20 Speed of Chemical Reactions

Introduction

From their previous experiences of chemical reactions, students already have an implicit knowledge of speed of reaction and the factors affecting these speeds. This chapter makes that knowledge more explicit and precise. Many examples used to illustrate reaction speeds involve reactions from earlier work in the section.

Chapter Opener (page 304)

1. To open the chapter, the following questions could be discussed. Precise answers are not needed at this stage.

   What are some examples of fast and some slow reactions?

   Answer: Refer to Section 20.1 in the Textbook.

   How can the speeds of chemical reactions be measured?

   Answer: Refer to Section 20.2 in the Textbook.

   What is a catalyst? What substances have you studied that are catalysts?

   Answer: A catalysts is a substance that changes the speed of a reaction but is not itself used up. Many transition metals or their compounds are catalysts.

   What are some applications of speed of reaction in daily life?

   Answer: Refer to the various examples in the Textbook.

2. Carry out an 'Inquiry Preview.'

Learning Outcomes

After completing this chapter, you should be able to:

- describe the effects of particle size, concentration, pressure and temperature on the speeds of reactions
- suggest a suitable method for investigating the effect of a given variable on the speed of a reaction
- interpret data obtained from experiments concerned with speed of reaction (including graphical data)
- explain speeds of reactions in terms of collisions between reacting particles
- define the term catalyst
- state that enzymes are biological catalysts
- describe the effect of catalysts (including enzymes) on the speeds of reactions
- explain how pathways with lower activation energy account for the increase in speeds of reactions
- state that some elements and their compounds act as catalysts in industrial processes
- give examples of daily life of these effects on speeds of chemical reactions

ChemMystery (page 305)

Why did the Kinzua Bridge collapse?

This mystery is about a slow chemical reaction — the rusting of iron and how it caused the bridge to collapse. The account involves the topics of speed of reaction, oxidation and reduction and electrolytic methods in protection against rusting.

Initial Team Investigation

- Steel, an alloy of iron.
- The bridge had been standing for 121 years before it collapsed.
- It experienced the forces exerted by travelling trains and also forces of nature such as hurricanes.

Teaching pointers

20.1 What Can We Observe About the Speed of Chemical Reactions? (page 306)

Stimulation

Introduce the topic using student's existing knowledge of fast and slow reactions. Demonstrate a few reactions and compare their speeds. Ask students what criteria they use to decide whether they are fast or slow. Examples are:

- How long it takes to use up all the reactants.
- The speed at which (bubbles of) gas are produced.
- How quickly energy (heat and light) is given out.

Following this, focus the discussion around the Skills Practice questions.

Note: In Question 1, students will probably not agree on the order of reaction speed indicating the need for a more accurate ways of measuring speeds, ways that are looked at in Section 20.2. Responses to Question 3 are based of the implicit knowledge students already have about reaction speeds. Do not expect sophisticated responses at this stage.

Skills Practice (page 306)

1. (a) Precipitation reactions, fireworks on National Day, magnesium burning in air, the reaction of calcium with cold water, the rusting of a motor car, milk turning sour / decay of food.

   (b) Note: Students are unlikely to have the same order of reaction speed. Putting these reactions in order of their reaction speed based on observation can be difficult. This indicates the need for a more accurate way of measuring speed of reaction (refer to Section 20.4 on pages 311–319 of the Textbook).

2. Examples of some other fast and slow reactions: Explosion of hydrogen with oxygen (very fast); neutralisation reactions (fast); potassium in water (fast); magnesium with steam (fast); magnesium with water (slow); burning petrol (fast); magnesium with hydrochloric acid (quite fast); magnesium with ethanoic acid (slower); rusting (very slow).

3. Examples are a higher temperature and a greater concentration of reagents. Responses to this question will be based on the implicit knowledge students already have about reaction speeds. Do not expect sophisticated responses at this stage.

Teaching pointers

20.2 How Can We Measure the Speed of a Reaction? (page 306)

1. Demonstrate a simple experiment using the set-up in Figure 20.3 on pages 307 of the Textbook to compare the speeds of two reactions. To ensure that the experiment can be carried out reasonable quickly, use acids that are not too dilute. It is preferable that the acid be in excess as students are more easily convinced that the reaction is complete if they can see that the solid has been used up. Also, use equal lengths of magnesium ribbon. (You should carry out the experiment before the lesson to get suitable amounts of each reactant.)

2. To compare the speed of two or more reactions, measure the time for these reactions to be completed. To follow the progress of *individual* reactions, measure the changes that occur over a period of time.

3. Methods that measure the change in mass or gas volume are only possible if one of the products, such as a gas, is lost from the reaction flask. This method cannot be used if all the products remain in the flask.

4. Any variable that changes in a reaction can be used to measure the progress of the reaction. For example, changes in the volume of gas produced, changes in colour, pH, temperature, conductivity and voltage. Changes in pH were measured in the neutralisation reaction in Experiment 16.1 of the Practical Workbook. Changes in pH can also be measured for the experiment in Figure 20.4 on page 308 of the Textbook by placing a pH sensor in the reaction flask and following the changes in pH, instead of measuring the volume of gas produced. Students will get to study more of these methods in higher level Chemistry.

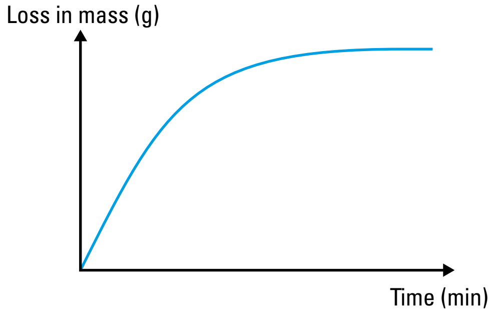
5. **(a)** Perform a demonstration, using the set-up in Figure 20.4 on page 308 of the Textbook. About five large marble chips and 0.2 mol/dm^3 hydrochloric acid are suitable for this experiment. Collect data for the volume of gas produced every half minute. Get the class to draw a graph and interpret it. (Remind students to draw a line of best fit through the data points.)

   (b) Alternatively,

   (i) React the marble chips with dilute acid and match the progress of the reaction to the arrows in the curve in Figure 20.5 on page 308 of the Textbook.

   (ii) Give students some ‘typical results’ which they can use to draw the graph (by hand or using a computer). See ‘Notes for Teachers’ on the next page.

6. (a) The graph of mass of reaction mixture against time in Figure 20.7 should also be taught. This can be done by demonstrating the experiment shown in Figure 20.6. The balance does not have to be connected to the computer; the balance readings can be recorded by hand with the class drawing the graph of mass on balance against time. Get students to appreciate that the shape of graph in Figure 20.7 is just the inverse of that in Figure 20.5.
   (b) An alternative method is to measure loss in mass of the reaction mixture as the reaction proceeds. The curve will then have the same shape as in Figure 20.5.



