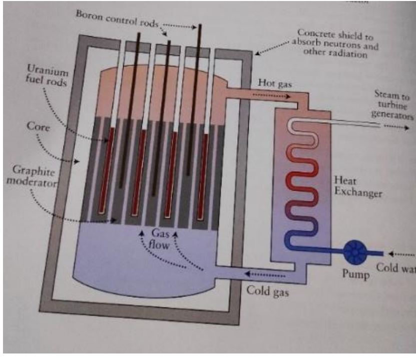
Why fusion difficult: maintain high temp for sufficient time

Nuclear Energy, Fission and Fusion

U fuel is enriched with U-235 as it only contains 0.7%



AGR is a **graphite moderated reactor**. Neutrons released by fission of U-235 collide with atoms of graphite moderator, are slowed to increase chance of further fission on U-245 than absorption by U-238.

Chain Reaction: neutrons released from fission of nucleus that don't escape or get absorbed by a neighbouring nucleus go on to cause further fission reactions with a neighbouring nucleus, releasing more neutrons. Rate neutron production > rate neutron loss to sustain reaction. **Controlled**-power station, **Uncontrolled**-bomb.

Critical Size: min size of reactor capable of sustaining chain reaction. Must have at least enough fissile material to reach critical mass. If core size too small, too many neutrons escape, and chain reaction stops.

Moderator: material such as graphite/(heavy) water which reduces speed of fast neutrons. U-235 undergoes fission w/ slow/thermal neutrons (U-238 fissile with very fast neutrons) **Control Rods**: change fission rate by capturing excessive neutrons and thus decreasing no. available neutrons. Eg. Boron coated steel rod capable of absorbing neutrons without undergoing fission. Max absorption when fully fitted. U in rod < critical size to prevent uncontrolled fission. **How melting control rods leads to uncontrollable reaction**: amount U > critical value, no control over neutrons. **Coolant:** captures/transfers heat released by fission and passes through heat exchanger which produces steam which drives turbine, generating electricity **Shielding:** Thick concrete shield prevents penetrating gamma waves and neutrons from escaping by absorbing them.

Fusion Temp: >15million °C to give H nuclei enough Ek to overcome electrical repulsion between protons. Repulsion causes Ek to decrease and Ep to increase so they must be projected together at very high speed.

Plasma: Ions and electrons (ionized gas/matter)/ gas of ions

Why use plasma confinement: provide correct conditions for fusion (temp, > time, > particle density) **Gravitational Confinement**: Gravitational F confine plasma in stars, not suitable for terrestrial fusion as a mass > earth required. **Inertial Confinement**: intense ion/laser beam directed towards solid fuel pellet to heat it to fusion temp and extract E before plasma escapes. **Magnetic Confinement:** toroidal coils generate magnetic field which exerts F on charged particles. Particles perpendicular to magnetic field move in circular path. Particles at an angle to the field travel in a spiral. $F = Bqv_{perp}$, $Bq = \frac{mv_{perp}}{r}$

Deuterium-Tritium (D-T) reaction: ${}^2_1D + {}^3_1T \rightarrow {}^4_2He + {}^1_0n$, large supply of D from sea water and T from Li, >E release than similar reactions, limited waste: no long-term storage required, single stage reaction, relatively low temp required, plasma easier to control, greater possibility of collisions

ITER Plasma Heating: **1**. induced current by EM induction allows electrons and ions to gain E however as temp and R increase the heating effect is reduced. **2.** D ions accelerated to high v by electric field. gain electron to become neutral, enter plasma and collide with particles, transferring their E to them and heating. **3.** High E microwaves transfer E directly to plasma particles. Specific freq. matches ion/electron type's natural/resonant freq.

Be blanket surrounding vacuum vessel: shields from and slows high E neutrons (absorbs, preventing them from escaping). Their Ek is transferred to heat energy which is collected by water coolant and used for electricity production.

Adv: low CO_2 & SO_2 emission (no contribution to global warming/acid rain/meet climate change targets), employment opportunities, little radioactive waste for fusion, easy to stop fusion reaction, prevent energy crisis due to overdependence on fossil fuels such as oil. **Disadv**: high E input before useful output obtained, expensive plants (superconducting magnets etc), non-renewable nuclear fuels, mining/refining/recycling fuel rods produces CO_2, radioactive materials into environment if accident, waste harmful to health for thousands of years, difficulty storing waste, risk of nuclear accident, power stations targeted for attacks/theft, nuclear power technology used for weapons, construction/decommission cost

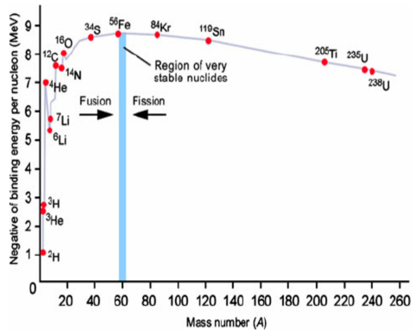


Figure 1- note that graph doesn't go over 9 MeV, peak at A=60 and downslope doesn't go below 6MeV

How $E = \Delta mc^2$. used for nuclear reactions: m of nuclei b4 reaction > m of nuclei after reaction, therefore Δm linked to E

Why could U → Ba + Kr + 2n + Q occur spontaneously? Daughter products are further up BE/n curve & are more stable than U

Nuclei to left of peak undergo fusion to move up curve – fusion of light nuclei to heavier nucleus. **Nuclei to right of peak undergo fission to move up curve** – fission of heavy nucleus to lighter nuclei. Nucleons w/ > BE/n more stable as it takes more E to disintegrate them. Reduction in m when E released. **Binding E**: E that must be supplied to separate nucleus to an infinite distance/ E required to split nucleus into component nucleons **Mass Defect**: difference between total no. constituent nucleons that make up nucleus & mass of nucleus when nucleons are combined. $E = \Delta mc^2$ **Fission**: massive nucleus divides into two less massive nuclei. Avg binding E of fragments > original. Due to >E, some mass of original nucleus converted to Ek of fragments. Release of E via fission only with heavier nuclei. **Fusion:** joining of 2 smaller nuclei to produce heavier more stable nucleus. Release of E since avg binding E of products>original. Due to >E, some mass of original nucleus converted to Ek of products (heat generated from these fragments). Mass heavier nucleus < combined mass of lighter nuclei. E release via fusion only with lighter nuclei. No fusion at room temp due to repulsive electric force between +ve charged nuclei. Only when speed of colliding nuclei is great enough to overcome repulsion and enter range of strong nuclear F is fusion triggered. 15 million °C for H nuclei. **Fusion v Fission:** more than 3 times as much E released per nucleon in fusion than fission. Fusion has no long-lived radioactive waste products. Almost unlimited supply of fuel for fusion

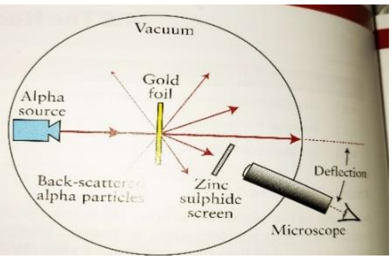
Exam Technique: work out Δm in u, convert to kg, multiply by $c^2$to get E in J, convert to MeV by dividing by $1 \cdot 6 \times 10^{-13}$, Binding E per nucleon = E/no. nucleons.

The Nucleus and Nuclear Decay

Atomic Structure: JJ Thompson developed Kelvin's idea into plum pudding model (+ charged sphere w/ electrons inside)

If this model was correct there would be no back scattering and a small no. deflected

Rutherford, Marsden & Geiger Experiment - α particles in vacuum to avoid deflection by collisions with air molecules, incident on gold foil, detected by scintillations produced on hitting fluorescent screen. Microscope moved to position, angle & no. flashes measures, microscope moved to new angle and repeat.



