3. Thermal Physics

Temperature = degree of hotness

Temperature of two objects in contact determines the direction of energy flow.

Hotter → Colder until thermal equilibrium is reached.

Energy flowing as a result of conduction, convection and thermal radiation is called heat.

Temperature is scalar.

°C + 273° = Kelvin

Absolute temperature = absolute zero = all particles have minimum kinetic energy

-273° C or 0 K

Internal energy
Substances consist of particles in random motion.

When particles move apart, potential energy increases.
When particles move faster, kinetic energy increases.

The internal energy of a substance is the total of the potential energy and the random kinetic energy of all the particles in the substance.

In gas particles, there is almost no potential energy.

Avoid using the term thermal energy for energy that is transferred due to temperature differences.

Specific heat capacity
Energy transferred to 1 kg of a substance causing it temperature to increase by 1 K.
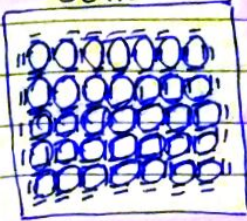
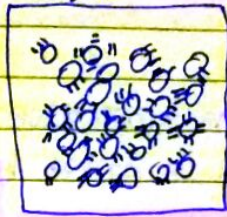$$m \, c \, \Delta t = Q$$

m = mass kg
c = SHC $Jkg^{-1}k^{-1}$
(KKY) Δt = change in temperature
Q = Energy transferred J
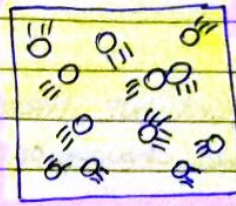
Solid   Liquid   Gas

Worked Example

A piece of iron mass 0.133kg is placed in a kiln until it reaches the temperature θ of the kiln. The iron is then quickly transferred to 0.476 kg of water held in a thermally insulated container. The water is stirred until it reaches a steady temperature. The following data are available.

SHC of iron = 450 $J kg^{-1} K^{-1}$
SHC of water = $4.2 \times 10^3 J kg^{-1} K^{-1}$
Initial temperature of the water = $16°C$
Final temperature of the water = $45°C$

SHC of container and insulation is negligible.

a) State and expression, in terms of θ and the above data, for the energy transfer of the iron in cooling from the temperature of the kiln to the final temperature of the water.
b) Calculate the increase in internal energy of the water as the iron cools in the water.
c) Use your answers to b) and c) to determine θ.

Solution

a) $m \times c \times \Delta t = Q$
    $Q = 0.133 \times 450 \times (\theta - 45)$
    $Q = 60 \times (\theta - 45)$

b) ~~$0.476 \times$~~ $mc\Delta t$
    $0.476 \times 4200 \times 29 = 57976.8 J$
        $= 58000 J = 5.8 \times 10^4 J$

c) $58000 = 60 \theta - 2700$
    $60700 = 60 \theta$
 $\theta = 1011.7°C$
      $= 1010 °C$

Specific latent heat

Energy is being applied but there is no temperature change. The energy required to achieve the change of phase is called latent heat.

- Specific latent heat of fusion - energy required to change the phase of 1kg of substance from a solid to a liquid without any temperature change.

- Specific latent heat of vaporization - energy required to change the phase of 1 kg of liquid into a gas without any temperature change.

$$\underset{J}{Q} = \underset{kg \times J\,kg^{-1}}{mL}$$
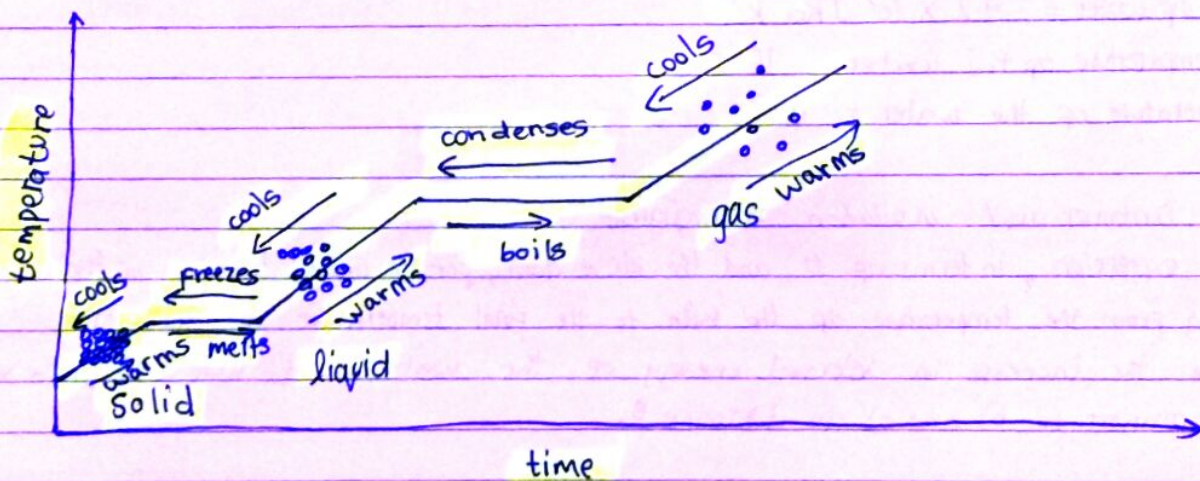
- Energy is supplied by a constant power source (Assumption) if graph looks like this.
- If you know the power, then gradient is ~~the~~ heat capacity of the substance solid, liquid and gas.
- Time of each horizontal section also helps calculate the specific heat capacity of solid & liquid phases.
- Cooling usually means falling temperature, not losing energy. If temp. is constant, cannot say cooling. (Flat part of graphs)

