**6.1.2 Collision theory**

**Learning objectives**

• Describe and explain the collision theory

• Define the activation energy of a reaction

• Understand the effects of surface area of solid reactants, temperature, catalysts, concentration and pressure on rate of reaction

• Understand that the average energy of particles in a gas is proportional to its temperature in kelvin

• Sketch the Maxwell–Boltzmann distribution and use it to explain the effect of a change in temperature on the rate of a reaction and how a catalyst speeds up a reaction

**Particles must collide to react**

**Collision theory** states that for a reaction to occur particles must collide. However, for these collisions to result in a reaction, two conditions must be fulfilled:

* a collision must involve more than a certain **minimum amount of energy (Activation energy)**
* molecules must collide with the **correct orientations**.

So not all collisions result in a reaction.

**The collision must involve more than a certain minimum amount of energy**

Particles must collide with sufficient energy in order to react. The minimum amount of energy that colliding particles must possess to result in a reaction is called the **activation energy (*E*a)**.

A collision that results in a reaction is called a **successful** or **effective** collision.

Activation energy is the energy needed to **overcome repulsions,** to start **breaking bonds**, to **deform molecules** and to allow **rearrangement of atoms**, electrons etc.

Potential energy profile for exothermic reaction

* Reactants are at higher PE than products
* Enthalpy change is negative
* Products are more stable than the reactants.

Imagine the reaction between two particles, A and BC:

A + B–C → A–B + C

As the two particles approach, repulsion between the atoms (internuclear and between electrons) causes an increase in the potential energy. The B–C bond begins to break and the A–B bond begins to form. The highest point along the curve is called the **transition state** (activated complex) **and all three atoms are joined together by partial bonds (A….B….C).** As the A–B bond continues to form, the potential energy falls.

**Molecules must collide with the correct orientation**

If molecules do not collide with the correct orientation they will not react.

**Not every collision with energy greater than the activation energy results in a reaction.**

Factors affecting reaction rate (Explain how and why each of these affects the rate of a chemical reaction)

The main factors that affect the rate of a chemical reaction are:

• concentration of reactants (collision frequency/ chances of successful collisions )

• pressure for (reactions involving gases)

• surface area of solid reactants

• temperature (Kinetic energy increases with temperature, collision frequency increases, **particles collide harder**)

• catalysis.

**The effect of concentration on the reaction rate**

Increasing the concentration of reactants increases the rate of reaction. This is because as concentration increases, the frequency of collisions between reactant particles increases.

**The effect of pressure on the reaction rate**

The effect of increasing the pressure is essentially the same as that of increasing the concentration of gaseous reactants. As the pressure is increased, the collision frequency increases.

Only reactions involving gases are significantly affected by changing the pressure.



**a** Lower pressure – the particles are further apart and collide less frequently; **b** higher pressure – the particles are closer together and collide more frequently.

**a** Lower concentration – the particles are further apart and collide less frequently; **b** higher concentration – the particles are closer together and collide more frequently.

**The effect of surface area of solid reactants**

Reactions generally only occur at the surface of a solid. Making a solid more finely divided increases the surface area and therefore the number of particles exposed at the surface.

The effective concentration of the particles of the solid has thus been increased and there is a greater chance of a particle of the other reactant colliding.



**a** Low surface area – only the particles coloured green are exposed on the surface and able to collide with the red particles; **b** high surface area – particles coloured both green and blue are exposed and are able to collide with the red particles.

**Effect of temperature on rate of a reaction**

**The average kinetic energy of the particles in a gas is proportional to its temperature in kelvin.**

Increasing the temperature causes an increase in the average kinetic energy of the particles.

Therefore if a sample of oxygen is heated from 300 K to 600 K, the **average** energy of the particles is doubled.

**Increasing the temperature has a major effect on the rate of the reaction. As the temperature increases, the rate of reaction increases exponentially.**

As the temperature increases, the molecules have more energy and therefore move faster. This means that the collision frequency increases, i.e. the particles collide more often. This is, however, only a minor effect and can explain only a small increase in rate (approximately 2% for a 10 K rise in temperature) as the temperature increases.

**The major cause of the increase** in rate as the temperature increases is that, not only do the particles collide more often, but they **also collide harder, with more energy**.

**Maxwell– Boltzmann distribution**

The molecules are constantly colliding with each other and, therefore, do not all have the same speed and hence energy. **Maxwell– Boltzmann distribution** **curve shows the distribution of energy in the molecules of a gas at a particular temperature.**

The vertical axis could be labelled as ‘number of particles with a certain amount of energy’ or ‘proportion of particles with a certain amount of energy’.