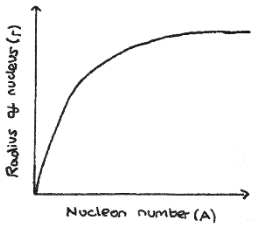
1. most particles passed though (didn't come close enough to any repulsive charge) therefore atom mostly empty space

2. Particles + charged & deflected therefore nucleus + charged

3. 1/8000 scattered back therefore nucleus much more massive than particle (factor 50)

Edge of nucleus doesn't have sharp edge

$r = r_0 A^{\frac{1}{3}}$,$r_0 = 1.2x10^{-15}$m, $V = \frac{4\pi r^3}{3} = \frac{4\pi r_0{}^3 A}{3}$, M=Am, $\rho = \frac{M}{V} = \frac{3Am}{4\pi r_0{}^3 A} = \frac{3m}{4\pi r_0{}^3}$, $r_0 = radius\ of\ nucleon$



Ratio of 10^{15} between atomic and nuclear density as atomic diameter $\sim 10^{-10}$ and volume $\sim 10^{-30}$, whereas nucleus diameter $\sim 10^{-15}$ and volume $\sim 10^{-45}$

Nucleons (protons & neutrons) held together by strong interaction (stronger than repulsion between nucleons). Isotopes – nuclei w/ same no. protons but differing no. neutrons

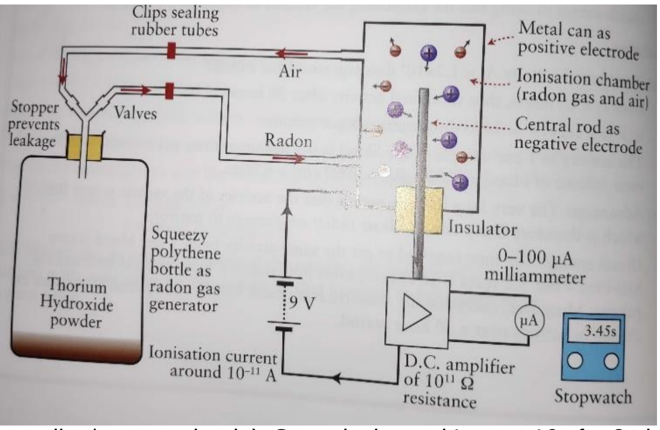
${}^{A}_{Z}X$, A: mass no. (no. nucleons), Z: atomic no. (no. protons)

Radioactive decay – unstable isotopes disintegrate spontaneously to a more stable nucleus with the release of α, β, or γ radiation. 1Bq = 1 disintegration/sec

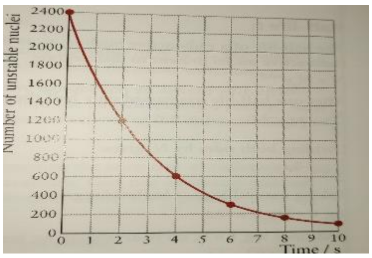
	Charge	Penetration	Ionization	${}^{A}_{Z}X$ →
α	+	Low (4cm air)	High	${}^{A-4}_{Z-2}Y + {}^{4}_{2}He$
β	-	Medium (meters air)	Medium	${}_{Z+1}^{A}Y + {}^{0}_{-1}e$
γ	no	High	Low	${}^{A}_{Z}X + \gamma$

α is slow (5% c) He nucleus, E loss by ionization, stopped by paper

Ionization – electrically neutral atoms convert to ions as decay particle causes electron ejection from atom, **Ion-Pair**: +&- ion produced together. **Decay** unaffected by temp, chem reactions etc



$N = N_0 e^{-\lambda t}$, Rate of decay directly proportional to no. unstable nuclei, A = -λN, $decay\ const. = fraction\ unstable\ nuclei\ that\ decay/sec$, $t_{\frac{1}{2}}$ = time for half nuclei to disintegrate/ activity to fall to half original = 0.693/λ from $\frac{N_0}{2} = N_0 e^{-\lambda t_{\frac{1}{2}}}$, Longer $t_{\frac{1}{2}}$ means low A so less radiation

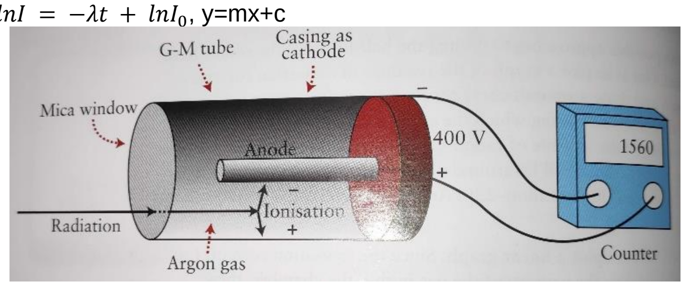


Why consider $t_{\frac{1}{2}}$ when source used for medical imaging: must be long enough to remain in bloodstream and be carries around body for detection. Must be short enough for minimal exposure

Finding $t_{\frac{1}{2}}$ w/ ionization chamber Adjust amplifier, fill chamber w/ gas (release clips/squeeze bottle), Start clock, read I every 10s for 3min

Ionization current directly proportional to no. & activity of gas atoms, $I = I_0 e^{-\lambda t}$, $lnI = -\lambda t + lnI_0$, y=mx+c

Finding $t_{\frac{1}{2}}$ w/ counter



Correct for background radiation (avg over 30min)

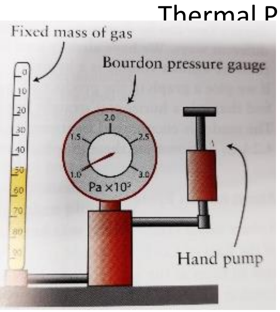
Protactinium-234 source from U-238 compound in bottle

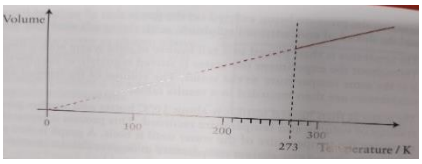
Reading in counts/ min from GM tube and ratemeter

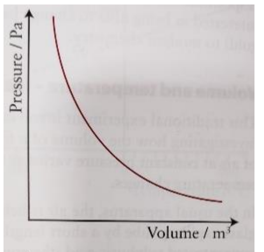
Characteristic of isotope that makes it suitable for exp: half life between 50s and 6 hrs (roughly), short half life

Plot count rate/ t, find t to half, repat+avg, or plot ln (corrected count rate) / t, grad = - λ, safety: shielding, distance, duration

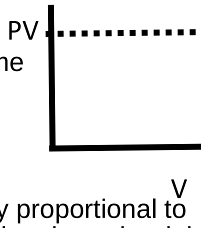
Thermal Physics







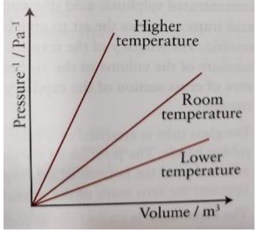
Boyle's Law: For a fixed mass of gas at const. temp, V is inversely proportional to P, pV = const

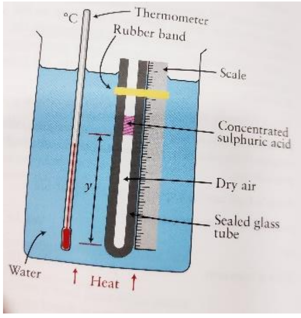


If column of air has constant CSA, length proportional to volume

Oil should have low vapor pressure to keep gas mass const.

Wait for air to return to room temp after using pump



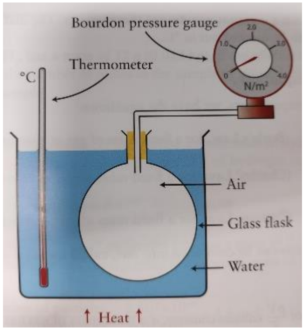


Charles' Law: For a fixed mass of gas at const. P, V is directly proportional to Kelvin (absolute) T, V/ T = const. L against T (in K) is straight line through origin

Acid dries air, length of trapped air is V as diameter const, P on gas from atmosphere and acid

Stir so T-Air = T-Water, Heated 10°C and readings taken (V & T)

Absolute Zero: -273°C/ 0K: theoretcal temp at which molecules stationary as substance has 0 thermal energy



Guy Lussac/ Pressure Law: For fixed mass gas at const. V, P is directly proportional to K/ absolute temp, P/T = const.

