Cambridge AS Chemistry

(Code: 9701)

Chapter 6
Enthalpy changes

What are enthalpy changes?

Exothermic or endothermic?

Chemical reactions that release energy to the surroundings are described as exothermic. The surroundings include:

- the solvent (in this case water)
- the air around the test tube
- the test tube itself
- anything dipping into the test tube (e.g. a thermometer).

Other examples of exothermic reactions include:

- the combustion of fuels
- the oxidation of carbohydrates in the bodies of animals and plants (respiration)
- the reaction of water with quicklime (calcium oxide)

Chemical reactions that absorb energy from the surroundings are described as endothermic. Other examples of endothermic reactions include:

- the decomposition of limestone by heating (all thermal decomposition reactions are endothermic)
- photosynthesis (in which the energy is supplied by sunlight)
- dissolving certain ammonium salts in water

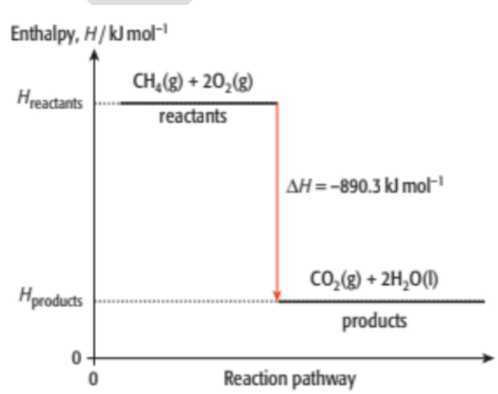
Enthalpy changes and enthalpy profile diagrams

We call the energy exchange between a chemical reaction and its surroundings at constant pressure the enthalpy change.

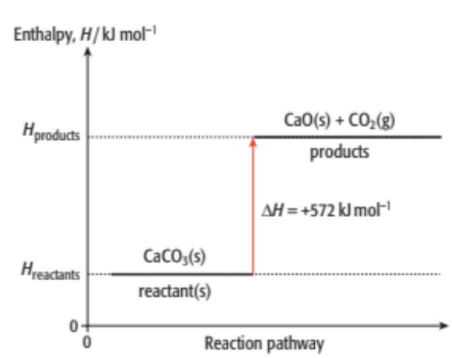
$$\Delta H = H_{Products} - H_{Reactants}$$

The units of enthalpy change are kilojoules per mole ($kJmol^{-1}$)

$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$ $\Delta H = -890.3\ kJ\ mol^{-1}$



$CaCO_3(s) \longrightarrow CaO(s) + CO_2(g)$ $\Delta H = +572\ kJ\ mol^{-1}$



Standard enthalpy change of neutralisation, ΔH_n^θ

The standard enthalpy change of neutralisation is the enthalpy change when one mole of water is formed by the reaction of an acid with an alkali under standard conditions.

Standard enthalpy change of solution, ΔH_{sol}^θ

The standard enthalpy change of solution is the enthalpy change when one mole of solute is dissolved in a solvent to form an infinitely dilute solution under standard conditions.

Standard enthalpy change of atomisation, ΔH_{at}^θ

The standard enthalpy change of atomisation is the enthalpy change when one mole of gaseous atoms is formed from its element under standard conditions.

Standard enthalpy change of hydration of an anhydrous salt

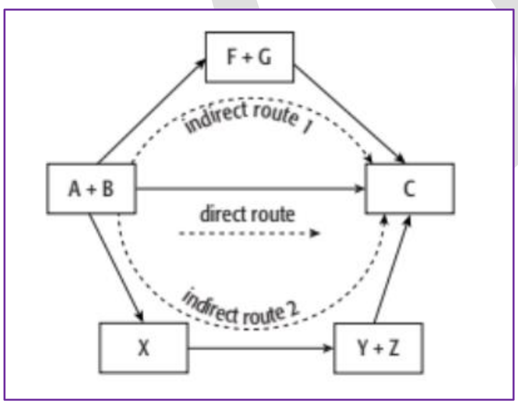
The standard enthalpy change of hydration of an anhydrous salt is the enthalpy change when one mole of a hydrated salt is formed from one mole of the anhydrous salt under standard conditions.

Hess's law

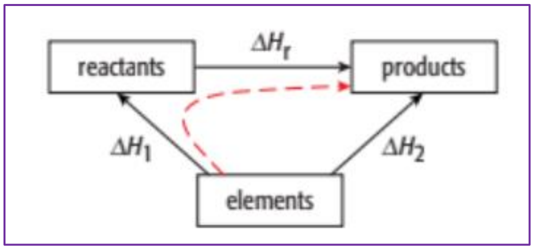
Conserving energy

Hess's law states that 'the total enthalpy change in a chemical reaction is independent of the route by which the chemical reaction takes place as long as the initial and final conditions are the same'.