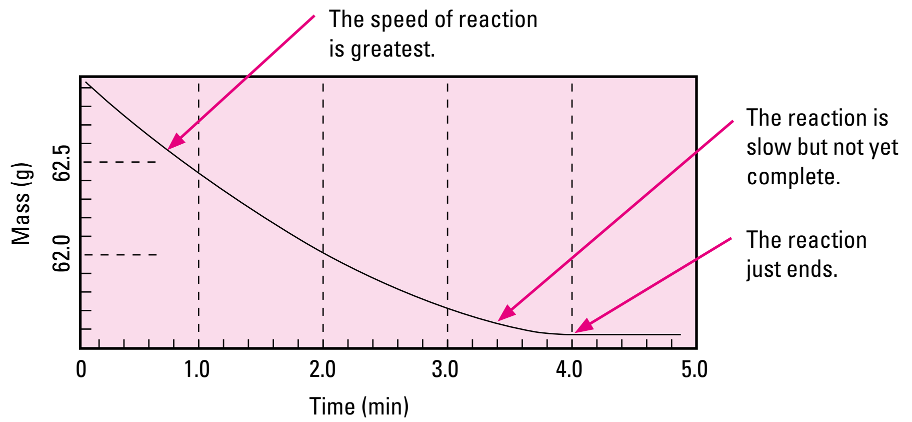
As the speed of a reaction is greatest at the start, the loss in mass will be greatest then.

7. As the pH of the reaction mixture changes (increases) during the reaction of magnesium or calcium carbonate and dilute hydrochloric acid, a pH sensor could also be used to follow the progress of the reaction. A graph of pH against time would have the same shape as that in Figure 20.5.

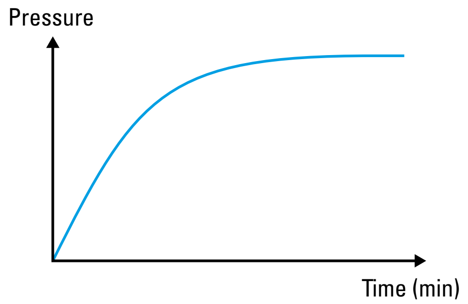
Skills Practice (page 310)

1. (a) About 4.5 min.
   (b) About 70 cm^3 of carbon dioxide gas.
   (c) (i) About 0.8 min.
       (ii) About 1.5 min.
   (d) As the reaction proceeds, the speed of the reaction slows down / decreases.

2.



3. (a) A plastic bottle is safer than a glass conical flask in case a pressure build-up in the bottle causes an explosion.
   (b)



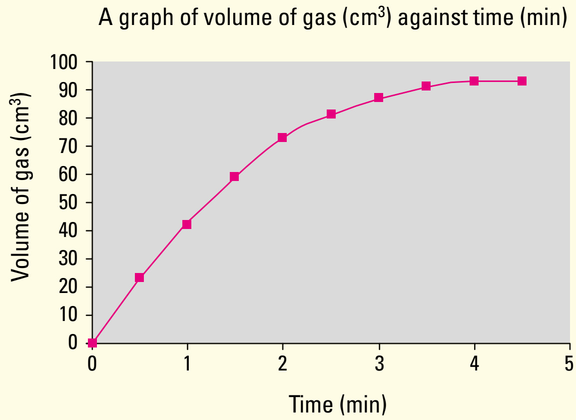
Notes for Teachers

Typical results' for a speed of reaction experiment

The table below shows typical results for an experiment carried out using the experimental set-up shown in Figure 20.4 on page 308 of the Textbook:

Time (min)	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5
Volume of gas (cm^3)	0	23	42	59	73	81	87	91	93	93

The graph obtained is shown below:



- Either the graph obtained from the experiment or that shown in Figure 20.5 on page 308 of the Textbook can be used to explain the significance of the gradient:
  1. The gradient is a measure of the rate of reaction.
  2. When the gradient is zero (i.e. the graph is horizontal), the reaction has stopped.
- Two conclusions can be made:
  1. The amount of product increases with time.
  2. The rate of reaction slows down with time (the gradient decreases).

Teaching pointers

20.3 How Can Differences in Speeds of Reactions be Explained? (page 310)

1. Assumption 2 *follows* Assumption 1. Hence, the greater the number of collisions that have sufficient energy to react, the faster the reaction.
2. In the collision theory, note that it is actually the *proportion* of successful collisions that affects the rate of a reaction and not merely the *number* of collisions between particles.
3. Get students to try to *visualise* the particles in Figure 20.9 reacting. This will help them to understand the idea of speed of reaction better.

Skills Practice (page 311)

1. (a) Molecules (of hydrogen and oxygen).
   (b) Zinc atoms and hydrogen ions (just as in the example in Figure 20.9).
   (c) Copper(II) ions and hydroxide ions (to form a precipitate of copper(II) hydroxide).
   (d) Hydrogen ions and hydroxide ions (to form water).
2. Energy is needed to provide the particles with enough energy to react.
3. [Accept any reasonable answers.]

Teaching pointers

20.4 What Factors Affect the Speed of Chemical Reactions? (page 311)

Particle Size

1. You may demonstrate the effect of particle size (or surface area) on the speed of a reaction using the following simple experiments:
   - Blow powdered flour or aluminium into a Bunsen flame. They both burn very brightly and quickly due to the large surface area of the powders.

     Note: This experiment is not safe for students to carry out. You must wear protective gear and do the demonstration behind a safety screen separating the demonstration from the class.
   - Using tongs, students or you can hold a piece of steel wool in a Bunsen flame. It burns brightly and quickly due to the large surface area. Compare this experiment when a steel nail is used. Nothing happens in the case of the steel nail.
2. Spend some time discussing how fair experiments are carried out by controlling variables, such as in Figure 20.11. See also the notes on controlling variables in Section A.9 on pages 32–33 of the Practical Workbook.
3. Surface area of liquids also increases the speed of reaction. This occurs when the liquid is in the form of a spray, i.e. small droplets. For example, petrol is sprayed into the combustion chamber of an engine to ensure rapid burning.

(page 311)

Mystery Clue

Temperature is the main factor that would affect the speed of the reaction.

Skills Practice (page 313)

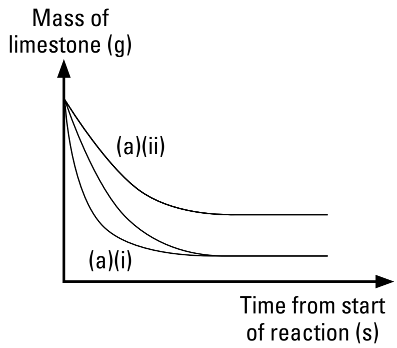
1. This increases the surface area of the food, allowing it to be cooked faster by increasing the speed at which it reacts with other ingredients.
2. (a) Small twigs have a larger surface area than a single large branch. This enables the fire to be started faster.
   (b) A large piece of fruit has a smaller surface area than several small pieces of fruit. Thus, a large piece of fruit has a slower reaction with oxygen and a slower rate of decay.
   (c) As small pieces of medicine have a larger surface area than a whole pill or tablet, they react faster.
3. Rice dust has a very large surface area. The large amount of rice dust in the air has the ability to burn rapidly, causing an explosion.
4. (a) 24 cm^2
   (b) 48 cm^2
   (c) The 8 smaller blocks will react faster as they have a greater total surface area.

