

## Rates of reactions

Collisions cause change. Car accidents, tenpin bowling, hitting a golf ball, hurricanes and striking a match; all of these collisions affect their surroundings. The more energy a collision has, the more dramatic are the changes produced. On a much smaller scale, collisions between atoms, molecules and ions are at the heart of all chemical reactions. The same ideas about energy and collisions causing change explain much about how chemical reactions occur.

**YOU WILL EXAMINE:**

- the concept of rate of a reaction
- the use of collision theory to explain reaction rates
- energy profile diagrams for exothermic and endothermic reactions and the concept of activation energy
- factors that affect the rate of a reaction
- how catalysts affect the rate of a reaction
- Maxwell–Boltzmann distribution curves and their use in explaining reaction rates.



Blasting is an important step in open-cut mining. It frees up the ore for collection and subsequent transport. The explosions that release the ore are chemical reactions designed to happen almost instantaneously, and they release huge volumes of gases and vast amounts of energy. The energy shockwave fractures the rock and ore into smaller, more convenient pieces. Not all chemical reactions happen so quickly, however. Chemists can control the rates of reactions using knowledge of various factors.

**study on**

Unit 3

AOS 2

Topic 1

Concept 4

**Do more**Energy profiles  
for endothermic  
reactions**study on**

Unit 3

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Topic 1

Concept 6

**Do more**

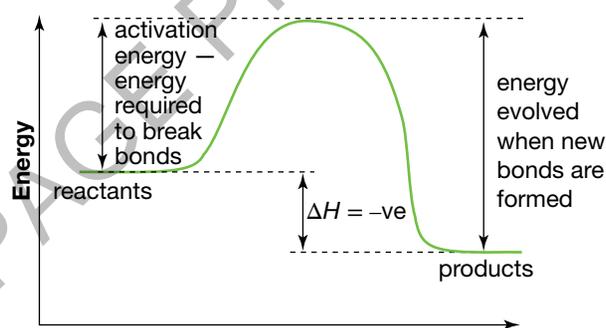
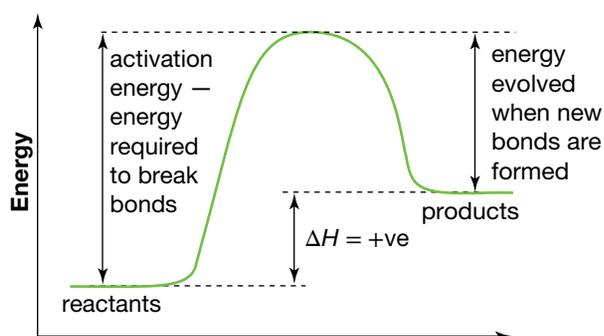
Activation energy

## How does a chemical reaction occur?

All chemical reactions involve the rearrangement of atoms that are already present. For such an arrangement to occur, existing (or old) bonds need to be broken and 'new' bonds allowed to form. This means that there is always an energy requirement before a chemical reaction can take place; this corresponds to breaking the 'old' bonds. This energy required to break these bonds is called the **activation energy** and comes from either or both:

- thermal energy (heating)
- the kinetic energy of colliding particles.

When new bonds form, energy is released as the particles involved organise themselves into stable arrangements that form the products. The total energy stored in a substance is called the **enthalpy**, or **heat content**, of the substance and is given the symbol  $H$ . It is not possible to measure  $H$  directly but the **change in enthalpy** ( $\Delta H$ ) can be measured when a substance undergoes a chemical reaction. Change in enthalpy was discussed in chapter 2. Energy changes can be conveniently summarised using the following energy profile diagrams.

**Energy diagram for an exothermic reaction****Energy diagram for an endothermic reaction**

Energy profile diagrams showing activation energies. A chemical reaction can be recognised as either exothermic or endothermic by its  $\Delta H$  value. If the  $\Delta H$  value is negative, the reaction is exothermic. If the  $\Delta H$  value is positive, the reaction is endothermic.

Chemical reactions involve breaking old bonds and forming new bonds. New substances form after the atoms rearrange themselves. The energy required to initiate this process is called the activation energy.

Energy profile diagrams are a convenient way of representing the energy changes during a chemical reaction. Depending on these changes, reactions may be classified as exothermic or endothermic. A **negative  $\Delta H$**  value indicates an exothermic reaction, while a **positive  $\Delta H$**  value indicates an endothermic reaction.

From these diagrams we can note a number of points:

- The energy required to break the old bonds is called the activation energy.
- For an **exothermic** reaction, the activation energy is less than the energy released when new bonds form. Consequently, there is a net release of energy (usually as heat released to the surroundings).
- In an **endothermic** reaction, the activation energy is greater than the energy released when new bonds form. Consequently, there is a net input of energy (in most cases, heat is absorbed from the surroundings).
- In both cases, however, the activation energy represents a requirement for the progress of the chemical reaction. This must be overcome before a reaction proceeds.

