Physics Component 2 - 2.1/Conduction of Electricity

Equations: $I = \frac{\Delta Q}{\Delta t}$

$I = nqvA$

A – cross-sectional area
v – drift velocity - caused by electric field
q – charge on each charge carrier
n – number density i.e. charge carriers per m^3

Charge: - Unit → Coulomb (C)
- An electron's charge is very small (-1.6×10^{-19}C)
- Charge can flow through materials called conductors

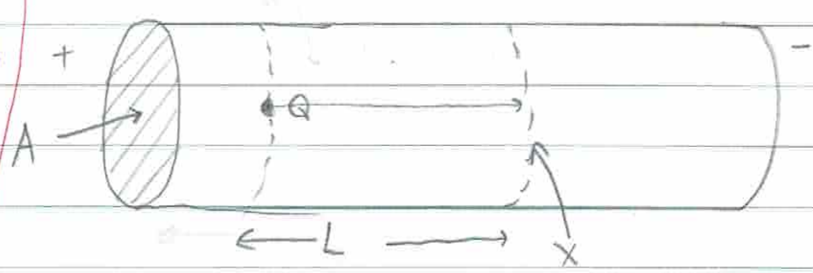
Current: - Electric current is the rate of flow of charge
- Unit → $\boxed{\text{Ampères (A)}}$ → $A = Cs^{-1}$

The mechanism of conduction in metals is the drift of de-localised, free ~~ell~~ electrons. Conventional current flows from positive to negative, but in reality the electrons move from negative to positive.

Derivation of $I = nqvA$

Let charge carriers have: charge q, drift velocity v (due to p.d. application).
Let the current have: uniform cross-sectional area A
Let there be: n charge carriers per unit volume

Find
1. Volume (use $L = vt$) - Avt
2. number - $nAvt$
3. ~~Th~~ charge = $neAvt$
4. current = $nevA$



consider the 'slug' of current, length L, which passes some point, x, in 1 second

I = charge that passes in 1 second ÷ 1 second
I = total charge of charge carriers in slug ~~in 1 second~~ × q ÷ 1 second
I = (no. of charge carriers per unit volume × volume) q ÷ 1 second

$$I = \frac{(n \times (AL))q}{1s} = nq\frac{L}{1s}A \qquad \frac{L}{1s} = \frac{\text{distance}}{\text{time}} = v$$

$$\therefore I = nqvA$$

Physics Component 2 - 2.2/ Resistance

Potential difference: - The electrical p.d between two points is the difference in electrical potential energy between those two points

- Units: volts (V) → $V = JC^{-1}$
- P.ds don't 'go through' things, they simply exist or do not exist
- 1V is the electrical p.d between two points such that 1J of work is done transfering 1C between them

same

$$E = VQ \qquad P.d = \frac{\Delta EPE}{Q} \qquad P = VI = I^2R = \frac{V^2}{R}$$

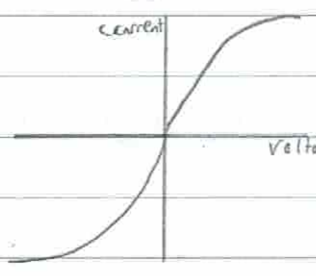
electrical energy

resistivity

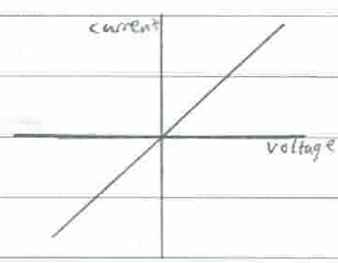
$$R = \frac{\rho L}{A} \qquad R = \frac{V}{I} \qquad V = IR$$

I-V Graph Characteristics

Filament lamp



metal wire



Resistance: - The electrical resistance of a component is defined by the equation $R = \frac{V}{I}$, where V is the pd across the component and I is the current that flows due to the p.d application

- Ohm's Law: Ohm's Law is obeyed if the current flowing through a component is directly proportional to the p.d across it provided that temp, length, cross sectional area, and material are constant
- Resistance Unit: Ohms (Ω) → $\Omega = VA^{-1}$

- Electrical resistance is caused by collisions between free electrons and ions, this increases ~~when~~ with temperature. This ~~[illegible]~~ increase is an almost linear variation, over a wide range.
- Ordinarily, collisions between free electrons and ions in metals increase the random vibration energy of the ions, so the temperature of the metal increases.