Concentration

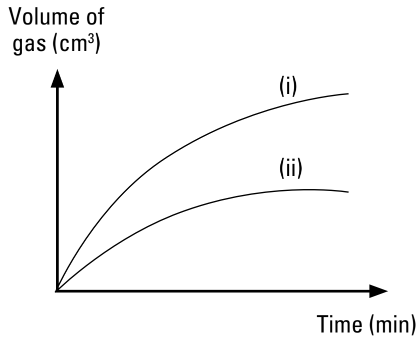
In most reactions, the vigour of the reactions involving solutions decreases over time. This is because the solutions are less concentrated as the reactants are consumed. Hence the graphs in Figures 20.5 and 20.7 on pages 308 and 309 respectively in the Textbook are curved as the speed of reaction decreases as the reaction proceeds.

Skills Practice (page 314)

1. (a)

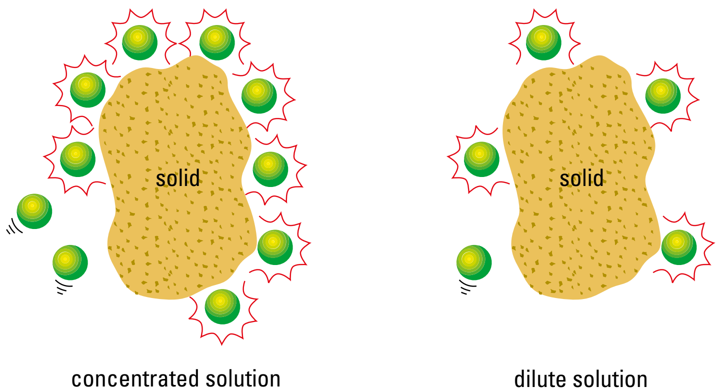


(b)



2. (a) This is a slow reaction as the acid in rain is very dilute.
   (b) Limestone blocks are cheap and it takes many years for acid rain to affect the limestone blocks.

3.



Notes for Teachers

Effect of acid rain on buildings

Acid rain attacks buildings and objects make from marble and limestone (forms of calcium carbonate). One source of acid rain is sulfur dioxide (see Chapter 23). Sulfur dioxide is an acidic oxide and reacts with moisture and oxygen in the air to form sulfuric acid. The concentration of acid fumes is greater in countries such as China that burn a lot of sulfur-containing coal. Thus, the concentration of the sulfuric acid produced is greater and so the speed of corrosion is also greater.

Pressure (page 314)

In most reactions, the vigour of the reactions involving solutions decreases over time. This is because the solutions are less concentrated as the reactants are consumed. Hence the graphs in Figures 20.5 and 20.7 on pages 308 and 309 respectively in the Textbook are curved as the speed of reaction decreases as the reaction proceeds.

Temperature (page 314)

1. Molecules move faster and collide more frequently as the temperature increases. Thus, reactions are faster at higher temperatures. Perhaps get the class to explain why a mixture of hydrogen and oxygen at room temperature does not react but explodes when a lighted match is placed in the mixture. Refer to the 'Notes for Teachers' below.
2. Additional Experiment 1 found at the end of this chapter gives students the opportunity to investigate the effects of concentration and temperature using a pressure sensor and a data logger connected to a computer. As students already know how the factors investigated will affect the reaction rate, they will be able to focus their attention on the technique of how to use a data logger and to appreciate that the graph obtained using the data logger is real time. For more details, refer to the notes for this experiment on the next page.

(page 315)

Mystery Clue

When the weather is hot and wet or humid (water is needed for rusting)

Note: Summers in Pennsylvania, where the bridge is, tend to be hot and humid. Hence most rusting would probably occur then.

Skills Practice (page 316)

1. The following methods can be used to increase the production of the gas: Increase the temperature; break the zinc into smaller pieces; use more concentrated acid.
2. **(a)** For cold-blooded animals, body temperature drops as the atmospheric temperature falls. Respiration, which involves the release of energy from chemical reactions, therefore slows down.

   (b) This is to keep the books cool so that the paper deteriorates less quickly.

Notes for Teachers

Explaining the effect of temperature on reaction rate

When the temperature is raised by 10 °C, the speed of many reactions increases by about 100%. However, the frequency of collisions only increases by 2%. So the increase in reaction speed is 50 times the increase in frequency of collision. Clearly the increase in collision frequency does not explain the increase in rate of reaction.

The explanation involves collision theory and activation energy. Although reactant particles are in continual motion and many collisions occur, only those collisions that exceed the activation energy lead to a reaction. In a typical reaction mixture, only one in 10 million collisions results in a reaction. At a given temperature, faster reactions have lower activation energies than slower reactions, so more colliding particles will have sufficient energy to react.

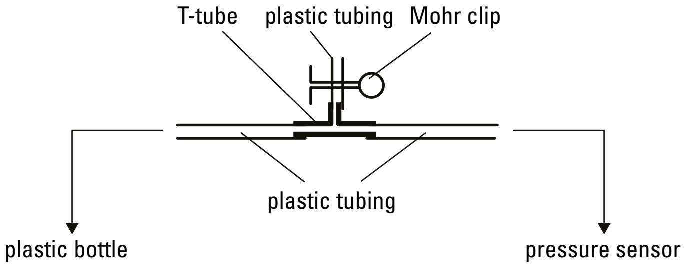
Therefore, the main reason for an increase in speed of reaction with an increase in temperature is that the *proportion* of reactant particles having the necessary activation energy to react increases. There are more *effective* collisions even though the number of actual collisions does not increase substantially.

For the reaction of hydrogen and oxygen, the activation energy is high. At room temperature, only a few collisions of the molecules in the mixture have the activation energy needed to react. Heating the mixture of gases with a match raises the temperature to several hundred degrees. At this higher temperature, most collisions will be effective, i.e. most collisions will have the activation energy to react, leading to a rapid reaction.

Additional Experiment 1: Investigating Speed of a Reaction (Using a Data Logger)

Notes on the experimental set up

- Carry out this experiment before the lesson to get the conditions right. It is dangerous to use acid that is too concentrated as the rapid formation of gas may cause the stopper to blow out. This should not happen with the quantities of reagents suggested in the Practical Workbook.
- Wash the marble chips (to remove dust) and then dry them (to remove water) before the experiment so that the acid reaches the surface of the marble chips immediately.
- A large plastic bottle of 1.5 litres or greater capacity is needed. Plastic drink containers or plastic bottles used to hold household reagents are suitable.
- A T-tube with a Mohr clip can be inserted in the plastic tubing as shown below. This acts as a safety vent. It also allows for an easy and quick release of gas pressure if necessary.



