Paper 2 Cheat Sheet

1 Thermal physics

1.1 Thermal energy transfer

Specific heat capacity - The energy required to raise the temperature of a unit mass of a given substance by one degree
Specific latent heat - The energy required to change the state of a material without changing the temperature
Temperature - The average kinetic energy of the atoms or molecules in the system
Heat - Energy transfer due to a difference in temperature

1.1.1 Continuous flow

By dividing the specific heat capacity formula by t it can be found that

$$IV = mc\frac{\Delta T}{t}$$

This gives the power per second, where a mass m flows in a time t

1.2 Ideal gases

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	$\frac{p_1}{T_1} = \frac{p_2}{T_2}$

The two formulas on the formula book for the gas laws have n moles and N molecules

1.2.1 Deriving Pressure volume work formula

$$W = FS = F \times \Delta L = \frac{F}{A} \times A\Delta L = P\Delta V$$

1.2.2 Types of masses

Molar mass - The mass of a mole of a substance
Molecular mass - The mass of the molecules

1.3 Molecular kinetic theory model

1.3.1 Brownian motion as evidence for the existence of atoms

Brownian motion - The random motion of smoke particles in a gas
As Newton's first law states that objects remain in motion until acted on by a force, the smoke particles should remain in motion, instead they move randomly, suggesting collisions with something else

1.3.2 Explanation of relationships between p,V and T

Increase pressure - More collisions, increase temperature. Same number of molecules, volume must decrease

1.3.3 Empirical gas laws but theoretical kinetic theory

By changing variables of a gas, the gas laws can be derived, however the kinetic theory is based on what else would be expected to be required to be constant.

1.3.4 Derivation

Newton's 3$^{\text{rd}}$ 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

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

2 Fields and their consequences

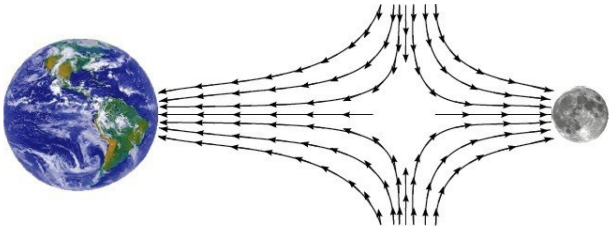
2.1 Fields

Similarities and differences between gravitational and electrostatic forces

Similarities	Differences
• Inverse square laws • Use of field lines • Use of potential • Use of equipotentials	Masses always attract, but charges may attract or repel

2.2 Gravitational fields

2.2.1 Gravitational field strength



2.2.2 Gravitational potential

Gravitational potential has a value of 0 at infinity, then reduces as it approaches the planet.
Gravitational potential - The work done in moving a unit mass from infinity to that point int he field
Gravitational potential difference - The work done in moving a unit mass from one point to another
Equipotential - The group of points with the same potential energy

The sign is negative because a negative amount of work has to be done to move the object from infinity to earth because the object is attracted to earth.