Worked Examples

A heater boils a liquid in a pan for a measured time.
Power rating of heater = 25W
Time for which liquid is boiled = 6.2×10^2 s
Mass of liquid boiled away = 4.1×10^{-2} kg
Use data to determine SLH of vapourization
of the liquid.
(KKY)

Solution

$25 \times 620 = 15500\,J = Q$

$15500 = mL$

$15500 = 0.041 \times L$

$L = 378048.8\,J$

$= 378\,kJ$

$= 3.8 \times 10^5\,J\,kg^{-1}$

Molecular expansion of phase change

As energy is transferred to a solid, internal energy of the solid increases. Random kinetic energy increases and intermolecular potential energy increases. Eventually molecules move far enough so that their neighbours don't influence them as much. Intermolecular bonds are broken. When this is happening, energy transfer does not increase the random kinetic energy but increases the potential energy of the molecules.

Eventually solid melts. The random kinetic energy increases again and temperature rises. Molecules are breaking away from each other and joining together at a constant rate. The potential energy does not change on average.

As the liquid reaches its boiling point, molecules start moving away from each other within their groups. Potential energy increases as molecules break away. A stage is reached when the kinetic energy remains constant until all molecules are separated from each other. The liquid vapourizes and temperature increases again with kinetic energy.

3.2 Modelling a gas
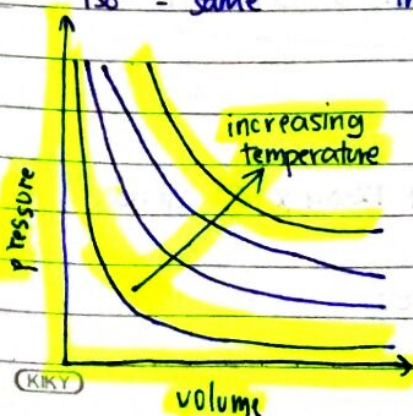
The gas laws

Ideal gas - obeys the gas laws under all conditions.

Boyle's law - For a fixed mass of gas at constant temperature the pressure is inversely proportional to the volume.

$$p \propto \frac{1}{V} \qquad pV = k \text{ (constant)}$$

pressure against volume graph at constant temperature - isothermal curve

"iso" = same   "thermal" = temperature

increasing temperature

pressure

volume

(KIKY)

Charles law – For a fixed mass of gas at constant pressure the volume is directly proportional to the absolute temperature.

$$V \propto T \quad , \quad \frac{V}{T} = k \text{ (constant)}$$

Pressure law – for a fixed mass of gas at constant volume, pressure is directly
(third gas law) proportional to the absolute temperature.

$$P \propto T \quad , \quad \frac{P}{T} = k$$

The number of particles in a gas at constant temperature and pressure is directly proportional to the volume of the gas.

$$n \propto V$$

$$\frac{n}{V} = \text{constant (at constant pressure and temperature)}$$

R = ideal gas constant

Equation of state of an ideal gas: $pV = nRT$

P = pressure (Pa) , V = volume (m^3), n = number of moles , R = 8·31 J K^{-1} mol^{-1}
T = temperature (K)

The mole and the Avagadro constant

"mol" is a measure of the amount of substance that something has.