Suggested teaching and learning sequence

Lesson 1: *Demonstration of the use of a data logger (1 period)*

- Introduce the use of sensors and data loggers if this has not been done before.
- Show how the apparatus, the computer and the data logger are connected for this experiment.
- Discuss how experimental data are converted into a graphical form and discuss the interpretation of a pressure against time graph.

Lesson 2: *Student experiment (1 period)*

- In groups, get students to carry out Additional Experiment 1A to investigate the effect of concentration on the speed of reaction.

Preparation before lesson 3:

- In groups, get students to design an experiment for Additional Experiment.1B to investigate the effect of temperature on speed of reaction. The various groups are to discuss their plans with you and make any necessary changes.
- The various groups are to hand their apparatus and materials lists to the teacher who passes them to the laboratory technician for preparation.

Lesson 3: *Performing experiment (1 period)*

- In the laboratory, get the various groups to perform their experiments.

Follow-up activities

- Get the various groups to prepare a written report on their investigation. This can be for Additional Experiment 1B only or it may include Additional Experiment 1A as well.

Suggestions for Additional Experiment 1B

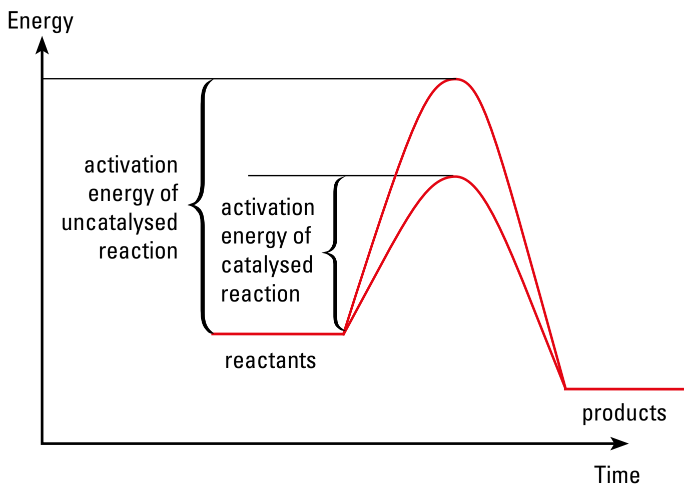
- As in Additional Experiment 1A, two experiments are carried out. The 0.4 mol/dm^3 of hydrochloric used in Additional Experiment 1A can be used again in Additional Experiment 1B. To obtain solutions of different temperatures, place the plastic bottle in a bath of warm water or in ice.

  Note: Do not use water that is too hot as the plastic bottle may soften. You need to control the other factors in the experiment. That is, there should be equal volumes of acid and an equal mass of marble chips (about 10 g as in Additional Experiment 1A).

Catalysts (page 316)

1. Catalysts that increase reaction speeds are called *positive* catalysts whereas those that decrease reaction speeds are called *negative* catalysts.
2. **(a)** If possible, show the class a bottle of hydrogen peroxide with a hole in the cap. Hydrogen peroxide decomposes very slowly in the bottle. The hole in the cap allows the oxygen gas to escape.

   (b) If the bottle has no hole in the cap, pour some hydrogen peroxide into a beaker. Bubbles of oxygen gas will appear on the walls of the beaker within a few minutes. This shows that hydrogen peroxide decomposes by itself. Then add a little manganese(IV) oxide to the hydrogen peroxide to show the increase in reaction speed. Bubbles of oxygen gas appear much faster after the addition of manganese(IV) oxide.
3. Perhaps also demonstrate the decomposition of hydrogen peroxide as shown in Figure 20.22 on page 316 of the Textbook as it can be used to teach some important points about catalysts. See 'Notes for Teachers below for details.
4. As catalysts are not used up in reactions, they do not appear in chemical equations.
5. Positive catalysts provide an alterative reaction pathway that lowers the activation energy of the reaction. The diagram below is useful in explaining how catalysts work:



6. Refer to the Haber process (see Chapter 17). Discuss how an increase in temperature speeds up the reaction (desirable) but decreases the yield (undesirable). The catalyst only speeds up the reaction but does not affect the yield. The use of a catalyst therefore allows a lower temperature to be used.

7. Experiment 20.4 involves planning and carrying out an investigation. One suggested method is described on pages 146–148 of the Teachers' Edition of the Practical Workbook. A simpler but less precise method is to carry out the reactions in boiling tubes and to measure the time for the reaction to be completed (similar to the reactions shown in Figure 20.22 on page 316 of the Textbook). To ensure that the reaction does not take too long, use only small quantities of reagents.

8. Some natural fruit juices, such as unripe papaya and pineapple, contain substances that act as enzymes in the digestion of proteins. You may demonstrate the effect of pineapple juice on proteins. See 'Notes for Teachers' on the next page on how to do this. Students who study Biology may perform an experiment to investigate the effect of ptyalin on starch.

9. Another use of enzymes is in the production of antibiotics, which are produced from enzymes in fungi. Penicillin and other antibiotics are extracted on a large scale from special strains of fungi.

Skills Practice (page 319)

1. (a) In the test tube on the left, little or no oxygen is produced so the glowing splint is not ignited. In the test tube on the right, the catalyst causes the hydrogen peroxide to decompose rapidly. The oxygen gas produced relights the glowing splint.
   (b) Weigh the catalyst (after drying) before and after the reaction. There will be no change in mass.

2. Inferences that can be made:
   - The volume of gas produced in the reaction involving 0.2 mol/dm^3 H_2O_2 is twice that produced in the reaction involving 0.1 mol/dm^3 H_2O_2. Therefore the volume of 0.2 mol/dm^3 H_2O_2 used must be twice that of 0.1 mol/dm^3 H_2O_2.
   - The gradient of the graphs is greatest at the start of the reactions; therefore the reaction rates are greatest at the start. As the reactions proceed, the rate at which oxygen is produced decreases.
   - The gradient of the graph is greater with 0.2 mol/dm^3 H_2O_2 than with 0.1 mol/dm^3. This shows that reactions are more rapid with higher concentration.

3. The use of catalysts saves money. It is more expensive to speed up reactions using higher temperatures than to use catalysts.

Notes for Teachers

Demonstration: Decomposition of hydrogen peroxide

1. Place a glowing splint in the mouth of a test tube containing hydrogen peroxide (see the diagram on the left in Figure 20.22 on page 316 of the Textbook). Observe that the glowing splint does not relight as little oxygen is produced.
2. Add a little manganese(IV) oxide to the test tube (see the diagram on the right in Figure 20.22 on page 316 of the Textbook). The glowing splint relights. Observe that the manganese(IV) oxide is still seen at the end of the reaction.

