BioMedical Admissions Test (BMAT)

Section 2: Chemistry

Topic C11: Energetics

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Key Definitions

- → **Endothermic reaction**: a reaction which **takes in energy from its surroundings** and therefore causes the **temperature of the surroundings to decrease.**
  - ◆ To **break existing** bonds between particles, **energy is required** and so the bond breaking process takes in energy from the surroundings. This an **endothermic process.**

- → **Exothermic reaction**: a reaction which **gives out energy into the surroundings** and therefore causes the **temperature of the surroundings to increase.**
  - ◆ In **making new bonds** between particles, **energy is given out** and so the bond making process releases energy into the surroundings. This is an **exothermic process.**

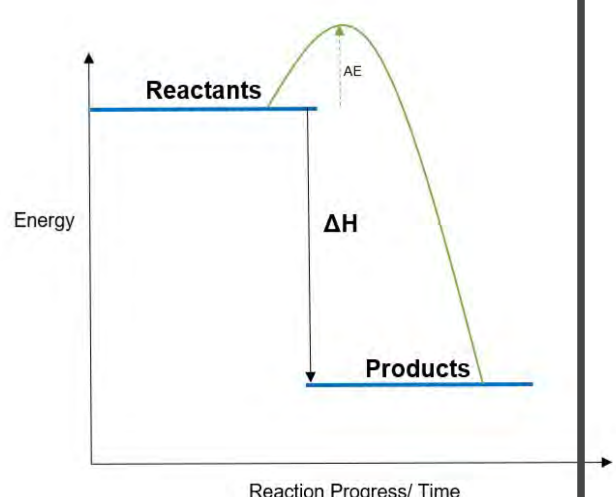
In a chemical reaction, **old bonds must first be broken before new bonds can be formed.**
- ○ If the energy taken in to break old bonds is greater than the energy given out by making new bonds, the overall reaction is endothermic.
- ○ If the energy given out by making new bonds is greater than the energy taken in to break old bonds, the overall reaction is exothermic.

ΔH can be used to **represent the enthalpy chang**e (energy change) of the reaction. This is energy change when reactants $\rightarrow$ products.
- A **positive** ΔH of reaction means overall, energy is taken in during the reaction - the reaction is **endothermic.**
- A **negative** ΔH of reaction means overall, energy is given out during the reaction - the reaction is **exothermic.**

This energy diagram shows an **exothermic reaction.**

The **products are at a lower energy level than the reactants**, which means **energy has been given out** to the surroundings- more energy has been released from making new bonds than was taken in to break old bonds.
ΔH of reaction is negative.

Initially the reaction curve rises in energy levels; this **initial rise is the activation energy** (AE) needed for the particles to successfully collide with each other.



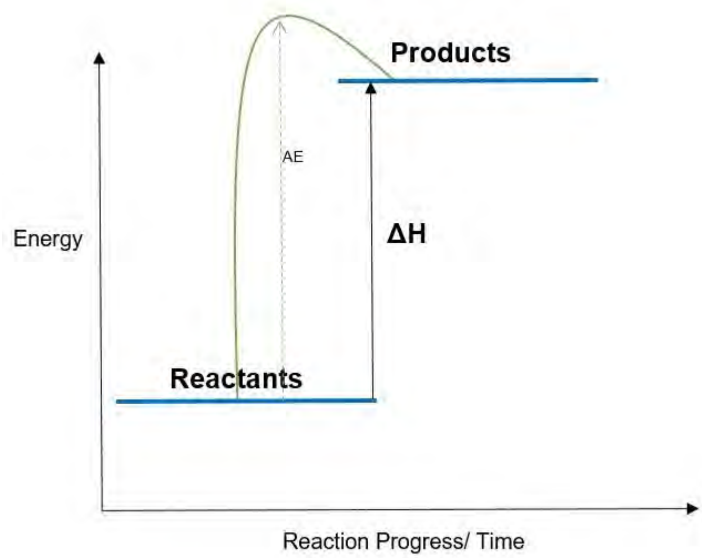
Examples of Exothermic reactions:

- **Combustion reactions** - when fuels are burnt they give out lots of heat
- **Oxidation reactions** - For example the oxidation of iron air generates heat. This reaction is used in commercial hand warmers that can be found in shops.
- **Neutralisation reactions** - reactions between acids and alkalis to produce salt and water are exothermic, heat energy is given out.