Apparatus may also be ised as thermometer with dial on pressure gauge set to °C (constant volume gas thermometer)

Ideal Gas Equ. PV/T = const. PV = nRT = NkT (in Kelvin)

Mole is amount of substance containing same no. particles as atoms in 0.012kh of C-12

$N_A = \frac{N}{n} =$ no. particles per mol.Molecular mass (m) = $\frac{molar\ mass}{N_A}$ No moles 1kg U-235 = 1000/235 = 4.2

Kinetic Theory – no intermolecular F, molecule's V negligible, const. v between perfectly elastic collsiions (Ek and ρ conserved) of negligible duration

Pressure = $\frac{Total\ F\ exerted\ by\ all\ colliding\ molecules}{A\ of\ wall}$: collisions cause Δρv (implying F and reactive F from Newton's Laws)

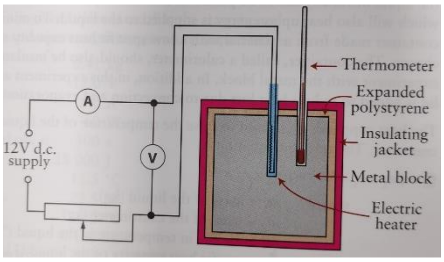
Boyle's Law: <V = <d between collsions, Δρ same but >freq therfore >P

Charles' Law: >T = >Ek therefore >Δρ per collsion, to maintain pressure const. freq decreases, >V =>d=<freq

Pressure Law: >T = >Ek, >Δρ &freq. therefore >P

Avogadro's Law: equal V of all gases under same conditions contain same no molecules. $k = \frac{R}{N_A}$

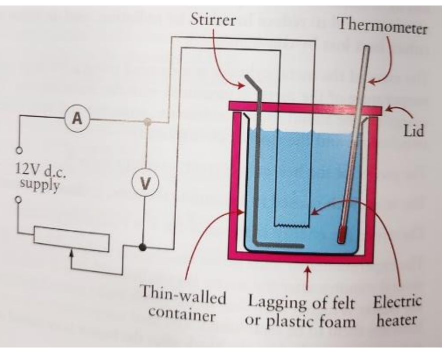
$PV = \frac{1}{3}\rho N m < c^2 >$, $root\ mean\ square\ speed = \sqrt{< c^2 >}$, $P = \frac{1}{3}\rho < c^2 >$, $\rho = Nm/V = M/V$, $\frac{F}{\Delta P} = A$, $\frac{1}{2}m < c^2 > = \frac{3}{2}kT$



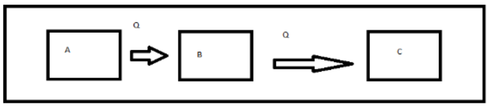
Real gas Ek+Ep, Ideal gas: only Ek,

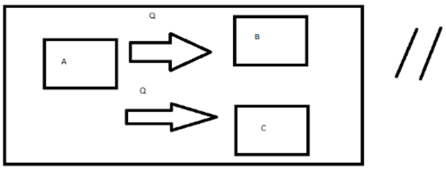
SHC exp: Oil around thermometer to improve thermal contact, insulator reduces heat loss by conduction, foil reduces loss by radiation & jacket by convection, mass measured w/ balance, record intial temp, switch on heater (heat 15°C), record V&I, t w/ stopclock, final temp takern as highest temp reached by block after heater switched off $c = \frac{Pt}{m\Delta\theta}$

Insulating lid reduces heat loss by evaporation & convection



Q = Q(liquid) + Q(calorimeter), heat loss to environment, reduce error: cool liquid to 5°C, start exp when liquiad & calorimeter both (room temp - 5), heat to (room temp + 5 so heat loss cancels heat gain (from environment)





SHC: quantity heat E required to raise 1kg of a sample by 1K/1°C

If block lagged, all heat supplied heats block (no loss)

Scales not used for final mass as mass lost to evaporation

Gas behaves more ideal at >T & <P, as Epot becomes less significan

For wind turbine: $P = \frac{1}{2}\rho A v^3$

Power only depends on v, as ρ and A are fixed

$\delta = \frac{F}{A}, \varepsilon = \frac{\Delta L}{L_0}, E = \frac{\delta}{\varepsilon}$

UCM, SHM, Deformation of Solids

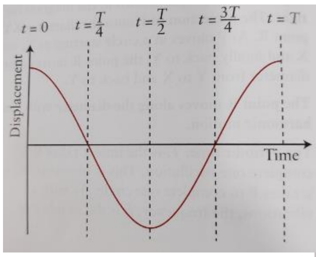
F is restoring force

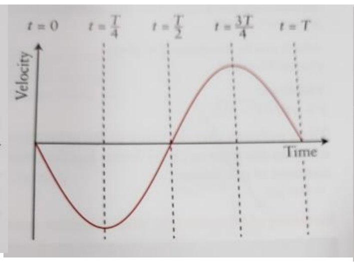
s=rθ, $\omega = \frac{2\pi}{T}$, v=r ω, $a = \frac{v^2}{r} = v\omega = r\omega^2$

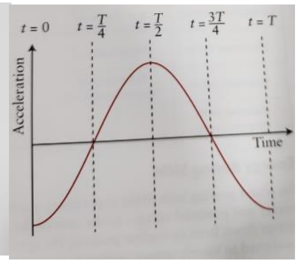
$E_k = \frac{1}{2}m\omega^2A^2sin^2\omega t, T = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{m}{k}}$, Tension = ke, F=kx, E=kA^2

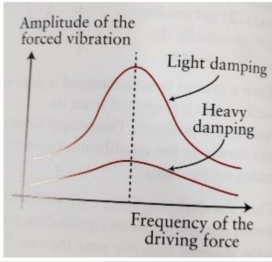
	Displacement	Velocity	Acceleration
Variation w/ t	$Acos\omega t$	$-\omega Asin\omega t$	$-\omega^2 Acos\omega t$
Max	Amplitude=A	At fixed point (equilibrium) x=0, v=ωA	Extremity of x, $a = \omega^2 A$
Min	At fixed point (equilibrium), 0	Extremity of x, 0	At fixed point, 0
Variation w/ x		$\omega\sqrt{(A^2 - x^2)}$	$\omega^2 x$

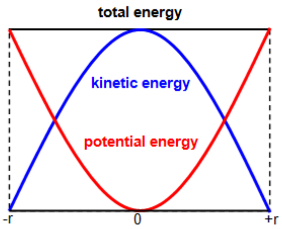
Free vibration/undamped – no E transfer to/from system, Forced vibration (ex Barton's Pendulums) – forced to oscillate at freq. of eternal oscillator which is giving it E, Condition for resonance: driving freq. = natural freq. Example of resonating system: singer and class, how to damp this system: fill with water, Oscillate in water to increase damping

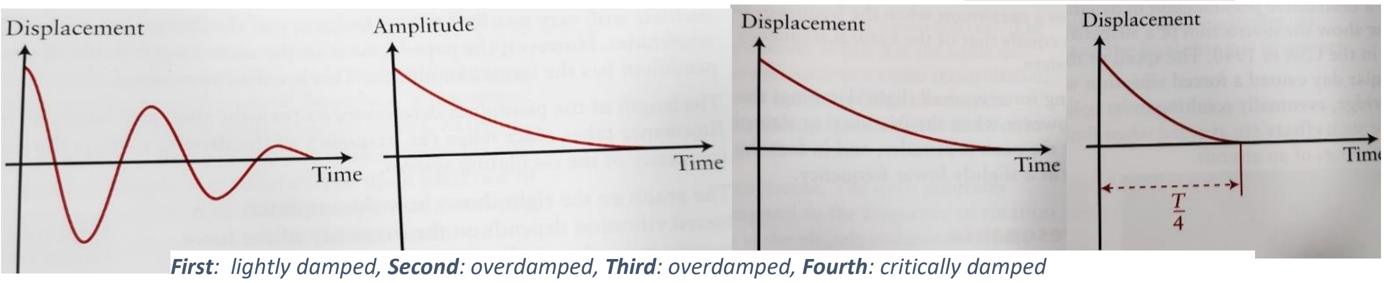








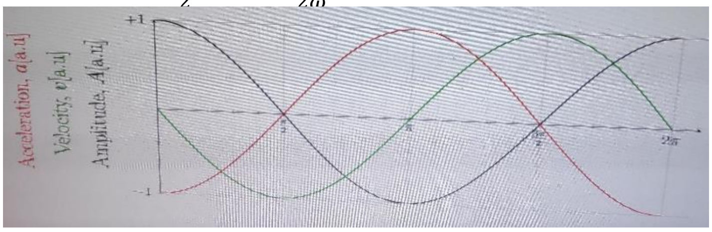




***First**: lightly damped, **Second**: overdamped, **Third**: overdamped, **Fourth**: critically damped*

Cyclist on bend has ω as they sweep an angle over time, Fr between tyres&road permit the UCM. **SHM**: a directly proportional to d from fixed point & direted towards fixed point**.** **Cause of damping** for moving obj is fr, effect is E loss and <A, **how travel in circle at const speed but have a?** direction & thus v changing, a is rate of change of v. **When obj first reaches equilibrium**: $x(t) = Acos\omega t, A\ can't\ be\ 0\ \therefore\ cos\omega t = 0, \omega t = \cos^{-1}(0) = \frac{\pi}{2}, \therefore\ t = \frac{\pi}{2\omega}$

	SHM	UCM
T	T for one oscillation	T for one revolution/orbit
F	Acts toward equilibrium	Acts toward centre of circle
	Varies depending on position of object	Const.