2.2.3 Orbits of planets and satellites

2.2.3.1 Kepler's law

$$F = \frac{GMm}{r^2} = \frac{mv^2}{r} \qquad \therefore \frac{GM}{r} = v^2$$

$$v = \frac{s}{t} = \frac{2\pi r}{T}$$

$$v^2 = \frac{4\pi^2 r^2}{T^2} = \frac{GM}{r}$$

$$\frac{r^2}{T^2} = \frac{GM}{4\pi^2}$$

RHS is a constant

$$r^2 \propto T^2$$

2.2.3.2 Escape velocity

$$\frac{1}{2}mv^2 = \frac{GMm}{r} \qquad \therefore v = \sqrt{\frac{2GM}{r}}$$

$$g = \frac{GM}{r^2} \qquad \therefore gr = \frac{GM}{r}$$

$$v = \sqrt{2gr}$$

2.2.3.3 Total energy of an orbiting satellite

$$\text{Total energy=KE+GPE}$$

$$KE = \frac{1}{2}mv^2$$

$$\frac{GM}{r^2} = \frac{v^2}{r} \quad \therefore v^2 = \frac{GM}{r}$$

$$KE = \frac{1}{2}m\frac{GM}{r}$$

$$GPE = mV \quad V = -\frac{GM}{r} \quad \therefore E_p = -\frac{GMm}{r}$$

$$E_T = E_K + E_P = \frac{GMm}{2r} + -\frac{GMm}{r} = -\frac{GMm}{2r}$$

2.2.3.4 Synchronous orbits

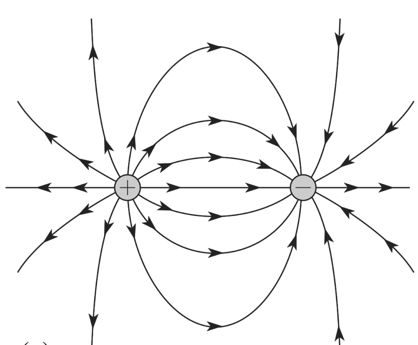
Geosynchronous orbit - Time period of 24h, will be seen at the same place at the same time every day
Geostationary orbit - Time period of 24h, but in the plane of the equator and travelling the same direction as the earth, appears stationary to an observer on the ground

The height at which these satellites must be is determined by Kepler's law

2.3 Electric fields

2.3.1 Coulomb's law

This is the first equation under electric fields on the data sheet, it describes the force between two point charges in a vacuum
Permittivity of free space - The charge per unit area in coulombs per square metre on oppositely charged plates when the electric field strength between the plates is one volt per metre
The difference between the permittivity of free space and the permittivity of air is so insignificant air can be treated as a vacuum.
Electric field strength - At a point in an electric field, the force per unit charge on a small positively charged object in that field



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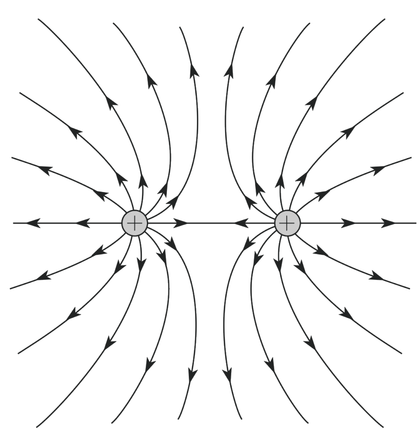

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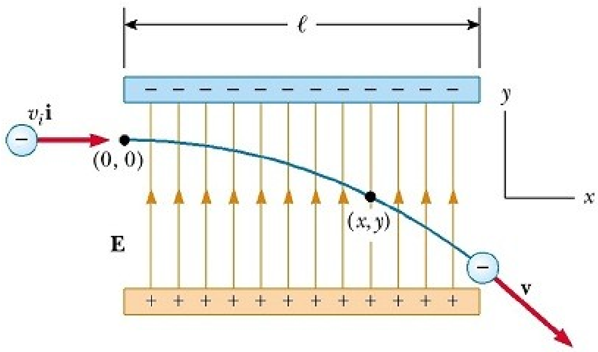
2.3.1.1 Derive $Fd = Q\Delta V$

$$F = EQ \quad E = \frac{V}{d} \quad \therefore F = \frac{QV}{d} \quad \therefore Fd = QV$$

2.3.1.2 Particle in a uniform electric field



2.3.2 Electric potential

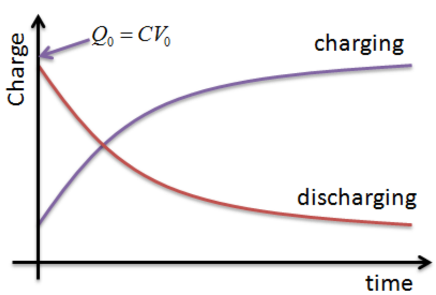
Absolute electric potential - At a point in an electric field, the work done per unit charge on a small positively charged object to move it from infinity to that point in the field

2.4 Capacitance

2.4.1 Capacitance, parallel plate capacitor and energy stored in a capacitor

Capacitance - The charge stored per unit p.d. of a capacitor
In the presence of an electric field, the polar molecules in the electric field will rotate, causing it to become polarised, and so a better dielectric. This is why polar molecules are used for dielectrics instead of non polar molecules