Superconductivity :- Superconductivity is the flow of electric current without resistance in certain metals, alloys and ceramics at temperatures near absolute zero, ~~[illegible]~~

- ~~[illegible]~~ Absolute zero - (0 K or −273°C)
- At a certain critical temperature, the smoothly decreasing resistivity as the temperature falls drops suddenly to zero. Electric current in a super conducting ring continues indefinitely without any driving field. This is the superconducting transition temperature.
- Most metals show superconductivity, and have transition temperatures a few degrees above absolute zero.
- Certain metals, called high temperature superconductors) have transition temperatures above the boiling point of ~~[illegible]~~ nitrogen ~~[illegible]~~ (−196°C)
- Superconductors are used in MRI scanners and particle accelerators.

Physics Component 2 - 2.3/D.C. Circuits

In a circuit:
- The current from a source is equal to the sum of the currents in the separate branches of a parallel circuit - this is due to the conservation of charge.
- The sum of the potential differences across components in a series circuit is equal to the potential difference across the supply, and ~~that~~ this is a consequence of the conservation of energy
- The potential differences across components in parallel are equal
- In series $\boxed{R_{Total} = R_1 + R_2 + \dots R_n}$

  In parallel $\boxed{\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots \frac{1}{R_n}}$
- The e.m.f of a (cell/battery) ~~[illegible]~~ electrical power supply is the energy converted from some other form (eg. chemical energy) to electrical potential energy per coulomb of charge flowing through the power supply

comes up often

basically (~~[illegible]~~ $\boxed{E.m.f = \frac{\text{energy converted to electrical}}{\text{charge}}}$

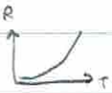
e.m.f is the '12V' on a cell ~~that it says it will give although~~ in practice some of this is lost due to internal resistance → $V = E.m.f - Ir = IR - Ir$

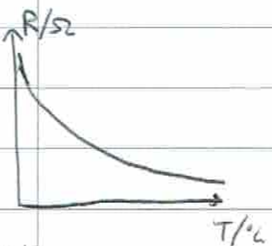
internal resistance

E.m.f Unit: volt (V) ~~- same as p.d~~

Thermistor:

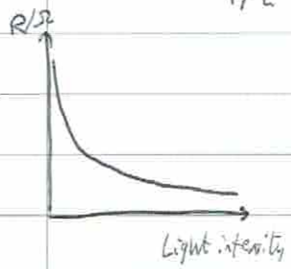
normal/ntc:



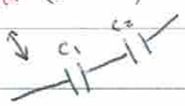


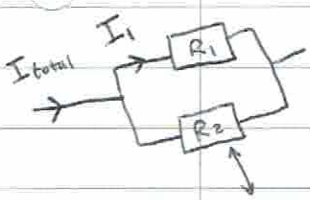
ptc:

LDR:



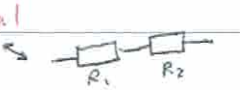
$V_{C_1} = \left(\frac{C_2}{C_1 + C_2}\right) V_{Total}$ (series)



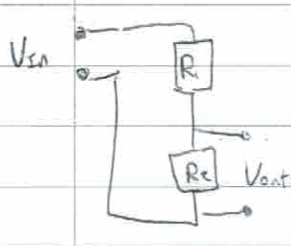


$I_1 = \left(\frac{R_2}{R_1 + R_2}\right) I_{total}$

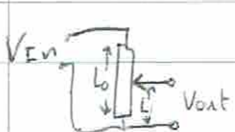
- Useful to remember: $V_{R_1} = \left(\frac{R_1}{R_1 + R_2}\right) V_{total}$



- A potential divider can be used to produce a desired potential difference. This can be an additional resistor that reduces the p.d across another component to the desired level and if a thermistor or LDR is used this can be dependant on light concentrations or ~~[illegible]~~ temperature



$V_{IN} = IR_1 + IR_2$ $\quad V_{out} = IR_2$ $\quad \frac{V_{out}}{V_{in}} = \frac{R_2}{R_1 + R_2}$



$V_{out} = \cancel{[illegible]} \; V_{In} \frac{L}{L_0}$

/

Physics Component 2 - 2.4 / Capacitance

A simple parallel plate capacitor consists of a pair of equal parallel ~~pa~~ metal plates separated by ~~an~~ a vacuum/air. Capacitors store energy by transferring charge from one plate to the other so that the plates carry equal but opposite charges (net charge is zero).

$\boxed{\text{Capacitance is defined by the equation}}$ $C = Q/V$ also $\overset{\text{energy stored}}{U} = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$

To calculate the capacitance of a parallel plate capacitor with no dielectric you can use $C = \frac{\varepsilon_0 A}{d}$
Where A is the area of the plates,
d. is the distance between the plates, and ε_0 is the permittivity of free space.

