REACTION RATES

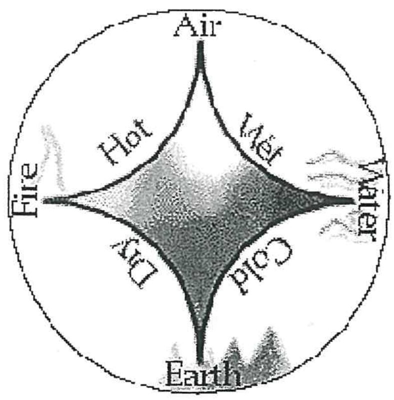
- Chemical reactions proceed at different rates depending on the chemicals involved and the environmental conditions. Some reactions are very fast (Caesium and Water) while others may take a considerable time (Rusting of Iron).
- Measuring the rate of a chemical reaction will involve one of two methodologies:
  - Measure the rate of disappearance of reactants.

    Eg: You may be able to measure the rate at which measured amounts of magnesium ribbon dissolve in acid.
  - Measure the rate of formation of products.

    Eg: You may be able to measure the rate of evolution of hydrogen gas in a reaction between magnesium and acid. This may involve measuring the inflation rate of a balloon or a syringe that is connected to the reaction vessel.
- There are many factors that influence the rate of a reaction:

NATURE OF REACTANTS

- Some elements and compounds are particularly unstable and will react vigorously in order to lower their chemical potential energy.
- In the case of metals their reactivity can be traced to the energy needed to remove electrons from their valence shells (***IONISATION ENERGY***) as metals always **lose electrons** (Oxidation) in reaction. Depending on the number of protons in the nucleus of the atom and the radius of orbit of the outer electrons, different metals will have different levels of attraction for these valence electrons. Differences in attraction for the valence electrons lead to different ionisation energies. Metals that react very easily have innately lower ionisation energies (Caesium, Potassium and Sodium) while others react far more slowly as their ionisation energies are higher (Copper, Gold and Silver).
- In the case of non-metals their reactivity is governed by their tendency to **gain electrons** (Reduction) in reaction. This is known as their ***REDUCTION POTENTIAL***. Different non-metals have different reduction potentials and so will react at different rates as a consequence.



COLLISION THEORY

- A chemical reaction can only occur if chemicals come in contact or COLLIDE with each other. There are many considerations that govern how often and how effectively chemicals come in contact and whether or not they react. The theory that governs reaction rate is called the COLLISION THEORY for this reason. Whenever you discuss reaction rates you should always relate the governing factors to this theory.

PHASE

- Whether materials are in the ***SOLID, LIQUID, GAS*** or ***AQUEOUS*** phase will have a big impact on the rate at which they react. In part this may be due to the extra energy that particles have in their particular phase. The melting and boiling points of different substances depend on the forces of cohesion that exist in the material. It goes without saying that a material in the liquid or gas phase is at a higher temperature than the same material in the solid phase. The effect of temperature on reaction rate will be discussed in the next section but all reactions occur at higher rates if the temperature is higher.

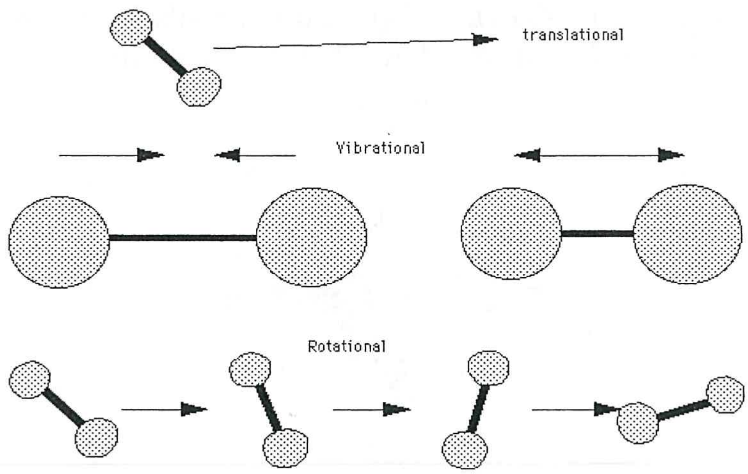
- The main reason that phase effects reaction rate is that it affects the *MOBILITY* of particles. In the liquid, gaseous and aqueous phases particles may move far more freely. If particles can move freely they are more able to encounter and **collide** with each other. The *ACCESS* of reactants for each other is a major influence on rate. Many reactions may be increased in rate by simply *STIRRING* chemicals together which increases access and enhances collision frequencies.

- Reactions in the solid phase are generally very slow unless a great deal of energy is supplied or the solids are finely divided and shaken together to promote access.

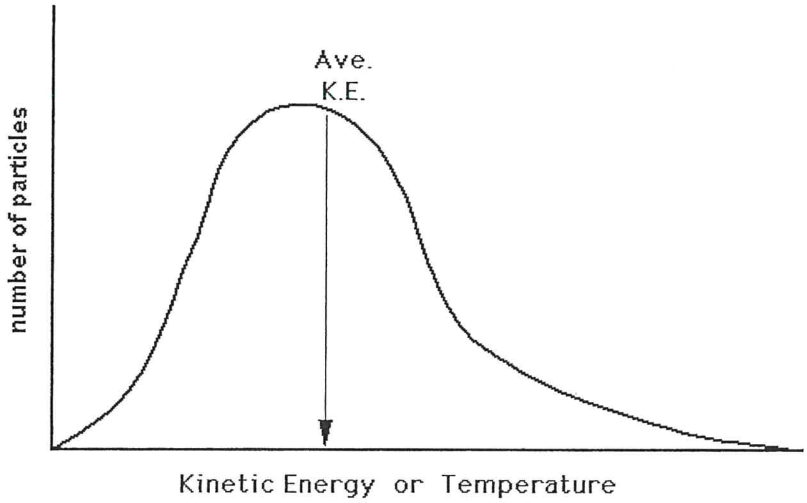
  Eg: The reaction between solid lead nitrate and solid potassium iodide is very slow, particularly if the solids are layered one on top of the other in a test tube. Reaction rate increases if the mixture is shaken vigorously. If however, the solids are dissolved in water and then mixed the reaction is almost instant.