This energy diagram shows an **endothermic reaction.**

The **products are at a higher energy level than the reactants,** which **means energy has been taken in** from the surroundings during the course of the reaction-

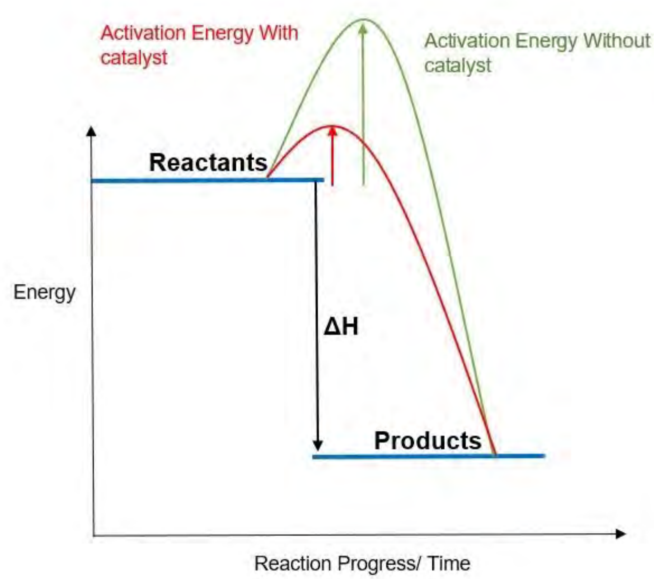
more energy has been taken in to break the old bonds than was released in making new bonds. **ΔH of reaction is positive.**



Examples of endothermic reactions:

Thermal decomposition reactions - e.g. the decomposition of $CaCO_3$ to CaO and CO_2 requires an input of heat, making it an endothermic reaction.

It is important to note, that when using a catalyst in a reaction, although the activation energy is lowered by the catalyst, the **overall energy change of the reaction, ΔH, will remain the same as if a catalyst was not used.** This can be seen on the graph below, where ΔH is the same size for both the catalyst pathway and non-catalyst pathway.



Calculating energy changes of reactions

In order to determine whether a reaction is exothermic or endothermic, the total energy change of the reaction first needs to be calculated.
A **negative energy change → reaction is exothermic** as overall energy is given out. More energy is released from making new bonds than what is taken in to break old bonds.

A **positive energy change → reaction is endothermic** as overall energy is taken in.More energy is taken in to break old bonds than is given out when new bonds are made.

The energy change of reaction can be calculated as follows:

Energy change of reaction, ΔH , = Total energy absorbed - Total Energy released.

Remember, energy is absorbed to break old bonds and energy is released to make new bonds.

Worked example: *Calculate the overall energy change for the reaction $N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_3(g)$ using the bond energy values provided in the table.*

Bond	Bond Energy kJ/mol
N≡N	950
H-H	435
N-H	390

First **calculate the total energy absorbed**; this is the energy needed to break the existing bonds.

Bonds broken: 1 N≡N bond broken in N_2 = 950kJ/mol
3 H-H bonds broken in $3H_2$ = 3 x 435 = 1,035 kJ/mol

Total energy absorbed to break bonds = 950 + 1,035 = 2,255 kJ/mol

Now **calculate the total energy released**;this is the energy formed from making new bonds

New bonds formed: 2 NH_3 bonds formed → i.e. 6 N-H bonds formed = 6 x 390 = 2,340 kJ/mol

Measuring Energy Transfer

The **amount of energy released by a chemical reaction can be measured by determining the heat evolved.**

- **Neutralisation** reactions are especially good to measure the energy release because when an acid and alkali react together, **heat energy is released** which can be measured fairly accurately with a minimal amount of apparatus.

