1.5 Kinetics

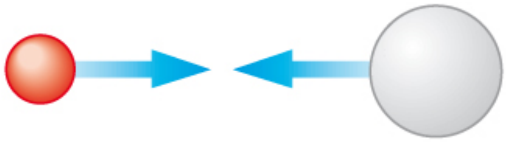
<u>Collision theory:</u>

- Reacting molecules have to collide with enough energy to break the initial bonds, **the activation energy**.

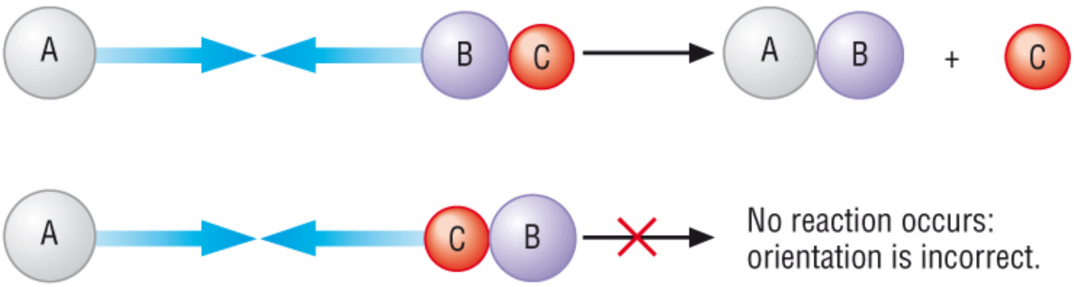
Activation energy

> **Activation energy**
> ***The minimum amount of energy that particles require to react when they collide by the breaking of bonds***

- Most collisions do not lead to a reaction due to:
  1) E > Ea - The collisions must be **greater than or equal to the activation energy.**



  2) Orientation - The molecules must collide in the correct orientation in order for the products to be made:



<u>Rate of reaction</u>

> **Rate**
> ***The rate of a reaction is the change in concentration of a reactant or product in a given time***

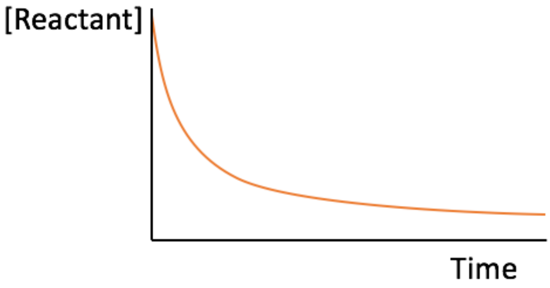
- The term rate is used to describe the speed of a reaction.

Units of rate:

$$\text{Rate} = \frac{\text{Change in concentration}}{\text{Time}} \qquad \text{Units: } \frac{\text{mole dm}^{-3}}{\text{s}} = \text{mol dm}^{-3}\,\text{s}^{-1}$$

- When a reaction starts the concentrations of the reactants are at their highest, the rate is at its fastest.
- As the reactants are used up the concentration decreases, so does the rate.
- When one of the reactants is used up the reaction stops. The rate is 0/

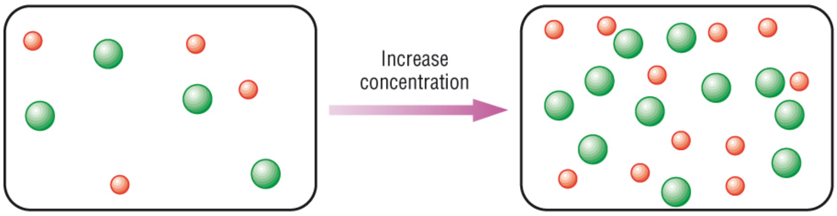
A reaction:



- As a reaction proceeds, the rate slows down.
- This is because the concentration of the reactants decreases.
- Gradient is a measure of rate:
  $\Delta y / \Delta x$ → change in concentration / time