   Teaching points:
   - Manganese(IV) catalyses the decomposition of hydrogen peroxide.
   - The catalyst is not used up.
3. Add more hydrogen peroxide into the test tube. The bubbling will start again.

   Teaching point:
   - The catalyst is not used up.

Watching the digestion of proteins

Pineapple juice contains an enzyme that digests protein. Make three jellies — one using fresh pineapple juice (not from a can), one using canned pineapple juice and the third without any pineapple juice. The jelly made using fresh pineapple juice is not able to set properly because the enzyme in pineapple breaks down the gelatine (protein in jelly). Canned juice does not have this effect as the heating process involved during the canning destroys the enzyme. So, jelly made using canned juice is able to set properly.

20 Chapter Review

Self-Management

Misconception Analysis (page 320)

1. **True** The speed of a reaction depends on the concentration of the reactants. At the start of a reaction, the concentrations of the reactants are the greatest. As the reaction proceeds and the reactants are used up, their concentrations decrease and so the reaction speed also decreases.

2. **False** A reaction only take place when the collisions between the particles have the minimum amount of energy needed to break the bonds in the particles. Without this minimum energy, the particles just bounce off each other.

3. **True** We only need to control variables that will affect the reaction. Some variables will have no effect on the speed of reaction (e.g. the shape of the reaction container). But as we do not usually know which variables will affect the reaction and which will not, in practice we control *all* variables, that is, we carry out experiments that are identical except for the one variable we want to investigate.

4. **False** An increase in concentration will increase the speeds of *most* reactions, but it does not increase the speeds of *all* reactions.

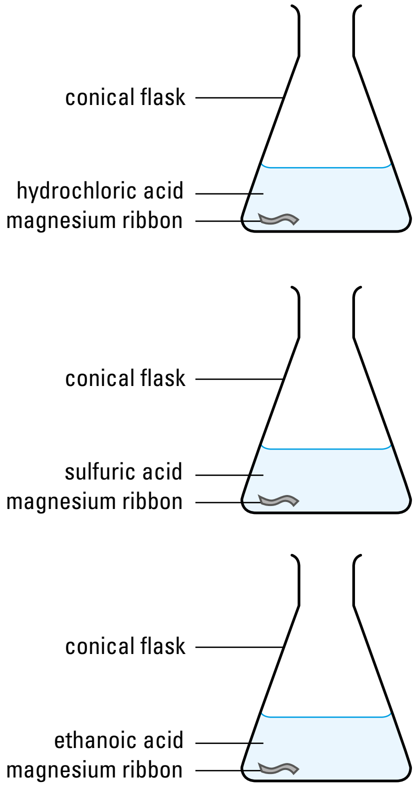
5. **True** This is an experimental observation. (You will learn a theoretical explanation for this observation in higher level Chemistry).

Practice

Structured Questions (page 321– 323)

1. (a) The reaction was fastest at about 1.5 minutes, when the graph was the steepest (biggest gradient).
   (b) The reaction stopped at about 5 minutes, when the graph became horizontal.
   (c) Half the acid was used up at about 2 minutes, when 45 cm^3 of gas had been produced.
   (d) The speed of reaction was constant.
   (e) Hydrogen gas. It will burn with a 'pop' sound.
   (f) The metal may be corroded.

2. (a) No more gas is produced. / All the magnesium is used up.
   (b)

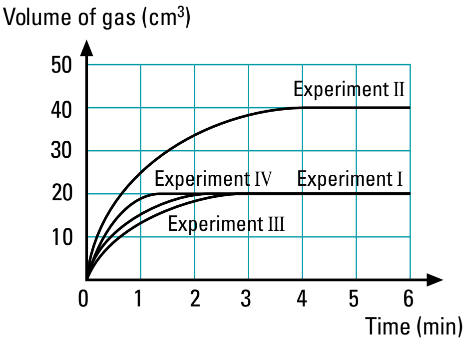


   Note:
   - Equal lengths of magnesium are placed in each flask.
   - As the three experiments are being compared, a gas syringe need not be included.
   - The time is taken for each reaction to be completed.

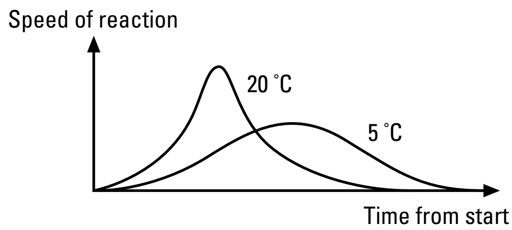
   (c) Experiment III is slower than Experiment I as ethanoic acid is a weak acid. The magnesium ribbon reacts with the hydrogen ions in the acid. As the sulfuric acid in Experiment II has twice the number/concentration of hydrogen ions as the hydrochloric acid in Experiment I, Experiment II is faster than Experiment I.
   (d) The speed of all three reactions would increase.
   (e) $Mg(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + H_2(g)$
   1 mole Mg (24 g) reacts with 2 moles acid (2000 cm^3 of 1 mole/dm^3)
   $\therefore$ 1.2 g Mg reacts with 100 cm^3 of 1 mol/dm^3 acid.
   $\therefore$ 0.8 g Mg remains when the reaction is complete.

3. (a) Doubling the volume of acid will have no effect on the speed of reaction as volume does not affect reaction rate.
   (b) Doubling the temperature to 70 °C will increase the speed of the reaction most. This is because doubling the temperature (in °C) increases the reaction speed by about 10 times.
   (c) Use powdered zinc.

4. (a) $CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + CO_2(g) + H_2O(l)$
   (b) The acid has been used up so the reaction has stopped. Thus the graph is horizontal.
   (c) The gradient is less steep at 2 minutes than at 1 minute because the concentration of the acid is smaller.
   (d)



5. (a)

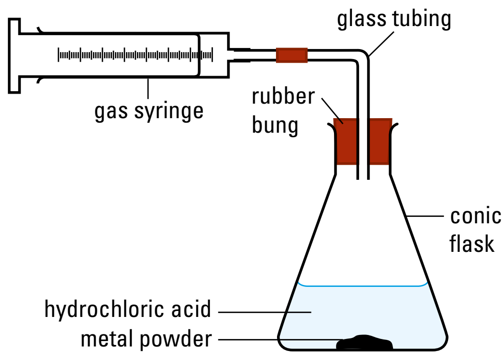


   (b) It would last 9 hours. This is because the decay reaction is twice as fast at 30 °C than at 20 °C, so the time that the milk can last is halved.
   (c) A pH indicator can be put in the milk. It changes colour when the lactic acid concentration increases. The indicator could be embedded in the plastic and be made part of the lining of the milk container so that the pH can be easily seen.