1. Capacitance is proportional to plate area
2. Capacitance is inversely proportional to the separation of the plates
3. You will only ever be asked questions on capacitors with air or vacuum between the plates, so you can use ε_0 ($8.85 \times 10^{-12}\ \text{Fm}^{-1}$ on data book)

Having a dielectric (an insulator between the plates) increases the capacitance of a ~~vacuu~~ vacuum-spaced capacitor (sometimes by a factor of thousands).
The E field within a parallel plate capacitor is uniform and is given by $E = \frac{V}{d}$

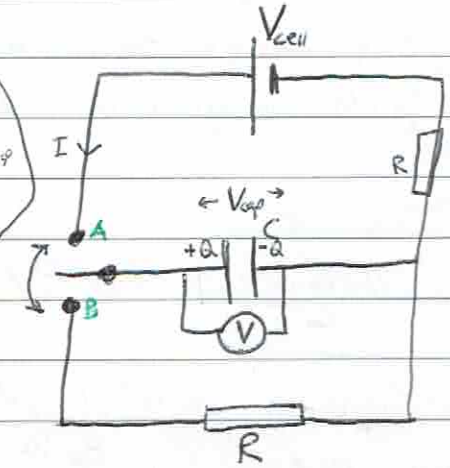
Combining Capacitors

Series: $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \dots$ ← leads to a reduction of capacitance to less than ~~smallest~~ than smallest capacitor

Parallel: $C_T = C_1 + C_2 + C_3 \dots$ ← effectively become one big capacitor with larger area

Charging and discharging capacitors

The 2 resistors are not necessarily the same but their symbols don't crop up together so both are R

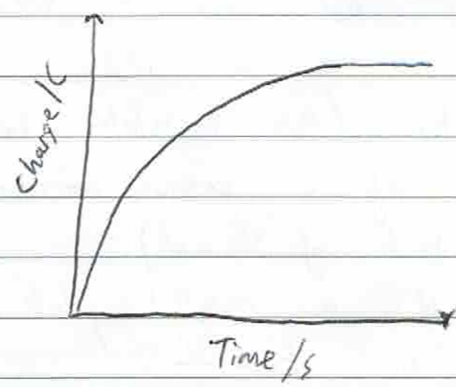


When the switch is up, the capacitor charges. When it is down it discharges through the resistor.
The capacitor provides a pd across the resistor during discharging, providing a current

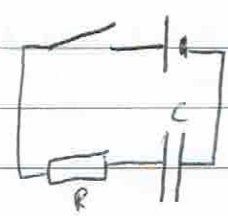
CHARGING

If the switch is moved into position A the capacitor will begin charging. At $t=0$, $Q=0$ so $V_{cap}=0$. After $t=0$ ~~the~~ charge will accumulate on the plates ~~and~~ so $Q \neq 0$. This means that $V_{cap} \neq 0$. ~~and~~ This voltage opposes the voltage of the cell (due to the creation of an induced electric field pushing current in the opposite direction) ~~whereas~~ and increases as time passes. Eventually $V_{cap} = V_{cell}$ ~~as~~ so $I = 0$, at this point the capacitor is 'fully charged'

The graph of this →



Circuit effectively



The equation that gives the time variation of the charge on the charging capacitor is:

$$Q = Q_0\left(1 - e^{-\frac{t}{RC}}\right)$$

max charge

RC = resistance x capacitance
= time constant

NB. after 1 time constant the capacitor should be 63% ~~different~~ charged both in charging and discharging (37% remaining after a discharge)
(VERY useful)

time constant = τ = RC

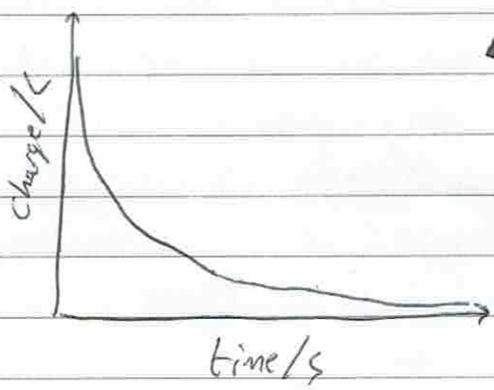
decay constant = $\frac{1}{\tau}$ = λ

DISCHARGING

When the switched into position B the capacitor will begin to discharge. From the P.O.V of the capacitor, the current through the resistor is the rate at which the capacitor is losing charge.

$$\therefore \frac{\Delta Q}{\Delta t} = -I = -\frac{V}{R} = -\frac{Q}{RC} \quad \left(\text{as } V = \frac{Q}{C}\right)$$

