density of water is 1.0 g/mL.)
4. What is the density of each of the following substances?
   a) 2.0-mL of mercury has a mass of 27.1 g
   b) 0.5-mL of silver has a mass of 5.25 g
   c) 2.5-mL of lead has a mass of 28.5 g
5. If you had 100 mL of each substance in question 4, which one would have the greatest mass?

Careers and Profiles

Soft-Drink Manufacturer

To make a soft drink, you need to experiment with different combinations of water, sugar, and flavourings to make a syrup. Flavours come from fruits and berries, as well as from tree bark, herbs, and roots. Once you've got exactly the right taste, this syrup will be your own secret formula!

Next, you'll carefully purify the water for your drink. Then, you'll mix your secret syrup with the right amount of water. Your drink is a solution, since the sugar and flavourings dissolve in water.

The last step is pumping your water and syrup solution into a machine called a carbonator. This machine mixes carbon dioxide gas into your solution under very high pressure. Now your drink is a mixture of a gas and a liquid! The drink goes straight from the carbonator into the bottle or can, which is then sealed so the gas won't escape.

- What would you need to know about science and technology to develop a soft drink?

3.3 Density, Temperature, and Buoyancy

Earlier in this unit, you discovered that viscosity changes with temperature. Does density also change when the temperature changes? The particle model of matter states that for each substance, the number of particles in a given volume remains constant if the temperature is kept constant. Density does not change as long as the temperature stays the same.

Give it a TRY — ACTIVITY

MEASURING DENSITY CHANGES

Is there a difference in density between a cup of cold water and a cup of hot water? You can test the question by using a hydrometer. A hydrometer is a device for measuring the density of liquids.

Caution!
Handle hot water carefully. If you spill any on your skin, immediately run cold water over the area.

Use a hydrometer to determine if the density of cold water is the same as the density of hot water.

You will need two beakers for the water and a hydrometer.

In a short paragraph, summarize your results. Use the particle model to help explain what you observed.

THE PARTICLE MODEL AS AN EXPLANATION FOR DENSITY CHANGES

Think about swimming in a lake on a hot summer day. The water on the surface of the lake is noticeably warmer than the water below it. The warm water floats on the cold water because it has a lower density than the cold water has.

According to the particle model, particles in a substance move more quickly when energy is added. As a solid changes to a liquid and eventually to a gas, the particles move faster and faster. This affects the density of the substance. As particles become more active, they move away from each other, and the space between them increases. This causes the volume to increase, but the number of particles stays the same. With the same number of particles in a larger volume, the density decreases. Recall that density is the ratio of mass to volume.

Different Temperature, Different Density

One substance, then, can have different densities depending on its temperature. What happens to a substance as it is heated? It changes state: at low temperatures, it will be a solid, and at higher temperatures, it will be a liquid, and at even higher temperatures, a gas. A substance (except water) has a greater density in its solid state than in its liquid state and gas state. Figure 3.8 shows how the particle model explains this.

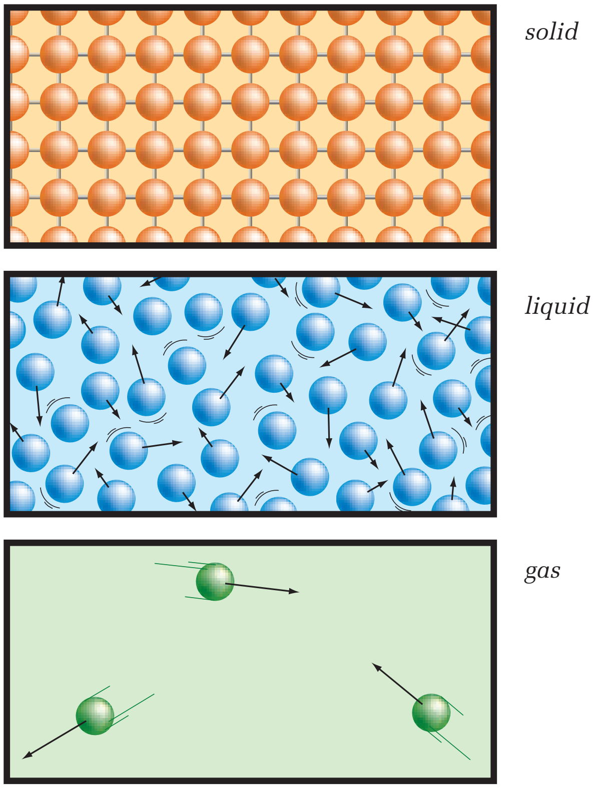

Figure 3.8 The particle model of matter describes particles in a solid and a liquid being packed close together compared with particles in a gas. A gas has more space between particles. This explains why a substance is most dense when it's a solid and least dense when it's a gas.

