CHAPTER 7

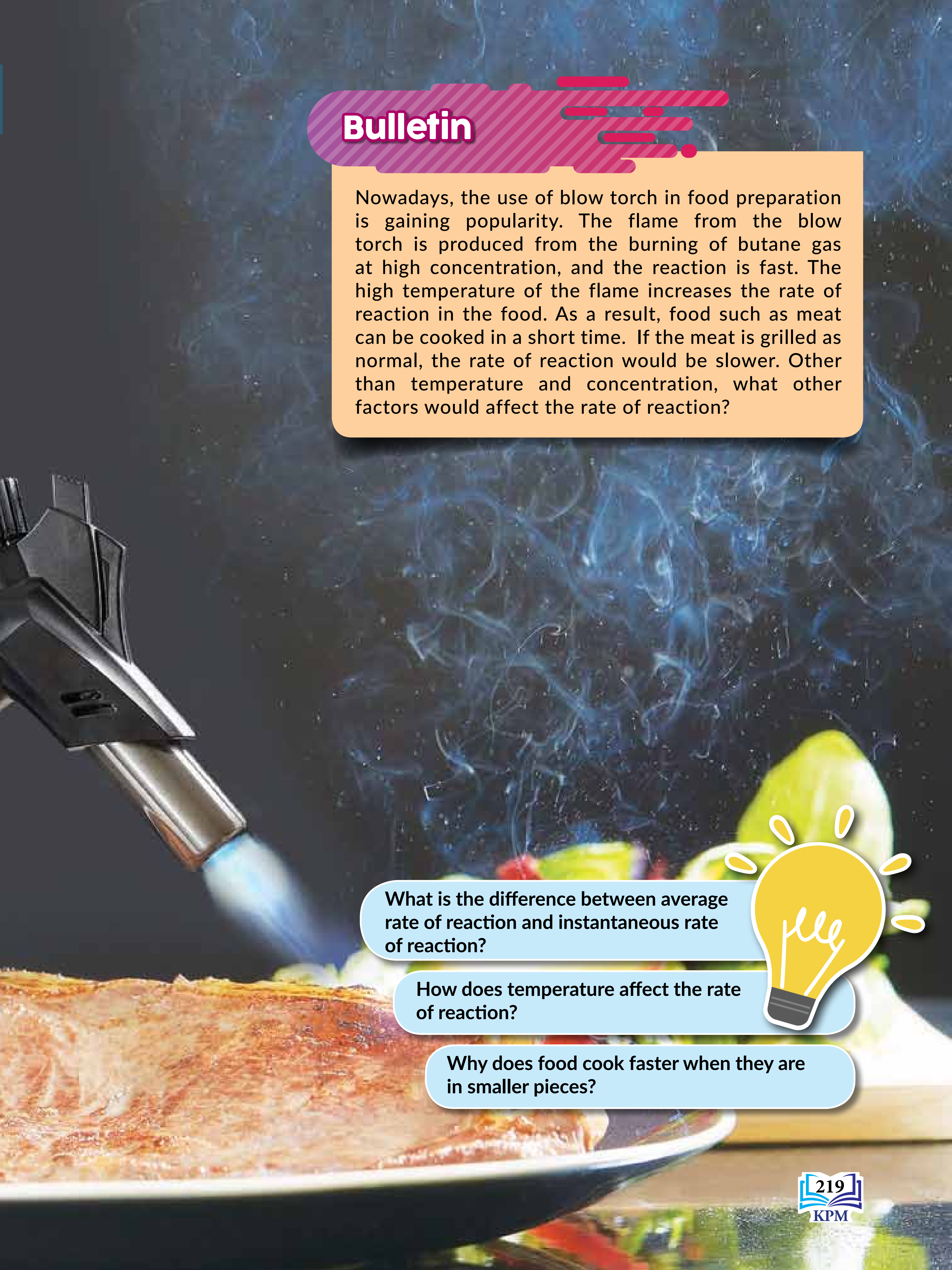
Rate of Reaction

Keywords

- Reactant
- Product
- Rate of reaction
- Catalyst
- Collision theory
- Activation energy
- Effective collision
- Energy profile diagram

What will you learn?

7.1 Determining Rate of Reaction
7.2 Factors Affecting Rate of Reactions
7.3 Application of Factors that Affect the Rate of Reaction in Daily Life
7.4 Collision Theory



Bulletin

Nowadays, the use of blow torch in food preparation is gaining popularity. The flame from the blow torch is produced from the burning of butane gas at high concentration, and the reaction is fast. The high temperature of the flame increases the rate of reaction in the food. As a result, food such as meat can be cooked in a short time. If the meat is grilled as normal, the rate of reaction would be slower. Other than temperature and concentration, what other factors would affect the rate of reaction?

What is the difference between average rate of reaction and instantaneous rate of reaction?

How does temperature affect the rate of reaction?

Why does food cook faster when they are in smaller pieces?

7.1 Determining Rate of Reaction

Classification of Rate of Reactions

There are a variety of chemical reactions that occur in our surroundings. Did you realise that chemical reactions also occur in our bodies? Do such reactions occur at a fast or slow rate? Figure 7.1 shows several chemical reactions taking place.

Learning Standard

At the end of the lesson, pupils are able to:

7.1.1 Classify fast and slow reactions that occur in daily life

7.1.2 Explain the meaning of the rate of reaction

7.1.3 Identify changes which can be observed and measured during chemical reactions through activity

7.1.4 Determine the
- average rate of reaction
- instantaneous rate of reaction

7.1.5 Solve numerical problems based on the average and instantaneous rate of reaction

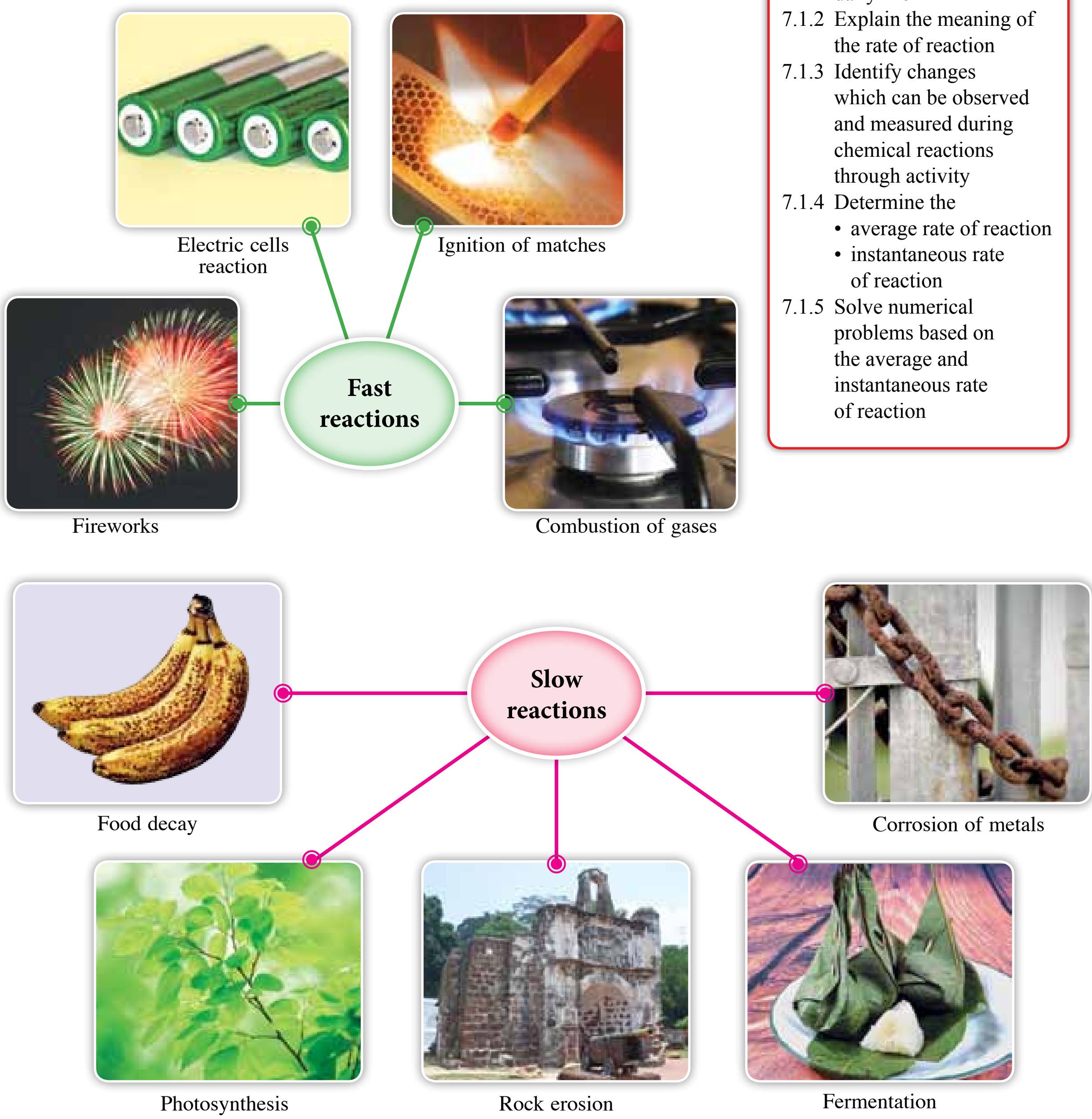


***Figure 7.1** Examples of fast and slow reactions*

Meaning of the Rate of Reaction

What do you understand by the rate of a reaction? The rate of reaction is the changes in the quantity of the reactant per unit time or the changes in the quantity of product per unit time.

$$\text{Rate of reaction} = \frac{\text{Change in the quantity of reactant or product}}{\text{Time taken for the change to occur}}$$

Chemistry & Us

In the chemical manufacturing factory, a chemical engineer needs to know accurately about the rate of reaction that happens or the duration of time that is needed for the reaction to complete. In other words, a chemical engineer needs to be proficient in rate of reaction.

During the reaction, the quantity of reactant used decreases, while the quantity of product formed increases.

The unit for mass of solids is measured in g, while the volume of gases in cm^3 or dm^3. For the quantity of soluble substances, the concentration is measured in mol dm^{-3}. The choice in unit of time depends on the rate of reaction. For fast reactions, the time is measured in seconds, while for slow reactions, minutes is used. Therefore, the units for rate of reaction that are commonly used are:

Unit for rate of reaction:
- g s^{-1} or g minute^{-1}
- cm^3 s^{-1} or cm^3 minute^{-1}
- mol dm^{-3} s^{-1} or mol dm^{-3} minute^{-1}

Changes that Occur during Reactions

Determining rate of reaction must be made based on the changes that are observable and can be measured in a certain period of time. What are these changes?