Bond breaking > bond forming  $+\Delta H$

Bond breaking < bond forming  $-\Delta H$

## study on

Unit 3

AOS 2

Topic 1

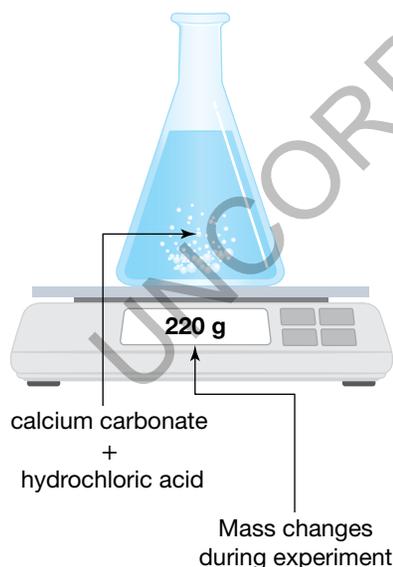
Concept 2



See more

Endothermic and exothermic reactions

The rate of a chemical reaction can be affected by the concentrations of reactants, the temperature, the presence of a catalyst and, in heterogeneous reactions, the surface area. Heterogeneous reactions have reactants in different phases, such as a powder and a gas.



Apparatus used to measure rate

## Collision theory

A chemical reaction involves particles that are moving around in constant random motion and sometimes colliding with each other. The greater the number of successful collisions there are the faster the rate. Not all collisions result in a reaction; the particles may simply bounce off each other. In summary, in order for a reaction to take place the reactants must:

- collide
- have the correct orientation for bond breaking to occur
- have sufficient energy for the reaction to occur. The reactant particles must contain enough energy to overcome the activation energy requirement, allowing the particles present to break their bonds and then rearrange themselves, forming new bonds, into the products.

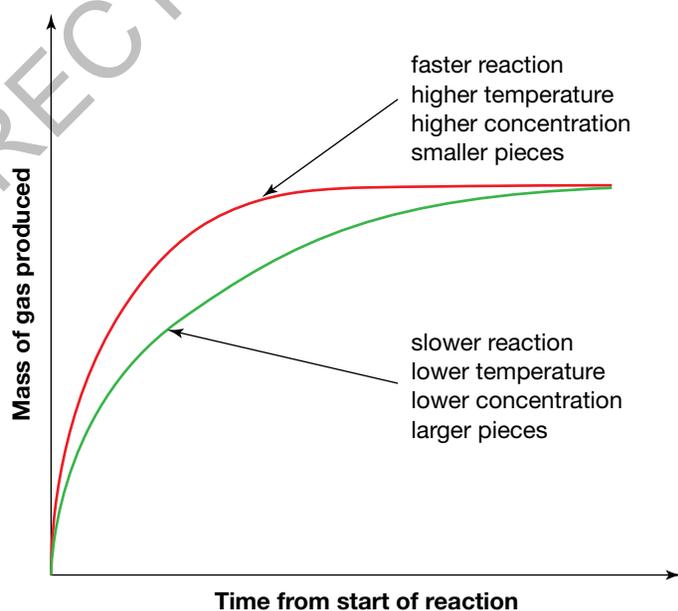
## Measuring reaction rates

The progress of a reaction may be conveniently monitored by following either the decrease in the amount of a reactant or the formation of a product. Methods used to observe reaction rates include measuring the change over a period of time of:

- the volume of a gas evolved
- the mass of a solid formed
- the decrease in mass due to gas evolving
- the intensity of colour of a solution
- the formation of a precipitate
- pH
- temperature.

A typical example of apparatus used to measure rates is illustrated below left. The rate of the reaction can be observed by measuring the change in mass over fixed intervals of time, such as grams per 10 seconds. As the reaction proceeds, the mass of the flask and contents decreases.

The variables that might be tested are temperature, concentration of the hydrochloric acid or the size of the particles of calcium carbonate (surface area).



Graph displaying mass of gas lost from apparatus

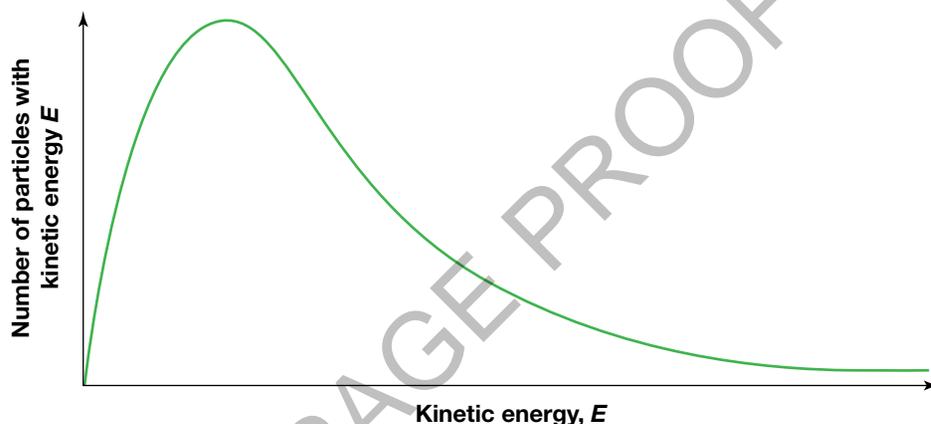
The graph displays the mass of gas lost and is found by subtracting the mass at each time interval from the initial mass of the apparatus. The gradient (steepness) of the red line is greater, indicating a faster rate than the green line. The graph flattens when the limiting reactant is consumed.