TEMPERATURE

- The temperature of a material is a measurement of the kinetic energy of its particles. Kinetic energy or movement energy may manifest itself as ***TRANSLATIONAL*** (movement from point a to b), ***VIBRATIONAL*** (movement back and forth) or ***ROTATIONAL*** (end over end revolution).



- The temperature of a material measures the *AVERAGE KINETIC ENERGY* of its particles motion. Because particles constantly collide with each other, whether or not they are particles of different chemicals that react, their energies are constantly re-distributed. This means that not all the particles at a particular temperature are moving as energetically. Some will be moving faster and others slower. Which particles move faster and which move slower changes dynamically with each collision that re-distributes energy but does not increase it. At any one temperature there will be a kinetic energy distribution that may be represented by a *KINETIC ENERGY DISTRIBUTION CURVE*.



- Irrespective of the type of kinetic energy, the more movement energy reacting particles have the more likely they are to collide with a reasonable *COLLISION FREQUENCY (f)* and the more likely they are to react.

- It is not only the fact that particles **collide** that governs reaction rate but the energy of their collisions is vital. Particles that are moving slowly may collide but simply bounce of each other and remain unchanged in any way other than to have perhaps re-distributed their energies. A collision that is not forceful enough is referred to as ***UNSUCCESFUL*** and does not result in reaction

- All reactions require that a certain minimum total energy value is reached from the combined TOTAL of the colliding particles in order that the collision is successful and results in chemical change. This minimum energy requirement is known as the *ACTIVATION ENERGY*.

- Increases in temperature will always increase the rate of a reaction as they allow for **greater collision frequencies** but much MORE IMPORTANTLY will result in a **greater proportion of collisions that are successful and overcome the activation energy barrier**.

- Just as increases in temperature will increase reaction rate the reverse is true of cooling. If we lower the temperature, particles will move more slowly and will collide **less often** and with **insufficient energy to overcome the activation energy barrier**. In society there are many chemical reactions that we would choose to occur at slow rates. These would include environmental corrosion of materials or even food spoilage.

CONCENTRATION

- The concentration of a chemical reactant has a very important bearing on collision frequencies and hence reaction rate.
- Concentration is a measure of the density of particle arrangement with respect to volume. If a chemical is dissolved it refers to the quantity, measured in moles or mass, of the ***SOLUTE*** per unit volume of ***SOLVENT***, in most cases water. If the chemical is in the gas phase it again refers to the relative quantity of gas when compared with the volume of the container. The pressure that the gas exerts in this container, as the particles **collide** with the walls, is a measure of this concentration or particle density.
- NB: Pure liquids and solids do not have concentrations as they are not dissolved or free enough to spread throughout their container. These phases have fixed volume.
- The **greater the concentration** of reactants the greater will be the reaction rate. This is simply because the particles, if mobile, will **collide more frequently** and this leads to an increased probability of some **successful collisions** occurring.

  Eg 1:. 6M HCl will react far faster with magnesium than will 0.1M.

  Eg 2: A glowing splint will glow faintly when burning in air but will burst into flames when added to pure oxygen!

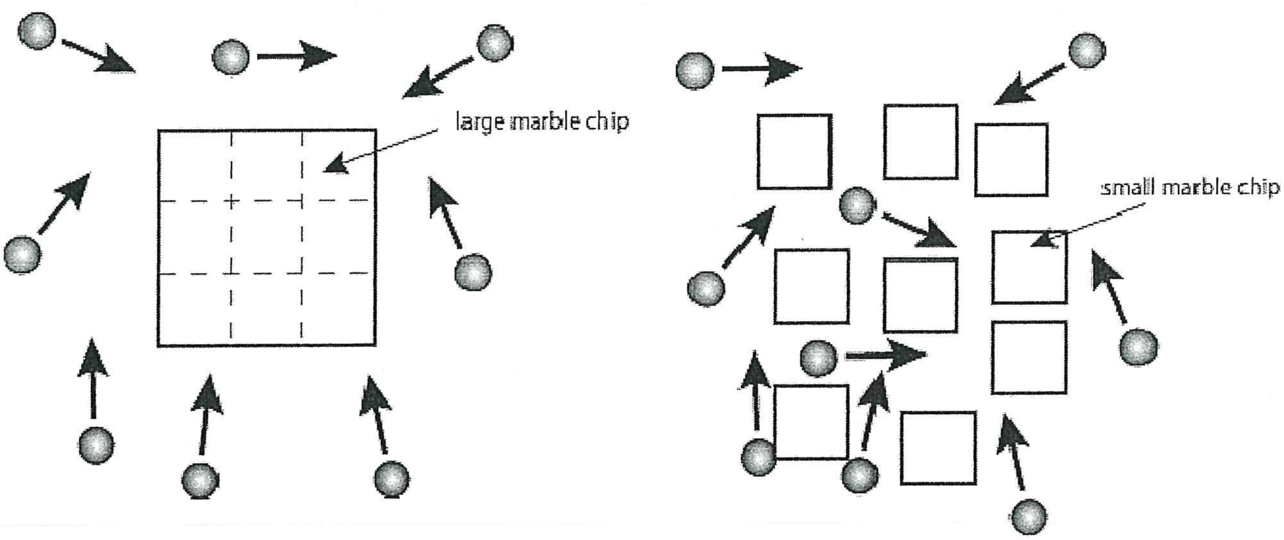
  Eg3: A steak will cook far faster in a hot frying pan.