Formation of precipitate occurs in reactions that produce insoluble salts. Photograph 7.1 shows before and after reaction between silver nitrate solution, $AgNO_3$ and sodium chloride solution, NaCl. In this reaction, silver chloride, AgCl and sodium nitrate, $NaNO_3$ are formed. The formation of silver chloride, AgCl can be seen and the precipitate causes the '×' mark to disappear, and the amount of precipitate can be measured.

Photograph 7.1
The reaction between silver nitrate solution, $AgNO_3$ and sodium chloride solution, NaCl

Photograph 7.2
The reaction between nitric acid, HNO_3 and limestone, $CaCO_3$

Decrease in the mass of the reactants also occurs in reactions that produce gases. Photograph 7.2 shows the reaction between nitric acid, HNO_3 and limestone, $CaCO_3$ that produces calcium nitrate, $Ca(NO_3)_2$, carbon dioxide, CO_2 and water, H_2O.
The loss in the mass of limestone can be measured by using an electronic balance.

Increase in volume of gases occurs for reactions that produce gases. Photograph 7.3 shows the reaction between hydrochloric acid, HCl, and magnesium, Mg. In this reaction, magnesium chloride, $MgCl_2$ and hydrogen gas, H_2 are produced. The hydrogen gas, H_2 is collected and the volume of the gas measured using a gas syringe.

Photograph 7.3
The reaction between hydrochloric acid, HCl and magnesium, Mg

Chemistry Lens

Other observable and measurable changes:
- Changes in pressure in reactions involving gases. The change in pressure is measured using a pressure meter
- Changes in the electrical conductivity of electrolytes in reactions involving mobile ions. An ammeter is used to measure the change in the electrical conductivities in the electrolyte
- Changes in pH values for reactions involving acids or bases in aqueous solutions. A pH meter is used to measure the changes in the pH values with time

Activity 7.1

Aim: Determining the time for reaction with reference to some observable and measurable changes.

Materials: Zinc powder, Zn, 0.1 mol dm^{-3} sulphuric acid, H_2SO_4, marble chips, $CaCO_3$, 2.0 mol dm^{-3} nitric acid, HNO_3, potassium iodide powder, KI, lead(II) nitrate powder, $Pb(NO_3)_2$ and distilled water

Apparatus: Retort stand with clamp, burette, basin, 250 cm^3 conical flask, 10 cm^3 and 100 cm^3 measuring cylinders, rubber stopper, delivery tube, electronic balance, stopwatch, cotton wool, petri dish, weighing bottle, filter funnel, ruler and filter paper

A Reaction between zinc, Zn and sulphuric acid, H_2SO_4

Procedure:

1. Add 20 cm^3 of 0.1 mol dm^{-3} sulphuric acid, H_2SO_4 into a conical flask.
2. Fill a burette with water and invert it into a basin of water. Clamp the burette vertically.
3. Adjust the water level in the burette so that the level of water is at the 50 cm^3 mark.
4. Arrange the apparatus as in Figure 7.2.

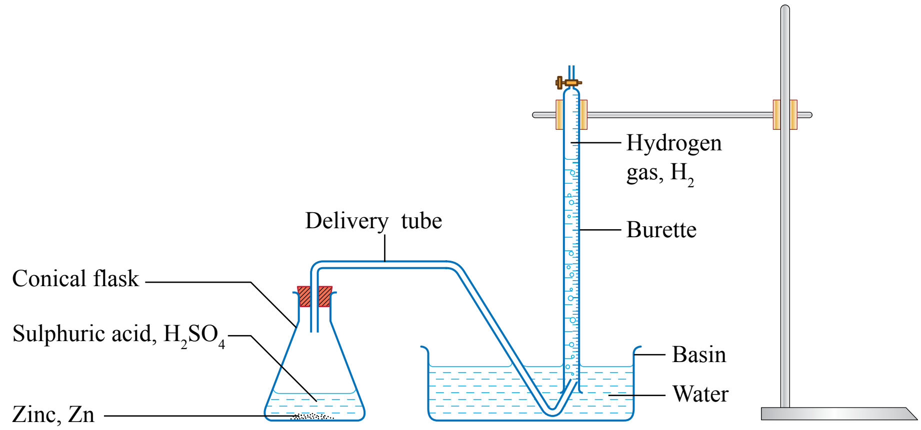


Figure 7.2

5. Add 5 g of zinc powder, Zn into the conical flask that contains sulphuric acid, H_2SO_4.
6. Immediately close the conical flask with the rubber stopper that is connected to the delivery tube. Start the stopwatch.
7. Record the burette reading at 0.5 minute intervals for 5 minutes.
8. Record your results in Table 7.1 given below.

Safety Precaution

Make sure the extension on the apparatus is tight so that the released gas flows to the burette.

Results:

Table 7.1

Time (minute)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
Burette reading (cm^3)	50.00										
Volume of gas (cm^3)	0.00										

Discussion:

1. State the observable changes and the measurement made in the activity.
2. Name the gas released.
3. Write a chemical equation for the reaction that occurred.
4. How would you know that the reaction is completed?

B **Reaction between nitric acid, HNO_3 and marble chips, $CaCO_3$**

Procedure:

1. Put 100 cm^3 of 2.0 mol dm^{-3} nitric acid, HNO_3 into a conical flask.
2. Close the mouth of the conical flask loosely with cotton wool.
3. Set up the apparatus as shown in Figure 7.3.
4. Add 10 g of marble chips, $CaCO_3$ into the conical flask.
5. Immediately close the conical flask and start the stopwatch.
6. Record the reading of the electronic balance at intervals of 30 seconds.
7. Observe the changes that occur in the conical flask and record all observations.
8. Record your data in a table.

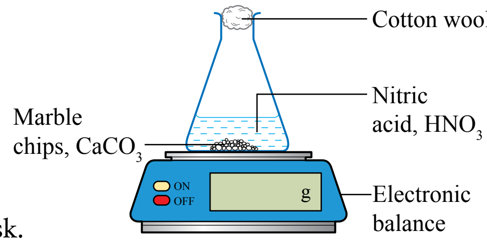


Figure 7.3

Discussion:

1. State the observable changes that was recorded in the activity.
2. Why does such a change occur? Explain your answer with the aid of a suitable chemical equation.
3. How would you know that the reaction is completed?

C **Reaction between potassium iodide solution, KI and lead(II) nitrate solution, $Pb(NO_3)_2$**

Procedure:

1. Using separate weighing bottles, weigh 2 g of potassium iodide powder, KI and 2 g of lead(II) nitrate powder, $Pb(NO_3)_2$ by using two different bottles.
2. Pour distilled water into the petri dish to a depth of 0.5 cm.
3. Add the potassium iodide powder, KI into the water at the edge of the petri dish.
4. Add lead(II) nitrate powder, $Pb(NO_3)_2$ diagonally across from the potassium iodide powder, KI as shown in Figure 7.4.
5. Start the stopwatch immediately.
6. Record the time when the reaction is completed, that is, when no more precipitate is formed.
7. Filter the contents in the petri dish and wash the precipitate with distilled water.
8. Dry and weigh the precipitate.
9. Record your data in a table.

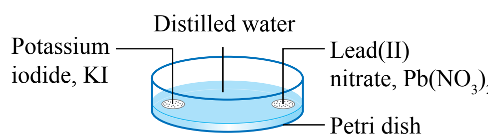


Figure 7.4

Discussion:

1. What is the colour of the precipitate formed?
2. Write an equation for the reaction that occurred.

Prepare a complete report after carrying out this activity.

Determine the time of reaction based on the observable and measurable changes shown through Activity 7.1. How would you determine the rate of reaction?

Average Rate of Reaction and Instantaneous Rate of Reaction

There are two types of rate of reaction, the average rate of reaction and instantaneous rate of reaction. The analogy for the average of reaction and instantaneous rate of reaction is shown in Figure 7.5.

A car intends to travel for 400 km. Due to the ever changing traffic conditions, the driver is not able to maintain a constant speed and took 4 hours to reach the destination. The average speed of the car is 100 km hour^{-1}. This is equated as the **average rate of reaction**.

A police officer aims the speed camera in the direction of the car because it is travelling at a speed above the speed limit. At that instant, the camera recorded a speed of 140 km hour^{-1}. The speed at that moment is equated to the **instantaneous rate**.

Figure 7.5 *Analogy of average rate of reaction and instantaneous rate of reaction*

The average rate of reaction is the average value for the rate of reaction that occurs in a particular time interval. The following explains the way to calculate the average rate of reaction for reactions that release gases.

☆ The overall average rate of reaction

$$= \frac{\text{Total volume of gas collected}}{\text{Time taken}}$$

$$= \frac{V}{t} \text{ cm}^3 \text{ s}^{-1}$$

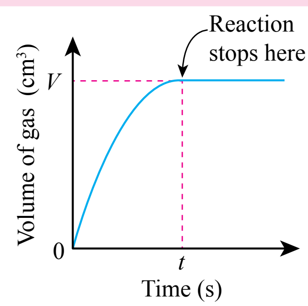


Figure 7.6 *The overall average rate of reaction*

☆ The average rate of reaction for the first t_1 seconds

$$= \frac{\text{Total volume of gas collected in the first } t_1 \text{ seconds}}{\text{Time taken}}$$

$$= \frac{V_1 - 0}{t_1 - 0} \text{ cm}^3 \text{ s}^{-1}$$

$$= \frac{V_1}{t_1} \text{ cm}^3 \text{ s}^{-1}$$

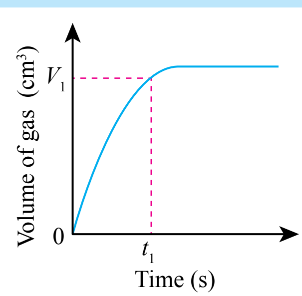


Figure 7.7 *The average rate of reaction for the first t_1 seconds*

☆ The average rate from t_1 to t_2

$$= \frac{\text{Total volume of gas collected from } t_1 \text{ to } t_2}{\text{Time taken}}$$

$$= \frac{V_2 - V_1}{t_2 - t_1} \text{ cm}^3 \text{ s}^{-1}$$

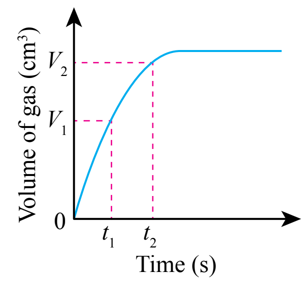
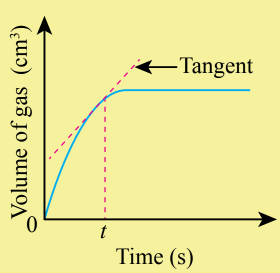


***Figure 7.8** The average rate of reaction from t_1 to t_2*

The instantaneous rate of reaction is the rate of reaction at a particular point of time. It is determined from the experimental data by plotting a graph of changes in the quantity of the reactants or products against time, and measuring the tangent gradient to the curve at that point of time. Figure 7.9 shows the way to calculate the instantaneous rate of reaction.