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Galileo's Thermometer

The thermometer shown here is Galileo Galilei's thermometer (or *thermoscope*), first invented in the 1590s. Can you determine how it works? Each temperature bulb acts like a hydrometer and floats to the top when the water's density is greater than that of the bulb.

Figure 3.9 Why is this swimmer floating so easily?

Changing Density by Changing Concentration

Have you ever tried to float in a lake, a river, or a swimming pool? How easy was it? It probably wasn't as easy as it is for the person in Figure 3.9. This person is floating in the Dead Sea in Israel. The Dead Sea is one of the saltiest bodies of water on Earth. Why do you think it might be easier to float in salt water than in fresh water?

Earlier, you learned that density depends on the number and kind of particles in a given volume. Distilled water has a density of 1 g/mL. What do you think would happen if you added salt to this water? Recall from the particle model of matter that dissolving one substance (salt) in another (water) increases the number of particles in a given volume. By adding more particles, you increase the density of the water solution. Increasing the concentration of salt in the solution increases the density. That means denser objects can float in the solution now than could in the distilled water.

So far, you have learned how density determines if one object will float in another. Less dense objects float in more dense substances. But is density the only factor that affects floating?

Buoyancy

In this unit, you have seen that an object sinks when its density is greater than the density of the fluid it is in. What is the connection between the object's density and the forces that act on it in a liquid? When an object is in a liquid, the force of gravity pulls it down. The liquid, however, exerts an opposite force, called the **buoyant force**, that pushes the object upward.

What happens when the density of the liquid is greater than the density of the object? The buoyant force of the liquid on the object is greater than the force of gravity pulling down on the object. The object floats.

What happens when the density of the object is greater than that of the liquid? The force of gravity acting on the object will be greater than the buoyant force of the liquid. The object sinks. **Buoyancy** is the tendency of an object to float when placed in a fluid. The buoyant force is the force in fluids that acts against gravity.

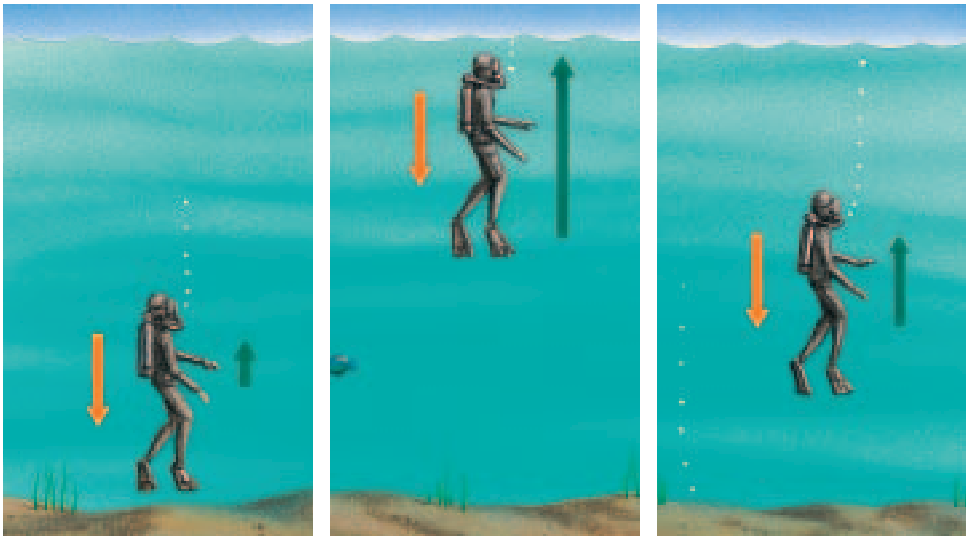

Figure 3.10a) The diver is able to move downward because of a combination of forces. The force of gravity acting on her, along with the force of her leg movement, is greater than the buoyant force of the water.

Figure 3.10b) The diver can move upward because the buoyant force, combined with the force of her leg movement, is greater than the force of gravity.

Figure 3.10c) The diver can float suspended in the water where the force of gravity equals the buoyant force. This situation is called *neutral buoyancy*.

Applications of Buoyancy

Buoyancy is an important factor in some transportation technologies. For example, ships are designed to float safely all over the world. But what happens when a ship moves from more dense to less dense water?