SPECIAL CASE:

- Solids do not have a concentration but collision frequency can be increased by finely dividing solids into powders or filings in which their surface area is greatly increased. Very high ***SURFACE AREA*** allows other reactants very effective access to the solid allowing them to **collide** with it much more effectively.

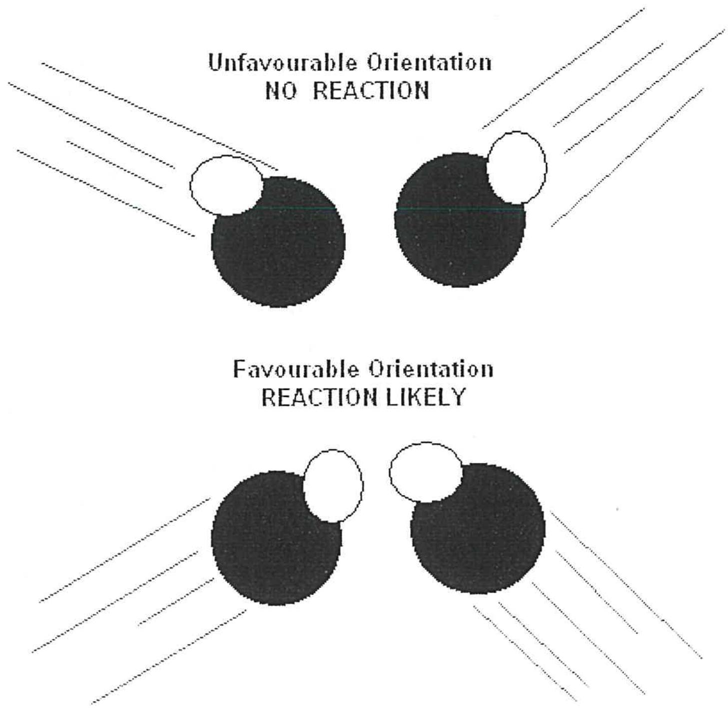
  Eg 1: The reaction of solid iron with air is very slow even when heat is applied. If the same reaction is tried using iron filings the filings will glow and sparkle as they react.

  Eg 2: Calcium carbonate in the form of marble chips will react quite well with 4M HCl but if the marble chips are ground using a mortar and pestle the mixture will effervesce and froth violently.



COLLISION GEOMETRY

In some reactions it is not only necessary that reactants collide with sufficient energy but that the collision occurs with a certain orientation of the **colliding** particles. All chemical species have certain geometry to their structure and if a collision occurs with a favourable orientation of reactants it may be more **successful** and lead to greater reaction rate.



REACTION MECHANISM

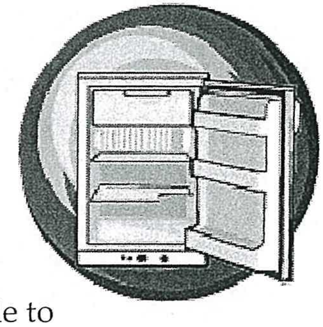
- Many chemical reactions do not simply involve the collision of two reacting particles to achieve reaction. The stoichiometry or balancing of equations frequently requires three, four or even higher numbers of reacting particles to come together. The chances of **more than two** particles colliding at any one time with the minimum energy requirement and correct orientation are very small. Most reactions involve a number of collisions with the formation of *INTERMEDIATE* substance between one collision and the next.

- The sequence of collisions and the intermediate stages involved in a reaction are known as the *REACTION MECHANISM*. Reactions that are simple two particle collisions will often occur far faster than those that require many stages, as long as access, mobility, orientation and energy issues are the same.

- In multi-stage reactions there is often one stage that is hardest to achieve and determines the progress of the reaction. This is known as the *RATE DETERMING STEP*.

RATES IN AND AROUND THE HOME

▶ The rates of chemical reactions are frequently important in and around the home as is an ability to modify them:



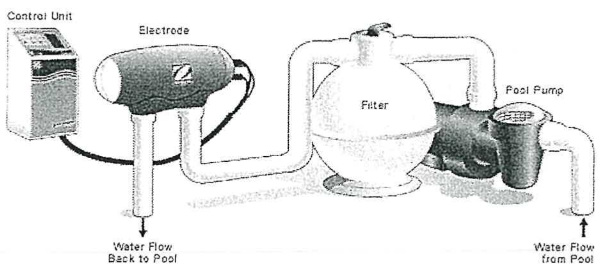
- The chemistry of food spoilage must be modified if we are to store our food for any prolonged period of time. By refrigerating our food we are able to remove a lot of the energy from these spoilage reactions. By reducing energy we lower the rates of these reactions as there is not enough activation energy or energy of collision for them to occur very quickly. By deep freezing it is possible to store food for a very long period of time.

- Any cooking process involves both chemical and physical change to the food we are cooking. We modify the rates of these cooking processes by controlling the temperature or state of sub-division. If we want to cook a potato we may boil it in hot water as this will obviously give it far greater energy than trying to cook it in cold water. We may choose to cut it into smaller segments with a greater surface area (particle subdivision) if we wish to cook it even faster!