Both overdamped and critically damped systems lose E and return to equilibrium position without oscillating, Critically damped does so in the quickest possible time, **Total E of system is not conserved** as E leaves the system to move air particles/ due to air resistance

Why chain w/ hammer can't be horz: W_hammer acts downwards and must be balanced by vertical tension component

Hooke's Law: F directly proportional to x produced provided proportional limit not exceeded, F=-kx

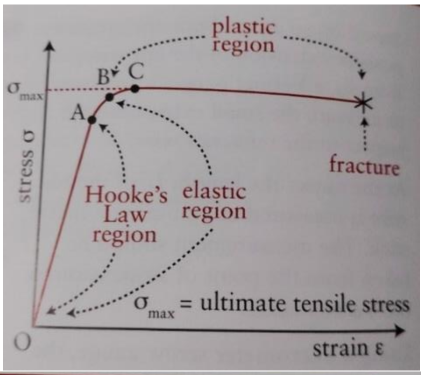
Elastic Limit: max load specimen can experience and return to original length when deforming F removed. **Elastic Deformation,** after this is **Plastic Deformation**

UTS: max stress applied to wire without breaking/fracturing

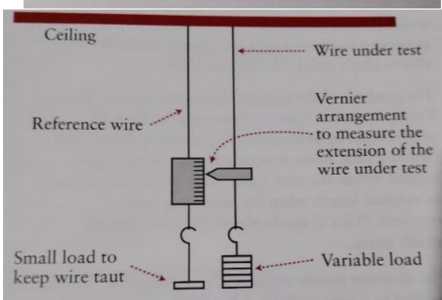
Elastic Strain Energy: Es = $\frac{1}{2}kx^2$ (work done in stretching material held as Ep)

Strain gauge to measure crack width in walls

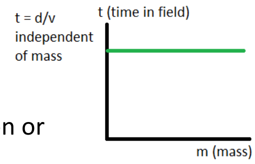
Experiment: measure unstretched L. Measure x for range of F, L with metre rule clamped to pointer, x with ruler, d of wire at several places with micrometre gauge and avg, wear goggles as wire could break under tension

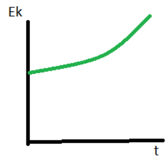


Combined spring constant: Series: $x_T = x_1 + x_2 = \frac{F}{k_T} = \frac{F}{k_1} + \frac{F}{k_2} \therefore \frac{1}{k_T} = \frac{1}{k_1} + \frac{1}{k_2} \therefore k_T = \frac{k_1 k_2}{k_1 + k_2}$ // F is same for all springs. **Parallel**: $F_T = F_1 + F_2 = k_1 x + k_2 x = k_T x \therefore k_1 + k_2 = k_T$ // x is the same for all springs



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

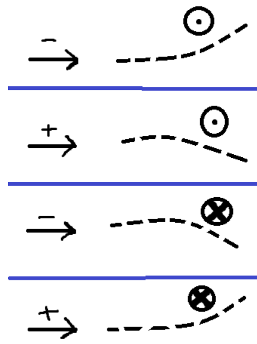


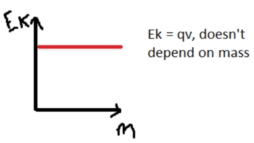


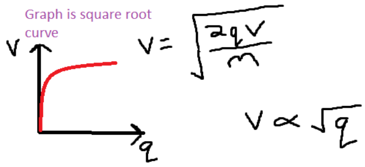
Deflection of Charged Particles and Particle Accelerators

Be careful which mass to use in deflection questions as it varies based on whether it says electron or proton beam

Experiment: beams of electrons produced by electron gun. Electrons with sufficient energy escape from the surface of heated wire filament (thermionic emission). They emerge into an electric field created by P.D between cathode & anode. They are accelerated – losing potential and gaining kinetic energy. Beam emerges through opening in anode. Fluorescent screen emits green light when struck by electrons. Positive Maltese cross electrode deflects electrons away from screen so shadow can be observed.







Parabolic path within uniform electric field. Final velocity of electron is resultant of the horizontal and vertical components of the velocity.

Particles move in circular arc as force acts at right angles to velocity. $F = Bqv = \frac{mv^2}{r}, r = \frac{mv}{Bq}$, lower v gives an arc of lower r

It is sometimes the case that the final velocity given refers to the final horizontal velocity after accelerating the ions as opposed to the final vertcal velocity where it meets the bottom plate

Flemings left hand rule considers conventional current flow.

$v_0^y = 0,\ v_F^y = v_0^y + at, a = \frac{F}{m} = \frac{Eq}{m}, v_F^y = at = \frac{Eq}{m}t$

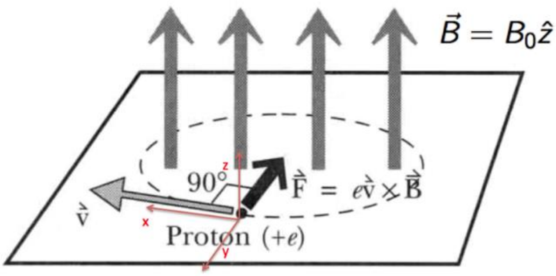
$E_K^{GAIN} = \frac{1}{2}mv^2 = \frac{1}{2}m(\frac{Eq}{m}t)^2 = \frac{E^2q^2}{2m}t^2$

Note there is still an initial Ek due to the horizontal velocity

F = qE, if q is negative, force has negative sign so is opposite direction to field. If q is positive, force is same direction as field

F = qvB Sin(α), If v and B aligned, then α = 0 so F = 0

Work Done = qv



The Lorentz (EM force) is a combination of the $\tilde{E}$ & $\tilde{B}$ fields. Derication of $F = qE + qv\ X\ B$ for the specific geometry shown (magnetic field only in z plane with origin of circle at 0,0) shows that the example path of charged particles in a constant B field perpendicular to v is:

$$\frac{mv_0}{qB_z}Sin(\frac{qB_zt}{m}), \frac{mv_0}{qB_z}Cos(\frac{qB_zt}{m})$$

The circular motion is a result of eigenvectors of a rotation matrix as the magnetic field is a rotating plane and thus the field does no work on the moving charge.

Synchrotron: Confines accelerated particles confined to circle of constant radius by B field in vacuum (to prevent energy loss by unintended collisions/ interaction with air particles). May collide particles (multiple loops to increase speed, which increases relativistic mass which weakens repulsive force) or be used to study radiation. Sends data to scientists globally. Max energy of around 6.5 Tev

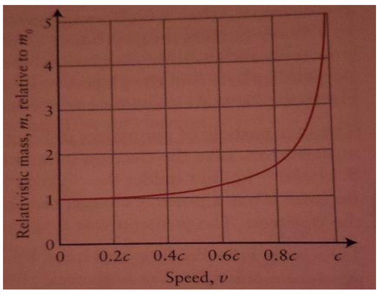
Particles accelerated by high frequency alternating voltage (P.D) at acceleration cavities (allows B field to only be applied to circumference). Cavities contain alternating electric fields synchronized with orbital period to accelerate charges as they reach and pass through each cavity. Particles are repelled from one electrode and attracted to the next. Particles may be accelerated in a booster ring and moved to a storage ring until needed. Electrodes connected to high frequency alternating voltage give particles energy.

As particle speed increases, frequency of a.c supply and thus magnetic force must increase to provide centripetal force to maintain synchronous acceleration. This ensures fixed radius as it takes particle less time to complete orbit. Unless it's an electron synchrotron as they travel close to c, so frequency is roughly const. and so a const. accelerating voltage is used. Large radius required to reach high energy as particles would collide with the side of a smaller loop due to the limitation on magnetic field strength. Linear accelerator injects particles into synchrotron at tangent.