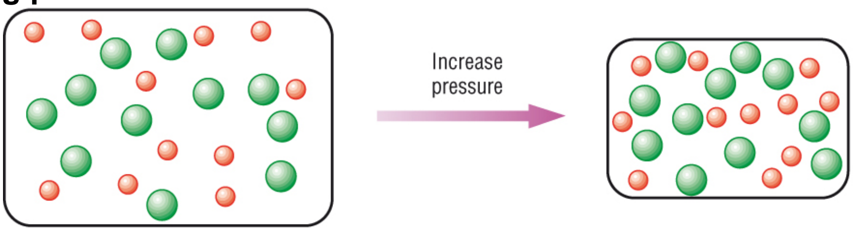
Factors affecting the rate of a chemical reaction:

1) **Increasing concentration increases reaction rate:**



- Increasing concentration increases the **number of particles per unit volume.**
- **More successful collisions per unit time.**
- **Increasing the rate** of reaction.

2) **Increasing pressure increase reaction rate:**



- Increasing the pressure decreases the volume.
- Increases the **number of particles per unit volume.** (same as concentration)
- **More successful collisions per unit time.**
- **Increasing the rate** of reaction.

3) **Increasing surface area increase reaction rate:**

- Decreasing the particle size reveals more surface for the other reagent to react with.
- **More successful collisions per unit time.**
- **Increasing the rate** of reaction

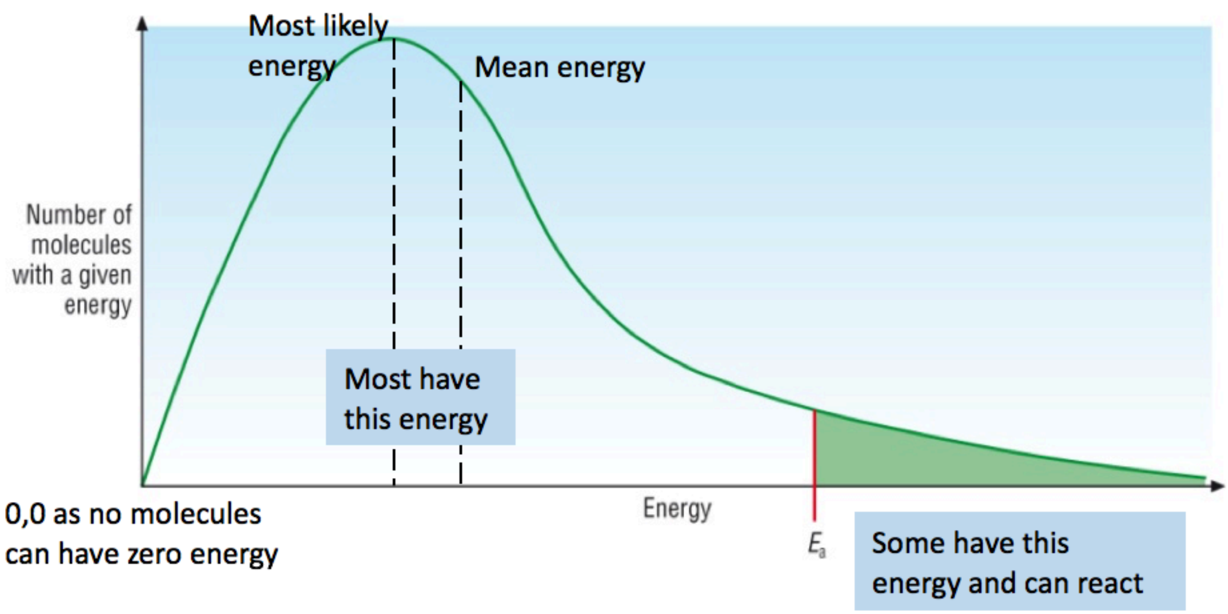
4) Increasing temperature increase reaction rate:

- Increasing the temperature means **more particles have energy > activation energy.**
- **Increases the collision frequency** and
- **More successful collisions per unit time.**
- **Increasing the rate** of reaction.
- More detail later with Maxwell – Boltzmann distribution.

5) Catalyst increase reaction rate:

- Provides an alternative route with a lower activation energy.
- Lowering the activation energy means **more particles have energy > lowered activation energy.**
- **More successful collisions per unit time.**
- **Increasing the rate** of reaction.
- More detail later with Maxwell – Boltzmann distribution and enthalpy profiles.