## Maxwell–Boltzmann distribution curves

During the second half of the seventeenth century, work by scientists such as James Clerk Maxwell and Ludwig Boltzmann led to what is now known as the Maxwell–Boltzmann distribution. This is a statistical analysis of the range of energies present in the particles of a gas sample. It has proven to be very useful in explaining some of the factors that influence chemical reactions and their rates. Although originally developed for gases, many of its ideas can also be applied to liquids and reactions in solution as well.

A Maxwell–Boltzmann distribution curve, such as that shown below, shows the number of particles with a particular energy graphed against the value of that energy.

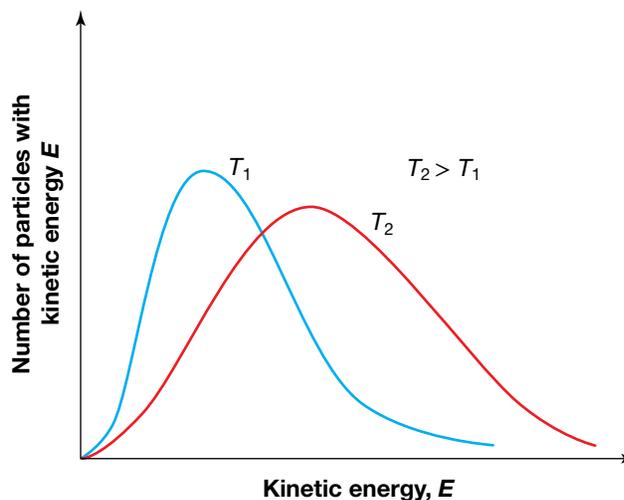
The Maxwell–Boltzmann curve shows the number of particles with a particular energy graphed against the value of that particular energy.



Some points to note about this graph include:

- The particles in a sample have a wide range of kinetic energies. As kinetic energy is given by the formula  $\frac{1}{2}mv^2$ , this means that there is also a range of velocities. This is due to the collisions that the particles are constantly undergoing.
- It is not symmetrical.
- The highest point represents the most probable velocity; however, this is not the same as the average velocity.
- The area under the graph represents the total number of particles in the sample.

If the temperature of a sample is increased, the graph changes in a very predictable manner as shown below.



Increasing the temperature of a gas sample stretches the Maxwell–Boltzmann curve to the right.

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Experiment 5.1 Reaction rates  
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Square brackets denote concentration in mol L<sup>-1</sup> (M).

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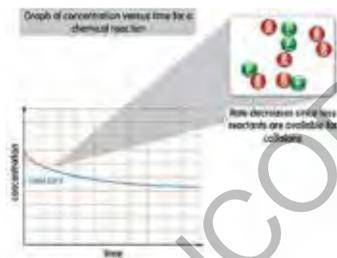
Unit 3

AOS 2

Topic 2

Concept 1

**See more**  
Increasing reaction rate



Increasing concentration and increasing temperature both increase the number of collisions each second and also increase the rate of a reaction. Temperature also affects the energy of a collision.

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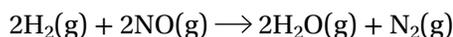
The effect of increasing the temperature is to 'stretch' the graph to the right. As a result, there are more particles with higher kinetic energies. Although the area under the graph is the same (the total number of particles has not been altered), on average they all move faster and the average kinetic energy is higher.

*Note:* At the higher temperature, the graph is *stretched* to the right, rather than *moved* to the right. The graph is always 'anchored' to the origin, as there are always a few particles with very low or zero velocity.

## Factors that affect the rate of a reaction

### Concentration

Table 5.1 shows some results from an experiment involving the reaction:



**TABLE 5.1** Rate of reaction between H<sub>2</sub> and NO (at 800 °C)

Experiment	Initial concentrations (M)		Initial rate of H <sub>2</sub> O production (M s <sup>-1</sup> )
	[NO]	[H <sub>2</sub> ]	
1	6.0 × 10 <sup>-3</sup>	1.0 × 10 <sup>-3</sup>	0.64 × 10 <sup>-2</sup>
2	6.0 × 10 <sup>-3</sup>	2.0 × 10 <sup>-3</sup>	1.28 × 10 <sup>-2</sup>
3	1.0 × 10 <sup>-3</sup>	6.0 × 10 <sup>-3</sup>	1.00 × 10 <sup>-3</sup>
4	2.0 × 10 <sup>-3</sup>	6.0 × 10 <sup>-3</sup>	3.90 × 10 <sup>-3</sup>

In experiments 1 and 2, [NO] is the same but [H<sub>2</sub>] is different. In experiments 3 and 4, [H<sub>2</sub>] is the same but [NO] is different. Therefore, each pair of experiments allows us to analyse the effect of changing the concentration of one of the two substances. Compare experiment 1 with experiment 2, and then compare experiment 3 with experiment 4. Increasing the concentration of either reactant causes an increase in the rate of the reaction. In terms of our model of a chemical reaction, we can explain this by the crowding together of the reacting particles as the concentration is increased. This results in an increased frequency of successful collisions during any given period of time and hence a higher rate of reaction.