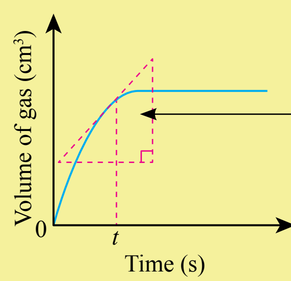
Method 1

Draw a tangent to the curve at time t.



Method 2

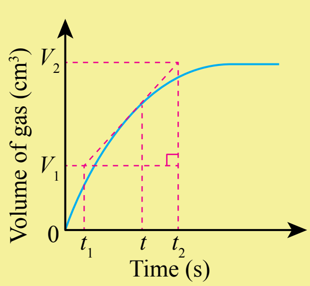
Use the tangent to complete a vertically-angled triangle.



The triangle can be drawn in various sizes. The bigger the triangle, the more accurate it can be to determine the tangent gradient.

Method 3

Calculate the gradient of the tangent to the curve.



Rate of reaction at time t

= Gradient of the tangent at time t

$$= \frac{\Delta V}{\Delta t}$$

$$= \frac{V_2 - V_1}{t_2 - t_1} \text{ cm}^3 \text{ s}^{-1}$$

***Figure 7.9** Methods to calculate the instantaneous rate of reaction*

For reactions that involve a decrease in the total mass of the reactants, a graph as shown in Figure 7.10 is obtained.

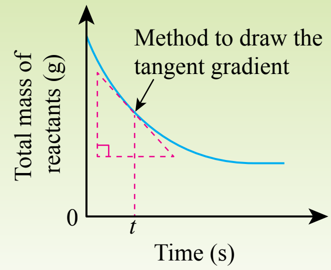


Figure 7.10 *The instantaneous rate of reaction that involves the decreasing of reactants*

Activity 7.2

Determining the average rate of reaction and instantaneous rate of reaction

Answer the following questions based on the data obtained from Activity 7.1.

1. For the reaction between zinc, Zn and sulphuric acid, H_2SO_4:
   (a) Plot a graph of gas volume against time.
   (b) Calculate the following average rates of reaction:
      (i) For the first minute
      (ii) For the fifth minute
      (iii) For the overall reaction
   (c) Based on the graph plotted, calculate the rate of reaction at the following time:
      (i) At the first minute
      (ii) At the third minute
      (iii) At the end of the reaction
2. For the reaction between potassium iodide solution, KI and lead(II) nitrate solution, $Pb(NO_3)_2$:
   (a) Calculate the average rate of reaction.
   (b) Can you determine the rate of reaction at 30 seconds? Explain.

Solving Numerical Problems Based on Rate of Reactions

Example 1

A student adds magnesium carbonate crystals, $MgCO_3$ until excess into sulphuric acid, H_2SO_4. The volume of carbon dioxide, CO_2 released is collected in a gas syringe and the volume of gas recorded in Table 7.2 for 1 minute intervals for 10 minutes.

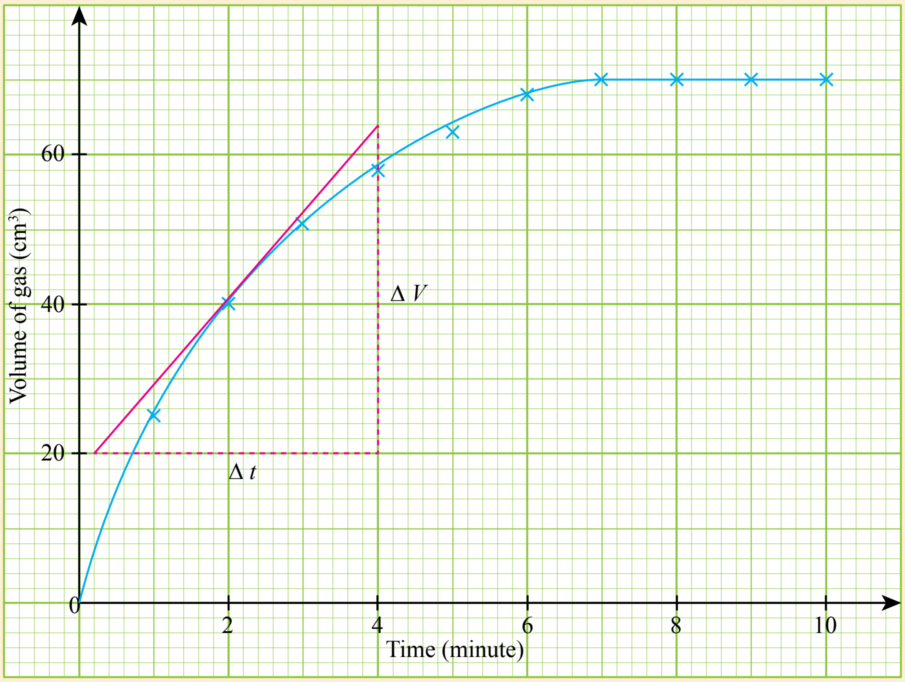
Table 7.2

Time (minute)	0	1	2	3	4	5	6	7	8	9	10
Volume of gas (cm^3)	0	25	40	51	58	63	68	70	70	70	70

(a) Based on Table 7.2, plot a graph of the volume of gas against time.
(b) Calculate the following average rate of reactions:
   (i) For the fifth minute
   (ii) For the overall reaction
(c) Based on the plotted graph, calculate the rate of reaction for the second minute.

Solution

(a)



(b) (i) Average rate of reaction for the 5th minute

$$= \frac{\text{Total volume of gas collected from the 4}^{\text{th}}\text{ minute to the 5}^{\text{th}}\text{ minute}}{\text{Time taken}}$$

$$= \frac{(63 - 58)\text{ cm}^3}{(5 - 4)\text{ minute}}$$

$$= \frac{5\text{ cm}^3}{1\text{ minute}}$$

$= 5\text{ cm}^3\text{ minute}^{-1}$

The average rate of reaction from the 4th to the 5th minute.

(ii) The overall average rate of reaction

$$= \frac{\text{Total volume of gas collected}}{\text{Time of reaction}}$$

$$= \frac{70\text{ cm}^3}{7\text{ minute}}$$

The reaction ends at the 7th minute and not 10th minute.

$= 10\text{ cm}^3\text{ minute}^{-1}$

(c) The rate of reaction at the second minute

= Gradient of the tangent to the curve at the second minute

$$= \frac{\Delta V}{\Delta t}$$

$$= \frac{(64 - 20)\text{ cm}^3}{(4 - 0.2)\text{ minute}}$$

$= 11.58\text{ cm}^3\text{ minute}^{-1}$

Activity 7.3

Solving numerical problems related to rate of reactions CT

In the presence of manganese(IV) oxide, MnO_2, hydrogen peroxide, H_2O_2 decomposes to water and oxygen. The oxygen gas released is collected in a gas syringe and the volume recorded at intervals of 0.5 minute. The data collected is shown in Table 7.3.

Table 7.3

Time (minute)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Volume of gas (cm^3)	0.0	13.5	22.0	28.0	33.0	37.0	40.5	43.0	45.0	47.0	48.0	49.0	50.0	50.0	50.0

1. Based on Table 7.3, plot a graph of volume of gas against time.
2. Calculate the following average rate of reaction:
   (a) For the first minute
   (b) For the fifth minute
   (c) For the whole reaction
3. Calculate the rate of reaction at the following time:
   (a) 1.5 minute (b) 4.0 minute

Test Yourself 7.1

1. Explain the meaning of rate of reaction.
2. Classify the following reactions as fast or slow:
   (a) Photosynthesis
   (b) Combustion of petrol in car engines
   (c) Rusting of iron gate
   (d) Explosion at oil factory
3. State the observable and measurable change(s) to determine the rate of reaction in the following examples of reactions:
   (a) $2HCl(aq) + CaCO_3(s) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$
   (b) $H_2SO_4(aq) + Na_2S_2O_3(aq) \rightarrow Na_2SO_4(aq) + H_2O(l) + SO_2(g) + S(s)$
   (c) $2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$
   (d) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
4. Metals react with acids at different rates.

   Metal + Acid → Salt + Hydrogen gas

   Three different metals, *P*, *Q* and *R* react separately with 100 cm^3 of acid. The time taken to collect 50 cm^3 of hydrogen gas for each of the metal is recorded in Table 7.4

   Table 7.4

Metal	Time (s)
P	60
Q	95
R	20

   (a) Calculate the average rates of reaction for each of the metal with acid.
   (b) Based on your answer in 4(a), arrange the three metals in order of descending reactivity. Explain your answer.

7.2 Factors Affecting Rate of Reactions

Learning Standard

At the end of the lesson, pupils are able to:

7.2.1 Investigate factors affecting the rate of reactions through experiment, based on:
- Size of reactants
- Concentration
- Temperature
- Presence of catalyst

Different chemical substances have different chemical properties. As a result, different chemicals have different reactions and occur at different rates. What are the factors that affect the rate of reactions?