From this we know that the capacitor is losing charge at a rate that is proportional to the charge on the capacitor $\left(\frac{\Delta Q}{\Delta t} \propto -Q\right)$ so when the capacitor is fully charged it loses charge quickly. As the charge decreases the capacitor loses its charge at a lower rate. The graph of this is below.



same shape as charging curve, just upside down

Here RC is still the time constant and remember after one time constant the capacitor will have 37% charge remaining

The equation that gives the time variation of the charge on the discharging capacitor is

$$Q = Q_0 e^{-\frac{t}{RC}}$$

beginning charge

Physics Component 2 - 2.5 / Solids Under Stress

Hooke's Law: The Force needed to extend/compress a spring or material is directly proportional to the distance extended/compressed

↳ $F = Kx$ $\quad$ $F = Kx$

↑ spring constant = force per unit extension

Stress: ratio of the force applied to the cross-sectional area

↳ $\boxed{\sigma = \frac{F}{A}}$ (Pa) ← normally use MPa or GPa

Strain: ratio of the total deformation to initial dimensions

↳ $\varepsilon = \frac{\Delta L}{L_0}$ or $\frac{x}{L}$ $\quad$ ΔL or x = extension/change in length always positive

L or L_0 = initial length

educas uses these so they use $\boxed{\varepsilon = \frac{\Delta L}{L}}$

Young's Modulus: ratio of σ to ε in the elastic region

↳ $E = \frac{\sigma}{\varepsilon}$ (Pa, MPa, GPa) $\quad$ ↑E = ↑stiff

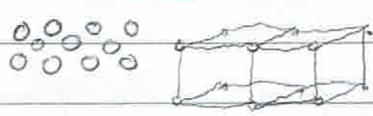
Work done: work done in deforming a solid is equal to the area under a force-extension graph, which is:

$W = \frac{1}{2}Fx$ if Hooke's law obeyed

$= \frac{1}{2}Kx^2$

Solid classification

* **crystalline**: orderly arrangement of the ~~atoms~~ particles over long ranges



Eg. diamond, Quartz, copper sulfate
(metals are polycrystalline mostly)

* **amorphous**: no order to particle arrangement

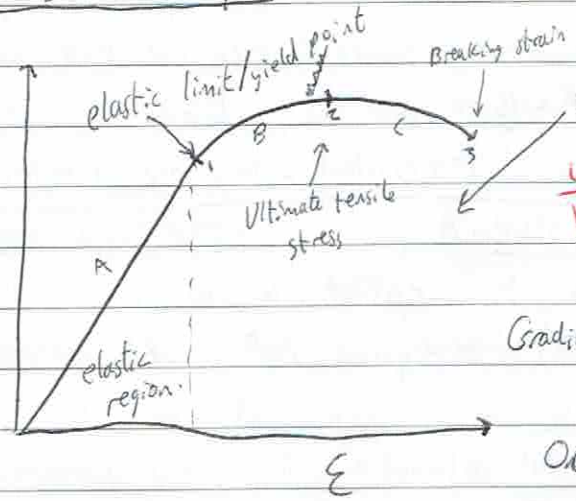
Eg. Glass/Ceramics (ceramics are often partly ~~crystal~~ crystalline)

* **Polymeric**: the particles are in long chains

Eg. Rubber

Stress- Strain Graph

F–x graphs and σ–ε graphs have the same shape for the same sample → just different scale factors.



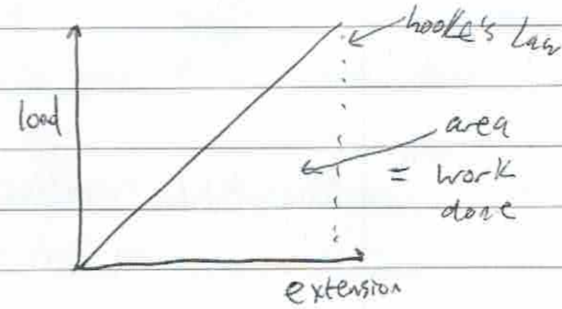
area = $\frac{W}{V}$

$$\frac{W}{V} = \frac{1}{2}\sigma\varepsilon = \frac{1}{2}E\varepsilon^2 = \frac{1}{2}\frac{\sigma^2}{E}$$