### Pressure

For reactions involving gases, the effect of increasing pressure is the same as increasing concentration. Both effects result in more crowding together of the particles and hence more successful collisions within a certain time.

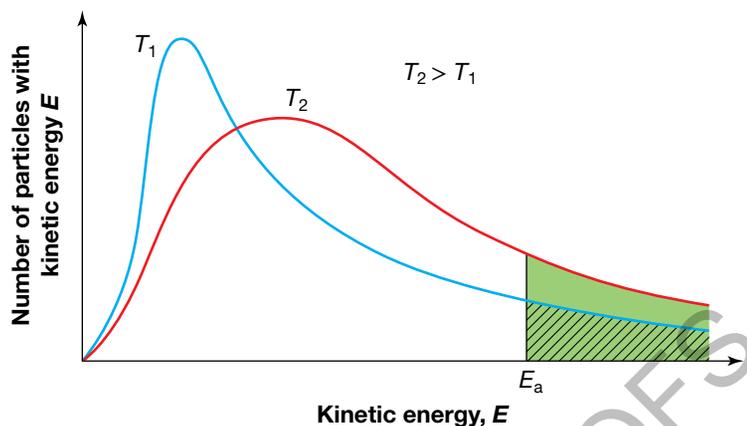
This can be verified using the universal gas equation. For a given temperature, it can easily be shown that pressure is proportional to concentration by manipulating the equation to produce  $P = \frac{n}{V}RT$ .

### Temperature

Most chemical reactions are observed to proceed more quickly as the temperature is increased. Examples from everyday life that demonstrate this are the cooking of food and setting of glues such as Araldite.

An examination of the following Maxwell-Boltzmann curves at different temperatures reveals why this is so.

Increasing the temperature means that there are more particles with enough energy to overcome the activation energy barrier.



For the given activation energy ( $E_a$ ), the shape of the graph clearly shows that there is more area under the graph (and hence more particles) to the right of  $E_a$  at the higher temperature than at the lower one. More collisions will therefore be 'successful' in overcoming the activation energy barrier.

Another effect of increasing the temperature is that there is an increased frequency of collisions due to the particles moving faster. However, a more sophisticated analysis of the situation reveals that this is secondary to the effect of the energy distributions mentioned above.

### Revision question

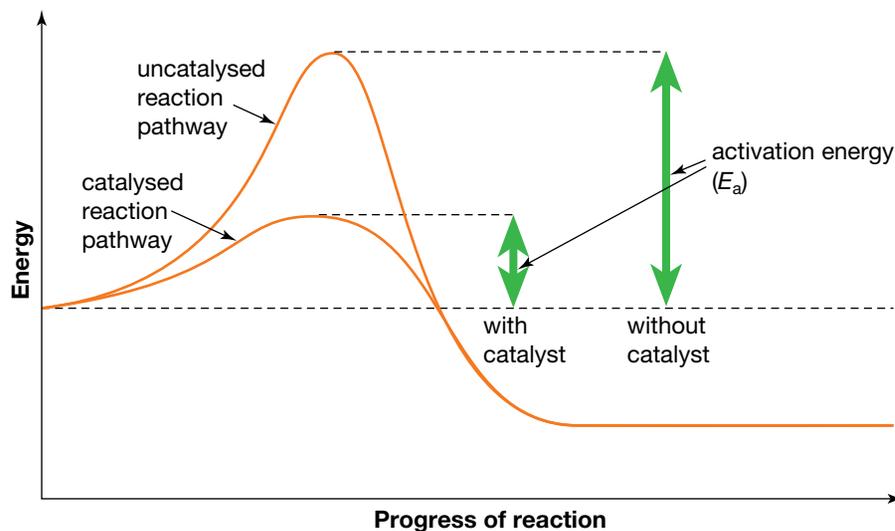
- The evolution of bubbles when a soft drink is opened is due to dissolved carbonic acid decomposing to carbon dioxide and water. The equation for this process is:



- This evolution is initially fast, but gradually slows down with time. Why does the rate of carbon dioxide evolution decrease?
- How would the rate of reaction be affected if the soft drink was warm?

## Catalysts

A **catalyst** is a substance that alters the rate of a chemical reaction without itself being consumed. It provides an alternative reaction pathway with a lower activation energy. This increases the proportion of collisions with energy greater than the activation energy.



A catalyst acts by providing an alternative pathway with a lower activation energy for reactants to form products.