For example, measuring the energy transfer in the neutralisation reaction between hydrochloric acid and sodium hydroxide:

$$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$$

1) Allow both the NaOH solution and HCl solution to sit in the laboratory at room temperature so **that both solutions reach the same temperature.**
2) Once both solutions are the same temperature, measure 25cm^3 of NaOH in a measuring cylinder and measure 25cm^3 of HCl into a polystyrene cup. **A polystyrene cup is used because it a good thermal insulator, which helps to prevent heat losses.**
3) Add the 25cm^3 of NaOH to the HCl in the polystyrene cup and **stir.**
4) Take the temperature of the mixture every 30 seconds and **record the highest temperature reached.**
5) If there is a **drop in temperature, then heat has been absorbed during the reaction (endothermic reaction); an increase in temperature shows that heat has been released (exothermic reaction).**
6) Using the temperature rise measured, calculations can then be done to work out the heat energy released. However for the purpose of the BMAT exam, you do not need to know how to do these calculations.

Despite the fact that the polystyrene cup is an insulator, there is still **energy lost to the surroundings, which decreases the accuracy of the results.** To overcome this:

- Place a **lid** on top of the polystyrene cup. This **reduces energy loss via evaporation**
- Place the polystyrene cup in a **beaker of cotton wool**. The cotton wool acts as a further **thermal insulator.**

Using calorimetry to calculate the energy released from a combustion reaction

The **burning of a fuel is known as combustion.** When fuels burn, **heat energy is released.** This **energy released can be measured using a calorimeter**. The calorimeter is a can-like apparatus used specifically for measuring heat released in chemical reactions. It is made from copper because **copper is a good insulator** and so will reduce energy loss to the surroundings. The whole apparatus described below should be **surrounded by shielding which will prevent draughts.**

Method:

1) Add a **known mass of water** e.g. 50g into the calorimeter. **Record the initial temperature of the water at this stage.**
2) **Weigh the spirit burner** containing the flammable fuel (e.g. ethanol).
3) Put the spirit burner under the calorimeter and light it. **Stir the water** in the calorimeter continuously while it is heated to ensure even heating.
4) Allow the water to be heated until it reaches a temperature of ~50°C.
5) Blow out the flame on the spirit burner and quickly **place a cap over the wick** to **prevent loss of liquid vapour. Record the final temperature of the water and reweigh the spirit burner.**

Energy transferred =
Mass of Water(g) x Specific Heat capacity of water x Temperature change($^\circ$C)

$$Q = mc\,\Delta T$$

The specific heat capacity of water (c) = 4.2

Worked example:
1 mole of hexane, C_6H_{14} was burnt completely to given carbon dioxide and water in a calorimetry experiment.

Mass of spirit burner containing hexane before experiment = 45g
Mass of spirit burner contain hexane after experiment = 44.4g
Original temperature of water = 19.7°C
Final temperature of water after heating = 51°C

Work out the energy released per gram of hexane spirit.

$Q = mc\,\Delta T$

i.e. Energy transferred (J) = Mass of Water (g) x SHC of water x Temp. change (°C)

Mass of water = 50g SHC of water = 4.2 Temp.change of water = 51°C - 19.7°C = 31.3°C

⇒ Q = 50 x 4.2 x 31.3 = 6573

⇒ Energy transferred overall = 6573J

The question asks for the energy released per gram of hexane.

To work this out:

Calculate the mass of fuel burnt in g:

= Mass of spirit burner containing fuel before experiment - Mass after

= 45g- 44.4g = 0.6g

So 0.6 of hexane releases 6573J of energy.

This means 1g of hexane releases 6573 ÷0.6 = **10,955 J of energy or 11.0kJ**

It is important to understand that the **value calculated for the heat energy released on combustion of the fuel is lower than what the actual value would be**. This is because **heat energy would be lost to the atmosphere and via absorption by the calorimeter** among other methods of heat loss in this experiment.