Gradient (of elastic region) = E

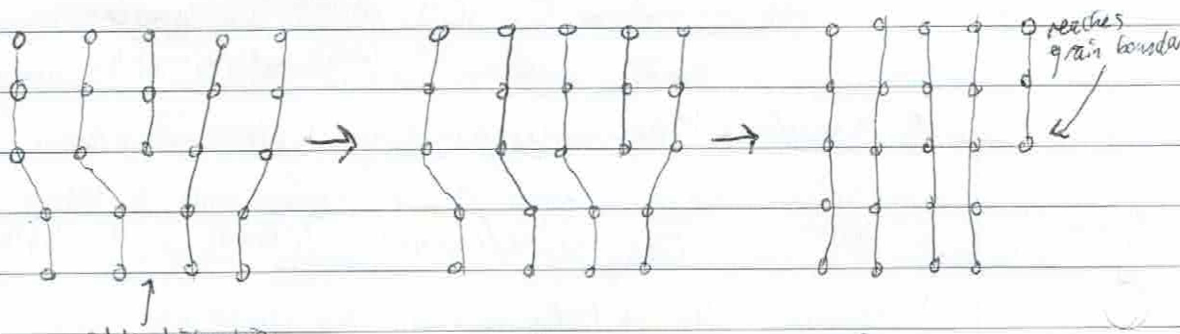
Once past elastic limit permanent deformation occurs

A = elastic region = $F = kx$ obeyed
B = Plastic region = permanent deformation
C = 'Necking' region
1 = elastic limit / yield point
2 = Ultimate tensile stress
3 = Breaking strain



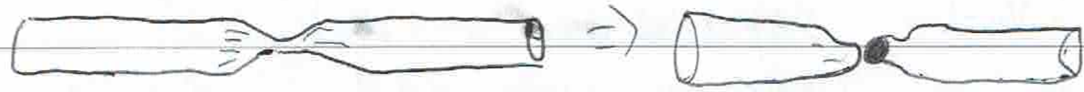
Ductile materials: can be made into wires
↳ significant deformation before rupture

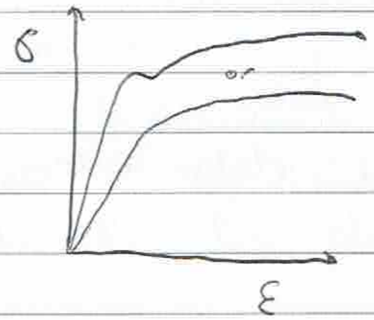
If large enough forces are applied (so the stress exceeds the yield stress) the edge dislocations will irreversibly change = permanent deformation. This movement can lead to large deformations as there are many edge dislocations, and also more can be created by high st leading to elongation of the crystals



Foreign (impurity) atoms, more grain boundaries, and other dislocations impede edge dislocation movement, increasing stiffness (higher E) ductile fracture

As the stress reaches the yield point, more and more edge dislocations are generated and migrate, causing the elongation. Because volume doesn't increase the C.S.A decreases (necking) which increases strain in that section, leading to a positive feedback loop until fracture.





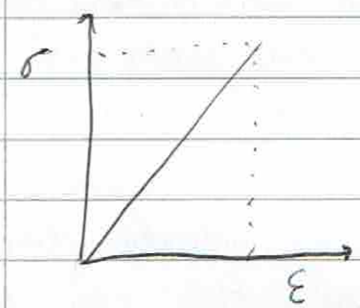
Eg. metals, like copper

Tough = not prone to shatter = high area + plastic behaviour (requires high energy to break)

Strong = high UTS

Creep = plastic deformation by loading force below elastic limit
↳ eg. stained glass & turbine blades

Brittle materials



Hooke's law obeyed until breaking stress
Often very low max. strain

Quench hardening = small grains = edge dislocations can't run = stronger and harder (slower cooling = larger crystals/grains)

Annealing = heat and cool slowly = large grains

Brittle fracture

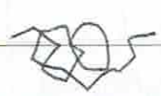
The tensile breaking stress of brittle materials is a lot lower than predicted from the strength of the bonds within the material. The material fractures sooner than expected due to the existence of microscopic cracks in the surface.
As stress is applied the stress is concentrated around the tip of the crack. In brittle materials there are no edge dislocations to relieve the stress so the crack breaks further, rapidly propagating.
They can act more normally under compression which can be done in toughened glass.

and pre-stressed concrete, or by reducing surface imperfections (eg. thin glass fibres). The reduction of surface imperfections reduces the no. of cracks that can propagate, and the compression helps prevent the cracks from opening up and propagating.