The amount of substance having the same number of particles as there 12 grams of carbon-12. 6.02×10^{23} = Avogadro's constant

Molar mass

N$_2$, One mole of nitrogen gas will contain 6.02×10^{23} molecules but 12.04×10^{23} atoms.
One mole of nitrogen atoms = 14·01g
→ One mole of nitrogen molecules = 28·02g – molar mass

Water = H_2O

2 moles of hydrogen = 1+1

1 mole of oxygen = 16

Mass of water   = 18g mol^{-1}

Worked Example

==Calculate the ps percentage change in volume of a fixed mass of an ideal gas when its pressure is increased by a factor of 2 and its temperature increases from 30°C to 120°C.==

$$T - 30°C \rightarrow 120°C$$
$$\text{or } 303k \rightarrow 393°k$$

mass = constant

$$pV = nRT$$

$$\frac{pV}{nRT} = \frac{pV'}{nRT'}$$

$$\frac{pV}{T} = \frac{p_1 V_1}{T_1}$$

$$\frac{pV}{303} = \frac{2pV_1}{393}$$

$$393 pV = 606 pV_1$$

$$393 V = 606 V_1$$

$$\frac{393}{606} = \frac{V_1}{V}$$

$$\frac{393}{606} \times 100 = \frac{V_1}{V} \times 100$$

$$= 65\%$$

$$pV_1 = nR(303) \qquad 2pV_2 = nR(393)$$

$$V_1 = \frac{nR(303)}{p} \qquad V_2 = \frac{nR(393)}{2}$$

$$\frac{pV_1}{303} = \frac{2pV_2}{393}$$

$$\frac{V_1}{303} = \frac{2V_2}{393}$$

$$393 V_1 = 606 V_2$$

$$V_1 = \frac{606}{393} V_2$$

$$\geqslant \frac{606}{393} V_2 - V_2$$

$$\frac{V_2 - \frac{606}{393} V_2}{\frac{606}{393} V_2} \times 100$$

$$= -35\%$$

Means that there is a 35% reduction in gas volume.

The microscopic interpretation of gases
Diffusion

==Movement for from higher concentration to lower concentration down a concentration gradient.==

Brownian motion

Smoke particles collide with air particles and move zig-zag.

Kinetic model of an ideal gas

Kinetic theory of gases is a statistical treatment of the movement of ~~the~~ gas molecules in which macroscopic properties such as pressure are ~~considered~~ interpreted by considering molecular movement.

Key assumptions of the kinetic theory are:

1) Gas consists of a large numbers of identical tiny particles called molecules which are in constant motion.
2) Number is large enough for ~~stastici~~ statistical averages to be made.
3) Each molecule has negligible volume when compared with the volume of the gas as a whole.
4) Molecules move in one direction as one instant.
5) Perfect elastic collisions between molecules and walls.
6) No intermolecular forces between the molecules between collisions.
7) Each molecule produces a force on the wall of the container.
8) Forces of individual molecules will average out to produce a uniform pressure throughout the gas. (ignore gravity)
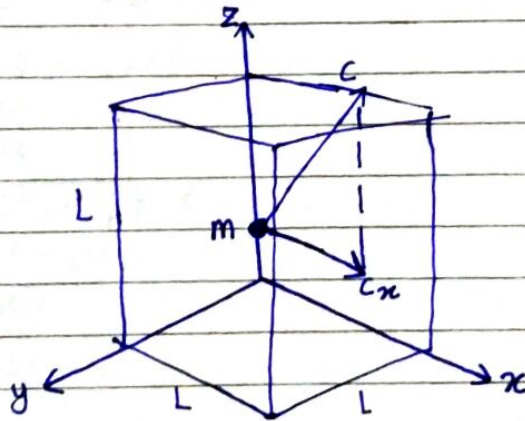
Ideal gas equation:

$$F_m = \frac{-mc_x^2}{L}$$

mass velocity → $-mc_x^2$
L → length of edge

Total force exerted on the right-hand wall =

$$F_x = \frac{m}{L}(c_{x_1}^2 + c_{x_2}^2 + c_{x_3}^2 + \dots + c_{x_n}^2)$$

$$\overline{c^2} = \overline{c_x^2} + \overline{c_y^2} + \overline{c_z^2}$$

$$P = \frac{1}{3}\rho \overline{c^2}$$

pressure (KiKY) density   mean square speed of the molecules

Molecular interpretation of temperature

Boltzmann constant $= \dfrac{R}{N_A} = k_B$

$$\frac{3}{2} k_B T = \frac{1}{2} m c^2$$

Total ~~#~~ internal energy of an ideal gas $= \dfrac{3}{2} N k_B T$

Chapter 3 questions → After

$$p = \frac{F}{A}$$

$$n = \frac{N}{N_A} \quad \text{—— Number of atoms}$$

No. of moles   Avagadro constant

$$pV = nRT \qquad \text{Ideal gas law}$$

$$E_k = \frac{3}{2} k_B T = \frac{3}{2} \frac{R}{N_A} T$$

Average kinetic energy per molecule of a gas.

Boltzmann Constant