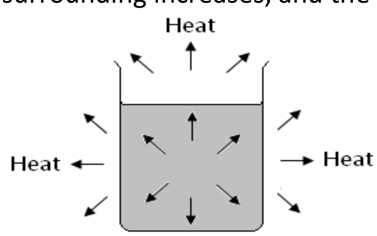
STUDYSMART
CHEMISTRY FORM 5
CHAPTER 4 : THERMOCHEMISTRY

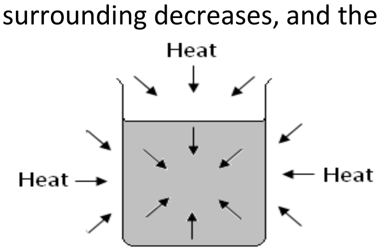
4.1 Evaluating energy changes in chemical reactions
4.2 Understanding heat of precipitation
4.3 Understanding heat of displacement
4.4 Understanding heat of neutralization
4.5 Understanding heat of combustion
4.6 Appreciating the existence of various energy sources

4.1 EVALUATING ENERGY CHANGES IN CHEMICAL REACTIONS

- Thermochemistry is the study of the changes in heat energy which takes place during chemical reaction.
- A chemical reaction involves bond breaking and bond formation. Bond breaking always required energy whereas bond formation releases energy.
- If bond formation release more energy than is required in the bond breaking, then the excess energy is released to the surroundings as heat. This happens in exothermic reaction
- An exothermic reaction is a chemical reaction that gives out heat to the surrounding.
  The temperature of the surrounding increases, and the container becomes hot



- Example of exothermic reaction
  a) Burning of charcoal
  $C(s) + O_2(g) \rightarrow CO_2(g) + heat$
  b) reaction of magnesium with acid
  $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g) + heat$
  c) Neutralization reaction
  $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) + heat$
- An endothermic reaction is a chemical reaction that absorbs heat from surrounding.
  The temperature of the surrounding decreases, and the container becomes cold



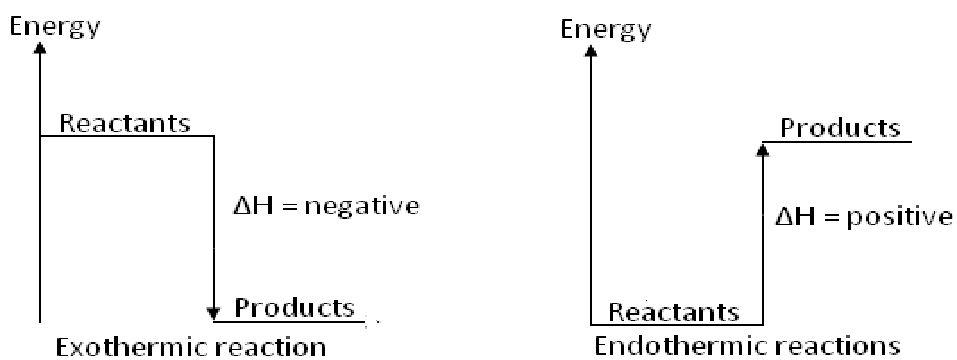
- In and endothermic reaction, the breaking of bonds requires more energy than energy that is released during the formations of bonds.

- Example of endothermic reaction
  a) Thermal decomposition
  $ZnCO_3(s) \xrightarrow{heat} ZnO(s) + CO_2(g)$
  b)Dissolving ammonium salts in water
  $NH_4Cl(s)$ + water → $NH_4Cl(aq)$
- In general, during a chemical reaction, a certain amount of energy is given out or absorbed. This heat is called the heat of reaction, ΔH.

$$\Delta H = H_{product} - H_{reactant}$$

ΔH = - (negative value) → exothermic reaction (temperature increase)
ΔH = + (positive value) → endothermic reaction (temperature decrease)

- Energy Level Diagram



- The steps to construct energy level diagram for exothermic and endothermic reactions are as follow :
  STEP 1 : Identify whether the reaction is endothermic or exothermic
  STEP 2 : Draw the energy axis
  STEP 3 : Draw the energy level for the reactants and products
  STEP 4 : Draw an arrow from the reactants level to the product level
  STEP 5 : Write in the reactants and products based on the balanced chemical equations
  STEP 6 : Label ΔH as positive or negative

TRY THIS 1
Construct energy level diagram for the following chemical reactions
a) $Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$ ΔH = -467 kJ

b) $CaCO_3(s) \rightarrow CaO + CO_2(g)$ $\Delta H = +178$ kJ

- Application of exothermic and endothermic reactions

  a) **Instant Cold Pack**

  Used to treat sports injuries. It have separate compartments of water and solid ammonium nitrate, NH_4NO_3 placed in a plastic bag. When the barrier between the two is broken by squeezing the outer bag, the ammonium nitrate dissolves in the water endothermically to provide instant coldness. Heat is absorbed from the surrounding such as the injured are of the athlete's body.