- When cooking a steak and causing the denaturation of the proteins we may use a high or low flame so as to cook the food more or less quickly.

- The rate at which the materials used in the construction of our homes corrode also needs to be modified. We use paints to provide a barrier between oxygen and the metal of our gutters so that the collision frequency with atmospheric oxygen and moisture is minimal. The rate of corrosion is very slow as a result and the gutters do not need replacing at great cost.

- In our swimming pools it is necessary to produce chlorine so as to kill harmful bacteria. Many pools do this by electrolysis of aqueous salts. The rate of this chlorination is modified and controlled precisely by varying the current flow to the electrodes. We can modify the time for this electrolysis with a timer and the concentration of salt can be kept at measured levels through addition of bags of salt when water analysis indicates the need.



ENERGY OF REACTION

LAW OF CONSERVATION OF ENERGY

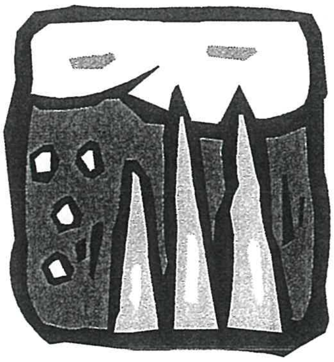
► The law of conservation of energy states that the ENERGY of a CLOSED SYSTEM will remain constant, regardless of the processes acting inside the system. An equivalent statement is that ENERGY can neither be CREATED NOR DESTROYED, although it may be redistributed. This implies that for any chemical process in a closed system, energy may be transferred between the *chemical reacting system* and the environment but cannot be lost and vice versa!

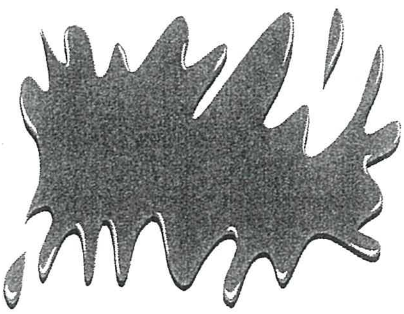
PHYSICAL PROCESSES

- Physical change involves a change in **the phase or particle division** of a chemical species. Typical physical changes include – melting, boiling, evaporation, sublimation and the reverse of these- freezing or solidification, condensation or liquefaction. The **chemical composition of materials is never altered** in a simple physical change!

- Any change from solid to liquid to gas must involve heat input to the chemicals. This heat may be extracted from the reaction environment. Reaction environments can be quite diverse. A flame in the reaction environment will provide the energy needed for physical change more rapidly. Wherever the energy comes from the chemicals will take it in as their kinetic and potential energies are increased. The **reaction environment loses energy to the chemicals in the chemical system** and will become **colder** as a result. As will be discussed with reference to reaction chemistry this type of process is described as being *ENDOTHERMIC*.

- Changes of phase from the higher potential states to the lower will require the materials to give out their energy as they condense. In going from gas to liquid to solid it is necessary that the chemicals have energy withdrawn from them. They **lose their energy to the reaction surroundings** which may in turn **warm up**. An ice water bath is a reaction environment that will aid condensation and solidification as it removes energy very effectively. Processes in which chemicals give out energy to their environment are referred to as *EXOTHERMIC*.





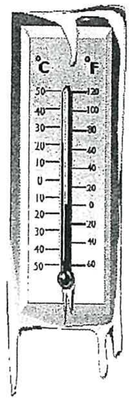
CHEMICAL PROCESSES

- A chemical change will involve changes in the chemical composition of materials. Old bonds will be broken and new bonds form as entirely different chemical species result. ***Chemical reactions*** are often accompanied by changes in the ***temperature*** of the reaction environment, changes in the ***colour*** of reactants as they form new products. If ***gases*** are formed in reaction then ***effervescence*** will be visible and energy may be given out as light of varying colours and intensities.

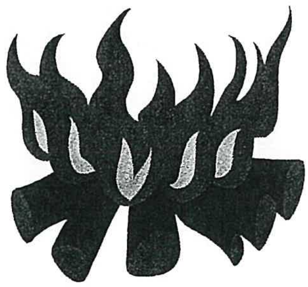
- All reactants require a certain amount of energy to overcome the activation energy barrier to a chemical reaction. Energy plays a vital part in the progress of a reaction.

- At all stages in the reaction mechanism chemical bonds are being broken and new bonds are forming.

- It stands to reason that if a chemical **BOND NEEDS TO BE BROKEN** in the journey towards new product formation, then energy will be required to break the chemicals apart. The amount of energy required will depend on the strength of the bond but if there is insufficient energy for this to occur, the collisions between reactants will not lead to change. The energy for **bond breakage** will be provided by the reaction environment. The reaction environment **loses energy** and any **reaction vessel will feel colder** to the observer. This process is therefore described as being *ENDOTHERMIC* (energy taken in by chemicals from the environment).



- In any reaction, as well as bond breakage occurring, **NEW BONDS WILL BE FORMING**. When chemicals form a bond their separation is reduced or they are said to lose chemical potential energy. The loss of energy from the chemicals translates into an increase in the energy of the reaction environment. The **reaction vessel will feel warmer** to the observer. This process is therefore described as being *EXOTHERMIC* (energy is lost from the chemicals to the environment).