Size of Reactants

Solid reactants can undergo change in sizes. A piece of marble chip can be cut into smaller pieces. The total surface area of all the smaller pieces is larger than the total surface area of the original piece of marble as shown in Figure 7.11

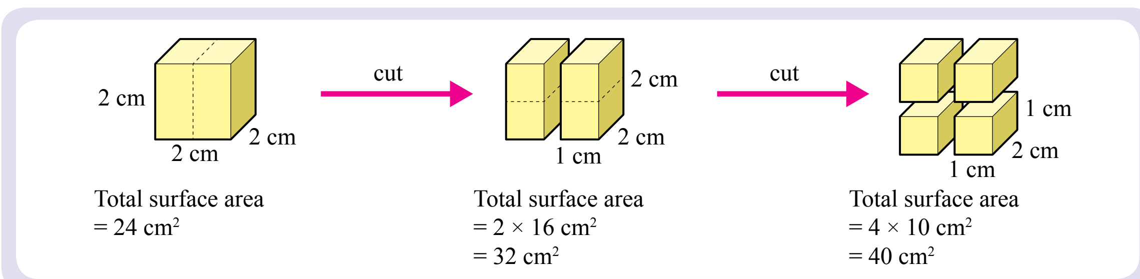


Figure 7.11 *Total surface area of different sizes of reactant*

For a fixed mass, the powdered form has a larger total surface area than the original pieces of the solid. Experiment 7.1 shows the effect of size of reactants on the rate of reaction.

Experiment 7.1

Aim: To study the effect of size of reactants on the rate of reaction.

Problem statement: How can size of reactant affect the rate of reaction?

Hypothesis: The smaller the size of the marble chips, $CaCO_3$, the higher the rate of reaction.

Variables:
(a) Manipulated : Size of marble chips, $CaCO_3$
(b) Responding : Rate of reaction
(c) Fixed : Mass of marble chips, $CaCO_3$, temperature, volume and concentration of hydrochloric acid, HCl

Materials: 0.1 mol dm^{-3} hydrochloric acid, HCl, large pieces of marble chips, $CaCO_3$ and small pieces of marble chips, $CaCO_3$

Apparatus: Conical flask 250 cm^3, retort stand with clamp, burette, basin, 100 cm^3 measuring cylinder, rubber stopper, delivery tube, electronic balance and stopwatch

Procedure:

1. Put 80 cm^3 of 0.1 mol dm^{-3} hydrochloric acid, HCl into a conical flask.
2. Fill the burette with water and invert it into a basin filled with water. Clamp the burette vertically.
3. Adjust the water level in the burette so that the water level reading is 50 cm^3.
4. Set up the apparatus as shown in Figure 7.12.
5. Weigh 5 g of large pieces of marble chips, $CaCO_3$ and add them into the conical flask.
6. Immediately close the conical flask with the rubber stopper which is connected to a delivery tube. At the same time, start the stopwatch.
7. Slowly swirl the conical flask throughout the experiment.
8. Record the burette reading at intervals of 30 seconds until the burette is completely filled with gas.
9. Repeat steps 1 to 8 by using smaller pieces of 5 g of marble chips, $CaCO_3$.
10. Record all the data in table form.

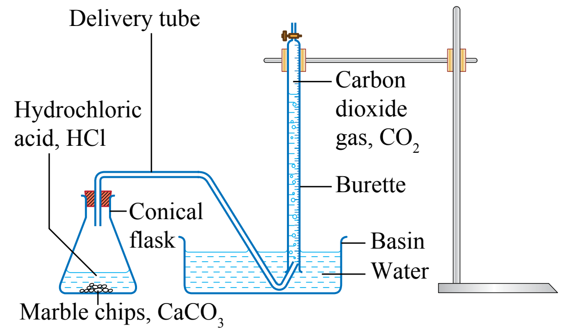


Figure 7.12

CAUTION

Acids are corrosive. Wear gloves and safety glasses when handling acids.

Interpreting data:

1. Based on the data obtained, plot two graphs of volume of gas against time on a same set of axis.
2. Based on the graph, determine:
   (a) The tangent gradient at $t = 0$ (initial rate of reaction).
   (b) The time taken for the complete reaction.

Conclusion:

Is the hypothesis acceptable? What is the conclusion of this experiment?

Prepare a complete report after carrying this experiment.

Concentration

The concentration of a solute in a solution can be changed. The concentration of the solution can be changed by adding solvent or solute.

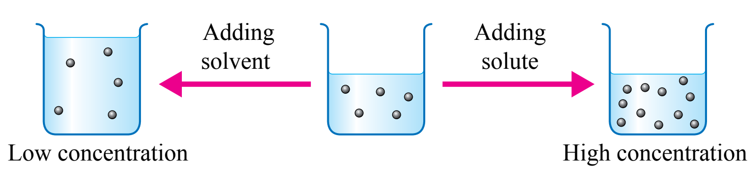


Figure 7.13 *Concentration of solution*

What is the effect of concentration of reactant on the rate of reaction?

Experiment 7.2

Aim: To investigate the effect of concentration of reactants on the rate of reaction.

Problem statement: How does the concentration of the reactants affect the rate of reaction?

Hypothesis: The higher the concentration of sodium thiosulphate solution, $Na_2S_2O_3$, the shorter the time taken for the '×' mark to disappear from view.

Variables:

(a) Manipulated : Concentration of sodium thiosulphate solution, $Na_2S_2O_3$
(b) Responding : Time taken for the '×' mark to disappear from view
(c) Fixed : Temperature, total volume of mixture, concentration and volume of sulphuric acid, H_2SO_4 and the size of the conical flask

Materials: 1.0 mol dm^{-3} sulphuric acid, H_2SO_4, 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$, distilled water and white piece of paper with a '×' mark at the centre

Apparatus: 150 cm^3 conical flask, stopwatch, 10 cm^3 and 50 cm^3 measuring cylinders

Procedure:

1. Put 45 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ into a conical flask.
2. Place the conical flask on the '×' mark on the white paper as shown in Figure 7.14.
3. Swiftly, pour 5 cm^3 of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 into the conical flask carefully and at the same time start the stopwatch.
4. Swirl the conical flask gently and place it again on the '×' mark.

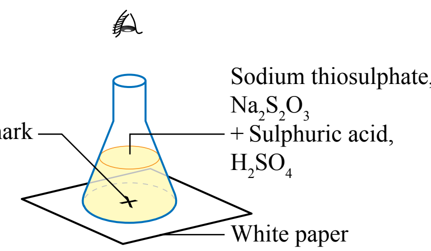


Figure 7.14

5. Observe the '×' mark vertically from the mouth of the conical flask.
6. Stop the stopwatch once the '×' mark disappears from view. Record the time taken.
7. Repeat the experiment by using 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ that has been diluted with distilled water as given in Table 7.5. The volume of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 is fixed at 5 cm^3.
8. Record all data in Table 7.5.

Results:

Table 7.5

Experiment	I	II	III	IV	V
Volume of sodium thiosulphate solution, $Na_2S_2O_3$ (cm^3)	45	40	30	20	10
Volume of distilled water (cm^3)	0	5	15	25	35
Volume of sulphuric acid, H_2SO_4 (cm^3)	5	5	5	5	5
Total volume of mixture (cm^3)	50	50	50	50	50
Time taken for the '×' mark to disappear from view (s)					

Interpreting data:

1. The concentration of dilute sodium thiosulphate solution, $Na_2S_2O_3$ is calculated using the formula $M_1V_1 = M_2V_2$.

M_1 = The original concentration of sodium thiosulphate solution, $Na_2S_2O_3$
V_1 = The volume of sodium thiosulphate solution, $Na_2S_2O_3$ used
M_2 = Concentration of the dilute sodium thiosulphate solution, $Na_2S_2O_3$
V_2 = Volume of the dilute sodium thiosulphate solution, $Na_2S_2O_3$

Use the given formula and the data collected to calculate the concentration of the dilute sodium thiosulphate solution, $Na_2S_2O_3$.

2. In the experiment, the rate of reaction is inversely proportional to the time taken for the '×' mark to disappear from view. Thus, rate of reaction = $\frac{1}{\text{time}}$. Use this formula and the data collected to calculate the rate of reaction for all the five experiments.
3. Record all answers from (1) and (2) in Table 7.6.

Table 7.6

Experiment	I	II	III	IV	V
Concentration of dilute sodium thiosulphate, $Na_2S_2O_3$ solution ($mol\ dm^{-3}$)					
Rate of reaction, $\frac{1}{\text{time}}$ (s^{-1})					

4. Use the data in Table 7.6 to plot a graph of rate of reaction, $\frac{1}{\text{time}}$ against concentration of sodium thiosulphate solution, $Na_2S_2O_3$, M_2.
5. Based on the graph, state the relationship between rate of reaction and concentration of sodium thiosulphate solution, $Na_2S_2O_3$.

Conclusion:

Is the hypothesis acceptable? What is the conclusion of this experiment?

Discussion:

1. Why does the solution in the conical flask turn cloudy?
2. Name the substance that causes the solution to turn cloudy.
3. The '×' mark disappears from view when the solution in the conical flask reaches a certain level of cloudiness. What are the steps required in this experiment so that the same level of cloudiness is achieved in all the five experiments?
4. What are the changes being measured in the experiment to determine the rate of reaction?

Prepare a complete report after carrying out this experiment.

Temperature

Most reactions occur faster at high temperatures, that is, the rate of reaction increases with increasing temperature. For reactions that occur at room temperature, each increase of 10 °C will increase the reaction rate by two times.

Experiment 7.3

Aim: To investigate the effect of temperature on the rate of reaction.

Problem statement: How does temperature affect the rate of reaction?

Hypothesis: The higher the temperature of the sodium thiosulphate solution, $Na_2S_2O_3$, the shorter the time taken for the '×' mark to disappear from view.

Variables:
(a) Manipulated : Temperature of sodium thiosulphate solution, $Na_2S_2O_3$
(b) Responding : Time taken for the '×' mark to disappear from view
(c) Fixed : Volume and concentration of sulphuric acid, H_2SO_4

Materials: 1.0 mol dm^{-3} sulphuric acid, H_2SO_4, 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ and a piece of white paper with an '×' mark in the middle

Apparatus: 150 cm^3 conical flask, 10 cm^3 and 50 cm^3 measuring cylinders, stopwatch, thermometer, Bunsen burner, wire gauze and tripod stand

Procedure:
1. Put 50 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ into a conical flask. Leave it for 5 minutes.
2. Record the temperature of the 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$.
3. Place the conical flask on the '×' mark of the white paper.
4. Quickly, add in 5 cm^3 of 1.0 mol dm^{-3} sulphuric acid, H_2SO_4 into the conical flask carefully. At the same time, start the stopwatch.
5. Swirl the conical flask gently and place it again on the '×' mark.
6. Observe the '×' mark vertically from the mouth of the conical flask.
7. Stop the stopwatch once the '×' mark disappears from view.
8. Record the time taken when the '×' mark disappears from view.
9. Repeat steps 1 until 8 by using 50 cm^3 of 0.2 mol dm^{-3} sodium thiosulphate solution, $Na_2S_2O_3$ that has been heated to 40 °C, 45 °C, 50 °C, and 55 °C.

