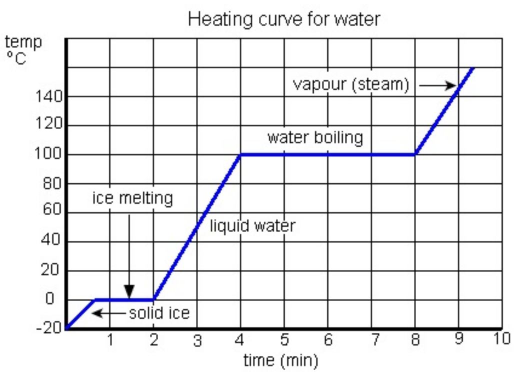
Thermal Physics

1 Differences between heat and temperature

	Heat	Temperature
Definition	Thermal energy(transferred from hot to cooler places)	A comparative measure of how hot something is
Unit	Joule	Kelvin
Measured using	Joulemeter	Thermometer

2 Graph of heating water



3 Specific heat capacity

Specific heat capacity - The energy needed to raise the temperature of 1kg of a material by 1K

$$c = \frac{Q}{m\Delta\theta}$$

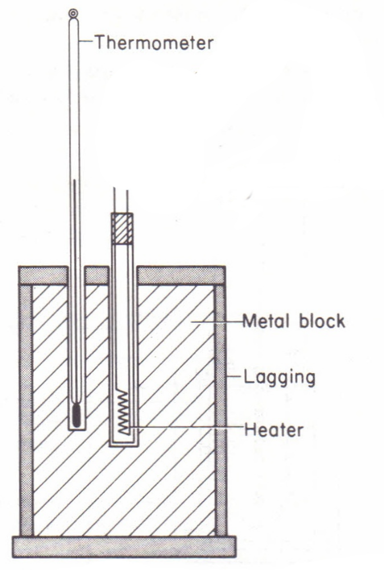
c=Specific heat capacity - $Jkg^{-1}\ ^{\circ}C$
m=Mass - kg
$\Delta\theta$ = Temperature change - $^{\circ}C$
Q = Heat energy - J

3.1 Latent heat

Specific latent heat of fusion, $\mathbf{L_f}$ $Q = mL_f$
The energy needed to change 1kg of a solid to a liquid without a temperature change

Specific latent heat of vaporisation, $\mathbf{L_v}$ $Q = mL_v$
The energy needed to change 1kg of a liquid to a vapour without a temperature change

3.2 How to determine the specific heat capacity of a metal



1. Set up the experiment with a voltmeter and ammeter to determine the electrical power of the heater
2. Allow time for the heat to conduct through the metal (until there is a temperature rise)
3. Start a stopclock, record the V, I and temperature
4. Record V, I and T every 2 minutes for 20 minutes

4 Gas laws

4.1 Boyle's law

Boyle's law - Pressure is inversely proportional to volume
Gases - Free moving particles, no forces

$$\text{Boyle's law: } P = kV^g$$

$$\ln(P) = \ln(k) + g\ln(V)$$

This is in the form y=c+mx

4.2 Summary of gas laws

Law	Proportionality	Constant	Equation
Boyle's	$p \propto \frac{1}{v}$	Temperature, moles	$p_1v_1 = p_2v_2$
Charles'	$V \propto T$	Pressure, moles	$\frac{v_1}{T_1} = \frac{v_2}{T_2}$
Gay-Lussac	$p \propto T$	Volume, moles	$\frac{p_1}{T_1} = \frac{P_2}{T_2}$

4.3 Ideal Gas equation

$$pV = nRT$$

p=Pressure(Pascals)
V=Volume(m^3)
n=Number of moles
R=Universal gas constant=8.31JK^{-1}mol^{-1}
T=Temperature(K)

5 Brownian Motion

The random and unpredictable motion of a particle such as a smoke particle caused by molecules of the surrounding substance colliding at random with the particle. Its discovery provided evidence for the existence of atoms.

6 Kinetic theory of gases

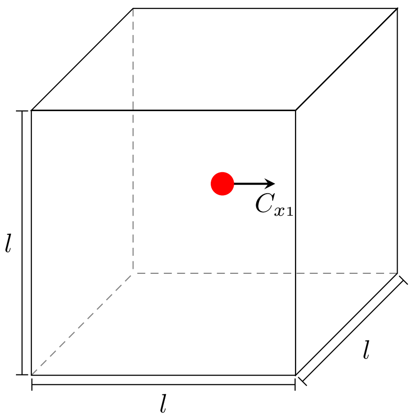
This is a model of gas behaviour based on known laws of physics.