Neutrons can't be used in synchrotrons as they aren't charged and can't experience a magnetic force in the same way as protons/electrons.

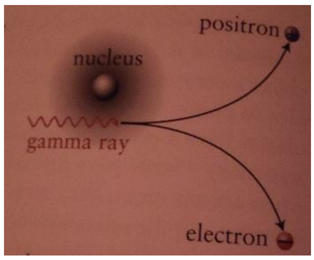
Magnets: Incoming beam deflected into orbit by dipole magnet and outgoing, accelerated beam deflected out. There are several extraction points at tangents to allow multiple groups of scientists to work simultaneously. Quadrupole magnets maintain circular orbit by focusing beam which means the intensity (particles per unit area/sec) increases and smaller gaps are required between magnet poles.

Why superconducting electromagnets used & how state achieved: Reduce resistance of coils to 0 to increase current and achieve large magnetic field strength. State reached by cooling electromagnets in liquid helium to their critical/transition temp.



Relativistic Mass Increase: mass increases with speed but is negligible in ordinary situations like speed of car, however close to c, it is significant.

No object with a rest mass can exceed the speed of light. Particles in synchrotrons are close to c, so the current applied to the coils (and thus B (flux density)) is increased under computer control. They can continue to gain Ek but not v as their m increases, where $m = \frac{m_0}{\sqrt{1-(\frac{v}{c})^2}}$



Deflection of Charged Particles and Particle Accelerators

Antimatter: material composed of anti-particles. **Anti-particles:** same m as ordinary matter but opposite charge/spin. Every particle has corresponding anti-particle (some of which have been produced in particle accelerators). First anti-particle was the anti-electron (positron).

Positron slightly above horizontal velocity vector and electron slightly below initially. Both can't be on one side as momentum must be conserved so there can't eb a resultant vertical momentum.

Annihilation: 2 protons emitted when particle and anti-particle collide as mass must be conserved (converted to energy of photons, E = m$c^2 = \frac{hc}{\lambda} = hf$, each have 0.5 of total E). Momentum must also be conserved so there must be 2 photons travelling in opposite directions.

Annihilation of x kg of antimatter releases E = 2xc^2

Positron emission tomography: $\boldsymbol{^{11}C}$ injected into patient, decays to emit positron, annihilation w/ electron, produces γ photons, detected by scintillations when reach scanning device, used to produce image of tissue

If for example the increase in speed $\frac{m_2}{m_1}$ is a factor of 8.09 then the % increase in mass is 709%

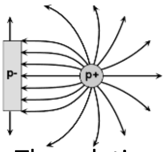
The 3 particles in the nucleus of ^3He if it were composed entirely of anti-matter would be 2 anti-protons and an anti-neutron.

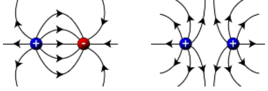
It is unknown why there are not equal amounts of matter & anti-matter in the universe or why anti-matter is so uncommon in interstellar space

2hf = $2mc^2$

Electron-Positron Collision: $\boldsymbol{{}_{-1}^{0}e + {}_{1}^{0}e \rightarrow \gamma + \gamma}$

Pair production: Photon to electron and positron, energy transfer: $\boldsymbol{E_K^{PARTICLE} = \frac{1}{2}(E_{PHOTON} - E_{PARTICLES}) = \frac{1}{2}(hf - 2mc^2)}$





Force Fields, Gravitational and Electric Fields

Field	Property
Gravitational	Mass
Electric	Charge
Magnetic	Moving Charge (accelerating?)

The relative no. of field lines (/density of lines) allow you to differentiate between a small positive charge and a large mass for example

Fig. 2.1
+2μC

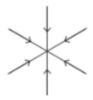


Fig. 2.2
4kg

Field of force: region/volume of space in which bodies with a particular property experience a force.

Field lines: visual representation of field, field direction = tangent to field line, Field lines can't cross as this would imply omnidirection but a field is unidirectional at a given point, closer lines = stronger field,parrallel&equally spaced = uniform field, Lines converge/diverge = radial non-uniform field, field strength = vector

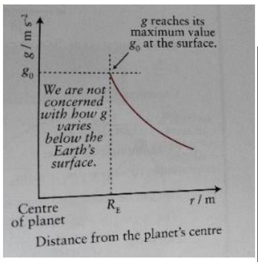
Newton'sLaw of Universal Gravitation: $F = G\frac{mM}{r^2}$, Every body in the universe attracts every other body. Between two point masses the gravitational force of attraction is directly propotional to the product of the masses and inversely proportional to the square of their separation

Gravitational Field Strength: Force per unit mass. **Gravitational field:** region where an object with mass experiences a force.

F has infinite range, field lines are radially inwards, field lines hit surface at right angles, as the radius is large, the lines can be considered uniform, not concerned with how g varies below earths surface.

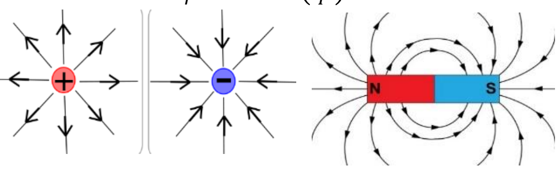
At the neutral point between two bodies, the field strength due to each is equal so total is zero, more difficult to travel from more massive body to less massive as more work needs to be done against a larger gravitational force for a longer distance (pulled to destination after passing neutral point).

Kepler's Third Law: The square of the period of revolution of the planets about the Sun is directly proportional to the cube of their mean distances from it. $\frac{T^2}{r^3}$ = const.

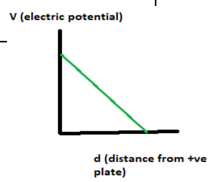


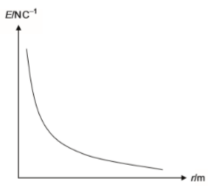
Geostationary	
T	24 hrs (geosynchronous) (note: same ω)
Height	3.59 × 10^7 m
Radius	4.23 × 10^7 m
Direction	Same as Earth's rotation
Energy	Don't require energy as Ek and Ep are constant
Use	Communication, meteorology etc
Position	Above equator

To link Kepler & Newton laws use: $F_c = F_g = mr\omega^2 = G\frac{mM}{r^2} = mr\left(\frac{2\pi}{T}\right)^2$



Electric field strength, $E = \frac{F}{q}$, **Force per unit charge**

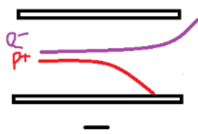




Vector **direction** of field strength is that of the force on the + charge.

Coulomb's Law: Between every two, point charges there exists an electrical force that is directly proportional to the product of the charges and is inversely proportional to the square of their separation

$F = \frac{kq_1q_2}{r^2} = \frac{q_1q_2}{4\pi\varepsilon_0 r^2}$, where ε_0 is the permittivity of free space (vacuum)



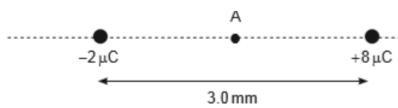
At neutral point between two charges the field strength as a result of each charge is equal. Field towards negative and away from positive by convention

Same E at all points on a charged sphere. Electric field strength within charged plates is uniform, however, electrical potential decreases as the distance from the positive plate increases. $E = -\frac{V}{d} = -\,potential\ gradient$

	Gravitational	Electric
Differences	Acts on mass, Always attractive (lines radially inwards), Can't shield from it	Acts on charges, Attractive or repulsive (lines radially inwards or radially outwards), Shielding is possible
Similarities	Both follow inverse square rule where field strength decreases from point as $\frac{1}{r^2}$ (and spacing between lines increases), Infinite range, Both radial	

If a charged sphere is placed beside another charged sphere on a string, then the horizontal component of tension in the string is equal to the magnitude of the repulsive force between the spheres

The neutral point for this system is located to the left of the -2μC charge as the forces must be opposing directions. This also increases the distance from 8μC charge, decreasing, it's magnitude. This allows for a balance of direction and magnitude, leading to a resultant force, at that point, of zero.