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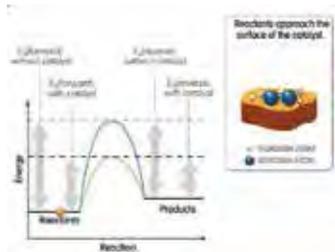
Unit 3

AOS 2

Topic 1

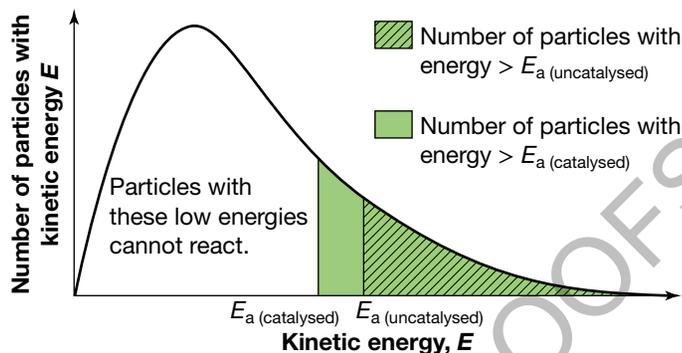
Concept 7

See more  
Catalysts



Catalysts are usually used to speed up a reaction. Sometimes, however, they are added to slow a reaction down, in which case they are called negative catalysts or inhibitors.

Adding a catalyst does not alter the value of  $\Delta H$ .



A catalyst provides an alternative pathway with a lower activation energy. Therefore, more particles have enough energy to overcome the new activation energy requirement.

Appropriate catalysts lie at the heart of many industrial processes, especially in green chemistry industries. Much money is spent by companies on research into new and improved catalysts, and the results of such research are often among a company's most closely guarded secrets. Biological catalysts, or enzymes, are also responsible for the management of thousands of biological reactions important in maintaining life.

In terms of the particle model of chemical reactions, particles must not only collide, but also do so with sufficient energy to break bonds. The presence of a catalyst provides an alternative pathway for the reaction. This pathway has a lower activation energy, as shown on the energy profile diagram at the bottom of the previous page. This means that the value of  $E_a$  on the Maxwell-Boltzmann curve shown above is shifted to the left. Therefore, there are now more particles under the curve to the right of this new  $E_a$  value. These are the particles that have enough energy to overcome the activation energy requirement, so the reaction occurs at a faster rate as there are more 'successful' collisions within a certain time.

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Experiment 5.2 Catalytic oxidation of ammonia

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Catalysts reduce the energy required for a reaction to occur.

## Catalytic converters – catalysts in car exhausts

Catalytic converters are used in the exhaust systems of cars to reduce the amount of gaseous pollutants emitted into the atmosphere. The essential feature of these converters is a rare metal catalyst made from platinum and rhodium. This is finely dispersed over an internal structure that provides a very large surface area over which the exhaust gases are forced to pass. Table 5.2 shows the effect that these catalysts have on the exhaust gases that pass over them.

**TABLE 5.2** The changes in exhaust gas composition caused by catalytic converters

Before reaction	After reaction
$\text{CO} + \text{O}_2$	$\text{CO}_2$
hydrocarbons + $\text{O}_2$	$\text{H}_2\text{O} + \text{CO}_2$
nitrogen oxides	$\text{N}_2 + \text{O}_2$

Catalysts increase the rate of a reaction by reducing its activation energy. Increasing the surface area of a reactant allows more reactant particles to come into contact with each other.

## The effect of surface area

This is an important factor in heterogeneous reactions — reactions where the reactants are in different phases, such as a solid and a liquid. Its effect is due simply to the fact that, by increasing the surface area, more of a substance is brought into contact with other substances with which it might react. The same mass of wood on a fire burns much faster if, for example, it is cut into small pieces than if it is left as a log. Powdered calcium carbonate reacts faster in acid solution than a block of calcium carbonate of the same mass.

In terms of collision theory, an increase in surface area means that more reactant particles can collide with one another and, therefore, there are more successful collisions between them in a given period of time. This leads to an increased rate of reaction.

Both beakers contain 25 mL of hydrochloric acid and 1 g of calcium carbonate (marble). The marble in the beaker on the left has been ground into a powder; in the beaker on the right, it is in large chunks. The powder has a much higher surface area than the acid, resulting in a much higher reaction rate, which is shown by the faster release of carbon dioxide bubbles.



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Experiment 5.3 Rate of hydrogen production — a problem-solving exercise

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## Exploding custard factories

The effect of increasing surface area on the rate of combustion reactions can lead to unexpected, and sometimes catastrophic, results.

A well-documented case in Banbury, Oxfordshire, England, in November 1981, involved a custard powder factory that exploded. Eight people were seriously burned as a result.

Like other solids such as coal and wheat, custard powder does not normally burn very fast. As a dust, however, all of these solids present a huge surface

area to the oxygen in air. All that is needed is an errant spark (from a machine or from static electricity) and the resulting reaction is so fast that it causes an explosion.

Wheat silos have been destroyed and many tragedies have occurred in underground mines from this effect.

### Sample problem 5.1

The use of powdered coal is being investigated in experimental railway locomotives as an alternative to oil.

Powdered coal can be introduced in smaller 'doses' that burn much faster than the traditional 'lump' coal once used in steam locomotives.