2.4.2 Capacitor charge and discharge



Voltage and charge follow the same pattern when charging and discharging, whereas current follows the opposite pattern.
The time constant(RC) is the time it until 37% of the charge on the capacitor is remaining.

$$T_{\frac{1}{2}} = 0.69RC$$

2.5 Magnetic fields

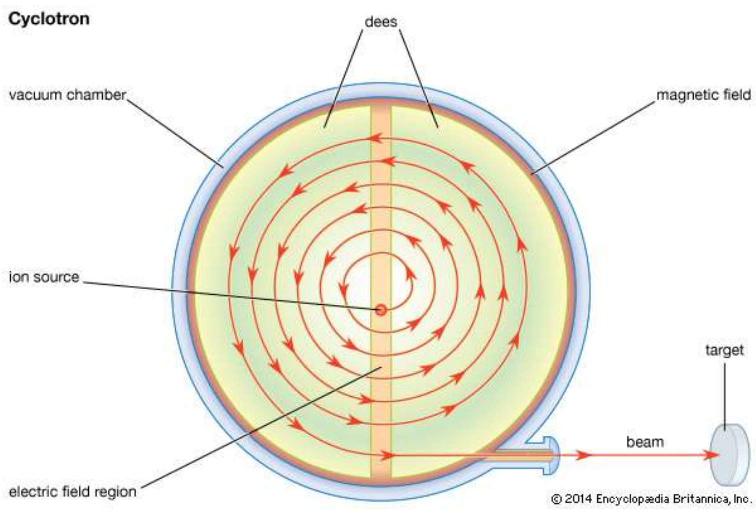
2.5.1 Magnetic flux density

Magnetic flux density - The magnetic force per unit length per unit current on a current carrying conductor at right angles to the field lines (Derive from F=BIl)

2.5.2 Moving charges in a magnetic field

$$F = BQv \quad \text{When the field is perpendicular to the velocity}$$

2.5.2.1 Cyclotron



This accelerates the particles to very high speeds, for use in medicine

2.5.3 Magnetic flux and flux linkage

$$\text{Magnetic flux:}\phi = BA \quad \text{Where B is normal to A}$$

Flux - $\phi = BA$ for a uniform magnetic field of flux density B that is perpendicular to an area A. Unit of Weber(Wb)
Flux Linkage - Through a coil of N turns, $N\phi = BAN\cos\theta$ where B is the magnetic flux density perpendicular to area A, unit also of Wb

2.5.4 Electromagnetic induction

Faraday's law - The induced emf in a circuit is equal to the rate of change of the magnetic flux linkage through the circuit
Lenz's law - When a current is induced in electromagnetic induction, the direction of the induced current is always such as to oppose the change that causes the current

2.5.5 Alternating currents

Peak to peak - The difference in the values between the two peak and the trough of an ac wave
Root mean square - The DC voltage that will give the same effect as the AC voltage

2.5.5.1 Oscilloscope

x axis - Time base
y axis - Y sensitivity
The position and size of the waveform should be adjusted so that it takes up as much of the screen as possible, reducing uncertainty.

2.5.6 Transformers

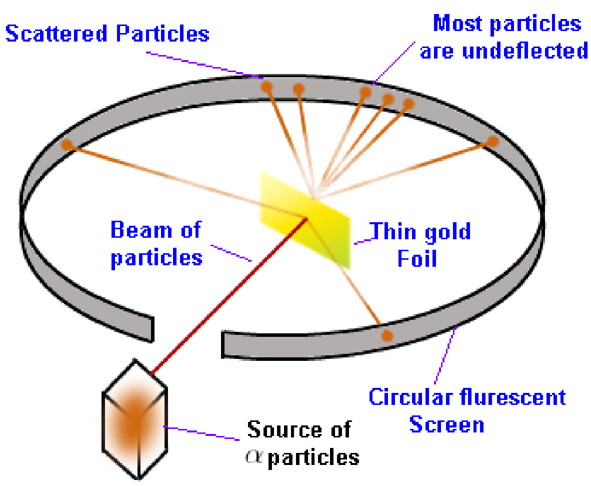
Eddy currents - Induced currents in metal parts of ac machines
Inefficiencies:
- Eddy currents form in the metal core of the transformer, leading to a loss in power
- Resistance in the windings around the transformer resulting in energy wasted as heat
- Magnetisation and demagnetisation of the core causes loss in energy