On the other hand the gas laws are empirical and are based on experimental results only.

6.1 Assumptions for an ideal gas

1. Newton's laws of motion can be applied
2. The molecules of a particular gas are identical
3. The size of the particles are negligible compared to the distance between them
4. The molecules exert NO forces on each other, including during collision. Gravitational force is neglected. When not colliding, the particles move with constant velocity, and that velocity is random.
5. All collisions are perfectly elastic
6. The duration of the collision is negligible compared to the time between collisions.
7. There are a large number of particles so that statistics can be meaningfully applied.

7 Derivation of the relationship between gas pressure and speed



Newton's 3rd law - Every action has an equal and opposite reaction

$\Delta mc = mc_{x1} - -mc_{x1} = 2mc_{x1}$

Use Velocity $= \frac{\text{Distance}}{\text{Time}}$

Time$=\frac{\text{Distance}}{\text{Velocity}} = \frac{2l}{c_{x1}}$

Use force$= \frac{\text{Change in momentum}}{\text{time}}$

Force $= \frac{\Delta mc}{\Delta t} = \frac{2mcx1}{2l/c_{x1}} = \frac{mc_{x1}^2}{l}$

Use Pressure$= \frac{\text{Force}}{\text{Area}}$

$p_1 = \frac{mc_{x1}^2/l}{l^2} = \frac{mc_{x1}^2}{l^3}$

Expand for N particles

$p = \Sigma p_n = p_1 + p_2 + p_3 ... + p_N$

$p = \frac{mc_{x1}^2}{l^3} + \frac{mc_{x2}^2}{l^3} + \frac{mc_{x3}^2}{l^3} + \frac{mc_{xN}^2}{l^3}$

$p = \frac{m}{l^3}(c_{x1}^2 + c_{x2}^2 + c_{x3}^2 ... + c_{xN}^2)$

The mean of all the squares of the velocities is written as $\bar{c_x^2}$

$\bar{c_x^2} = \frac{c_{x1}^2 + c_{x2}^2 + c_{x3}^2 ... + c_{xN}^2}{N}$

$N\bar{c_x^2} = c_{x1}^2 + c_{x2}^2 + c_{x3}^2 ... + c_{xN}^2$

Simplify expression for pressure

$p = \frac{Nm\bar{c_x^2}}{l^3}$

Consider in 3 dimensions

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

Average of mean square velocity for each dimension are equal

$\bar{c_x^2} = \bar{c_y^2} = \bar{c_z^2}$

Simplify 3D formula

$\frac{\bar{c^2}}{3} = \bar{c_x^2} = \bar{c_y^2} = \bar{c_z^2}$

Simplify pressure formula

$p = \frac{1}{3} \times \frac{Nm\bar{c^2}}{l^3}$

Insert Density formula

$\rho = \frac{\text{Mass}}{\text{Volume}} = \frac{Nm}{l^3}$

Substitute into Pressure formula

$$p = \frac{1}{3}\rho\bar{c^2}$$

8 The relationship between kinetic energy and temperature

$p = \frac{1}{3}\rho \bar{c^2}$

Replace density with mass divided by volume

$p = \frac{1}{3} \times \frac{M}{V} \bar{c^2}$

Multiply both sides by V and rearrange to have kinetic energy in brackets

$pV = \frac{2}{3}(\frac{1}{2}M\bar{c^2})$

Replace M(Mass of all particles) with Nm(Number of particles $\times$ the mass of one particle)

$pV = \frac{2N}{3}(\frac{1}{2}m\bar{c^2})$

Replace pV with nRT from Gas law equation

$nRT = \frac{2N}{3}(\frac{1}{2}m\bar{c^2})$

Divide both sides by n and simplify $\frac{N}{n}$ to Avagadro's constant

$RT = \frac{2}{3}N_A(\frac{1}{2}m\bar{c^2})$

Divide both sides by Avagadro's constant and simplify $\frac{R}{N_A}$ to Boltzman's Constant

$kT = \frac{2}{3}(\frac{1}{2}m\bar{c^2})$

Rearrange to have only kinetic energy on one side

$\frac{3}{2}kT = \frac{1}{2}m\bar{c^2}$

This shows that Average KE $\propto$ Temperature

9 Root mean square velocity

$C_{\text{RMS}} = \sqrt{\bar{c^2}}$