Enthalpy cycles

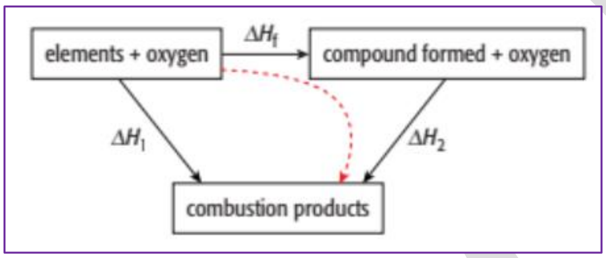


Enthalpy change of reaction from enthalpy changes of formation



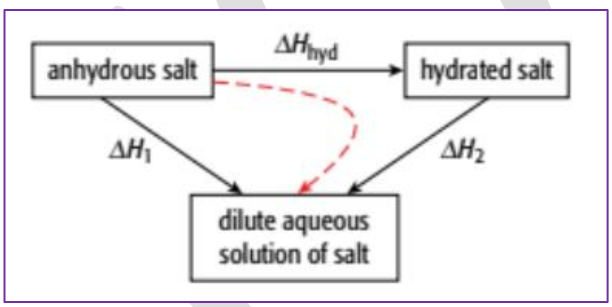
$$\Delta H_2 = \Delta H_1 + \Delta H_r$$

Enthalpy change of formation from enthalpy changes of combustion



$$\Delta H_1 = \Delta H_f + \Delta H_2$$

Calculating the enthalpy change of hydration of an anhydrous salt



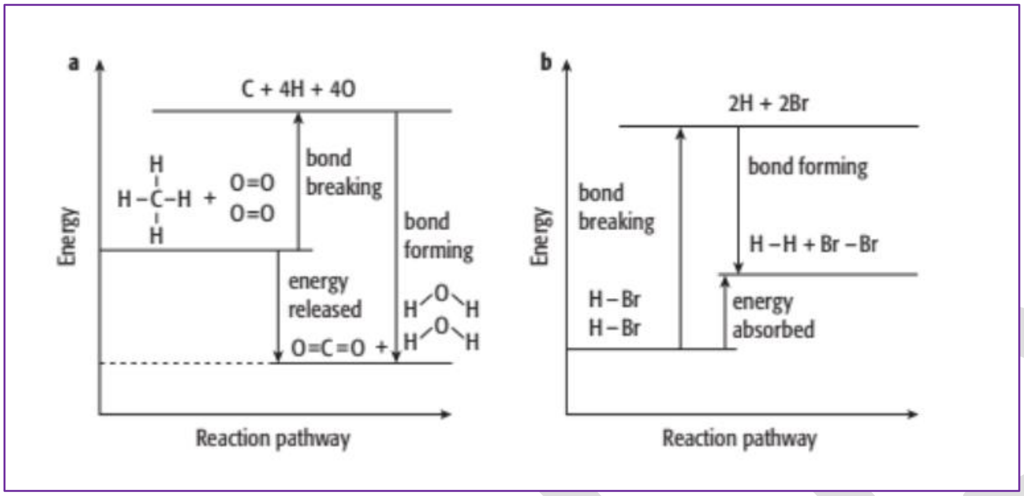
Bond energies and enthalpy changes

Bond breaking and bond making

Bond breaking is endothermic and bond forming is exothermic. In a chemical reaction:

- if the energy needed to break bonds is less than the energy released when new bonds are formed, the reaction will release energy and is exothermic.

- if the energy needed to break bonds is more than the energy released when new bonds are formed, the reaction will absorb energy and is endothermic.



Bond energy

The amount of energy needed to break a specific covalent bond is called the bond dissociation energy. We sometimes call this the bond energy or bond enthalpy. The symbol for bond energy is E. The bond energy for double and triple bonds refers to a mole of double or triple bonds.

EXCERSISE

1. Iodine reacts with chlorine to form dark brown iodine monochloride. I2 + Cl2 → 2ICl This reacts with more chlorine to give yellow iodine trichloride. An equilibrium forms between these iodine chlorides.

   $ICl(l) + Cl_2(g) \rightleftharpoons ICl_3(s)$

   dark brown yellow

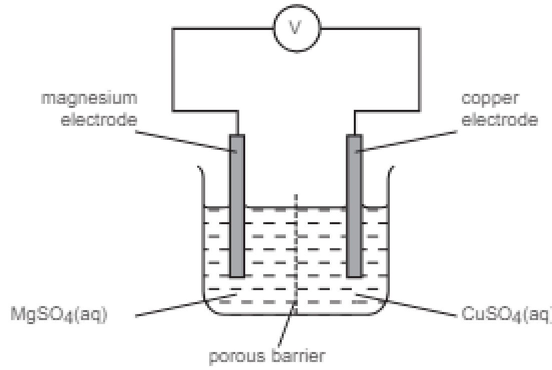
   a. What do you understand by the term equilibrium?
   b. When the equilibrium mixture is heated, it becomes a darker brown colour. Suggest if the reverse reaction is endothermic or exothermic. Give a reason for your choice.
   c. The pressure on the equilibrium mixture is decreased.
      i. How would this affect the position of equilibrium? Give a reason for your choice.
      ii. Describe what you would observe.
   d. Calculate the overall energy change for the reaction between iodine and chlorine using the bond energy values shown.
      Show your working.