Why does the powdered coal have a much faster rate of combustion?

**Solution:** The larger surface area of powdered coal means that it can combust at a much faster rate than lump coal due to the increased frequency of collisions between  $O_2$  and coal.

### Sample problem 5.2

Gas leaks in confined spaces can be very dangerous. A single spark can lead to an explosion. Explain, in terms of reaction rates, why this is so.

**Solution:** Initially the gas and oxygen mixture is non-reactive due to the reaction having a high activation energy. Although the molecules are constantly colliding, there is not enough energy in these collisions to break bonds. This prevents a reaction in the absence of an external energy source.

A spark, however, supplies energy to the molecules in its immediate vicinity and increases their kinetic energy. Some collisions between these molecules now have energy in excess of the activation energy, and bond breaking followed by the formation of new bonds to make products can occur. As this reaction is exothermic, the energy released increases the energy of more reactant molecules, leading to further reactions.

The reaction, therefore, proceeds very quickly with respect to temperature and rate.

### Revision questions

- In an investigation of the rate of reaction of gas produced from magnesium and hydrochloric acid, HCl, a student has available three forms of magnesium: powder, small turnings and a strip. Also available are reagent bottles of 0.5 M HCl, 1 M HCl and 2 M HCl. The student could also use a hot water bath and a cool water bath.
  - Which combination of reactants and conditions would produce the fastest rate of reaction?
  - Which combination would produce the slowest rate of reaction?
- The reaction between two gases occurs at a measurable rate at 700 °C. If the temperature is held constant at 700 °C and the reacting mixture is compressed, predict and explain what will happen to the rate of this reaction.

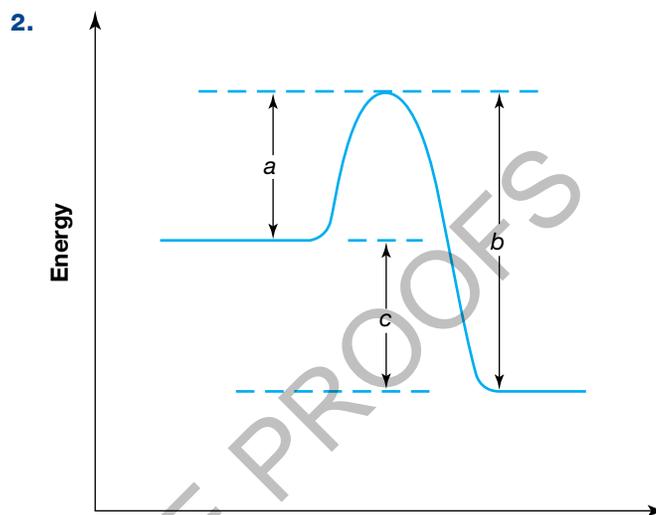
# Chapter review

## Summary

- Chemical reactions show a wide range of reaction rates.
- Chemical reaction rates may be explained in terms of collisions between the particles involved. The rate depends on factors such as the kinetic energy involved in the collision, the activation energy, the number of collisions per unit time and whether a catalyst is present.
- The activation energy is the energy required to break the original bonds, before new bonds can form.
- A catalyst is a substance that provides an alternative pathway for a reaction — one that has a lower activation energy. Although a catalyst plays an important role in a reaction, it is not used up and does not affect the nature of the actual products formed.
- A chemical reaction is exothermic (and has a negative  $\Delta H$  value) if the energy released as new bonds form is greater than the energy required to break the old bonds.
- A chemical reaction is endothermic (and has a positive  $\Delta H$  value) if the energy released as new bonds form is less than the energy required to break the old bonds.
- The rate of a chemical reaction is affected by factors such as the concentration of the particles, the pressure, the temperature, the presence of a catalyst and surface area. Each of these can be explained using collision theory.
- A Maxwell-Boltzmann distribution curve is a graph that shows the number of particles with a particular energy graphed against kinetic energy.
- Maxwell-Boltzmann curves are useful in explaining how factors such as temperature increase and catalysts affect the rate of a chemical reaction.

## Multiple choice questions

1. Most chemical reactions display a rate increase with increasing temperature. This can be explained by:
  - A the temperature lowering the activation energy
  - B the particles having more collisions involving higher energies
  - C the temperature making the reactant's bonds weaker
  - D the temperature making the collisions between the particles more elastic.

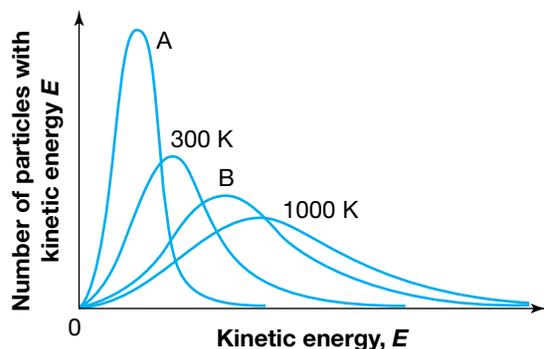


An energy profile diagram for a chemical reaction is shown above. On this graph:

- A  $a$  represents the activation energy for the forward reaction and  $c$  represents the activation energy for the backward reaction
  - B  $a$  represents the activation energy for both the forward and the reverse reactions
  - C  $b$  represents the activation energy for both the forward and the reverse reactions
  - D  $a$  represents the activation energy for the forward reaction and  $b$  represents the activation energy for the backward reaction.
3. The following reaction has an activation energy of  $183 \text{ kJ mol}^{-1}$ .
$$2\text{HI}(\text{g}) \rightarrow \text{H}_2(\text{g}) + \text{I}_2(\text{g})$$
The reverse reaction:
$$\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightarrow 2\text{HI}(\text{g})$$
has an activation energy of  $157 \text{ kJ mol}^{-1}$ . The  $\Delta H$  value for the first equation above is:
    - A  $-340 \text{ kJ mol}^{-1}$
    - B  $+340 \text{ kJ mol}^{-1}$
    - C  $-26 \text{ kJ mol}^{-1}$
    - D  $+26 \text{ kJ mol}^{-1}$ .
  4. Which of the following statements about activation energies is correct?
    - A Activation energies are always positive.
    - B Activation energies are always negative.
    - C Activation energies are positive only for endothermic reactions.
    - D Activation energies are negative only for exothermic reactions.
  5. When zinc is added to hydrochloric acid, the rate at which hydrogen gas is evolved can be used as a measure of reaction rate. Which of the following

combinations produces the fastest rate of hydrogen gas evolution?

- A Powdered zinc added to 2 M HCl at 20 °C
  - B Powdered zinc added to 2 M HCl at 40 °C
  - C Granular zinc added to 2 M HCl at 20 °C
  - D Granular zinc added to 2 M HCl at 40 °C
6. A sample of gas is heated. Which of the following statements is *incorrect*?
- A The most common speed for its molecules increases.
  - B The average speed of its molecules increases.
  - C The number of collisions between molecules, per unit time, increases.
  - D The area under the Maxwell-Boltzmann distribution curve increases.
7. The Maxwell-Boltzmann distribution graphs for a sample of gas at four different temperatures is shown below.



Which of the following statements is true?

- A Graph A represents the highest temperature.
  - B The area under graph A is greater than the area under graph B.
  - C A possible temperature for graph B could be 600 K.
  - D Graph A contains more fast-moving molecules than graph B.
8. When a reaction occurs at a higher temperature, two important things happen.  
Effect 1: More collisions between particles occur each second.  
Effect 2: More energy is involved in these collisions.  
Which of the following is a true statement?
- A Effect 1 is more important than effect 2 for increasing the rate of a reaction.
  - B Effect 2 is more important than effect 1 for increasing the rate of a reaction.
  - C Effects 1 and 2 are both equally significant for any increase in reaction rate.
  - D Neither 1 nor 2 affects the rate of the reaction.
9. An industrial process involving an exothermic reaction requires that the reaction be slowed down so that the heat evolved can be collected safely. In order to achieve this:
- A the  $\Delta H$  value of the reaction needs to be decreased

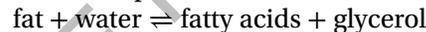
- B the  $\Delta H$  value of the reaction needs to be increased
- C the activation energy of the reaction needs to be increased
- D the activation energy of the reaction needs to be decreased.

## Review questions

### Using energy profile diagrams

- Using the concepts of activation energy and reaction pathways, explain how a catalyst can speed up the rate of a chemical reaction.
- Enzymes are a very important class of biochemical molecules that are often described as biological catalysts. The enzyme lipase, for example, is an important digestive enzyme that assists in the breakdown of fats according to the following generalised equation.

lipase



- Using the concept of activation energy, explain why the rates of reactions such as this are very much greater in the presence of lipase.
  - How does the amount of lipase present at the start of a reaction such as this compare with the amount present at its completion?
3. The decomposition of ammonia to produce nitrogen and hydrogen according to:
- $$2\text{NH}_3(\text{g}) \rightarrow \text{N}_2(\text{g}) + 3\text{H}_2(\text{g})$$
- has an activation energy of 330 kJ mol<sup>-1</sup> and a  $\Delta H$  value of +92 kJ mol<sup>-1</sup>. If tungsten is used as a catalyst, the activation energy is 163 kJ mol<sup>-1</sup>.
- Give a definition for the term 'catalyst'.
  - Show all of the information above on an energy profile diagram for this reaction.  
The reverse reaction to this as shown by the equation:
- $$\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightarrow 2\text{NH}_3(\text{g})$$
- is a very important reaction in industry.
- Calculate the activation energy for the uncatalysed version of this reaction.
  - Calculate the activation energy when tungsten is used as a catalyst.
4. Sometimes, a catalyst is described as a substance that *lowers the activation energy*. Why is it more correct to describe it as *a substance that provides an alternative pathway with a lower activation energy*?

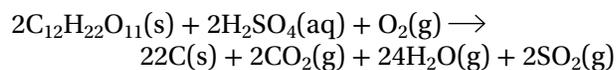
### Explaining reaction rates

- Comment on the rates observed for each of the following situations. For each one, use the

particle theory for chemical reactions to explain the rate behaviour observed.