  b) **Hot Pack**

  Hot pack can be produced by using substance containing either calcium chloride, $CaCl_2$ or magnesium sulphate, Mg,SO_4 and water in separate compartments, Its works same like in instant cold pack but provide warmth since the $CaCl_2$ / MgSO4 dissolve in water exothermically.

  c) **Reusable heat pack**

  Uses a sodium acetate crystallization and resolution system. By bending the metal disc in the bag, the sodium acetate crystallizes and gives off heat. Placing the bag in boiling water redissolve the sodium acetate crystal and thus can be reused.

  d) **Lye (drain cleaner)**

  Solid sodium hydroxide , NaOH is sold in the market as lye, a common drain cleaner. Dissolving lye in water is an exothermic process and the heat liberated may melt the grease, allowing it to be flushed from a clogged drainpipe.

4.2 UNDERSTANDING HEAT OF PRECIPITATION

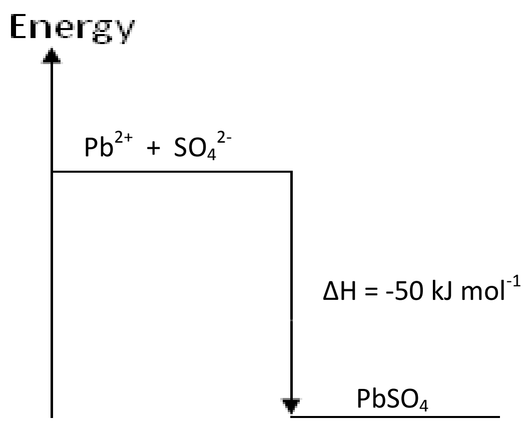
- The heat of the precipitation is the heat change when one mole of a precipitate is formed from ions in aqueous.
- Example – Potassium sulphate, K_2SO_4 and Lead(II) Nitrate, $Pb(NO_3)_2$ are mixed, lead(II) sulphate, $PbSO_4$ is precipitated.

  $$\underset{(aq)}{Pb(NO_3)_2} + \underset{(aq)}{K_2SO_4} \rightarrow \underset{(s)}{PbSO_4} + \underset{(aq)}{2KNO} \qquad \Delta H = -50 \text{ kJ mol}^{-1}$$

  The thermochemical equation for the reaction can be also be written in the ionic form

  $$\underset{(aq)}{Pb^{2+}} + \underset{(aq)}{SO_4^{2-}} \rightarrow \underset{(s)}{PbSO_4} \qquad \Delta H = -50 \text{ kJ mol}^{-1}$$

  The energy Level Diagram



- Thermochemical equation is the chemical equation together with the heat of the reaction
- When ΔH is expressed without the " mol^{-1} " is referred as heat change

TRY THIS 2 - PROBLEM SOLVING

1. In an experiments to determine the heat of the precipitation of lead(II) sulphate, 50 cm^3 of 0.5 mol dm^{-3} lead(II) nitrate solution is added to 50 cm^3 of 0.5 mol dm^{-3} of sodium sulphate solution in a plastic. The following results are obtained

Initial temperature of $Pb(NO_3)_2$ solution	= 28.0 ^OC
Initial temperature of Na_2SO_4 solution	= 28.0 ^OC
Highest temperature reached when two solution are mixed	= 30.5 ^OC

Calculate the heat of the precipitation of lead(II) sulphate. heat capacity of solution : 4.2 J g^{-1} ^OC. Density of solution : 1 g cm^{-3}]

2. In an experiment, 50 cm^3 of 1 mol dm^{-3} hydrochloric acid, HCl is added to 50 cm^3 of 1 mol dm^{-3} of silver nitrate solution, $AgNO_3$. The reacting mixture is stirred and the highest temperature obtained is recorded. The results of the experiment are shown below.

Initial temperature of hydrochloric acid, HCl	= 28.0 ^{O}C
Initial temperature of $AgNO_3$ solution	= 28.0 ^{O}C
Highest temperature reached when two solution are mixed	= 30.5 ^{O}C

Calculate the heat of the precipitation of silver chloride. heat capacity of solution : 4.2 J g^{-1} ^{O}C. Density of solution : 1 g cm^{-3}]

4.3 UNDERSTANDING HEAT OF DISPLACEMENT

- The heat of displacement is the heat change when one mole of metal is displaced from its salt solution by one mole of more electropositive metal
- Example
  $Zn (s) + Cu^{2+} (aq) \rightarrow Zn^{2+} (aq) + Cu(s) \quad \Delta H = -210 \text{ kJ mol}^{-1}$

TRY THIS 3 - PROBLEM SOLVING

1. Excess aluminium powder is added to 100 cm^3 of 0.5 mol dm^{-3} lead(ii) nitrate solution. The mixture is stirred using a thermometer. The results of the experiment are shown below

   Initial temperature of lead(ii) nitrate solution. = 29.0 ^{O}C
   Highest temperature of the mixture = 33.5 ^{O}C