Power is transmitted at high voltage in transmission lines so they can be at a low resistance, and as power dissipated is I^2R, the lower the current, the less power is wasted

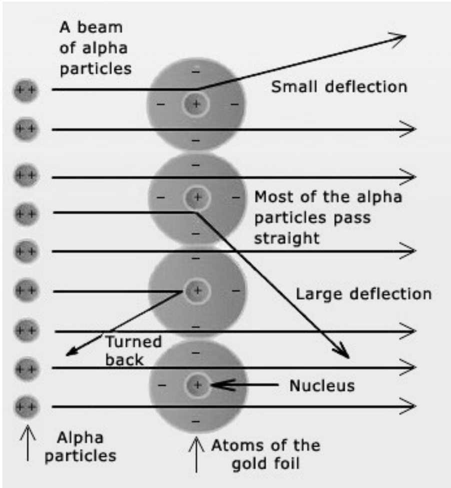
3 Nuclear physics

3.1 Radioactivity

3.1.1 Rutherford scattering



Rutherford's experiment involved firing a beam of alpha particles at gold foil and measuring the paths of particles from the foil.
- Gold was used as it was expected to have a large nucleus
- The screen fluoresces when collided with
- This showed the atom was mostly empty space with a positive nucleus



Observation	Explanation
Most electrons pass all the way through	Atoms are mostly empty space
Some are deflected	The atom has a positive centre
Some are deflected by significant angles	The positive charge is condensed in a small area

3.1.2 α, β and γ radiation

	Alpha	Beta	Gamma
Nature	2 Protons+2 Neutrons	High speed electron or positron	High energy photon
Range	Up to 10cm	Up to 1m	Infinite
Deflection in a magnetic field	Deflected	Opposite direction to α particles and more easily deflected	Not deflected
Absorption	Paper	Aluminium	Lead
Ionisation	10^4 ions per mm	100 ions per mm	Very weak ionising effect
Energy of each particle	Constant for a given source	Varies up to a maximum for a given source	Constant for a given source

3.1.2.1 Inverse square law for gamma radiation

$$I = \frac{k}{x^2}$$

3.1.2.2 Safety

Those working in areas of high radiation, for example nuclear power plants, should wear film badges which monitor a persons exposure to radiation

3.1.2.3 Background radiation

Background radiation has many sources:
- Air (Radon gas)
- Medical
- Ground and buildings
- Food and drink

3.1.2.4 Uses of radiation in medicine

The health benefits from using radiation in medicine almost always outweigh the risks, but doctors must protect themselves as repeated exposure is dangerous

3.1.3 Radioactive decay

$$\frac{\Delta N}{\Delta t} = -\lambda N$$
$$N = N_0 e^{-\lambda t}$$
$$A = \lambda N$$
$$A = A_0 e^{-\lambda t}$$
$$m = m_0 e^{-\lambda t}$$
$$C = C_0 e^{-\lambda t}$$
$$T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

N - Number of nuclei
λ - Decay constant
A - Activity
m - Mass of the isotope
C - Count rate on a Geiger counter
$T_{\frac{1}{2}}$ - Half life of the isotope

3.1.3.1 Constant decay probability

There is a constant decay probability of an isotope, and the decays happen at random, this means that the number of nuclei that decay in a certain time interval depends only on the total number of nuclei present.

3.1.3.2 Applications

3.1.3.2.1 Carbon dating

The half life of carbon-14 is a known value and so can be used to determine the age of objects. By looking at the activity of a live equivalent of equal mass and comparing it, the age can be found.
Example:
Activity =0.28Bq, Live activity=1.3Bq, half life = 5570 years

