4

Thermochemistry

Exo- and endo-

A large number of chemical reactions produce heat during the reaction—the test tube gets hot. These reactions are described as **exothermic** reactions. A few reactions take in heat—the test tube gets colder. Such reactions are called **endothermic**.

Exothermic: heat is given out

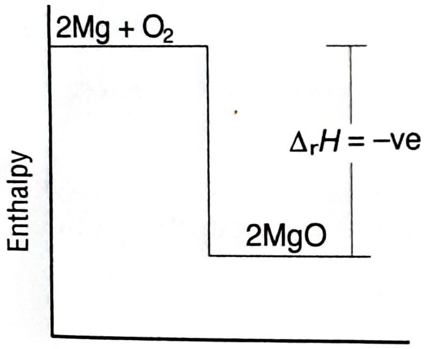
Endothermic: heat is taken in.

Remember **en**ter/**en**doth
exit/**ex**othermic = go ou

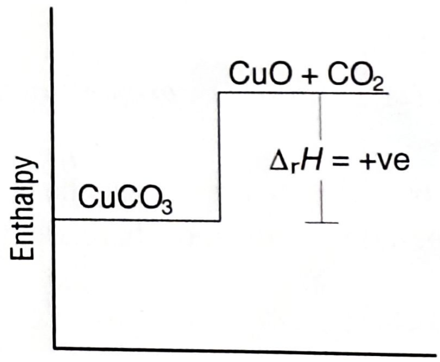
Enthalpy

When heat is produced or absorbed during reactions, the heat content or **enthalpy** (think 'entHalpy' for Heat) of the reactants and products must be different. Scientists use the symbol Δ ('delta') to mean *change in*, so ΔH means *change in enthalpy*, and $\Delta_r H$ means *change in enthalpy of reaction*.

$$\Delta_r H = \textit{enthalpy of products} - \textit{enthalpy of reactants}$$



Exothermic reaction: reactants have more energy than products, $\Delta_r H$ is negative.



Endothermic reaction: reactants have less energy than products, $\Delta_r H$ is positive.

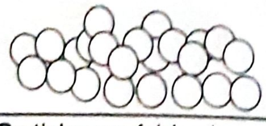
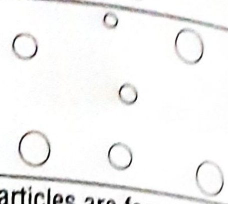
Heat is a form of energy, and the amount of energy released or absorbed depends on the amount of the reagents involved, so the unit of enthalpy is kJ mol^{-1}.

Enthalpy changes are particularly important in industrial chemistry. If a reaction is endothermic, the chemist needs to know how much fuel must be burnt (and paid for) for a given quantity of product formed. With exothermic reactions, enthalpy change is even more important because the rate of reactions increase with temperature, so exothermic reactions can speed up and become explosive if the temperature is not carefully controlled with suitable cooling systems.

Phases and phase changes

States of matter

One of the first things we learn about the world is the differences between solids, liquids and gases. Your Year 9 science notes probably contain this summary of the structure of matter:

Solid	Liquid	Gas
		
Particles are close together and held in fixed positions.	Particles are fairly close together but able to move freely throughout the liquid.	Particles are far apart and moving rapidly in all directions.

POINT
theory

It doesn't matter whether the 'particles' are atoms, ions or molecules, the particles in solids are always in a fixed pattern, while in liquids they are free to move, and in gases they are far apart and moving quickly.

Effect of heat on matter

Heat versus temperature

Also in your junior science classes you will have discovered that hot water has a greater volume than cold water, that solids and gases also expand when heated and contract when cooled and that dye spreads throughout hot water much more rapidly than through cold water. From investigations like these we conclude that particles move more rapidly when heated.

It is important not to confuse *heat* with *temperature.*

- ***Heat is the sum of the kinetic energies of all the particles in a sample.***
- ***Temperature is proportional to the average kinetic energy of the particles.***

The particles in a spark may have a high average kinetic energy (ie a high temperature), but since there are few particles the heat doesn't burn you.