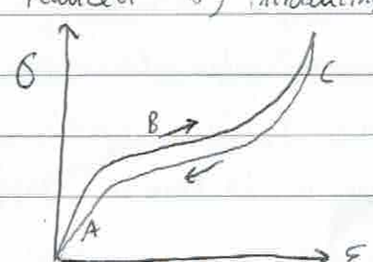
~~Rubber Properties~~ :) **Rubber Behaviour**

- Non-linear: steep → less steep → very steep.
  - ↳ hooke's Law approx. obeyed for very low stresses
- large strains
- Low Young's Modulus
- Loading & unloading curves different: elastic hysteresis
- Work done <u>by</u> band during contraction is less than work done <u>on</u> during stretching
- Area between curves represents energy dissipated on force-extension graph and energy dissapated/volume on stress-strain graph during one movement around hysteresis loop which converts to random vibrational energy of molecu

$\boxed{\text{Why does it behave like this?}}$



Rubber molecules in unstressed state are naturally tangled and folded up. Applying a small load rotates the bonds and straightens out the molecules - no bonds are stretched - large extensions can be produced with the small load (Low E). The force works against the thermal motions of the molecules which tend to pull the ends in and try to refold and tangle the molecules. When the force is relaxed the natural vibrations tangle it up again. Because of the work done, the molecules vibrate more ⇒ hysteresis. Elastic hysteresis can be useful eg. shock absorbers, and a nuisance eg. car tyres, and can be reduced by introducing molecular cross linkages between molecules (or same molecule) which is called vulcanisation



A: Van der Waal's weak cross-bonds account for initial stiffness

B: Molecules unfolding and straightening = low E (no bonds stretch

C: Where molecules are already straight so further strain must stretch bo so E is high and fractur

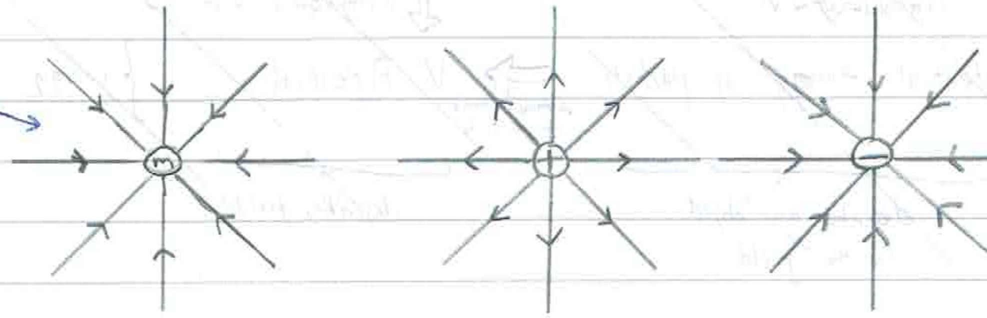
Physics Component 2 - 2.6 / Electrostatic and Gravitational Fields of Force

NB
By convection, attractive forces are negative and repulsive forces are positive.

Fields ⇒ field strength = how close field lines are

Point mass | Point charge

radial pattern

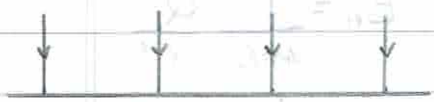


Force is always attractive | Force direction is dictated by the force that would be applied on positive test charge

Uniform Fields = parallel field lines equally spaced

Gravitational

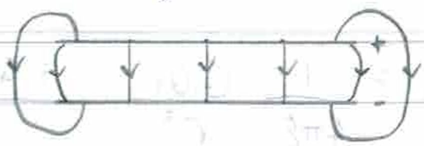
Close to a large mass the radial field can act like a uniform field



Earth

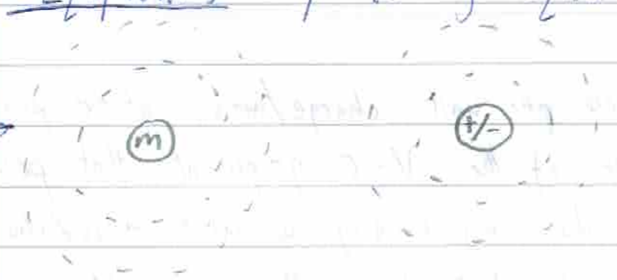
Electric

Uniform field between 2 charged plates



Equipotentials = points of equal potential

spherical or circular equipotentials



gravitational uniform field has parallel equipotentials

Earth

How equations relate to each other
↳ easier to remember than individual equations

F = force applied to a particle	$\xrightarrow{\div m \text{ or } Q_2}$	E = field strength	Force (vector)
$\times r$ ↓ (integrated in respect to r)		$\times r$ ↓ (integrated in respect to r)	
PE = potential energy of a particle at that point	$\xrightarrow{\div m \text{ or } Q_2}$	V = field potential	Energy (scalar)
describes particle		describes field	