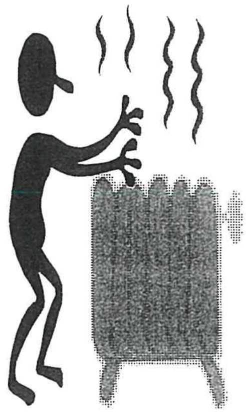
- If one examines the **total energy needed in a reaction mechanism** for **bond breakage** and relates that to the energy released **in new bond formation** an overall thermochemistry of the reaction can be arrived at. If more energy is needed for bond breakage than is releases in bond formation, the overall reaction will be *ENDOTHERMIC.* On the other hand, if more energy is released in new bond formation than is required for bond breakage, then the process will be *EXOTHERMIC.*

THERMAL PROCESSES IN AND AROUND THE HOME

EXOTHERMIC:

▶ In nature there are many chemical reactions that are ***exothermic*** and these may be used in and around the home:

- The burning of petrol and other hydrocarbon fuels is used to power our cars as a major form of transport.
- To cook the food that we eat we often burn natural gas (a hydrocarbon) in a highly exothermic reaction. We also use this gas to warm our homes in winter.



- We eat and digest both cooked and uncooked food to provide the fuel for cellular respiration. This reaction that occurs in every one of the cells in our body is exothermic and allows our body temperature to be maintained at 37^0C.
- The dissolution and hydration of certain ionic solids in water provides the basis of instant warmth in applications such as a diver's hand warmer.
- We must always add the acid that we use for our swimming pools to water rather than the other way around. The reaction is highly exothermic and may cause small amount of water to boil as they dilute the acid. This is very dangerous as the acid will "spit" and may come in contact with our skin.

ENDOTHERMIC:

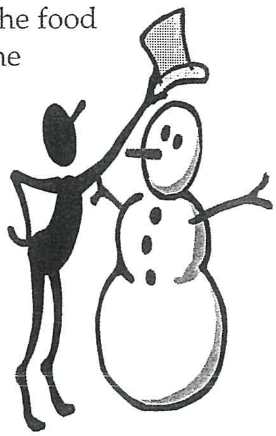
▶ It is far rarer for a ***chemical process*** to be endothermic as this will mean that the products of the reaction have more energy than the reactants, a less stable result.

There are however a few examples that you may come across:

- The hydration of some ionic solids produces an instant cold that may be used to freeze water as an instant ice pack in a first aid kit.

▶ Physical processes are often endothermic:

- Heat must be provided to de-frost food as the water in the food must go through a phase change from solid to liquid. The chemical system needs more energy and this must be taken from the environment.



- When we steam vegetables we must also provide heat as the water requires heat to go through the phase change to steam (latent heat) and this must be obtained from the surroundings
- Our evaporative air conditioners work on the principle that as the water evaporates in an endothermic phase change it takes the heat from the environment and cools it as a result.

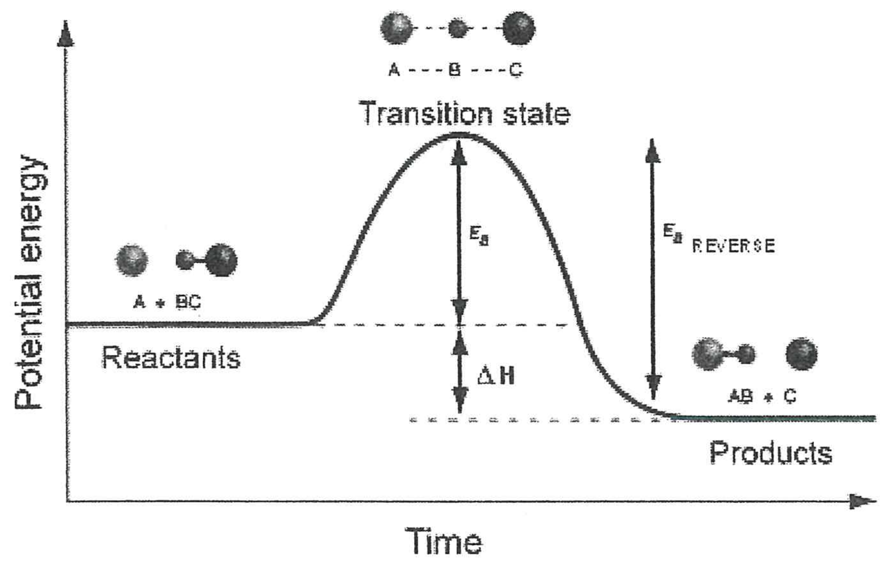
REACTION PROFILE DIAGRAMS

- As potential reactants approach each other and collide there are a series of changes in the **total energy of the colliding particles** that will determine whether the collision is successful or not. An energy profile diagram tracks the changes in total energy of reactants and products during the course of a chemical reaction. The time scale of these changes is variable but is often in the order of split seconds for fast reactions.
- By tracking the change in relative energy or ENTHALPY of the chemicals in a reaction we can find out if the reaction is exothermic or endothermic. All chemicals have a certain amount of ***stored energy***, whether it is energy of motion or potential it contributes to the energy that they bring to the reaction. A reaction profile diagram also enables us to **quantify** the amount of energy that will be either taken in from the reaction environment or released to it from the **REACTING SYSTEM** (chemicals involved in reaction).
- Chemical reactions can often be reversed, under appropriate conditions, and so a reaction profile diagram can be used to track and quantify energy changes for either the forward or reverse direction of reaction. Reactions that have significant possibility of reversal will lead to a situation known as *EQUILIBRIUM*.
- When interpreting reaction profile diagrams there are several key terms that need to be defined:
    - **ENTHALPY** (Heat, Potential Energy) **:** A term for the energy content of the various chemicals and species involved in the reaction.
    - **ACTIVATION ENERGY :** The minimum combined energy of colliding particles that will lead to a successful collision and hence a chemical change.
    - **TRANSITION STATE (ACTIVATED COMPLEX) :** A point in the reaction mechanism where colliding particles are **half way between old bond breakage and new bond formation**. The species formed is very transient in that it may exist for a tiny amount of time but while it does exist it is the point of highest energy in the mechanism.
    - **Δ H :** The difference in energy content between the products and the reactants. It is always defined as the heat content of the products subtract the heat content of reactants ($\Delta H = H_P - H_R$).