If a -4μC charge is placed at A then the resultant force on it will be $\frac{KQ_8Q_4}{(1.5mm)^2} + \frac{KQ_2Q_4}{(1.5mm)^2}$

May need to equate electrostatic force with either weight or centripetal force for some questions

For an electron accelerated through a potential difference (not the same as the voltage of the plates): $eV = \frac{1}{2}mv^2$

Fundamental Particles

Elementary/fundamental particle: Particle not known to be made up of smaller particles. It has no substructure; other particles are made from it.

Why proton/neutron not elementary: Can't explain why the electrical repulsion of positively charge protons don't split nucleus or the forces involved in radioactive decay producing alpha, beta and gamma radiation.

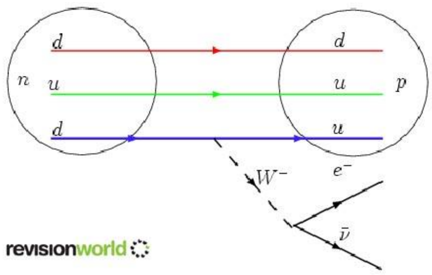
Standard Model: classification of particles based on properties as either gauge bosons, leptons, or hadrons.

Force	**What it does**	**Strength**	**Range**	**Gauge boson**
Strong	Holds nucleus together	1	$1x10^{-15}m \sim$ diameter of nucelus	Gluons
EM	Attractive/repulsive force between charged particles	$\sim\frac{1}{150}$	Infinite	Photon
Weak	Induces beta decay	$1x10^{-6}$	$1x10^{-18}m \sim$ diameter of proton	W and Z bosons (W^+, W^-, Z^0)
Gravity	Attractive force between masses	$\sim 1x10^{-39}$	Infinite	Graviton (theoritical)

Electrons not affected by strong interaction as its range is too short so only acts on hadrons in the nucleus

Leptons: Fundamental. Muons, tau, electron. Not affected by strong interaction. Charged leptons affected by electromagnetic force. Affected by weak interaction. Leptons w/ mass affected by gravity. **Particles** have charge of -1 and lepton number of 1. **Antiparticles** have a charge of 1 and lepton number of -1. **Neutrinos** have no mass or charge and symbol v

Hadrons: Not fundamental. Affected by strong interaction. **Baryons** (neutrons and protons). **Mesons** (pions). Mesons consist of a quark-antiquark doublet whereas baryons consist of a triplet.



Leptons	**Hadrons**
Not affected by strong interaction	Affected by strong interaction
Fundamental (no quark structure)	Composite (have quark structure)

Baryons: particles have a baryon number of 1, anti-particles have a baryon number of -1

Mesons: particles and anti-particles have a baryon number of 0

Equations: Charge, baryon number and lepton number are all conserved in interactions.

Gauge bosons: exchange particles which mediate the force between the fundamental particles involved in the four fundamental forces

In research: Electrons, unlike protons and neutrons are not affected but the strong nuclear force and so may be used to bombard nuclei.

Quark	**Charge**	**Baryon**
u	$+\frac{2}{3}e$	$\frac{1}{3}$
d	$-\frac{1}{3}e$	$\frac{1}{3}$

Beta minus Decay: result of the weak nuclear interaction

$^1_0n + \rightarrow {}^1_1p + {}^0_{-1}e^- + {}^0_0\overline{v}_e$ $\quad udd + \rightarrow uud + {}^0_{-1}e^- + {}^0_0\overline{v}_e$ $\quad d \rightarrow u + W^- \, followed \, by \, W^- \rightarrow e^- + \overline{v}_e$

Quark Models: p uud, n udd, $\pi^0 \, u\bar{u}$, $\pi^+ \, u\bar{d}$, $\pi^- \, d\bar{u}$, $\overline{\pi^0} \, u\bar{u}$

Anti-quarks have oppposite charge and baryon number

Magnetic Fields and Capacitors

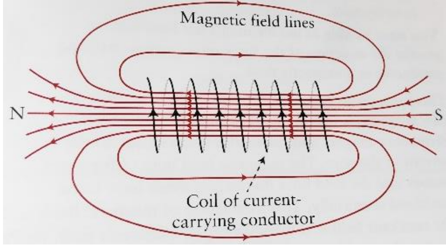
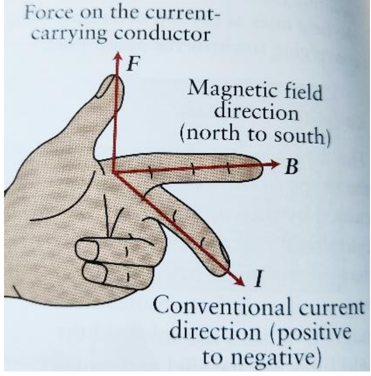


Figure 1: uniform centre, loop outside

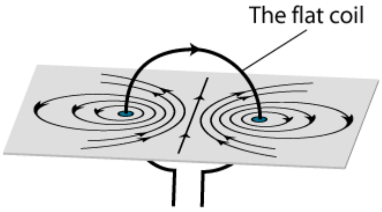


Direction: direction of F that acts on a North pole placed at that point, from north to south

Asked for direction of B: if it is into th epage then write it as perpendicular to and into the page, for full marks

Strength uniform in central portion of field, weakens at edges

Right hand grip rule: thumb points in direction of conventional current, direction fingers are turning gives field direction



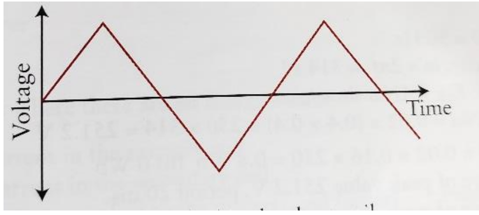
Magnetic field pattern generated by a flat coil

Shape and Direction of field produced by current in straight wire: closed circles around the vertical wire

Increase strength: >I, >N, add soft iron rod in coil with axis perpendicular to coil plane

Force due to interaction of two magnetic fields (field due to 1. Magnet and 2. Current in wire)

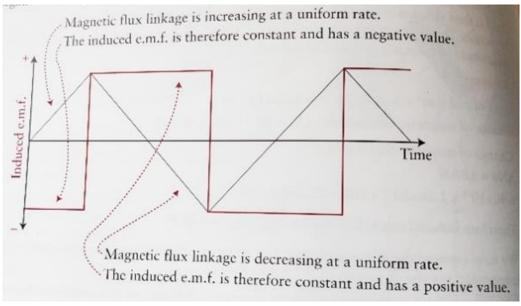
$B = \frac{F}{IL}$ **Magnetic flux density** = force per unit carrying length



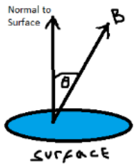
How variable d.c supply can change emf: Magnitude: increase rate of change/ change current faster, Direction: reverse polarity of supply/ increase current

Force on current carrying conductor in magnetic field measured on balance: F on wire causes by I flowing in B field, Upward force on wire, Equal and opposite downward F on magnet assembly (giving higher reading on scales). May need to use F = Δmg. More I is needed for same readings with smaller wire, safety- don't let I get too high as it causes heating

To get 2 readings (one +ve and one -ve) for each current you can reverse B field direction or reverse current direction by reversing polarity of power supply



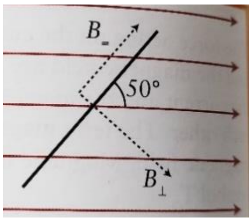
Principle of electric motor Left side of loop experiences upward force while right side, downward. Resultant moment turns coil. $F = NIBL$



$\emptyset = BA$, $N\emptyset = BANcos\theta = BANcos(\omega t)$, where $N\emptyset$ = magnetic flux linkage in webers (Wb), $E = BAN\omega sin(\omega t)$

Weber: (Magnetic) flux linking a 1 turn coil producing 1 V per second

Tesla: One tesla is the magnetic flux density which will cause a conductor 1 meter long carrying a current of one amp at right angles to the field to experience a force of one newton.