Interpreting data:
1. Use the data obtained to plot a graph of rate of reaction, $\frac{1}{\text{time}}$ against temperature of sodium thiosulphate solution, $Na_2S_2O_3$.
2. Based on the graph, state the relationship between rate of reaction and the temperature of sodium thiosulphate solution, $Na_2S_2O_3$.

Conclusion:
Is the hypothesis acceptable? What is the conclusion of the experiment?

Discussion:
1. Write the ionic equation for the reaction between sodium thiosulphate solution, $Na_2S_2O_3$ and sulphuric acid, H_2SO_4.
2. Can sulphuric acid, H_2SO_4 be replaced with hydrochloric acid, HCl? Explain.

Prepare a complete report after carrying out this experiment.

Presence of Catalyst

Catalysts are chemical substances that alter the rate of chemical reactions without undergoing any chemical changes at the end of the reaction. Although the chemical properties of the catalyst does not change, but its physical properties can change. For example, a lump of catalyst can turn into powder.

Catalysts do not change the quantity of products. Does the addition of a catalyst increase the rate of reaction?

Experiment 7.4

Aim: To investigate the effect of catalyst on the rate of reaction.

Problem statement: How does the presence of catalyst affect the rate of reaction?

Hypothesis: Presence of catalyst increases the rate of reaction.

Variables:
(a) Manipulated : Presence of catalyst
(b) Responding : Rate of reaction
(c) Fixed : Mass of manganese(IV) oxide, MnO_2, temperature and volume of hydrogen peroxide solution, H_2O_2

Materials: 20-volume hydrogen peroxide solution, H_2O_2, manganese(IV) oxide powder, MnO_2 and distilled water

Apparatus: 10 cm^3 measuring cylinder, test tubes, test tube rack, glowing wooden splinter, filter funnel, filter paper, 150 cm^3 beaker, spatula and electronic balance

Procedure:
1. Label two test tubes as I and II.
2. Put 5 cm^3 hydrogen peroxide solution, H_2O_2 into test tube I and test tube II separately.
3. Place the two test tubes in the test tube rack.
4. Add 0.5 g manganese(IV) oxide powder, MnO_2 into test tube II. Place a glowing wooden splinter into the mouth of both test tubes quickly.
5. Observe the changes that occur to the wooden splinter and record your observations.

Concentration of hydrogen peroxide solution
http://bit.ly/2W0iIKD

Conclusion:
Is the hypothesis acceptable? What is the conclusion of this experiment?

Discussion:
1. What are the changes observed and measured in this experiment?
2. Explain how the observation in (1) can assure your hypothesis.

Prepare a complete report after carrying out this experiment.

Chemistry Lens

The mass of catalyst does not change before and after the reaction. You can compare the mass of manganese(IV) oxide, MnO_2 before and after Experiment 7.4 for confirmation.

Diagram 7.15 summarises the effect of concentration, size of reactants, temperature and catalyst on the rate of reaction.

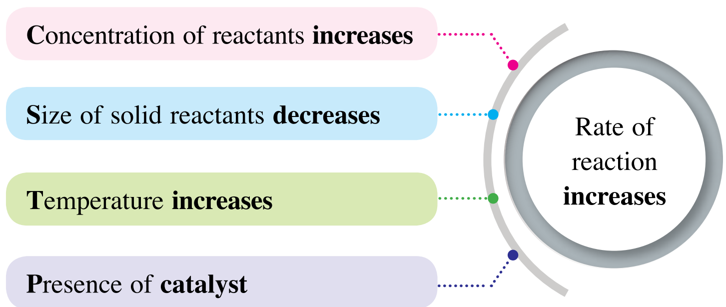


Figure 7.15 *Factors affecting rates of reactions*

Literacy Tips

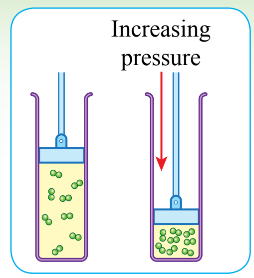
Acronym **CSTP** can help you to remember the factors that affect the rate of reaction.

Effect of pressure on the rate of reaction

http://bit.ly/33zfz6O

Chemistry Lens

Pressure is another factor that affects the rates of reactions. Increasing the pressure on reactions involving gases will affect the rate of reaction. When a gas is compressed at constant temperature, the gas particles are pushed into a smaller volume of space. Increasing pressure, increases the concentration of the gas and the rate of reaction. Changes in pressure does not affect the rate of reaction involving solids and liquids reactants as the volume does not change with pressure.

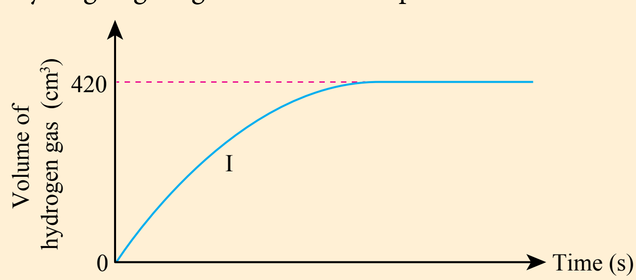


Example 2

Reactive metals such as potassium reacts with water to release hydrogen gas.

$$Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$$

Two experiments are carried out to determine the rate of reaction between 0.7 g of calcium and 200 cm^3 of water at different temperatures. Experiment I is carried out at room temperature. In experiment II, the temperature of water is increased by 10 °C. The diagram below shows the graph of volume of hydrogen gas against time for experiment I.

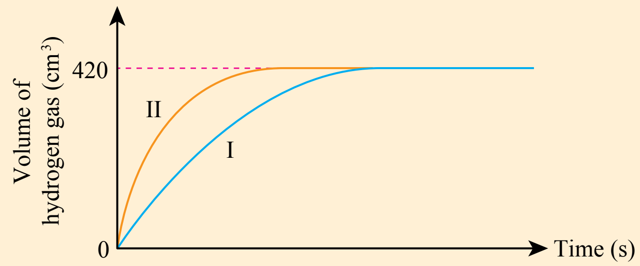


(a) What is the total volume of hydrogen gas produced in experiment II? Explain your answer.
(b) Copy the graph above and sketch the curve for experiment II.
(c) What is the effect of temperature on the rate of reaction?

Solution

(a) Total volume of hydrogen gas produced in experiment II = 420 cm^3.
The quantity of reactants (calcium and water) is the same in both experiments.
So, the results of (hydrogen gas) reaction must be the same.

(b)



(c) Increase in water temperature increases the rate of reaction.

Example 3

Gastric is caused by the production of too much acid in the stomach. Doctors use antacid tablets to neutralise the acid in the stomach. Table 7.7 shows the time taken by each antacid tablet to react completely in excess hydrochloric acid, HCl under different conditions.

Table 7.7

Experiment	Volume of hydrochloric acid, HCl (cm^3)	Concentration of hydrochloric acid, HCl (mol dm^{-3})	Temperature of hydrochloric acid, HCl (°C)	Time of reaction (s)
I	50	1.0	30	120
II	50	2.0	30	60
III	100	2.0	30	60
IV	50	2.0	40	30

(a) Why the time of reaction is different for experiment I and II?
(b) Which of the following experiment shows that the change in volume of hydrochloric acid, HCl does not affect the rate of reaction?
(c) Why is the rate of reaction for experiment IV higher than experiment II?
(d) Other than temperature and concentration of the hydrochloric acid, HCl, what changes can be made to increase the rate of reaction in experiment I?

Solution

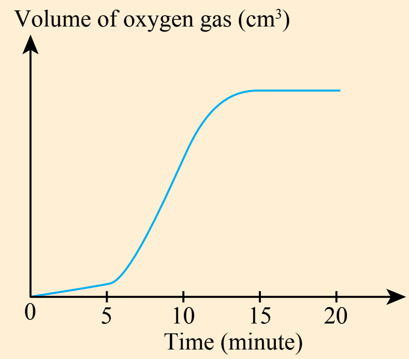
(a) Experiment I uses 1.0 mol dm^{-3} hydrochloric acid, HCl while experiment II uses 2.0 mol dm^{-3} hydrochloric acid, HCl. The concentration of hydrochloric acid is different.
(b) Experiment II and III.
(c) The temperature of the hydrochloric acid, HCl in experiment IV is higher than in experiment II.
(d) The size of the antacid tablet. Crush the tablet into smaller pieces so as to increase the total surface area.

Example 4

Adnan carries out an experiment to investigate the decomposition of hydrogen peroxide, H_2O_2. He records the volume of oxygen gas released. At the 5^{th} minute, he adds one spatula full of black powder into the hydrogen peroxide solution, H_2O_2. The diagram shows the graph of volume of oxygen gas released against time.

(a) What is the effect of the black powder on the rate of reaction?

(b) What is the function of the black powder?



Solution

(a) The addition of the black powder increases the rate of reaction.

(b) The black powder acts as a catalyst.

Activity 7.4

CT

Discussing the solution involving the rate of reactions and determine the variables involved in the reactions

As a group, solve the following problems:

1. Figure 7.16 shows the graph of volume of carbon dioxide against time for the two experiments, I and II.

   Table 7.7 shows the conditions of the two experiments.

Table 7.7

Experiment	Reactants
I	1.0 g of marble chips, $CaCO_3$ + 50 cm^3 of 0.5 mol dm^{-3} hydrochloric acid, HCl at room temperature
II	Marble, $CaCO_3$ + 50 cm^3 of 0.5 mol dm^{-3} hydrochloric acid, HCl

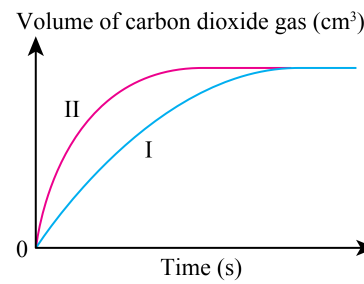


Figure 7.16

   Suggest two ways to carry out experiment II so that a similar graph as in Figure 7.16 can be obtained. State all the variables involved.

2. Hydrogen peroxide, H_2O_2 decomposes slowly at room temperature to produce water and oxygen. The decomposition of hydrogen peroxide, H_2O_2 can be accelerated by the presence of a catalyst. Three experiments are carried out to determine the effect of three different catalysts on the complete decomposition of 50 cm^3 of 10-volume hydrogen peroxide solution, H_2O_2. Table 7.8 shows the results of the experiments.