   Calculate the heat of the displacement of lead by aluminium and draw the energy level diagram for the reaction. [Specific heat capacity of solution : 4.2 J g^{-1} ^{O}C. Density of solution : 1 g cm^{-3}]

2. In an experiment, 1g of zinc powder is added to 50 cm^3 of 0.2 mol dm^{-3} copper(II) sulphate, $CuSO_4$ solution. The solution is stirred continuously and the and the highest temperature reached is recorded. The results are as follows :

Initial temperature of copper(II) sulphate, $CuSO_4$ solution	= 28.0 ^{O}C
Highest temperature of the mixture	= 33.0 ^{O}C

Calculate the heat of the displacement of copper in the reaction and draw the energy level diagram for the reaction. [Specific heat capacity of solution : 4.2 J g^{-1} ^{O}C. Density of solution : 1 g cm^{-3}. Relative Atomic mass : Zn, 64]

4.4 UNDERSTANDING HEAT OF NEUTRALIZATION

- The heat of neutralization is the heat change when one mole of water is formed from the reaction between acid and alkali
- Example
  $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l) \quad \Delta H = -57.3 \text{ kJ mol}^{-1}$
  $H^+ + \cancel{Cl^-} + \cancel{Na^+} + OH^- \rightarrow \cancel{Na^+} + \cancel{Cl^-} + H_2O$
  $H^+ + OH^- \rightarrow H_2O \quad \Delta H = -57.3 \text{ kJ mol}^{-1}$
- Heat given out when one mole of water formed is 57.3 kJ mol^{-1}.
- When **monoprotic acid** is used, it produces **one** mole of water, therefore the heat of neutralization will be -57.3 kJ mol^{-1}.
  $HNO_3 + NaOH \rightarrow NaNO_3 + H_2O \quad \Delta H = -57.3 \text{ kJ mol}^{-1}$
- When **diprotic acid** is used, it produces **two** mole of water. Thus the heat of neutralization will be doubled, -114.6 kJ mol^{-1}
  $H_2SO_4 + NaOH \rightarrow Na_2SO_4 + H_2O \quad \Delta H = -114.6 \text{ kJ mol}^{-1}$
- The heat of neutralization would be constant whichever acid and alkali (monoprotic/diprotic) used in neutralization reaction. This is true only when the acid and alkali completely dissociated into ions (strong acid + strong alkali)
- When weak acid and strong alkali (Weak acid + strong alkali) / strong acid and weak alkali (Strong acid + weak alkali) is used, the heat released will be lesser than 57.3 kJ for every mole of water. This is because weak acid / weak alkali dissociate partially into ions.
- When weak acid and weak alkali is used, the heat of neutralization is much lesser. This is because more energy is needed to dissociate both the weak acid and weak alkali completely to produce H^+ and OH^- which then react together to form one mole of water.

TRY THIS 4 - PROBLEM SOLVING

1. In an experiment to determine the heat of neutralization between hydrochloric acid and ammonia solution, 50 cm^3 of 1.0 mol dm^{-3} hydrochloric acid is added to cm^3 of 1.0 mol dm^{-3} ammonia solution. The temperature increases from 29.0 ^OC to 35.5 ^OC. Calculate the heat of neutralization. [Specific heat capacity of solution : 4.2 J g^{-1} ^OC. Density of solution : 1 g cm^{-3}]

2. The thermochemical equation for the reaction between nitric acid, HNO_3 and potassium hydroxide, KOH solution is as follow:

$$HNO_3(aq) + KOH(aq) \rightarrow KNO_3(aq) + H_2O(l) \qquad \Delta H = -56.7 \text{ kJ mol}^{-1}$$

When 150 cm^3 of 2.0 mol dm^{-3} nitric acid, HNO_3 is added to 250 cm^3 of 1.0 mol dm^{-3} potassium hydroxide, KOH solution what is the change in temperature?
[Specific heat capacity of solution : 4.2 J g^{-1} ^{O}C. Density of solution : 1 g cm^{-3}]

4.5 UNDERSTANDING HEAT OF COMBUSTION

- The heat of combustion is the heat change when one mole of a substance is completely burnt in oxygen under standard condition
- Example – Combustion of propane
  $C_3H_8 (g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l) \quad \Delta H = -2202 \text{ kJ mol}^{-1}$

TRY THIS 5 - PROBLEM SOLVING

1. An experiment is carried out to determine the heat of combustion of methanol, CH_3OH. The results of the experiment are shown below.

Volume of water used	= 100 cm^3
Initial temperature of water	= 29.0 ^OC
Highest temperature of water reached	= 51.0 ^OC
Mass of spirit lamp and methanol before combustion	= 156.55 g
Mass of spirit lamp and methanol after combustion	= 156.05 g

   Based on the results, calculate the heat of combustion for methanol, CH_3OH and hence construct the energy level diagram for the combustion of methanol. [Specific heat capacity of solution : 4.2 J g^{-1} ^OC. Density of solution : 1 g cm^{-3}. Relative Atomic mass : H,1 ;C,12 ;O, 16]