6. (a) (i) An example is magnesium hydroxide.
   (ii) $Mg(OH)_2(s) + 2HCl(aq) \longrightarrow MgCl_2(aq) + 2H_2O(l)$
   (b) The reaction in Experiment 2 is faster as the time for the reaction to be completed is less.
   (c) (i) Experiments 2 and 3.
   (ii) Experiments 1 and 5.
   (iii) Experiments 1 and 4.
   (d) (i) The reaction speed increases.
   (ii) The surface area of the crushed tablet is greater than that of the whole tablet. Therefore, the collision rate between the acid particles and the crushed tablet is greater than that with the whole tablet. This results in a faster reaction.

Free Response Questions (page 323)

1. Responses to this question may include the following points:
   (a)



   (b) Briefly:
   - Put a known mass of one metal powder into a flask and add a known volume of hydrochloric acid. Record the time taken for the syringe to be filled with 100 cm³ of gas.
   - Repeat the experiment with the other metal, using the same mass of metal powder and same volume of acid.

   (c) Use the same mass of metal, same concentration of acid, same volume of acid, same temperature and same apparatus for both experiments.
   (d) The metal that takes a shorter time to produce 100 cm³ of gas is the metal that reacts with hydrochloric acid more quickly.

2. Responses to this question may include the following points:
   - Mix known amounts of zinc and dilute sulphuric acid and record the time it takes to fill a test tube full of hydrogen gas (collected over water) or to fill a gas syringe.
   - Repeat the experiment using the same amounts of zinc and acid, but adding a few drops of copper(II) sulphate solution. The time to collect the same volume of gas should be shorter. Keep all other conditions the same for both experiments (e.g. the temperature, the concentration of the acid, the mass and size of the zinc granules).

3. Responses to this question may include the following points:
   - Put one tablet of each type separately in the same volume and concentration of hydrochloric acid in a flask, which is connected to a gas syringe. Record the time taken for the same volume of gas to be collected (e.g. 20 cm³). Alternatively, record the volume of gas produced every half-minute and plot a graph of volume of gas produced against time for each tablet.
   - The more effective tablet is the one that produces the same volume of gas in a shorter time (i.e. a faster reaction) or gives the greatest initial gradient in the two graphs.

Extension (page 323)

Search and Presentation of Information

Applications of speed of reaction in daily life:
- *Particle size*: For example, the speed at which lime/calcium carbonate dissolves/reacts with acids in the soil, chopping up solid food for faster cooking and the use of liquid sprays for burning.
- *Temperature*: For example, cooking food at high temperatures to ensure that it is cooked faster and food that is stored at low temperature decays slower.
- *Pressure*: For example, pressure cookers use high pressure in order that the reactions will take place at a fast rate.

Possible websites:
http://en.wikipedia.org/wiki/Enzymes#Applications
http://antoine.frostburg.edu/chem/senese/101/kinetics/faq/everyday-kinetics.shtml
http://www.google.com.hk/url?sa=t&rct=j&q=application+of+speed+of+reaction+in+daily+life&source=web&cd=3&ved=0CC4QFjAC&url=http%3A%2F%2Fwww.efisien.edu.my%2Fpte%2FImages%2FStories%2FNotes%2F1.4%2520Rate%2520of%2520reaction(1.2d).ppt&ei=j2AnT5zaG8zIrQeIm9TBAQ&usg=AFQjCNGM57oYFzZCpYhOnk_fGoI_LAaNfw

Additional Teaching Material

Additional Experiment 1: Investigating Speed of a Reaction (Using a Data Logger)

Objectives

- To study the effects of concentration and temperature on the speed of reaction using a pressure sensor attached to a computer

Apparatus and materials

- large plastic bottle with rubber bung
- measuring cylinder (100 cm^3)
- retort stand, boss and clamp
- pressure sensor
- dry cotton cloth
- electronic balance
- data logger, computer (loaded with software program)
- marble chips

Key Skills and Competencies

Practical skills: handling apparatus safely, observing
CIT: sound reasoning [*inferring, comparing, interpreting graphs*], reflective thinking [*evaluating*]; creativity [*planning an investigation*]
ICS: management of information [*appropriate use/ access of technology*]; communicating effectively [*collaborating with others, written report*]

Safety Warnings

- hydrochloric acid (0.4 mol/dm^3)
- hydrochloric acid (0.2 mol/dm^3)

Introduction

In this experiment, the effects of acid concentration and temperature on the speed of the reaction between marble chips and hydrochloric acid are investigated. The speed of the reaction can be followed by recording the pressure produced by the carbon dioxide with time, using a pressure sensor.

A To Investigate the Effect of Concentration on Speed of Reaction

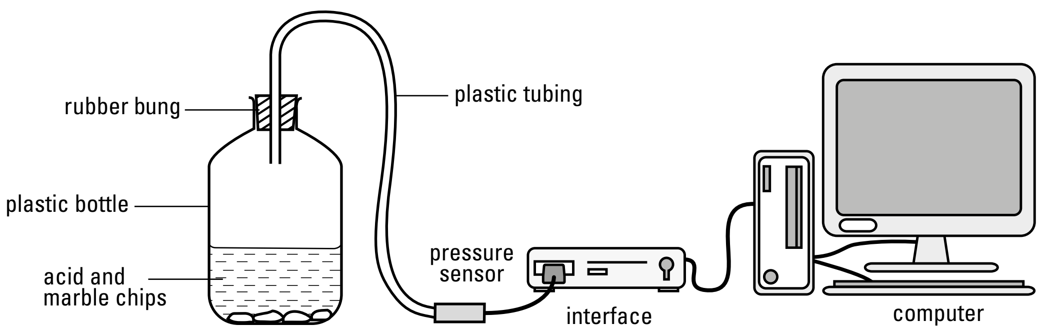
Two experiments are carried out.

Experiment 1: Using 0.4 mol/dm^3 hydrochloric acid
Experiment 2: Using 0.2 mol/dm^3 hydrochloric acid

> The pressure increase inside the plastic bottle might blow out the rubber bung. This should not happen with quantities of chemicals in these instructions, but precautions should be taken. It is very important to wear safety goggles.

Preparation and Procedure

1. Set up the apparatus as shown in the diagram.



2. Connect the pressure sensor to the correct port on the interface. Then connect the interface to the computer. Switch on the power to the interface and computer.

3. Open the computer file (as directed in your school) to record and display your results. You will be recording pressure against time.

4. Set the program recording conditions to:
   (a) sampling rate high
   (b) recording time of 5 minutes

Experiment 1: Using 0.4 mol/dm³ hydrochloric acid

5. Weigh approximately 10 g of large marble chips. It is not possible to be exact, but make it as close to 10 g as possible. Then wash the chips with water to remove dust, and dry the chips with a dry cotton cloth. Weigh the chips once more and record the mass in grams.