Table 7.8

Type of catalyst \ Time(s)	10	20	30	40	50	60
	Volume of oxygen gas collected (cm^3)					
Manganese(IV) oxide, MnO_2	57	82	93	100	100	100
Copper(II) oxide, CuO	12	19	25	28	30	31
Iron, Fe	33	47	55	58	59	60

(a) Write the chemical equation for the decomposition of hydrogen peroxide, H_2O_2.

(b) Explain briefly how the experiment was conducted. Include the following in your explanation:
   (i) Problem statement
   (ii) Hypothesis
   (iii) All the variables
   (iv) Diagram for the set-up of the apparatus

(c) Which catalyst is more effective in speeding up the rate of decomposition of hydrogen peroxide, H_2O_2? Explain your answer.

Test Yourself 7.2

1. The rate of reaction is affected by various factors.

(a) State four factors that would affect the rate of reaction.

(b) Zinc, Zn reacts with excess sulphuric acid, H_2SO_4 according to the following equation:

$$Zn(s) + H_2SO_4(aq) \rightarrow ZnSO_4(aq) + H_2(g)$$

State four ways to speed up the reaction. In your answer, state the manipulated and the fixed variables.

2. Four experiments to study the reaction between 2 g of marble, $CaCO_3$ with 15 cm^3 of hydrochloric acid, HCl is shown in Figure 7.17.

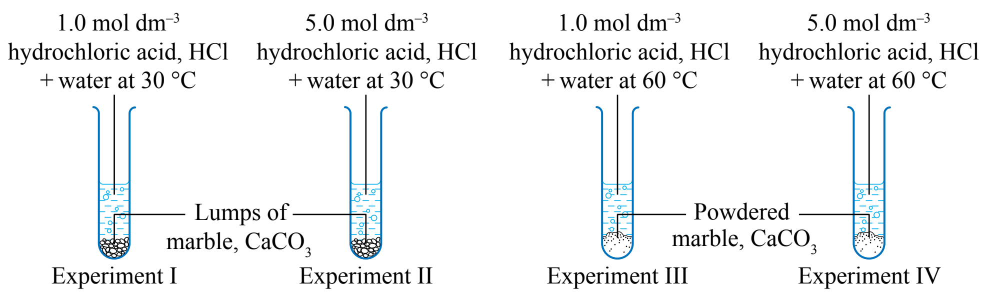


Figure 7.17

(a) State the variable that can be observed and measured to determine the rate of reaction.

(b) What is the manipulated variable in the experiment?

(c) Which experiment has the highest initial rate of reaction? Explain your answer.

7.3 Application of Factors that Affect the Rate of Reaction in Daily Life

Learning Standard

At the end of the lesson, pupils are able to:
7.3.1 Explain with examples the application of factors that affect the rate of reaction in daily life

Rate of reactions are important in daily life whether at home or in industry. Have you ever wondered how to cook food fast?

Activity 7.5

Solving problems in various daily life activities

21st Century Skills CT

1. Carry out the Role-Play activity.
2. Collect information from various sources to solve the following problems:
   (a) How to cook food fast?
   (b) How to maintain the freshness of milk?
   (c) How to remove a blood stain on a shirt?
3. Discuss and prepare the script with suitable equipment.
4. Present your group performance in front of the class within the time allocated.

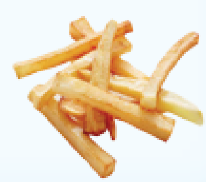
The Size Factor

Action of medicines

Antacid tablets are used to treat gastric. Doctors advise patients to chew the tablet instead of swallowing. Breaking up the tablet into smaller pieces increases the total surface area exposed and increases the rate of reaction between the medicine and the acid in the stomach.

Cooking food

Potatoes are cut into thin slices or long strips so that it can be cooked faster. Thin slices or long strips increases the total surface area exposed to the cooking oil compared to uncut potatoes.



Photograph 7.4 *Potato strips*

Concentration Factor

Corrosion due to acid rain

Buildings made of iron that are located near the industrial areas will corrode fast due to acid rain. The atmosphere around industrial areas contains a high concentration of sulphur dioxide. When the concentration of the acidic pollutants increases, the level of acid rain increases and the rate of corrosion increases.

Combustion of petrol in car engines

Petrol vapour and air are compressed in the car engine combustion chamber before being burned. The compression increases the concentration of the petrol vapour allowing the petrol to burn very quickly until it explodes. The energy released from the combustion of petrol will make the car move.

Photograph 7.5 *Combustion of petrol in a car engine*

Temperature Factor

Cleaning

Washing clothes using detergent powder and hot water combines two factors that increase the rate of reaction. The process of washing clothes will be even quicker in this situation.

Photograph 7.6 *Washing clothes*

Cooking food

Other than decreasing the size, food also cooks faster at high temperatures. Water boils at 100 °C while cooking oil would not boil even the temperature reaches 180 °C. Therefore, frying food in oil will cook the food even faster.

Catalyst Factor

Catalytic converter

Modern cars are fitted with catalytic converters as shown in Photograph 7.7 to cut down atmospheric pollution. Exhaust gas from car engines contains pollutants. Figure 7.18 shows how catalytic converters change pollutants into non-harmful products that are safe to be released into the atmosphere in the presence of platinum catalyst, Pt.

Photograph 7.7 *Catalytic converter*

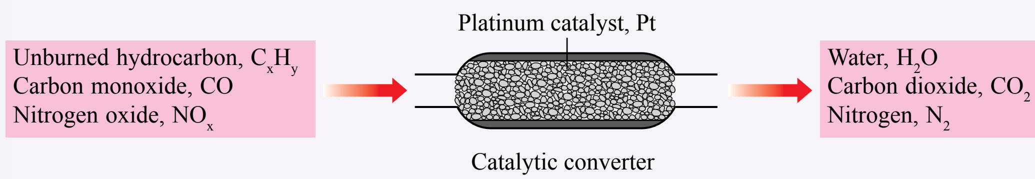


Figure 7.18

Making alcohol

Ethanol, C_2H_5OH, is the main ingredient in alcoholic drinks. Ethanol is produced through the fermentation of glucose with the help of enzyme in yeast as a catalyst at 37 °C.

Activity 7.6

Discussing the application of the knowledge on the factors that affect the rate of reactions in daily activities

CT

1. Carry out the activity in groups.
2. Find information from various reading sources and the internet related to the application of the knowledge on the factors that affect the rate of reactions in the following daily activities.
   (a) Burning of coal
   (b) Food storage in the refrigerator
   (c) Cooking using pressure cooker
   (d) Fermentation process in the making of '*tapai*'
3. Based on the information collected, start a forum titled 'Rate of Reaction in Daily Life'.

TestYourself 7.3

1. Fill in the blanks.
   (a) Meat cooks faster if it is cut into ___________ sizes.
   (b) In the refrigerator, the ___________ temperature decreases the growth of bacteria that causes food decay.
   (c) Food cooks faster in a pressure cooker because of high ___________.
   (d) Coal burns faster in small chips because of the large surface area that is ___________.

2. In industry, ammonia, NH_3 is produced by the direct combination between nitrogen, N_2 and hydrogen, H_2. Ammonia, NH_3 is used to make nitrogeneous fertilisers. Figure 7.19 shows the percentage yield of ammonia, NH_3 under different conditions.

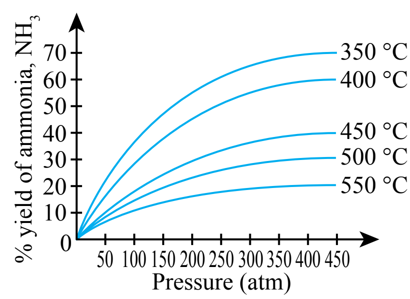


Figure 7.19

   (a) State the effect on the percentage yield of ammonia, NH_3 with increasing:
      (i) Temperature (ii) Pressure
   (b) Explain the advantages and disadvantages of using 350 °C and 550 °C in the process of producing ammonia, NH_3. How can the disadvantages be overcome?

3. Car exhaust gas contains polluting gases formed from the burning of fossil fuels in the car engine.
   (a) Name three polluting gases in the car exhaust.
   (b) In the car engine, nitrogen, N_2 combines with oxygen, O_2 to produce nitrogen monoxide, NO. At room temperature and pressure, this reaction occurs very slow. Why can this reaction occur in the car engine?

7.4 Collision Theory

According to the kinetic theory of matter, matter is made up of tiny and discrete particles that are constantly moving; vibrating at fixed positions for solid, and moving freely for liquids and gasses. As a result, particles collide with one another.

During collision, transfer of energy occurs. Fast moving particles transfer some of their energy to slow moving particles and increases their kinetic energy. This process is repeated with other particles. As a result, particles do not have the same kinetic energy and are constantly changing.

The collision theory explains how reactant particles interact with one another to cause reactions to occur and form products.

According to the collision theory,
- reactant particles must collide with one another for reaction to occur
- the rate of reaction depends on the frequency of **effective collisions**

Not all collisions between reactant particles result in reactions and the formation of products. Only effective collisions would cause reactions to occur. To produce effective collisions, the reactant particles must have energy equal to or more than the **activation energy** and collide in the **correct orientation**.

Learning Standard

At the end of the lesson, pupils are able to:
7.4.1 Describe the collision theory
7.4.2 Explain activation energy using examples
7.4.3 Interpret an energy profile diagram for exothermic reaction and endothermic reaction

Chemistry Lens

Collision between particles with energy less than the activation energy or in the wrong orientation is called an ineffective collision.

Collision theory
http://bit.ly/35RRzhl

Activation Energy

Reactant particles need to have enough energy to initiate a reaction. In other words, activation energy is required to start a reaction. Activation energy is like an energy barrier that needs to be overcomed before a reaction can take place. Photograph 7.8 shows the analogy of such a barrier. The energy required for a horse to overcome the barrier is identical to the activation energy that the particles require to initiate a reaction.

Reactant particles need to acquire the minimum energy known as activation energy so as to break the bonds in the reactant particles and form new bonds in the products. Different reactions have different activation energy.

Photograph 7.8
Analogy of activation energy

The activation energy is represented by the symbol E_a. In the energy profile diagram, the activation energy is the difference in energy between the energy level of the reactants and the energy at the peak of the curve in the graph.