Specific heat capacity

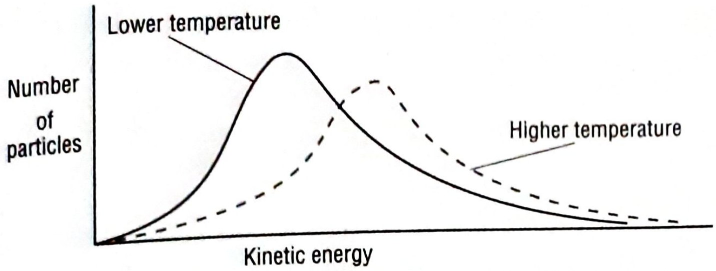
When you go to the beach on a hot, sunny day, the sand can be very hot while the water in a rock pool is only warm. It takes much more energy to raise the temperature of water than to heat the same mass of sand. We say water has a high **specific heat capacity**.

A substance's specific heat capacity, c, is the amount of heat energy required to raise the temperature of 1.00 g of the substance by 1.00 K (= 1.00 °C).

Water has an unusually high specific heat capacity of 4.18 J g^{-1} K^{-1}. Most metals have specific heat capacities of between 0.3 and 1.0 J g^{-1} K^{-1}. Published data normally relates to heating the substance from room temperature, since specific heat capacity changes slightly with temperature and relates only to temperature changes within a phase (eg heating a solid).

Boltzmann and absolute temperature

A physicist called Ludwig Boltzmann studied the kinetic energy of particles in more detail. He showed that not all particles in a sample at a particular temperature have the same kinetic energy.



The **absolute temperature** is temperature on the Kelvin scale. 0 °C = 273 K. A doubling of the absolute temperature from 200 K to 400 K (−73 °C to 127 °C), will double the kinetic energy of the particles. Going from 10 °C to 20 °C will *not* double the kinetic energy of the particles.

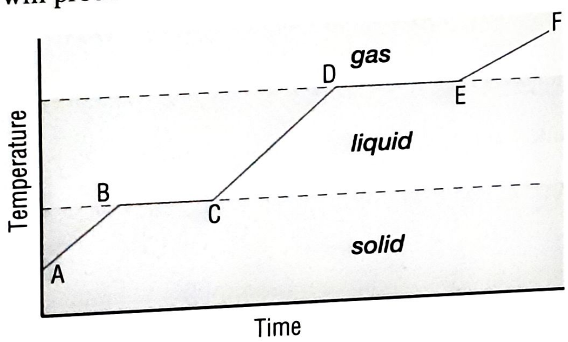
A consequence of Boltzmann's discovery is that at absolute zero (0 K), the kinetic energy of the particles is zero.

Heating or cooling curves

Any pure substance, on heating, undergoes a characteristic pattern of periods of constant temperature and temperature increase. This can be observed by melting ice, boiling water, or heating naphthalene. If the temperature changes are plotted against time for a constant rate of heating, any pure solid will produce the following graph.

REVISION

4A 1a Interpreting a data table



ENCOUNTER

4A Using phase change materials

- Regions of the graph where the temperature increases (A to B, C to D and E to F) represent periods when the *kinetic* energy of the particles is increasing. The particles in the solid vibrate more quickly, and the particles in the liquid and gas move around more quickly.
- Where the temperature remains constant (B to C and D to E) the chemical *potential* energy of the particles is increasing. During this time the substance is changing phase—from solid to liquid at B to C, and from liquid to gas at D to E. The energy increase allows the particles to partially (as the solid melts) or fully (when the liquid boils) overcome the attractive forces between them.

Fusion and vaporisation

Molar heat of fusion

The energy required to change one mole of a substance from a solid to a liquid at the melting point is called the **molar heat of fusion** ($\Delta_{fus}H$).

H_2O(solid at 0 °C) $\longrightarrow$ H_2O(liquid at 0 °C) $\quad \Delta_{fus}H = 6.0$ kJ mol^{-1}

The molar heat of fusion provides a measure of the strength of the force holding the particles together in the solid phase.

PRACTICAL

4.1 P 165 Heat and phase changes

Molar heat of vaporisation

The energy required to change one mole of a substance from a liquid to a gas at the boiling point is called the **molar heat of vaporisation** ($\Delta_{vap}H$).

H_2O(liquid at 100 °C) $\longrightarrow$ H_2O(gas at 100 °C) $\quad \Delta_{vap}H = 41.0$ kJ mol^{-1}

Molar heat of vaporisation indicates the strength of the force between particles in the liquid phase.