6. Use a measuring cylinder to place 100 cm^3 of 0.4 mol/dm^3 hydrochloric acid into the plastic bottle.

7. Drop the marble chips into the plastic bottle and quickly push the rubber bung to close the flask. As soon as you have done this, press the 'record' button.

8. When recording stops automatically (or press the 'stop' button), remove the rubber bung from the bottle and wash out the contents.

9. Your results will be recorded as 'Run #1'.

Experiment 2: Using 0.2 mol/dm³ hydrochloric acid

10. Repeat the whole procedure from 5 to 8, using 50 cm^3 of the 0.4 mol/dm^3 HCl and 50 cm^3 of water. The concentration of the acid in the bottle is then 0.2 mol/dm^3.

11. Your results will be recorded as 'Run #2'.

Results

1. Save your data.

2. Print out your graphs and paste them on the next page.

Questions

1. **(a)** From your graph, which reaction was faster?

   ____

   (b) How did you decide this?

   ____

2. Explain how the concentration affects the speed of reaction.

   ____

   ____

   ____

   ____

3. List the features which are kept the same in both experiments so that a fair comparison can be made of the effect of concentration of the acid on the rate of reaction.

____

____

____

____

B To Investigate the Effect of Temperature on Speed of Reaction

1. Design and carry out an experiment to study the effect of temperature by modifying the experiment in Part A. Write out your procedure. Remember to plan a fair test.
2. Discuss the design with your teacher. After making any necessary changes, carry out the experiment.
3. Save your results and print out your graphs.
4. Interpret the results and draw a conclusion.
5. Evaluate the experiment on completion.
6. Prepare a written report on your investigation.

Additional Teaching Material

Additional Exercise 1: Use of Mapping Techniques

Objectives

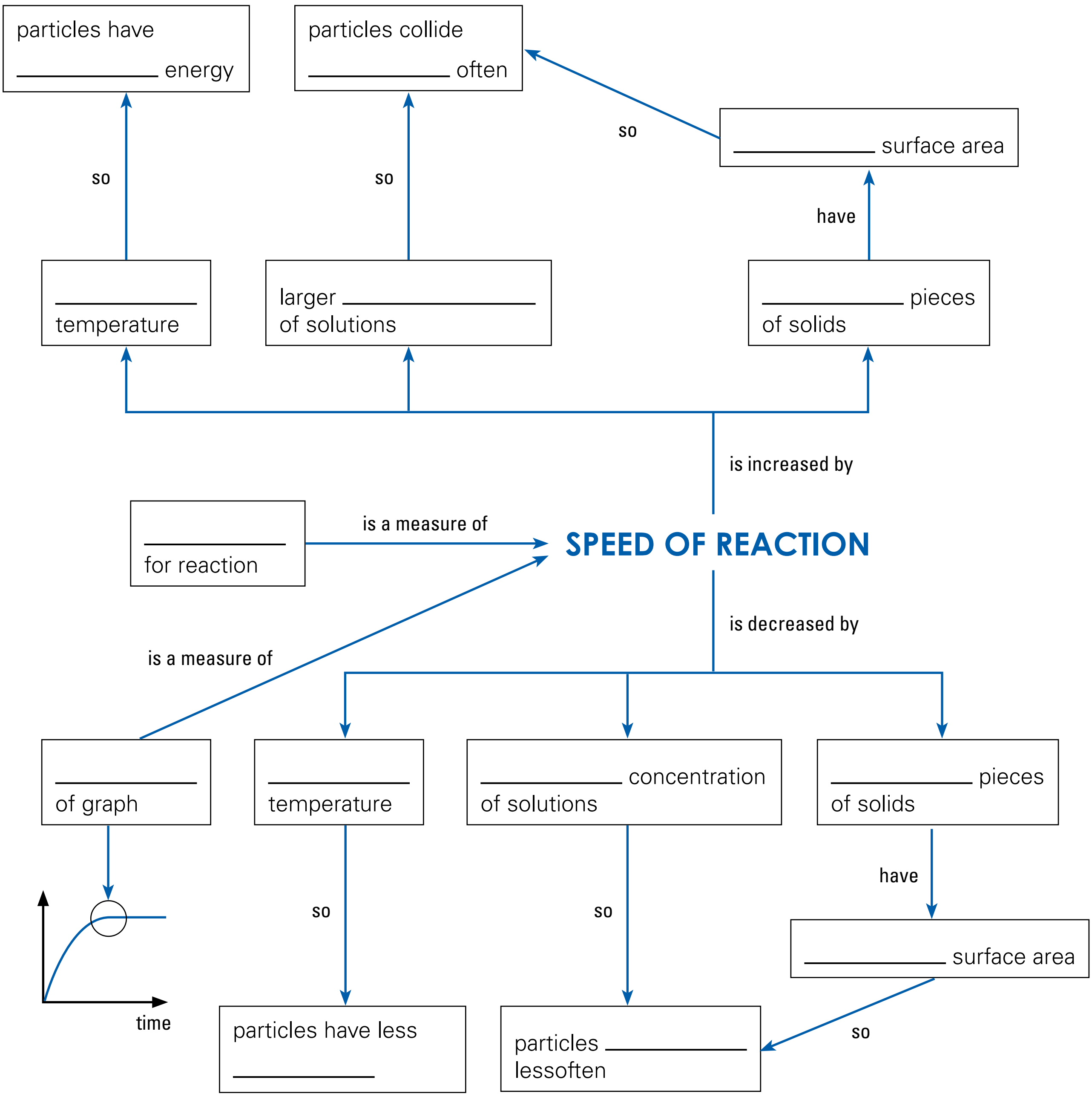
- To complete a concept map and a mind map for speed of reaction

Key Competency

CIT: sound reasoning [*analysis of data*], creativity [*mind map*], reflective thinking [*self-reflection*]
ICS: openness [*peer review, feedback*], communicating effectively [*concept map, mind map*]

A Concept map

1. Fill in suitable concept words and link words in the following concept map.



2. **(a)** On a sheet of paper, construct your own concept map for the concepts in this chapter. Leave blank spaces as in the example above.
   (b) Get a classmate to complete your concept map and to comment on it. At the same time, complete your classmate's concept map and suggest how it might be improved.
   (c) From your classmate's comments and suggestions, revise your concept map. Draw the revised version in the space below.

B Mind map

On a large sheet of paper, or by means of appropriate mapping software, create a mind map for the topic of speed of reaction that includes the main ideas you learnt in this chapter. Then, compare your mind map with those of other classmates and suggest ways to improve them.

Additional Teaching Material

Additional Exercise 2: Analysing a Household Glass Cleaner

Objectives

- To calculate the concentration of ammonia in glass cleaner

Competencies

CIT: sound reasoning [*problem solving through data analysis, calculating*], creativity [*planning an investigation*]
ICS: openness [*collaboration*], communicating effectively [*oral/written report or presentation*]

Many glass cleaners contain solutions of dilute ammonia. An experiment was carried out to find the concentration of ammonia in one such cleaner as follows:

25.0 cm^3 of the glass cleaner was diluted to 250.0 cm^3 in a volumetric flask. 25.0 cm^3 portions of the diluted solution were transferred to a conical flask and titrated against 0.23 mol/dm^3 hydrochloric acid until the end point was reached.