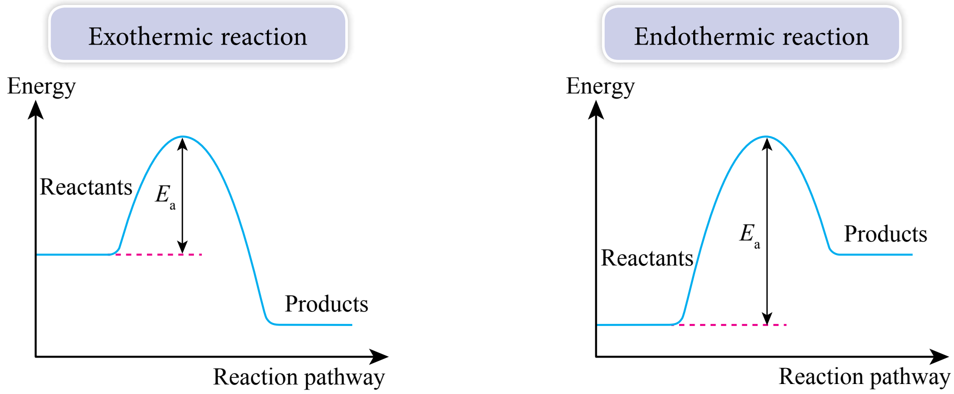


Figure 7.20 *Energy profile diagram*

In an exothermic reaction, the total energy of the reactants is higher than the total energy of the products. In an endothermic reaction, the total energy of the products is higher than the total energy of the reactants.

Collision Orientation

Reactant particles must be in a specific orientation to result in effective collisions. Figure 7.21 shows the collision between reactant particles in the correct orientation to allow old bonds to be broken and new bonds to form.

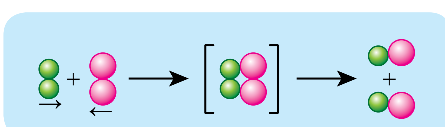


Figure 7.21

If the reactant particles collide in incorrect orientations, the particles will bounce back and no reaction occurs. Figure 7.22 shows the collision between reactant particles in the wrong orientation.

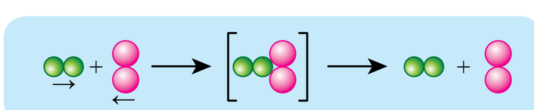


Figure 7.22

Collision theory (Part 2)

http://bit.ly/35Q8DnZ

Collision theory (Part 3)

http://bit.ly/35RRRor

Effective Collision and Rate of Reaction

The rate of reaction depends on the rate of successful collisions between the reactant particles. The higher the frequency of collision between reactant particles with enough energy and in the correct orientation, the faster the reaction occurs. In other words, the rate of reaction depends on the frequency of effective collisions.

The higher the frequency of effective collisions, the higher the rate of reaction.
The lower the frequency of effective collisions, the lower the rate of reaction.

Effect of Concentration on the Rate of Reaction

Based on Figure 7.23, which has a higher frequency of collision?

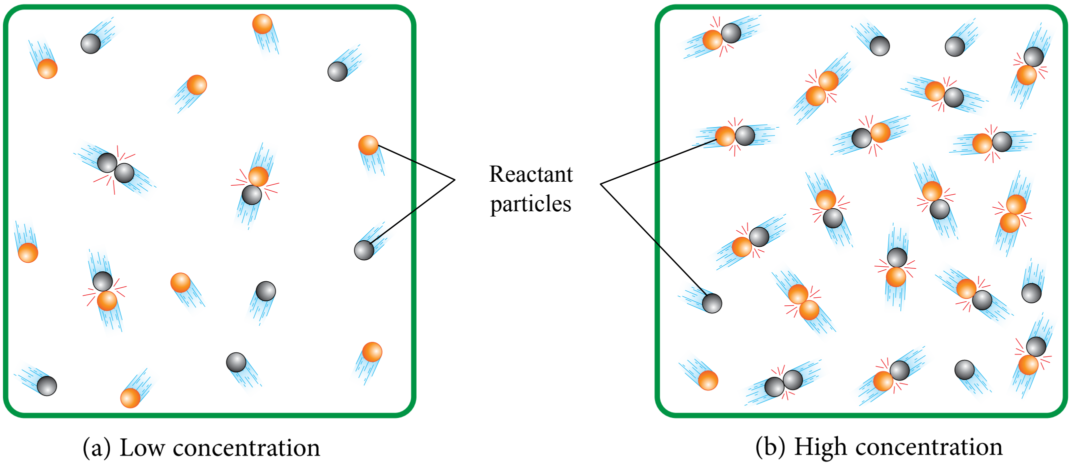


Figure 7.23 *The effect of concentration of reactants on the rate of reaction*

When the **concentration** of the reactant particles increases,
- the number of particles per unit volume increases
- the frequency of collisions between particles increases
- the frequency of effective collisions between particles increases
- the rate of reaction increases

For reactions involving gases, changes in pressure is the same as changing the concentration of the gas. What is the effect of gas pressure on the rate of reaction?

When the **pressure of a gas** increases,
- the number of particles per unit volume increases
- the frequency of collisions between particles increases
- the frequency of effective collisions between particles increases
- the rate of reaction increases

Effect of Size of Reactant on the Rate of Reaction

When a large piece of a solid reactant is broken up into smaller pieces, the total volume of the substance remains the same. However, the total surface area of the reactant increases. Figure 7.24 explains the effect of particle size on the rate of reaction.

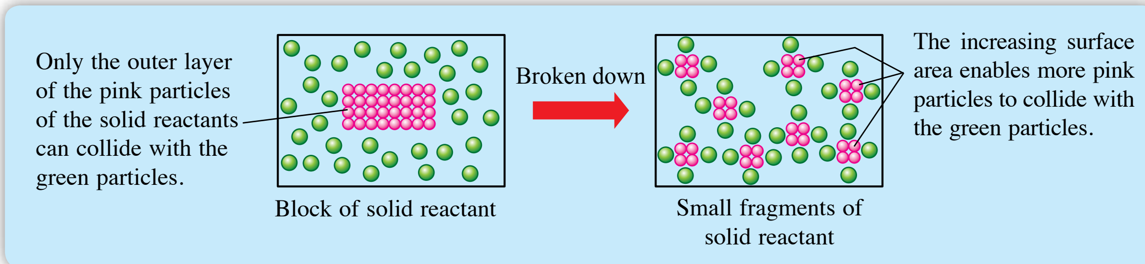


Figure 7.24 The effect of size of reactant on the rate of reaction

When the **total surface area** of the reactant increases,
- the total surface area exposed to collision increases
- the frequency of collisions between particles increases
- the frequency of effective collision increases
- the rate of reaction increases

Effect of Temperature on the Rate of Reaction

When the temperature increases, the rate of reaction increases. This phenomenon is explained in Figure 7.25.

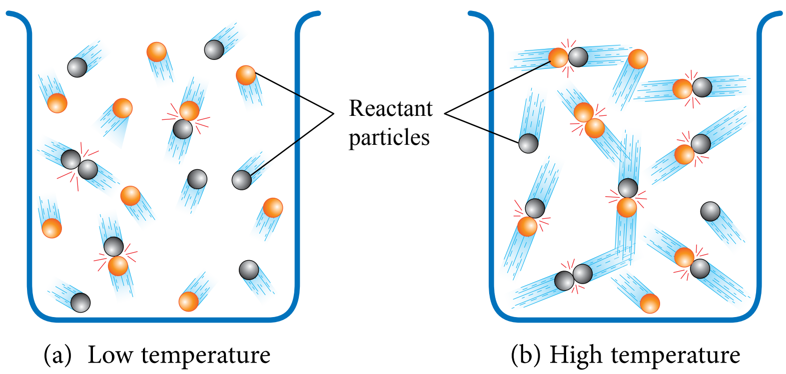
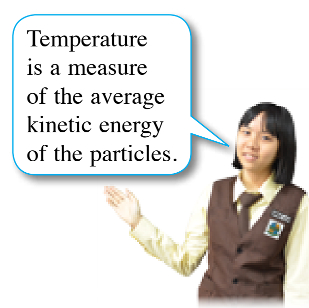


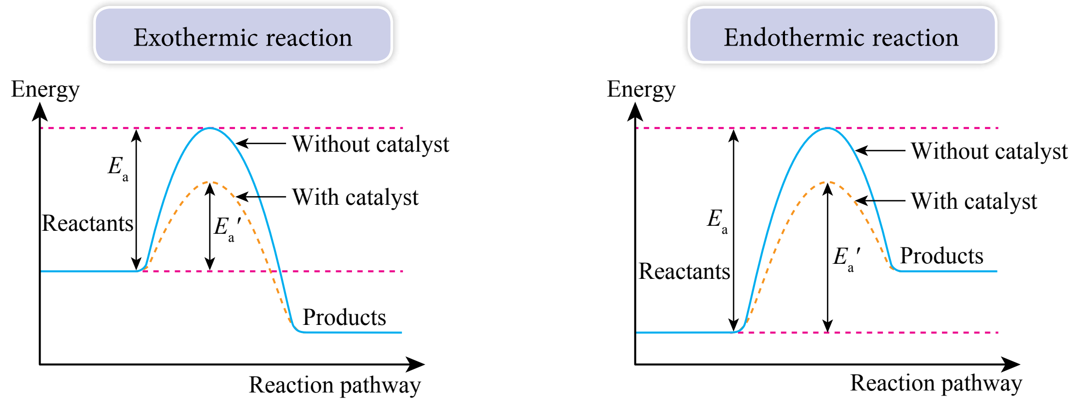
Figure 7.25 The effect of temperature on the rate of reaction

When **temperature** increases,
- the kinetic energy of the reactant particles increases
- more particles have energy to overcome the activation energy
- the frequency of effective collisions between particles increases
- the rate of reaction increases



Effect of Catalyst on the Rate of Reaction

A catalyst is involved in a reaction but remains chemically unchanged at the end of the reaction. The catalyst allows the reaction to occur by providing an alternative pathway with lower activation energy, E_a' as compared to the original activation energy, E_a.