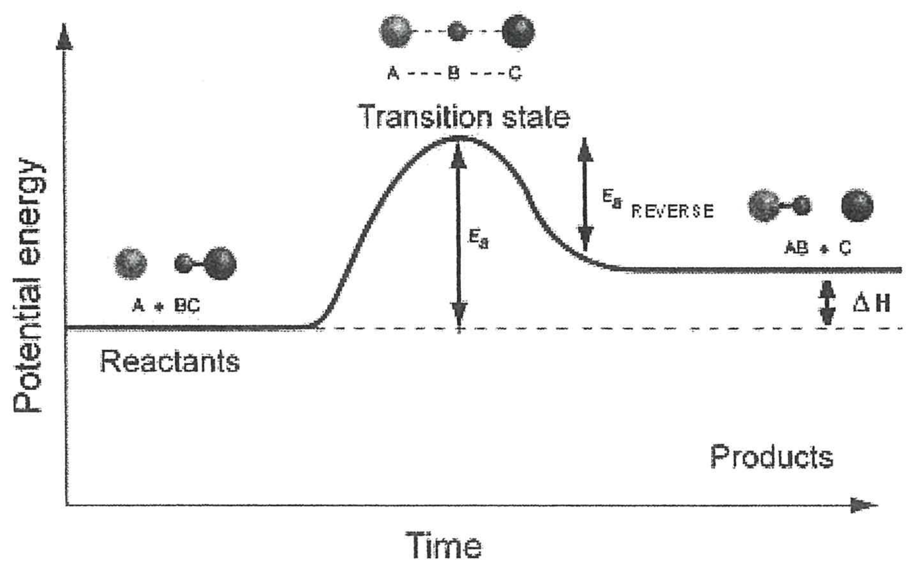
► If the value of this expression is *NEGATIVE* this indicates that the products have less energy than the reactants and this must be given out to the surroundings making them **warmer**. The reaction is *EXOTHERMIC*. The **CHEMICALS** of the **REACTING SYSTEM** have **LOST** energy so it stands to reason that from the system's perspective that the heat content has gone down, making the negative sign logical!

► If the value of this expression is *POSITIVE* this indicates that the products have more energy than the reactants and this must be taken in from the surroundings making them **colder**. The reaction is *ENDOTHERMIC*. The **CHEMICALS** of the **REACTING SYSTEM** have **GAINED** energy so it stands to reason that from the system's perspective that the heat content has gone up, making the positive sign logical!

EXOTHERMIC REACTION PROFILE DIAGRAM

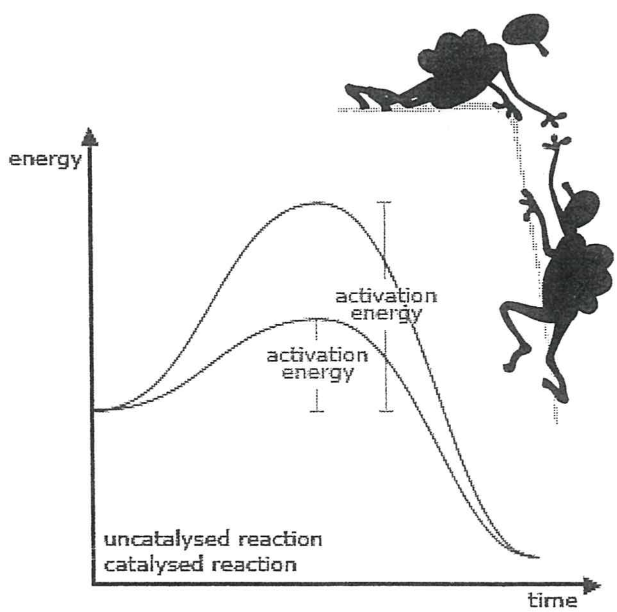


ENDOTHERMIC REACTION PROFILE DIAGRAM:



EFFECTS OF CATALYSTS:

- A Catalyst is a substance that increases the rate of a chemical reaction. It provides an alternative reaction mechanism of lower activation energy. The effect of a catalyst can be clearly seen on a reaction profile diagram. The activation energy barrier is lowered yet the eventual products formed are identical. The catalyst has **no impact** on the **ΔH** of a reaction as the relative energies of reactants and products are not changed by the difference in mechanism.



THERMOCHEMICAL EQUATIONS

- The quantity of heat given out or taken in during the course of a reaction is dependent on the amount of reactant consumed and eventual product formed.

- The quantity of heat given out or taken in may be included in the equation for a reaction, making it a **thermochemical equation**. The quantity is related to the **number of moles of reactant consumed** and **product produced**. The stoichiometry or balancing numbers may be used to calculate precisely the energy evolved or absorbed per mole of any chemical in the reaction.