The following results were obtained:

Titration number	**1**	**2**	**3**	**4**
Final burette reading (cm^3)	29.3	30.0	29.8	29.7
Initial burette reading (cm^3)	0.0	1.3	1.0	1.1

(You may assume that ammonia is the only substance in the glass cleaner that reacts with hydrochloric acid.)

(a) What liquid is used to dilute the glass cleaner?

(b) What piece of apparatus is used to transfer 25.0 cm^3 of the diluted sample to the conical flask?

(c) Before the burette is used, it is cleaned by rinsing with a liquid. State the liquid that should be used.

(d) Write the balanced chemical equation for this reaction.

(e) Based on the titration results, calculate a reasonable average for the volume of the hydrochloric acid used.

(f) Calculate the concentration, in mol/dm^3 of ammonia in (i) the diluted solution and (ii) the original sample of glass cleaner.

(g) Suggest a reason why the glass cleaner is diluted.

Answers

Additional Experiment 1:

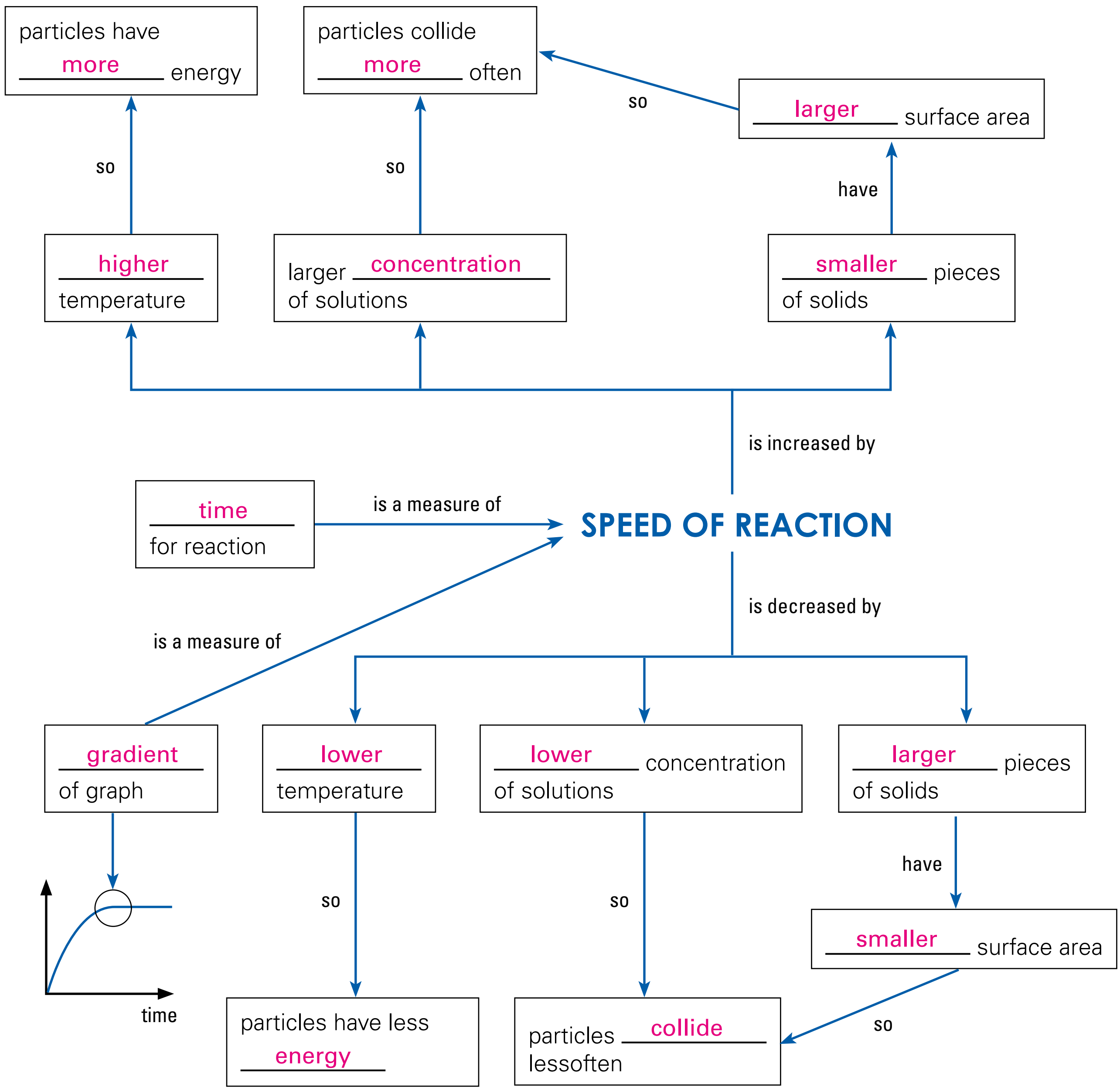
Questions

1. **(a)** The reaction with the 0.4 mol/dm³ HC*l* was faster.
   (b) The graph has a steeper gradient at the start.
2. For the same volume of HC*l*, there are more acid particles in 0.4 mol/dm³ HC*l*. Thus the acid particles are closer together and have more frequent collisions with the marble. This makes the reaction faster.
3. The temperature (although it is not measured), the mass and size of the marbles, the total volume of the acid and the plastic bottle are some of the variables that are kept constant.

Additional Exercise 1:

A Concept map

1.



Additional Exercise 2:

(a) Distilled/Deionised water

(b) A pipette is used.

(c) The hydrochloric acid that is used for the titration is used to rinse the burette.

(d) $NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$

(e) Volumes of acid used (cm^3): 29.3, 28.7, 28.8, 28.6
The first volume is probably too high. Average of other volumes = 28.7 cm^3.

(f) Volume of hydrochloric acid reacting = $\frac{28.7}{1000}$ dm^3 = 0.0287 dm^3
Moles of hydrochloric acid that reacted = 0.23 (mol/dm^3) × 0.0287 (dm^3) = 0.0066 mol
From the equation, 1 mole of ammonia reacts with 1 mole of HCl.
Therefore, moles of ammonia reacting = 0.0066 mol
Volume of ammonia in diluted sample = 250.0 cm^3 = 0.25 dm^3

(i) Concentration of diluted ammonia = $\frac{0.0066}{0.25}$ = 0.0264 mol/dm^3
(ii) Concentration of ammonia in original sample = 0.264 mol/dm^3

(g) The volumes of acid needed in the titrations would be too large for the burette to hold.