Key: E_a = Activation energy without catalyst E_a' = Activation energy with catalyst

Figure 7.26 *The effect of catalyst on the magnitude of the activation energy*

In the presence of a **catalyst**,
- the catalyst provides an alternative pathway by lowering the activation energy
- more reactant particles can achieve the activation energy
- the frequency of effective collisions between the particles increases
- the rate of reaction increases

Activity 7.7

21st Century Skills CT

Conceptualising the collision theory in reactions that are affected by temperature, reactant size, pressure, concentration and catalyst

1. Carry out the Gallery Walk activity.
2. Get the following information from various reading and search the Internet.
   (a) Collision theory
   (b) Use of the collision theory to explain the effect of the following factors on the rate of reaction

Concentration | Pressure | Size of reactant | Temperature | Catalyst

3. Discuss with your group members and prepare an interesting presentation.
4. Present your group's work in the class. Move in groups to see the works of other groups.
5. Write two stars and a wish about the works of the other groups on sticky notes and paste on the work.

Exothermic Reaction and Endothermic Reaction

Changes in energy can occur during chemical reactions. Reactions that release heat energy to the surroundings are called **exothermic reactions**. Otherwise, reactions that absorb heat energy from the surroundings are called **endothermic reactions**. All exothermic reactions or endothermic reactions have activation energy, E_a that must be overcomed by the reactant particles.

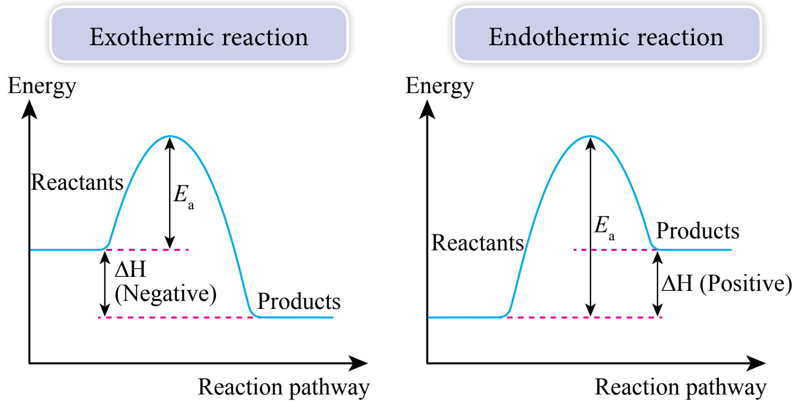


Figure 7.27 *Energy profile diagram for exothermic reaction and endothermic reaction*

Literacy Tips
You will learn more about exothermic and endothermic reactions in the topic of thermochemistry in Form 5.

The change in energy content that occurs when reactants are changed into products is known as the heat of reaction and is represented by the symbol ΔH.

Test Yourself 7.4

1. The Kinetic Theory of Matter states that the particles in matter are constantly moving. Mark (✓) for true statements and (✗) for false statements.
   (a) At constant temperature, all particles move with the same velocity. ☐
   (b) Particles in solids are moving freely. ☐
   (c) Collisions between particles are random. ☐
   (d) The kinetic energy of particles increases with increasing temperature. ☐

2. Scientists use the collision theory to explain how chemical reactions occur. State two important conditions for effective collisions.

3. Catalysts can help to speed up chemical reactions. How does a catalyst speed up a chemical reaction?

4. All reactions including exothermic reactions and endothermic reactions have activation energy that must be overcome by reactant particles.
   (a) What do you understand by the term activation energy?
   (b) Mark and label the activation energy in Figure 7.28.
   (c) Complete the following statements:
      (i) Exothermic reactions ___________ heat to ___________.
      (ii) Endothermic reactions ___________ heat from ___________.

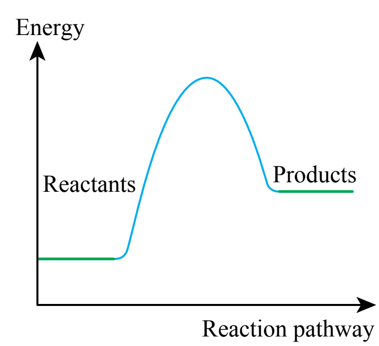


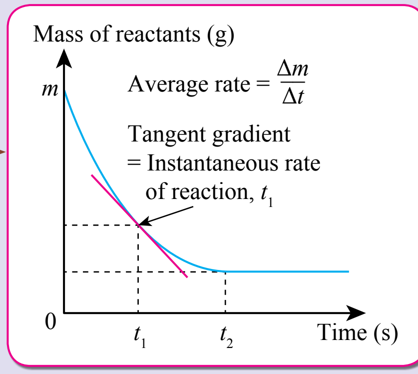
Figure 7.28

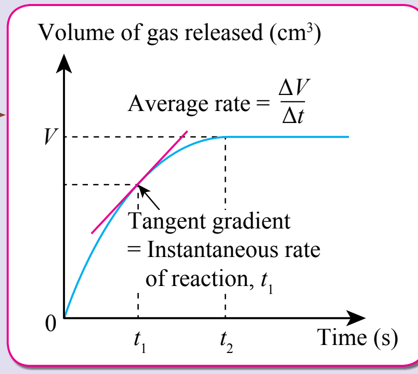
Chain Concept

Rate of Reaction

definition

$$\frac{\text{Change in the quantity of reactants or products}}{\text{Time taken}}$$





Quick Quiz

http://bit.ly/33X1ksG

explained by

Collision Theory

- Reactant particles must collide with one another
- Frequency of effective collisions between particles increases, the rate of reaction increases

affected by

Concentration
- Concentration of reactant ⬆, rate of reaction ⬆
- Number of particles per unit volume ⬆

Size of reactant
- Size of reactant ⬇, rate of reaction ⬆
- Total surface area exposed to collision ⬆

Temperature
- Temperature ⬆, rate of reaction ⬆
- Temperature ⬆, kinetic energy of particles ⬆

Presence of catalyst
- Presence of catalyst, rate of reaction ⬆
- Alternative pathway with lower activation energy, E_a'.

SELF Reflection

1. What new knowledge have you learned from **Rate of Reaction**?
2. Which is the most interesting subtopic in **Rate of Reaction**? Why?
3. Give a few examples of the application of **Rate of Reaction** in daily life.
4. Rate your performance in **Rate of Reaction** on a scale of 1 to 10; 1 being the lowest while 10 the highest.
   Why would you rate yourself at that level?
5. What can you do to improve your mastery in **Rate of Reaction?**

https://bit.ly/32lEzyv

Achievement Test 7

1. Rate of reaction measures the change in the quantity of reactants or products per unit time.
   (a) State three units for measuring the quantity of substances.
   (b) For each unit of measurement for the quantity of substances in 1(a), state the corresponding unit for the rate of reaction.

2. There are chemical reactions that are fast or slow in daily life. Some examples are given below. Arrange the reactions in the descending order of the speed of reaction.
   (a) Banana decaying
   (b) Baking a cake
   (c) Boiling eggs
   (d) Combustion of domestic gas
   (e) Rusting of iron nails

3. A protein-digesting enzyme is used to study the effect of temperature on the rate of protein digestion in milk. The set-up of the apparatus is shown in Figure 1. The time measured is the time taken for the enzyme to digest all the protein and the milk becomes clear, that is until the '×' mark is visible. Table 1 shows the results of the experiment.

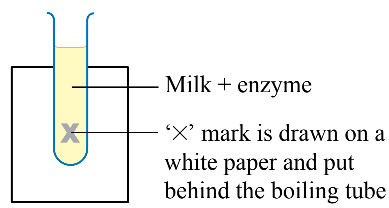


Figure 1

Table 1

Temperature (°C)	15.0	25.0	35.0	45.0	55.0	65.0
Time taken for the '×' mark to be visible (minute)	12.0	7.0	2.5	4.0	7.0	19.0
$\frac{1}{\text{time}}$ (minute^{-1})						

   (a) State the changes that are observed and measured.
   (b) State the manipulated variable and the fixed variables.
   (c) The time of reaction is determined by measuring the time taken for the milk solution to turn clear.
      (i) What is the relationship between the rate of reaction and time?
      (ii) Complete Table 1 by calculating the value of $\frac{1}{\text{time}}$.
      (iii) Plot a graph of $\frac{1}{\text{time}}$ against temperature.
      (iv) What conclusion can be formulated based on the graph in (c)(iii)? Explain your answer.

4. The collision theory explains how reactant particles interact for reaction to occur and products formed.
(a) What are the **two** main principles of the collision theory?
(b) Dinitrogen monoxide, N_2O, known as laughing gas, is produced from the following reaction:

$$NH_4NO_3(aq) \rightarrow N_2O(g) + H_2O(l) + \text{Heat}$$

(i) Balance the above equation.
(ii) Draw the fully labelled energy profile diagram, including the activation energy, for the reaction.

(c) Dinitrogen monoxide, N_2O reacts with nitrogen monoxide, NO to produce nitrogen, N_2 and nitrogen dioxide, NO_2.

$$N_2O(g) + NO(g) \rightarrow N_2(g) + NO_2(g)$$

The reactants, dinitrogen monoxide, N_2O and nitrogen monoxide, NO have to collide in the correct orientation to produce effective collisions and for the reaction to occur. Figure 2 shows the atomic arrangement of the reactants and products.

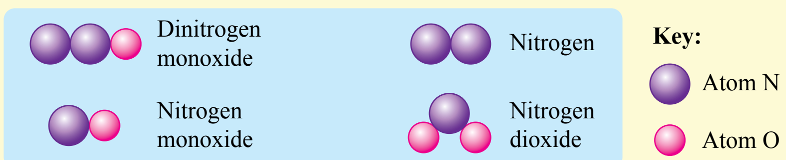


Figure 2

Draw the orientation of the reactant particles, dinitrogen monoxide, N_2O and nitrogen monoxide, NO that results in effective collisions.

Enrichment Corner

1. 1.0 g marble powder, $CaCO_3$ is added simultaneously to 50 cm^3 of hydrochloric acid, HCl of concentrations 0.5 mol dm^{-3} and 1.0 mol dm^{-3}. Excess acid is used in each beaker. Which reaction proceeds fastest? Explain your answer using the collision theory.

2. Acids reacts with metals to produce salt and hydrogen gas. One example of the reaction is shown below:

Tin + Hydrochloric acid → Tin(II) chloride + Hydrogen

The time of reaction can be obtained by recording the volume of gas released at fixed time intervals. Plan an experiment to determine the effect of particle size on the rate of reaction. In your answer, include the followings:
(a) Sketch the set-up of the apparatus
(b) Volume and concentration of the acid used
(c) Mass and the physical state of tin used
(d) Temperature of the reaction
(e) Procedure of the experiment
(f) Appropriate graphs
(g) Explanation on the conclusion obtained

Check Answers
https://bit.ly/35RsfIt