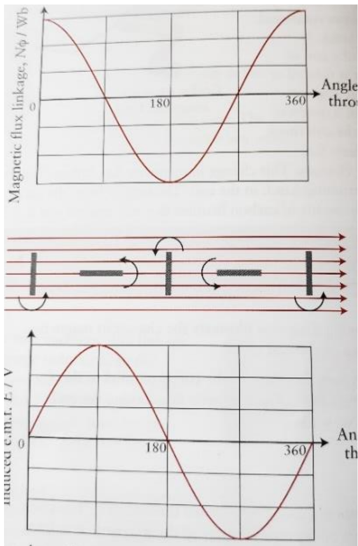


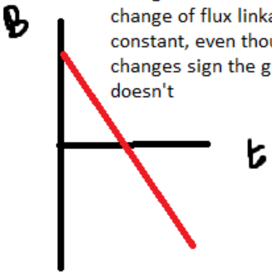
$N\emptyset$ = BAN when e.m.f = 0, when e.m.f is max, $N\emptyset = 0$

$N\emptyset$ is cosine function, e.m.f is sine function, Note: one is max when the other is zero

|F| = BILsin(α), where α is the angle between the magnetic field and current direction

Max F when I and B fields perpendicular, Min F (zero) when I and B field in same direction (when wire is parallel to field lines) or act 180° to each other





For a selenoid, current doesn't change direction as the rate of change of flux linkage is constant, even though the field changes sign the gradient doesn't

For one coil, ie N=1: $E = \frac{BAN}{t} = \frac{BA}{t}, A = m \cdot m = l \cdot l, E = \frac{B \cdot l \cdot l}{t}, v = \frac{l}{t}, E = Blv$

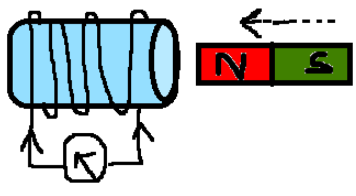
For **EM Induction** there must be relative motion between the magnet and conductor

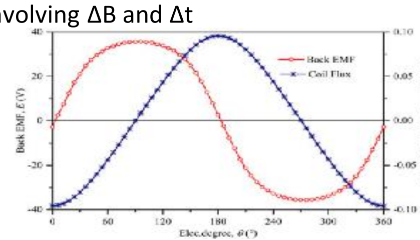
Faraday's Law of EM Induction: induced emf is equal to rate of change of flux linkage/ proportional to rate of change of flux, demonstrated by changing the speed of movement of magnet/coil

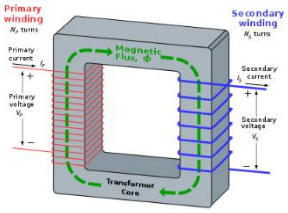
Lenz's Law: direction of induced current opposes change in magnetic flux producing it, demonstrated by changing the direction of the magnet which changes the direction of the meter deflection

Why emf goes from + to – when magnet dropped through coil: induced N pole at top of coil as magnet approaches causes a + emf at point of entry, polarity reverses as magnet leaves (attraction), so the direction of current and thus emf reverses to -, there will be a larger negative emf peak as the magnet is moving faster so rate of change increases

$E = \frac{-\Delta N\phi}{\Delta t}$ ie minus the gradient of the magnetic flux linkage against time graph. When Coil is perpendicular to field, Magnetic flux through coil is maximum so rate of change of flux = 0 (Thus emf induced is zero), also note than if the e only takes 1s to go from max to min, important for questions involving ΔB and Δt

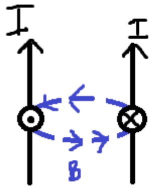






ds and Capacitors

Assuming no E loss, but, it is lost due to:



Two parallel wires carrying current in same direction: force between them is attractive due to the circular magnetic field

Transformer: a.c input to primary coil produces changing ϕ which produces changing ϕ in secondary coil (as they are linked by a (laminated, continuous loop, soft etc) soft iron core which maximizes ϕ) a.c output (emf) induced in secondary coil, $\frac{N_S}{N_P} = \frac{V_S}{V_P} = \frac{I_P}{I_S}$

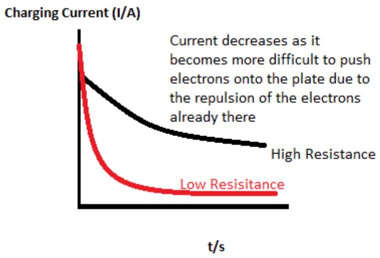
Problem	Solution
Resistive wire heat (windings of both coils)	Oil as coolant/ use lower R wire
Not all magnetic flux passes through secondary coil (flux leakage/loss)	Wind both coils on one limb of core/on top of each other/ continuous loop structure core
Reversing magnetization direction results in large eddy currents which increase the heat of iron core (which heats wires and increases their resistance)	Laminate core
Hysteresis (lag between induction and force)	Soft iron

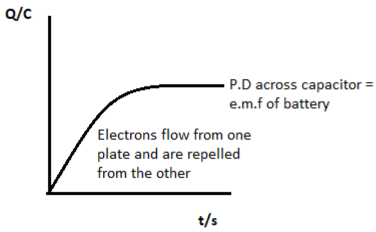
Transmission: Step up, transmit, step down: $P_{LOSS} = I^2R$, decreasing R with large wires isn't feasible so we step up voltage (which in turn reduces current). $I = \frac{P_{Gen}}{V} \therefore P_{LOSS} = \frac{P_{Gen}^2}{V^2}R = I_S^2R,\ eff = \frac{P_S}{P_P}$

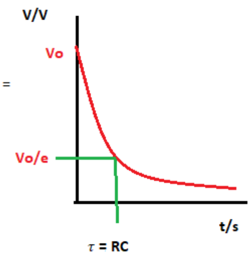
Step Up	Step Down
$N_S > N_P$	$N_S < N_P$
$V_S > V_P$	$V_S < V_P$
$I_S < I_P$	$I_S > I_P$

Capacitance/Farad: charge stored per volt, $C = \frac{Q}{V}$, Parallel: $C_T = C_1 + C_2$, Series: $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2}$, E = $\frac{1}{2}QV = \frac{1}{2}CV^2$

Charging/Discharging experiment: Switch closed: charges*. Switch open: discharges through resistor (which slows rate of discharge). *Electrons flow from capacitor plate to positive terminal of battery and flow to other plate from negative side of battery. Until there is no voltage difference







Measuring variation of voltage with time: Start timer when charging starts, record voltage at (regular) intervals until voltage reaches the supply voltage (i.e. stops rising)

The **time constant** (τ) is the product of the capacitance and resistance. It is the time taken for the voltage across the capacitor to fall to $\frac{V_0}{e}$ $(\sim 37\% \textit{ of the original value})$

Determining time constant: Charge the capacitor by closing switch. Open switch and allow capacitor to discharge, recording voltage and time.

Plot voltage vs time and read time when voltage falls to $\frac{V_0}{e}$ $(\sim 37\% \textit{ of the original value})$ or do the following plot where τ = -1/grad

$$V = V_0 e^{\frac{-t}{\tau}},\ y = mx + c,\ ln(V) = \frac{-1}{\tau}t + ln(V_0)$$

V above can be replaced with Q or I and the same equations and rules apply.

For experiment involving last graph, you can find t = 2τ as well (t to fall to ~14%) and avg

Flash gun: shutter on camera pressed causes rapid discharge of the capacitor through a gas filled flash tube producing an intense flash

Defibrillator: when hearts rhythm is disturbed a defibrillator can provide a controlled shock to stop ventricular fibrillation. It transfers a precise amount of energy in a short time using a capacitor which stores electric charge in the electric field between metal plates separated by an insulator. The circuit has minimal resistance for fast charging, but it can't be too small as this would damage the power supply. The voltage of a mains operated defibrillator should be stepped up and changed to d.c before charging the capacitor

A capacitor marked "47uF, 12V" indicates in normal use the ration of Q to P.D across capacitor is $47x10^{-6}CV^{-1}$ and that is it is designed to work <= 12V, above this the insulator (dielectric) between the plates will break down and charge will leak from one side of the capacitor to the other.

For questions like: How would you use a number of these capacitors to get a total capacitance of x and a maximum voltage of y. Use the fact that voltage splits in series to work out the number of capacitors in series then work out how many parallel branches will be required to get the target total capacitance required.