*(Use this curve to explain the effect of temperature on the rate of a chemical reaction, comment on the peaks)*

The shaded area represents the number of particles with energy greater than or equal to the activation energy at the lower temperature. The checked area represents the number of particles with energy greater than or equal to the activation energy (*E*a) at the higher temperature.

At higher temperatures the curve is flatter and the maximum has moved to the right and so there are more particles with energy greater than the activation energy.

A greater proportion of collisions will be successful, and therefore the rate of reaction will increase.

**The main reason that the rate of reaction increases with temperature is an increase in the number of particles with energy greater than or equal to the activation energy.**

Features to note on the figure above:

• it is **not** symmetrical

• no molecules have zero kinetic energy

• at higher energy the line does not reach the energy axis

• the area under the curve represents the total number of particles and will not change as the temperature changes.

The areas underneath the curves are the same because the number of particles (amount of substance) does not change if the temperature is increased.

**Effect of a catalyst (use the diagrams to explain the effect of catalyst on a chemical reaction)**

**A catalyst is a substance that increases the rate of a chemical reaction without itself being used up in the reaction.**

Most catalysts work by **providing an *alternate route* for the reaction that has a *lower activation energy*.**

Figure below is the Maxwell–Boltzmann distribution to show how a catalyst increases the proportion of particles having values of kinetic energy greater than the activation energy.



Catalysts bring about an equal reduction in the activation energy of both the forward and the reverse reactions, so they do not change the position of equilibrium or the yield.

Every biological reaction is controlled by a catalyst, known as an **enzyme**. Thousands of different enzymes exist as they are each specific for a particular biochemical reaction. Catalysis is also an important aspect of **Green Chemistry**, which seeks to reduce the negative impact of chemical processes on the environment.

Catalysts can frequently be **reused,** catalysts do not contribute to the **chemical waste,** and so they increase the **atom economy**.

Practice

**1.** (i) Draw a graph to show the distribution of energies in a sample of gas molecules. Label the axes and label your curve T1.Using the same axes, draw a second curve to represent the distribution of energies at a higher temperature. Label this curve T2.

(3)

(ii) State and explain, with reference to your graph, what happens to the rate of a reaction when the temperature is increased.

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 (2)

(Total 5 marks)

**2.** (a) Identify **two** features of colliding molecules that react together in the gas phase.

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(2)

(b) For many reactions, the rate approximately doubles for a 10°C rise in temperature.
State **two** reasons for this increase and identify which of the two is the more important.

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(3)

(Total 5 marks)

**3.** (a) Define the term *rate of reaction*.

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(b) The reaction between gases **C** and **D** is slow at room temperature.

(i) Suggest **two** reasons why the reaction is slow at room temperature.

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(2)

(ii) A relatively small increase in temperature causes a relatively large increase in the rate of this reaction. State **two** reasons for this.

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(iii) Suggest **two** ways of increasing the rate of reaction between **C** and **D** other than increasing temperature.

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(2)

(Total 7 marks)

Answers

**1.** (i)



 both axes correctly labelled;

 T2 peak/lower;
and to right of T1; 3

Area under graph is not important.

(ii) rate increased/changes;
as more molecules with ≥ *E*a; 2

No explicit reference to graph required.

[5]

**2.** (a) molecules must have sufficient/minimum energy/energy ≥ activation energy;
appropriate collision geometry/correct orientation; 2

(b) increased frequency of collisions/collisions more likely;

Not just “more collisions”, there must be a reference to time.

 increased proportion of molecules with sufficient energy to react/*E* ≥ *E*a;

Not “activation energy is reduced”.

 Proportion of molecules with *E* ≥ *E*a is more important;
*(dependent on correct second marking point);* 3

[5]

**3.** (a) increase in product concentration per unit time/decrease in reactant concentration
per unit time; 1

Accept change instead of increase or decrease.

(b) (i) high activation energy/not enough molecules have *Ea/OWTTE;*

incorrect collision geometry/*OWTTE;*

infrequent collisions; 2

Award **[1]** for any two reasons.

(ii) more energetic collisions/more molecules have (energy ) *Ea;*

more frequent collisions/collide more often; 2

(iii) add a catalyst;

increase the (total) pressure/decrease the volume of the container;

increase the concentration of C (or D); 2

Do not accept surface area.

Award **[1]** for any two.

[7]