The Maxwell – Boltzmann distribution



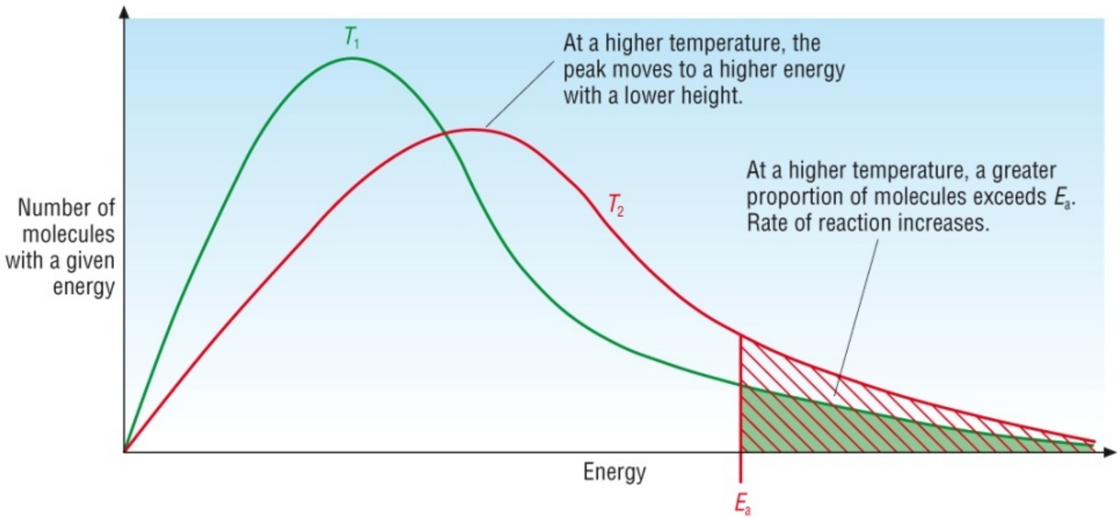
Features:

- Energy and speed are linked by $E_k = \frac{1}{2} mv^2$

Some will have high energy	This means they will move very fast
Some will have low energy	This means they will move very slow
Most will have average energy	Most will move with the average speed

The area under the curve is equal to the total number of molecules in the sample:	The area does not change
No molecules have zero energy:	The curve starts at 0,0
There is no maximum energy for a molecule:	The curve never touches the axis
Only molecules with energy greater than the activation energy are able to react	The activation energy is the minimum energy required to react

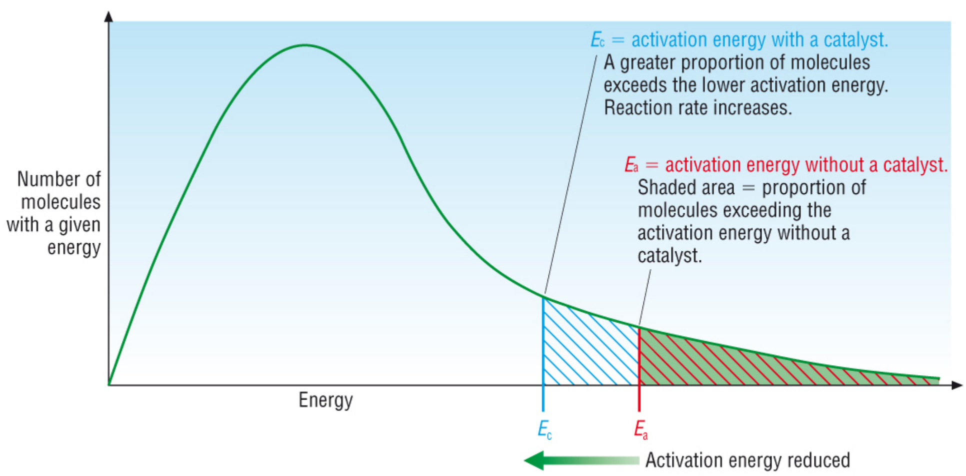
The effect of temperature on reaction rate – Maxwell Boltzmann distribution



Explanation:

- Temperature $T_2 > T_1$
- Peak lowers and moves to the right
- Same area as same number of particles
- Increase in temperature increases the kinetic energy of the particles
- More particles have $E > E_a$ so more successful collisions per unit time
- There is also an increase in collision frequency as the particles are moving faster
- These 2 effects give a large increasing the rate of reaction

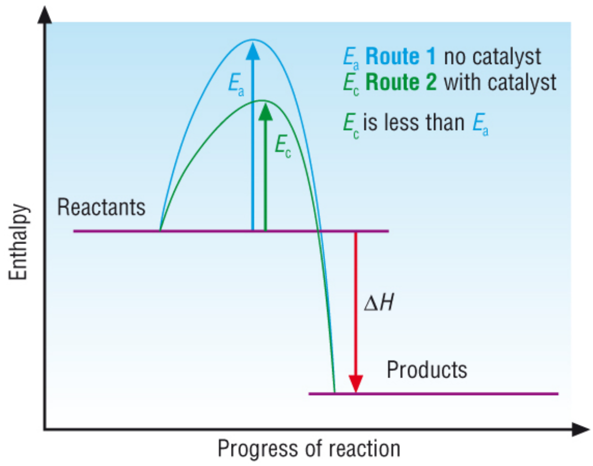
The effect of a catalyst on reaction rate – Maxwell Boltzmann distribution



Explanation:

- Catalysts provide an alternative route with a lower activation energy
- More particles now have energy greater than the lowered catalytic activation energy
- More successful collisions per unit time
- Increasing the rate of reaction
- Catalysts come out unchanged

The effect of a catalyst on reaction rate – Enthalpy profile diagram



- We know that reverse reactions have the 'mirror image' enthalpy profile
- A catalyst lowers the activation energy for the reactions in both directions (covered more in equilibria)
- Catalysts can dramatically reduce energy costs associated with reactions
- Catalysts are specific – only catalyse certain reactions

Required Practical 3

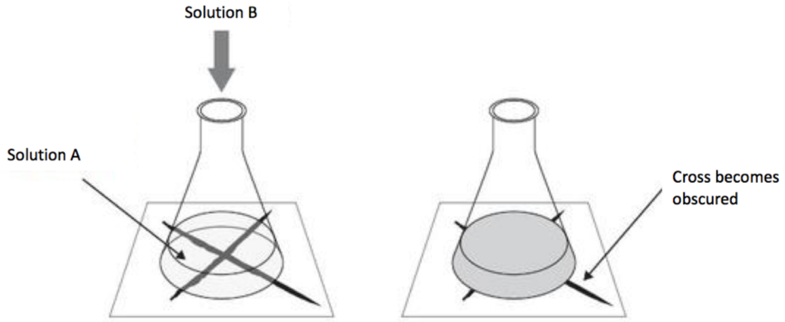
Measuring reaction rates:

1) Precipitates

- Measure the time taken for a precipitate to obscure a cross

$$Na_2S_2O_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + S_{(s)} + SO_{2(aq)} + H_2O_{(l)}$$

- Solid sulphur is made which will change the appearance:



Clear and colourless → Yellow solid

- As you cannot see through the yellow solid, a specific amount of sulphur will be made that will obscure a cross underneath on a piece of paper.
- This can be used to investigate the effect of temperature or concentration:

Temperature:

Independent variable: Temperature

Dependent variable: Time

Control variables: Concentrations, pressure

Concentration:

Independent variable: Concentration

Dependent variable: Time

Control variables: Temperature, pressure

Method

- Place 10 cm^3 of 1.0 mol dm^{-3} hydrochloric acid into a boiling tube, place in a water bath until the desired temperature.
- Place 10 cm^3 of 0.1 mol dm^{-3} sodium thiosulphate into a comical flask, place in a water bath until the desired temperature.
- Record the initial temperature then add the hydrochloric acid to the sodium thiosulphate starting the stop clock.
- When the cross is no longer visible, stop the clock and record the final temperature of the reaction mixture.
- Repeat the experiment at 5 different temperatures

Results

Initial temperature / °C	Final temperature / °C	Average temperature / °C	Time for cross to disappear / s	Rate (1/t) / s^{-1}
14	14		115	
21	19		75	
23	23		65	
29	29		48	
41	39		26	
51	49		15	

Analysis

- Plot a graph of average temperature vs rate (1/t)
- Axes **must** be labelled with units
- Mark all points with a x
- You **must** use more than half of the graph paper provided

Analysis questions

- What is the independent variable?