$$T_{\frac{1}{2}} = 1.76 \times 10^{11}$$

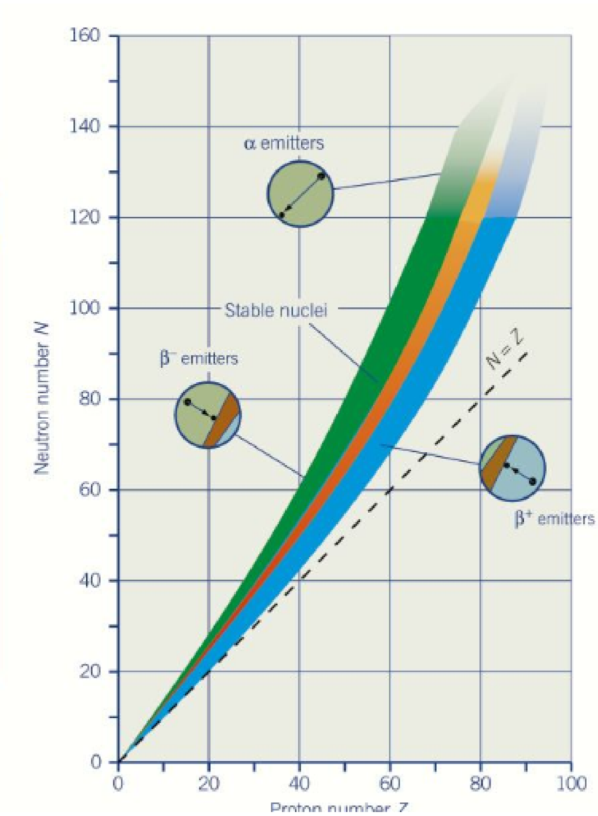
$$\lambda = \frac{\ln 2}{1.76 \times 10^{11}} = 3.95 \times 10^{12}$$
$$A = A_0 e^{-\lambda t} \Rightarrow 0.28 = 1.3 e^{-\lambda t} \Rightarrow \lambda t = 1.535$$
$$t = \frac{1.535}{\lambda} = \frac{1.535}{3.95 \times 10^{-12}} = 3.88 \times 10^{11} s$$

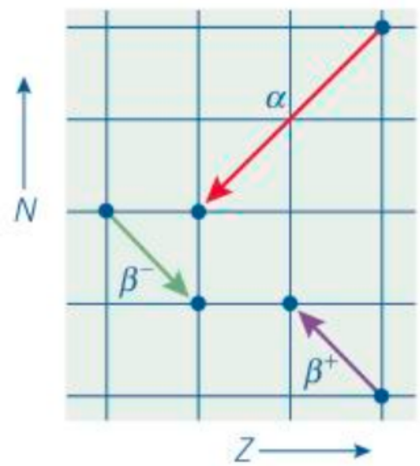
3.1.3.2.2 Radioactive tracers

Radioactive tracers should:

- Have a half life long enough for the necessary measurements to be made, but short enough to decay quickly after use
- Emit β or γ radiation so that it can be detected outside the body

3.1.4 Nuclear instability





▲ Figure 2 N–Z changes

Electron capture would be a horizontal line to the left

3.1.4.1 Nuclear excited states

The nuclear excited state is where the nucleus has more energy than its basic state, to counteract this, the nucleus gives off the energy in the form of a γ ray
This can be used to make artificial gamma ray emitters

3.1.5 Nuclear radius

3.1.5.1 Closest approach of alpha particles

By determining the percentage of α particles that are deflected by more than 90°, around 1 in 10,000. Given n layers of atoms, the probability is 1 in 10,000n. Then determine the cross sectional area of the radius of the atom and nucleus as a ratio.

$$\frac{\frac{1}{4}\pi d^2}{\frac{1}{4}\pi D^2} = \frac{1}{10,000n}$$

$$d^2 = \frac{D^2}{10000n}$$

A typical value of n is 10,000

$$d = \frac{D}{10000}$$

As the diameter of an atom can be more easily measured, this gives a result of around 1fm

3.1.5.2 Electron diffraction

The diffraction of electrons can be used to give a more accurate answer for the nuclear radius. Electrons are accelerated so that their de Broglie wavelength is approximately the radius of the nucleus so that they diffract best.
There is an angle θ_{min} away from the normal at which there is a local minimum intensity, using the relation

$$R \sin\theta_{min} = 0.61\lambda$$

The value of R can be found, λ is the wavelength of the electrons