~~General equation conversion technique~~

~~F = Force applied on particle $\xrightarrow{\div \text{ mass or charge of particle}}$ E = Field strength } force~~

~~$\downarrow$ integrated dr or $\times r$ $\qquad\qquad$ $\downarrow$ integrated or $\times r$~~

~~PE = Potential energy of particle $\xrightarrow{\div \text{ mass or charge of particle}}$ V = Potential } energy~~

~~describes an object in the field $\qquad$ describes field~~

Gravitational

$$F_{grav} = -\frac{Gm_1 m_2}{r^2} \xrightarrow{\div m_2} E_g = \frac{GM}{r^2}$$

$$\downarrow \times r \qquad\qquad \downarrow \times r$$

$$GPE = \frac{Gm_1 m_2}{r} \xrightarrow{\div m_2} V_g = \frac{GM}{r}$$

need to know this

Electrostatic

$$F_{el} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2} \xrightarrow{\div Q_2} E_{el} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1}{r^2}$$

$$\downarrow \times r \qquad\qquad \downarrow \times r$$

$$EPE = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r} \xrightarrow{\div Q_2} V_{el} = \frac{1}{4\pi\varepsilon_0}\frac{Q_1}{r}$$

E = field strength = the force per unit charge/mass at that point
= − slope of the $V-r$ graph at that point

V = work done by bringing a unit mass/charge from infinity to that point within the field

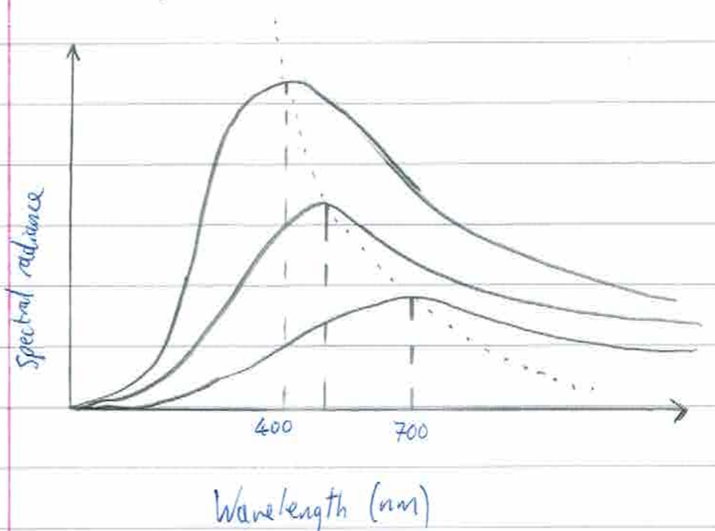
Physics Component 2 - 2.7/Using Radiation to Investigate Stars

A star's spectrum consists of:-

- A continuous spectrum of radiation arising from the dense opaque gas of the star's surface
- A superimposed line absorption spectrum due to atoms in the star's atmosphere which the radiation must ~~pth~~ pass through
  - ↳ from the wavelengths of the dark lines physicists can identify the absorbing atoms responsible for them

Bodies that absorb all incident radiation are known as black bodies and stars are very good approximations to black bodies. (no reflection)

Black body spectrum



Wien's Displacement Law

$$\lambda_{max} = \frac{W}{T}$$

$$W = 2.9 \times 10^{-3}\ K\cdot m$$

Stefan's Law

$$P = A\sigma T^4 \qquad \sigma = 5.67 \times 10^{-8}\ Wm^{-2}K^{-4}$$

Luminosity = The total power of em ~~rdti~~ radiation a star emits

Intensity = The energy per unit time, per unit area (through an area perpendicular)

Inverse Square Law = $\frac{\text{Luminosity}}{4\pi r^2}$

Multiwavelength Astronomy = the detection and analysis of em radiation from objects over multiple λ. Our ~~At~~ atmosphere absorbs gamma rays, x-rays, most ultraviolet, and all but narrow wavelength bands of infrared. As a result, we do most multiwavelength astronomy through space stations or 'observatories'. By looking in different wavelengths, we can learn about the different processes which took place there.