- What is the dependent variable?

- What is the relationship between rate and temperature? Explain your answer using collision theory:

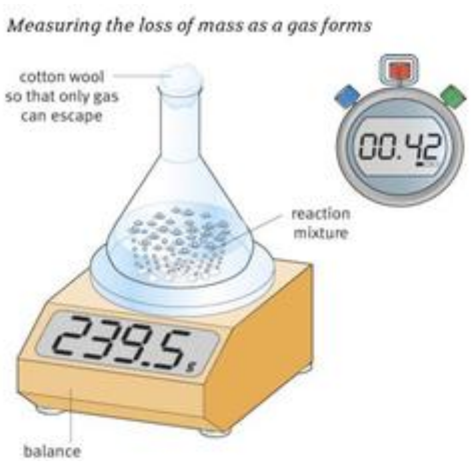
- Sketch a **labelled** Maxwell Boltzmann distribution curve showing how an increase in temperature affect the rate of a reaction:

- Use your Maxwell Boltzmann distribution curves above to explain the effect of temperature on rate:

2) Change in mass

- Record the time as a reaction that loses mass proceeds:

$$Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow 2NaCl_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$



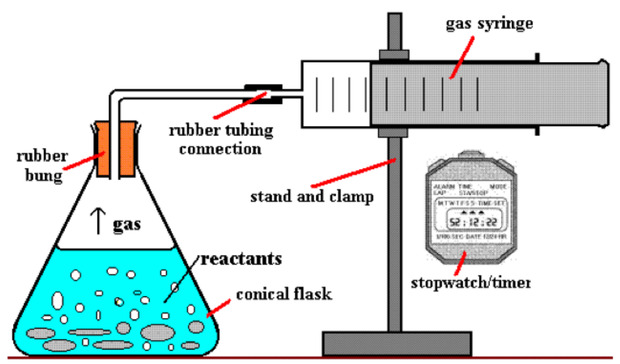
- Carbon dioxide is made which escapes the reaction mixture.
- This will change the mass on the balance.
- As the reaction proceeds, the concentration of the acid decreases.
- The rate at which the mass is lost will be proportional to the concentration of the acid.
- As the reaction proceeds, the rate therefore will slow down.

- This can be used to investigate the effect of temperature or concentration.

3) Gas volumes

- Record the time as a reaction that loses mass proceeds:

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$



- Carbon dioxide is made which escapes the reaction mixture.
- This can be collected in a gas syringe.
- As the reaction proceeds, the concentration of the acid decreases.
- The rate at which the gas is collected will be proportional to the concentration of the acid.
- As the reaction proceeds, the rate therefore will slow down.

- This can be used to investigate the effect of temperature or concentration:

Questions:

1) The Maxwell Boltzmann distribution shows the distribution of energies of molecules in a gas.
   a. In the space below sketch the Maxwell Boltzmann distribution. Add the activation energy and clearly label the axis.

   b. Outline 2 of the key features of the Maxwell Boltzmann distribution curve:

   c. Draw a second Maxwell Boltzmann distribution curve at a higher temperature. **Use the completed diagram** above to explain why an increase in temperature increases the rate of reaction:

2) The production of ammonia is an important industrial process. The reaction is shown below:

$$N_{2(g)} \quad + \quad 3H_{2(g)} \quad \rightarrow \quad 2NH_{3(g)} \qquad \Delta H = -92.0 \text{ kj mol}^{-1}$$

   a. In the space below sketch the enthalpy profile diagram. Add and clearly label the **axis**, the **activation energy** and the **enthalpy change**.

   b. The reaction is catalysed using iron, Fe. Add the profile for this reaction, clearly labelling the activation energy when a catalyst is used

   c. The rate of reaction is also increased using pressure. Explain using collision theory how pressure increases the rate of a reaction