- The equation for **RESPIRATION**, where sugars are metabolised by every cell in our bodies to provide energy is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 2{,}803\ kJ$$

► This equation tells us that for each mole of glucose metabolised 2,803 kJ of energy are released. At the same time as the glucose is metabolised 6 moles of oxygen will be consumed and 6 moles of both carbon dioxide and water will be produced.

- The same equation could have been presented with a ΔH value. The sign of this ΔH would need to be interpreted correctly to tell whether the reaction energy should be written on the reactant or products side of the equation.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \quad \Delta H = -2{,}803\ kJ\ mol^{-1}$$

- The balancing coefficient in a thermochemical equation may be greater than 1 as in the combustion reaction for ethane, a type of gaseous hydrocarbon that burns exothermically.

$$2\ C_2H_6\ (g) + 7\ O_2(g) \rightarrow 4\ CO_2(g) + 6H_2O\ (g) \quad \Delta H = -3{,}082\ kJ$$

► This equation tells us that for every 2 moles of ethane combusted that 3,082 kJ of energy are released. At the same time as the ethane is burnt, 7 moles of oxygen will be consumed, 4 moles of carbon dioxide and 6 moles of water will be produced.

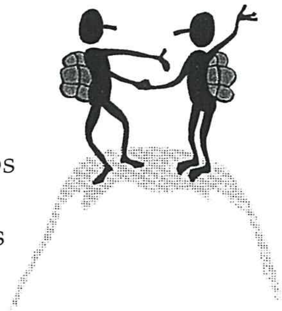
► If only one mole of ethane was burnt the energy released would be half of this value (1,041 kJ). The MOLAR HEAT OF COMBUSTION for ethane is therefore **1,041 kJ mol $^{-1}$.**

SUMMARY:

ΔH	Type of Reaction	Reaction Surroundings
+	ENDOTHERMIC	COLDER
-	EXOTHERMIC	HOTTER

CATALYSTS

- The particular reaction mechanism that a reaction follows may be different if there are different substances introduced to the reaction environment. A material that influences the set of reaction steps in a way that increases the rate of a reaction is known as a *CATALYST*.

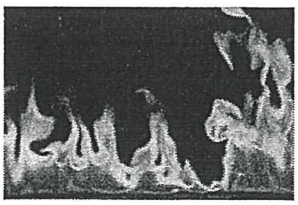


- Catalysts raise the rate of reaction by providing an ***ALTERNATIVE REACTION MECHANISM*** that has steps with lower activation energy. If the activation energy barrier is lowered then more collisions between reactants will be successful and lead to reaction.
- Catalysts may be many and varied. They may be solid surfaces where chemicals bind and are brought together to facilitate reaction or even ions in solution. The chemistry of life is governed by complex biological catalysts called ***ENZYMES***. Enzymes are complex protein molecules with very specific geometry that catalyse the reactions of life such as Respiration, Digestion or Photosynthesis. The specific geometry allows an enzyme to catalyse only a very specific reaction, they are said to be substrate specific.
- A unique feature of the role played by a catalyst is that it is REGENERATED at the end of the reaction mechanism. The catalyst takes part in the reaction and forms intermediate compounds but when the chemicals have finished reacting is left unchanged by its intervention. This means that the catalyst is not consumed and is able to catalyse further reactions. It may appear that the catalyst has not taken part in reaction for this reason but nothing could be further from the truth!

SUMMARY : ROLE OF CATALYSTS

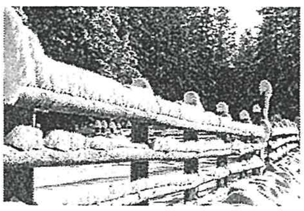
- A catalyst increases the rate of a chemical reaction by providing an *ALTERNATIVE REACTION MECHANISM* of *LOWER ACTIVATION ENERGY*. It takes part in the reaction, ***FORMING INTERMEDIATE COMPOUNDS***, but is ***REGENERATED*** in an unchanged form at the end of the reaction.

SUMMARY:



HIGH REACTION RATE:

➢Reactive chemical.
➢High temperature.
➢Mobile phase (liquid,gas, aqueous).
➢High concentration of reactants (high gas pressure, finely divided solids).
➢Presence of a catalyst.



LOW REACTION RATE:

➢Unreactive or inert chemical.
➢Low temperature.
➢Resticted phase (solid).
➢Low concentration of reactants (low gas pressure, lumpy solids).
➢Absence of a catalyst.

Energy Transfer in Reactions

So, endothermic and exothermic reactions are all about taking in and giving out energy to the surroundings. I think endothermic reactions are a bit self centred really — they just take, take, take...

Combustion reactions (where something burns in oxygen — see page 72) are always exothermic.

Reactions are Exothermic or Endothermic

An EXOTHERMIC reaction is one which gives out energy to the surroundings, usually in the form of heat and usually shown by a rise in temperature of the surroundings.

An ENDOTHERMIC reaction is one which takes in energy from the surroundings, usually in the form of heat and usually shown by a fall in temperature of the surroundings.

The Change in Energy is Called the Enthalpy Change

The overall change in energy in a reaction is called the ENTHALPY change. It has the symbol ΔH.

Δ is the Greek letter 'delta'. It means 'change in'. The H means enthalpy.

1) The units of ΔH are kJ/mol — so it's the amount of energy in kilojoules per mole of reactant.
2) Enthalpy change can have a positive value or a negative value.
   - If the reaction is exothermic, the value is negative because the reaction is giving out energy.
   - If the reaction is endothermic, the value is positive because the reaction takes in energy.