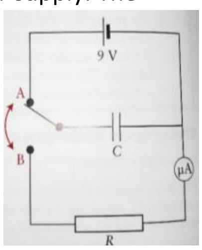
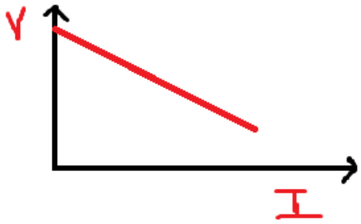


Figure 2: Alternatively use voltmeter in parallel to capacitor or resistor

Practical Techniques and Data Analysis

$E = V + Ir$

$V = -Ir + E$



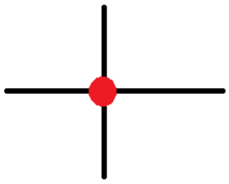
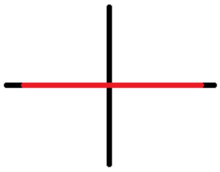
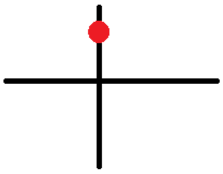
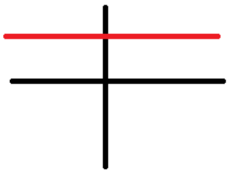
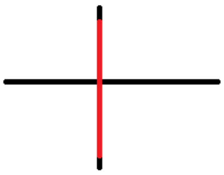
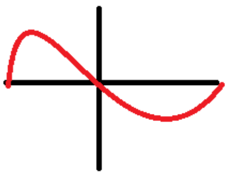
Percentage change in voltage = $\frac{V_0 - V_F}{V_0}$

Plotting linear graphs: $T = kM^n \rightarrow ln(T) = nln(M) + ln(k)$

$\theta_t = \theta_R + Ae^{-kt} \rightarrow ln(\theta_t - \theta_R) = ln(Ae^{-kt}) = ln(A) + ln(e^{-kt}) = ln(A) + -ktln(e)$

$ln(\theta_t - \theta_R) = -kt + ln(A)$

$y = mx + c$

Voltage	**Timebase**	**CRO Display**
None	Off	
	On	
+DC	Off	
	On	
AC	Off	
	On	

If a straight line graph through the origin is expected but the line of best fit of the plotted points doesn't go through the origin, this is an indication of a systematic uncertainty

If there is a large scatter of points around the line of best fit, this is an indication of a large uncertainty, possibly due to random errors

State the longest and shortest length a string measured 0.12m could be to 3 decimal places

Longest = 0.124m, shortest = 0.115m

When finding the average period of a pendulum we assume that the period doesn't change with each amplitude of the swing/oscillation and therefore the total time for several oscillations can be divided by the number of swings to find the period

When multiple readings are taken then the uncertainty is half the range in the results therefore the answer is given as the average plus or minus half the range

To plot error bars - plot the mean value with lengths of half the range of the data points on either side

$\%\ \text{uncertainty in gradient} = \frac{\Delta Gradient}{Gradient_{BestFit}} x100$

Parallax error - occurs when scale not viewed at right angles or placed too far from the object

For lengths greater than one metre it is better to use a tape measure with 1mm divisions which can measure

Liquids in glass containers curve up at the edges and down at the middle therefore the reading should be taken from the bottom of the meniscus

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To improve meniscus visibility a card with a dark stripe may be placed behind the measuring cylinder

In liquids and materials where the curvature occurs in the opposite way where the edges of the liquid curve down and the centre rises then the reading should be taken from the top of the meniscus

Protractor uncertainty - angle measurement uncertainty is half the division ie half a degree but there is also the uncertainty in aligning the protractor with the normal which is another half degree uncertainty therefore the total uncertainty when measuring an angle with a protractor is +/- 1 degree

Thermometer usually has divisons of 1°C so a temperature reading has an uncertainty of ±0.5°C and a temperature change of of ±1°C

Uncertainty in single reading is typically of ± ($\frac{1}{2}$ smallest division)

Volume of stone found by change in water volume when stone added, to find volume of floating object like cork attach it to a stone

In electrical experiments read values for current as voltage is increased to the desired value and decreased to the desired value and find the average of the two currents

Line of best fit gives best intercept and the range of intercept values can be found between the points where the lines of minimum and maximum slope cross the y axis. The percentage uncertainty in the intercept is the intercept from the best fit plus or minus half the range.

Precise and accurate - measurements close to the true value and readings are similar ie random/systematic uncertainties are small

Precise and inaccurate - measurements show small difference but average far from the true value

Imprecise and accurate - measurements show large variation but the average is close to the true value

Imprecise and inaccurate - measurements show large variation and the average is far from the true value

Object on ramp may not travel in a straight line giving more uncertainty in the distance travelled and in the experimental results

Max/min method:
The average diameter of a wire is 0.32mm with an uncertainty of +- 0.01mm
Find the uncertainty in the calculation of the cross sectional area

$A = \frac{\pi D^2}{4}$

$A_{BEST} = \frac{\pi(0.32*10^{-3})^2}{4} \approx 8.0 * 10^{-8}m^2$

$A_{MIN} = \frac{\pi(0.31*10^{-3})^2}{4} \approx 7.55 * 10^{-7}m^2$

$A_{BEST} = \frac{\pi(0.33*10^{-3})^2}{4} \approx 8.55 * 10^{-7}m^2$

Range = Minimum area - Maximum area $= 1.0 * 10^{-8}m$

Area written as $(8.0 \pm 0.5) * 10^{-8}m^2$

In an experiment to determine g, using light gates explain why only light fate 2 should be adjusted in varying distance h using the equation $\frac{2h}{t} = gt + 2u$ [2]
Distance between the release point of the object and the 1st light gate should be constant to ensure u is constant

There could be uncertainty in a measurement if the quantity being measured isn't constant

Uncertainty is the interval/range in which the true value can be considered to lie

Error is the difference between the measurement and the true value

precision is the degree of uncertainty in a measurement

accuracy is how close a measurement is to the true value

a precise measurement contains more information

there is no limit to how far away from the average a measurement can be

size of random uncertainty reduced by taking more readings

Systematic uncertainty shifts all measurements away from true value by the same amount, significantly affecting accuracy - Occurs when instrument goes out of alignment or not calibrated properly

Taking more readings will not affect systematic uncertainty as it is present in every measurement

subtract zero error from every measurement

adding or subtracting measurements : add uncertainties

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multiplying or dividing measurements : add percentage uncertainty

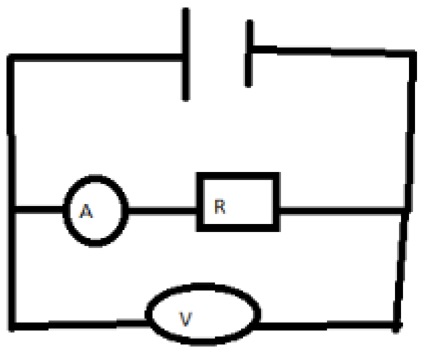
functions of measurements (log sin etc) : same percentage uncertainty

sometimes error bars are not shown as they would be too small to be of any significance

projecting beyond the limit of measured data is called extrapolation

Important to ensure everything other than the independent variable being changed and the dependent variable being observed are kept constan

Sensors, data loggers and computer interfaces can be used to take reading

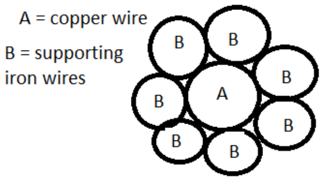


Given that the ammeter used has negligible resistance and the resistance of the voltmeter is of the same order of magnitude as the resistor

Explain why the resistance determined from this arrangement should give an inaccurate value:

The current recorded on the ammeter is high as it includes the current that goes into the voltmeter

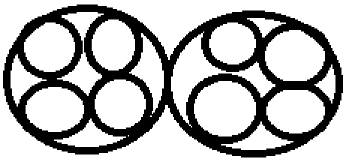
General Physics A2 Notes not specific to topics



$$R_T = \frac{1}{\frac{1}{\frac{R_B}{7}} + \frac{1}{R_A}}$$

$$R = \frac{2\rho l}{4\pi r^2}$$

2 conductors in series, each with 4 interior strands



Where 2 is the number of conductors in series, 4l is the length of each conductor, 4 is the number of strands in each conductor and r is the radius of one of the strands

From spec:

(h) sketch simple functions including

$y = \frac{k}{x}$, $y = kx^2$, $y = \frac{k}{x^2}$, $y = \sin x$, $y = \cos x$ and $y = e^{-x}$.

Be careful with questions with mass in g or cm etc, remember to convert to correct units

AS Equations that could come up again:

$$\lambda = \frac{h}{\rho} = \frac{h}{mv}$$

TODO: add AS equations