- Ten mL of spilt petrol evaporates faster than 10 mL of petrol in a narrow container.
  - A piece of steel wool burns in a Bunsen flame, but the same mass of solid steel does not.
  - A pinch of manganese dioxide added to hydrogen peroxide continues to produce oxygen for as long as fresh hydrogen peroxide is added.
  - The chemicals mixed by a panelbeater to make body filler harden faster on a hot day than on a cold day.
  - Nail polish remover evaporates faster if you shake your fingers than if you don't.
  - The addition of vinegar to some 'bicarbonate of soda' causes an evolution of gas that is quick at first but then slows down.
  - Photographers using infrared-sensitive film store it in a refrigerator before use.
6. The reaction between hydrogen gas and nitrogen(IV) oxide is represented by the equation:
- $$2\text{H}_2(\text{g}) + 2\text{NO}_2(\text{g}) \longrightarrow 2\text{H}_2\text{O}(\text{g}) + \text{N}_2(\text{g})$$
- Explain why the rate of this reaction decreases with time.
  - Explain why the progress of this reaction can be monitored by measuring the drop in pressure.
7. The dehydration properties of concentrated sulfuric acid are often demonstrated using sucrose,  $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ . Black carbon and steam, along with

sulfur dioxide and considerable heat, are produced. The equation for this reaction is:



Explain why this reaction occurs much faster when castor sugar, rather than granulated sugar, is used as a source of sucrose.

- Maxwell-Boltzmann curves show that particles have a wide range of velocities (and hence energies). Using collision theory, explain why this is so.
- The rate of a chemical reaction is a very important consideration in industrial chemistry where chemicals are made on a large scale. Reactions need an acceptable rate to be economical. A number of important industrial reactions have rates that are too slow at even moderate temperatures and, therefore, need to be sped up. Further increasing the temperature is a common means of achieving this; however, sometimes this is an inappropriate strategy. Suggest two other methods by which an increase in reaction rate may be produced in these situations.
- (a) Use a Maxwell-Boltzmann curve to clearly explain why:
  - a catalyst can alter the rate of a reaction
  - increasing temperature usually increases the rate of a reaction.(b) Mark an X on the graph showing the average energy of particles in your sample.

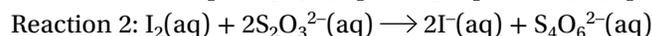
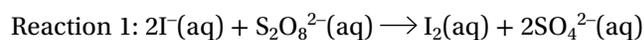


## Exam practice questions

In a chemistry examination, you will be required to answer a number of multiple choice and extended response questions.

## Extended response question

1. In chemistry, a number of reactions are collectively referred to as 'clock reactions'. These reactions produce a sudden colour change after a period of time. One of the better known examples of such reactions is that between iodide ions and persulfate ions in the presence of thiosulfate ions and starch. Two reactions are involved:



The iodine produced by reaction 1 is immediately removed by reaction 2. However,  $\text{S}_2\text{O}_3^{2-}(\text{aq})$  ions are also removed and are eventually all used up. After this time, iodine builds up and is detected by the starch present, which forms an intensely coloured dark blue complex. This occurs at iodine concentrations as low as  $10^{-5}$  M, making starch an excellent indicator for this reaction.

If the amount of  $\text{S}_2\text{O}_3^{2-}(\text{aq})$  is kept constant, the appearance of the dark blue colour may be used to measure the rate of reaction 1.

In one such experiment using 0.2 M KI(aq) solution, 0.2 M  $\text{Na}_2\text{S}_2\text{O}_8(\text{aq})$  and 0.1 M  $\text{Na}_2\text{S}_2\text{O}_3(\text{aq})$  solutions, the following results were obtained.

Trial number	V(I <sup>-</sup> (aq)) solution (mL)	V(S <sub>2</sub> O <sub>8</sub> <sup>2-</sup> (aq)) solution (mL)	V(S <sub>2</sub> O <sub>3</sub> <sup>2-</sup> (aq)) solution (mL)	V(water) (mL)	V(starch) solution (mL)	Time for blue colour to appear (s)
1	20	20	20	40	10	220
2	20	40	20	20	10	150
3	40	20	20	20	10	142

- (a) Explain how these results show that increasing  $\text{S}_2\text{O}_8^{2-}(\text{aq})$  concentration produces a faster rate in reaction 1. Compare two appropriate trials from the data above as part of your explanation. **2 marks**
- (b) Use the results above to explain how the rate of reaction is affected by the concentration of iodide ions. Select two appropriate trials to support your explanation. **2 marks**
- (c) The experiment is repeated using solutions that were stored in a refrigerator for 24 hours. These solutions were used immediately after being removed. How would the reaction times in the table above be affected? **1 mark**
- (d) What is the purpose of the two different amounts of water used in the above trials? **2 marks**
- (e) Explain why the amount of  $\text{S}_2\text{O}_3^{2-}(\text{aq})$  solution is kept constant in each trial. **1 mark**