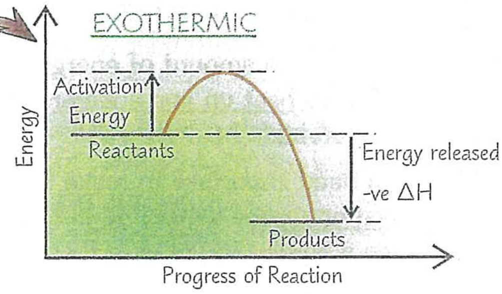
Paper 2

Reaction Profiles Show Energy Changes

Reaction profiles are sometimes called energy level diagrams.

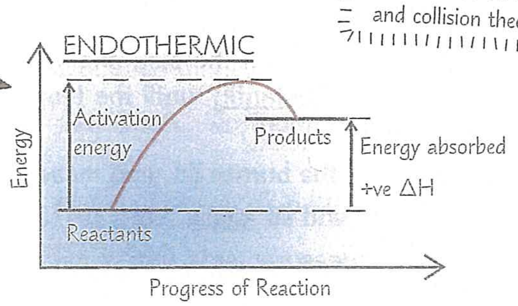
Reaction profiles are diagrams that show the relative energies of the reactants and products in a reaction, and how the energy changes over the course of the reaction.

1) This shows an exothermic reaction — the products are at a lower energy than the reactants. The difference in height represents the energy given out (per mole) in the reaction. ΔH is negative here.
2) The initial rise in energy represents the energy needed to start the reaction. This is the activation energy (E_a).
3) The activation energy is the minimum amount of energy the reactants need to collide with each other and react.



There's more on activation energy and collision theory on page 59.

1) This shows an endothermic reaction because the products are at a higher energy than the reactants.
2) The difference in height represents the energy taken in (per mole) during the reaction. ΔH is positive here.



Energy transfer — make sure you take it all in...

Remember, "exo-" = exit, "-thermic" = heat, so an exothermic reaction is one that gives out heat (and warms its surroundings) — and endothermic means just the opposite. Once you've got that firmly in your noggin, read on...

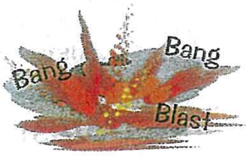
P2 Q1 Here is the equation for the combustion of methane in air: $CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$
Draw a reaction profile for this reaction. [3 marks]

Rates of Reaction

Rates of reaction are pretty important. In the chemical industry, the faster you make chemicals, the faster you make money (and the faster everyone gets to go home for tea).

Reactions Can Go at All Sorts of Different Rates

1) The rate of a chemical reaction is how fast the reactants are changed into products.
2) One of the slowest is the rusting of iron (it's not slow enough though — what about my little Mini).
3) An example of a moderate speed reaction would be the metal magnesium reacting with an acid to produce a gentle stream of bubbles.
4) Burning is a fast reaction, but explosions are even faster and release a lot of gas. Explosive reactions are all over in a fraction of a second.

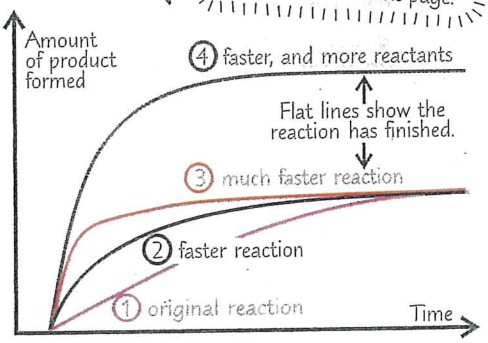


You Need to Understand Graphs for the Rate of Reaction

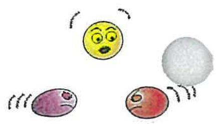
1) You can find the speed of a reaction by recording the amount of product formed, or the amount of reactant used up over time (see page 62).
2) The steeper the line on the graph, the faster the rate of reaction. Over time the line becomes less steep as the reactants are used up.
3) The quickest reactions have the steepest lines and become flat in the least time.
4) The plot below uses the amount of product formed over time to show how the speed of a particular reaction varies under different conditions.

For more on the conditions that affect the rate of reaction — see next page.

- Graph 1 represents the original reaction.
- Graphs 2 and 3 represent the reaction taking place quicker, but with the same initial amounts of reactants. The slopes of the graphs are steeper than for graph 1.
- Graphs 1, 2 and 3 all converge at the same level, showing that they all produce the same amount of product although they take different times to produce it.
- Graph 4 shows more product and a faster reaction. This can only happen if more reactant(s) are added at the start.



Particles Must Collide with Enough Energy in Order to React



Reaction rates are explained perfectly by collision theory. It's simple really.
The rate of a chemical reaction depends on:

1) The collision frequency of reacting particles (how often they collide). The more collisions there are the faster the reaction is. E.g. doubling the frequency of collisions doubles the rate.
2) The energy transferred during a collision. Particles have to collide with enough energy for the collision to be successful.

A successful collision is a collision that ends in the particles reacting to form products.

The minimum amount of energy that particles need to react is called the activation energy. Particles need this much energy to break the bonds in the reactants and start the reaction. The greater the activation energy, the more energy needed to start the reaction — this has to be supplied, e.g. by heating the reaction mixture.

Factors that increase the number of collisions (so that a greater proportion of reacting particles collide) or the amount of energy particles collide with will increase the rate of the reaction (see next page for more).

Get a fast, furious reaction — tickle your teacher...

Collision theory's essential for understanding how different factors affect the rate of reaction — so make sure you understand it before moving on to the rest of the section.

Q1 What is meant by the term activation energy? [1 mark]