$I_2 + Cl_2 \rightarrow 2ICl$

Bond	Energy / kJ per mol
I–I	151
Cl–Cl	242
I–Cl	208

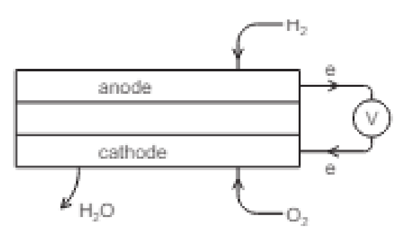
e. Draw a labelled energy level diagram for the reaction between iodine and chlorine using the information in (d).

2. Chemical reactions are always accompanied by an energy change.
   a. Aluminium is extracted by the electrolysis of a molten mixture which contains aluminium oxide, Al2O3. This decomposes to form aluminium at the negative electrode and oxygen at the positive electrode.
      i. W rite an ionic equation for the reaction at the negative electrode.
      ii. Complete the ionic equation for the reaction at the positive electrode.
      2O2– → .... + ...
      iii. Is the reaction exothermic or endothermic? Explain your answer
   b. The cell shown below can be used to determine the order of reactivity of metals.



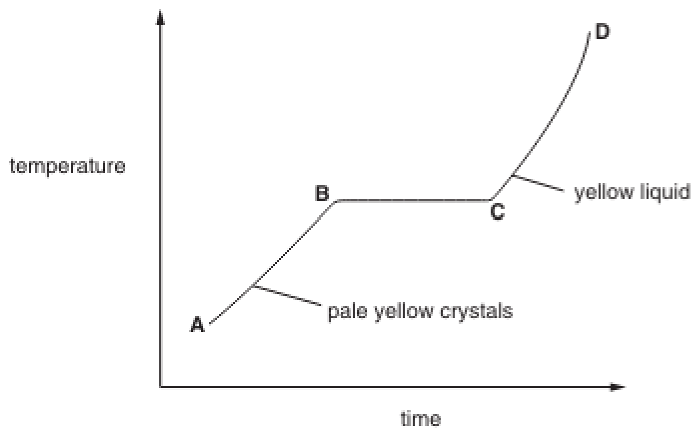
      i. Is the reaction in the cell exothermic or endothermic? Explain your answer.
      ii. Explain why the mass of the magnesium electrode decreases and the mass of the copper electrode increases.
      iii. How could you use this cell to determine which is the more reactive metal, magnesium or manganese?

3. A fuel cell produces electrical energy by the oxidation of a fuel by oxygen. The fuel is usually hydrogen but methane and methanol are two other fuels which may be used. A diagram of a hydrogen fuel cell is given



   a. When the fuel is hydrogen, the only product is water. What additional product would be formed if methane was used?
   b. Write the equation for the chemical reaction that takes place in a hydrogen fuel cell.
   c. At which electrode does oxidation occur? Explain your choice
      i. Write an ionic equation for the reaction at this electrode
   d. Fuel cells are used to propel cars. Give two advantages of a fuel cell over a gasoline-fuelled engine.

4. Nitrogen dioxide, NO_2 , is a dark brown gas
   a. Most metal nitrates decompose when heated to form the metal oxide, nitrogen dioxide and oxygen.
      i. Write a symbol equation for the decomposition of lead(II) nitrate.
         $Pb(NO_3)_2 \rightarrow$ .... + ... + ...
      ii. Potassium nitrate does not form nitrogen dioxide on heating. Write the word equation for its decomposition.
   b. When nitrogen dioxide is cooled, it forms a yellow liquid and then pale yellow crystals. These crystals are heated and the temperature is measured every minute. The following graph can be drawn



      i. Describe the arrangement and movement of the molecules in the region A–B.
      ii. Name the change that occurs in the region B–C
   c. Nitrogen dioxide and other oxides of nitrogen are formed in car engines.
      i. Explain how these oxides are formed.
      ii. How are they removed from the exhaust gases?
   d. Nitrogen dioxide, oxygen and water react to form dilute nitric acid. Describe how lead(II) nitrate crystals could be prepared from dilute nitric acid and lead(II) oxide.

5. An ore of the important metal zinc is zinc blende, ZnS. This is changed into zinc oxide which is reduced to the impure metal by carbon reduction.
   a.
      i. How is zinc oxide obtained from zinc sulfi de?
      ii. Write a balanced equation for the reduction of zinc oxide by carbon.
      iii. The major impurity in the zinc is cadmium. The boiling point of zinc is 907°C and that of cadmium is 767 °C. Name a technique which could be used to separate these two metals.
   b. In common with most metals, zinc is a good conductor of electricity. It is used as an electrode in cells.
      i. Give two other uses of zinc.
      ii. Describe the metallic bonding in zinc and then explain why it is a good conductor of electricity