Physics - Component 2 - 28/Orbits and the wider Universe

Kepler's laws

1st Law: The planets orbit in elipses with the Sun at one foci.
2nd Law: Equal areas are swept by the orbits in equal times.
3rd Law: The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit. ($T^2 \propto r^3$)

$$F_{grav} = G\frac{M_1 M_2}{r^2}$$

Derivation of Kepler's III

elliptical orbit approximates to a circle

$$F_{centripetal} = F_{grav}$$

$$mr\omega^2 = \frac{GmM}{r^2}$$

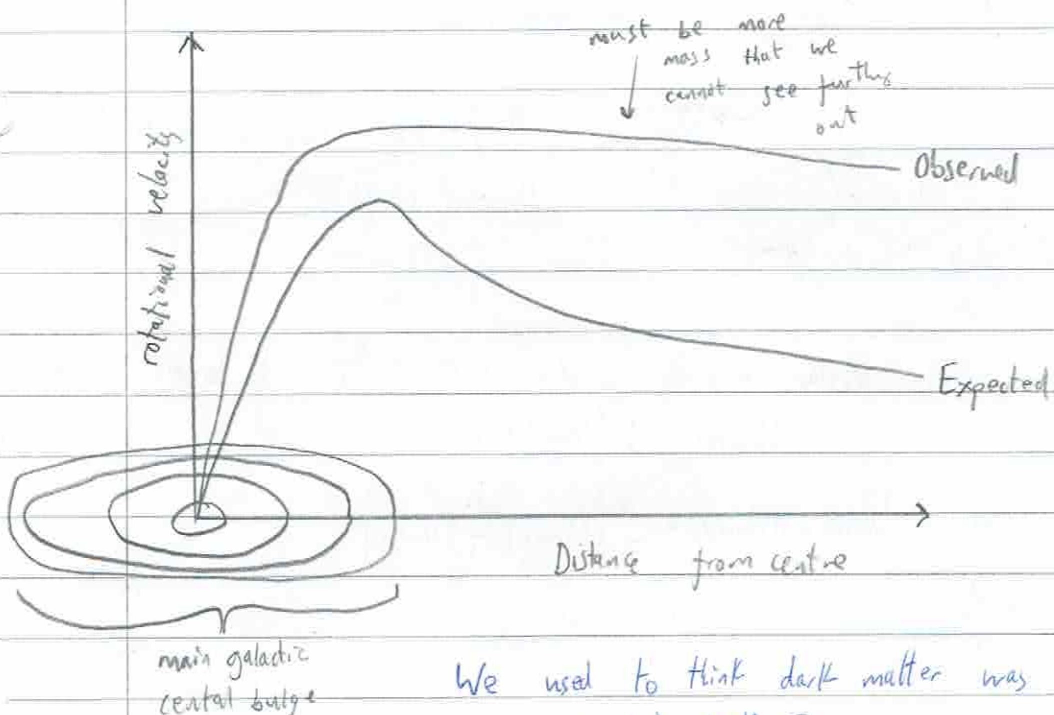
$$\left(\frac{2\pi}{T}\right)^2 = \frac{GM}{r^3} \Rightarrow T^2 = \frac{4\pi^2 r^3}{GM}$$

$$\boxed{\therefore\ T^2 \propto r^3}$$

Doppler effect

$$\frac{\Delta\lambda}{\lambda} = \frac{\Delta f}{f} = \frac{v}{c}$$

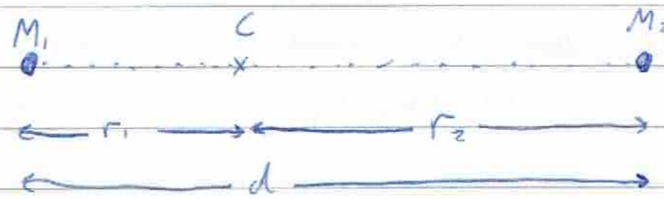
Dark Matter



We used to think dark matter was WIMPs (weakly interacting massive particles). These involve supersymmetry but have been difficult to experimentally indentify. Dark matter may come from certain decay modes of the Higgs boson.

Binary Systems

The position of the centre of mass of two bodies is found by the equations below.



$$r_1 = \frac{M_2}{M_1 + M_2} d \qquad r_2 = \frac{M_1}{M_1 + M_2} d$$

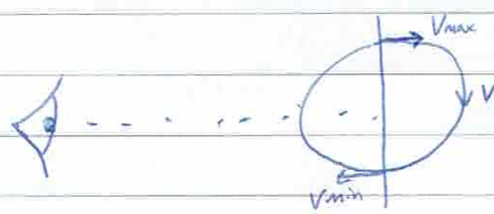
Period of binary systems: $T = 2\pi \sqrt{\dfrac{d^3}{G(M_1 + M_2)}}$

assuming circular orbits

Doppler effect

$$\frac{\Delta \lambda}{\lambda} = \frac{\Delta f}{f} = \frac{V_{rad}}{c}$$

V_{rad} is negative if it is coming towards us



A star will have a regularly changing Doppler shift.

If it remains a constant distance from us: $V_{orbital} = c \dfrac{\Delta \lambda}{\lambda}$

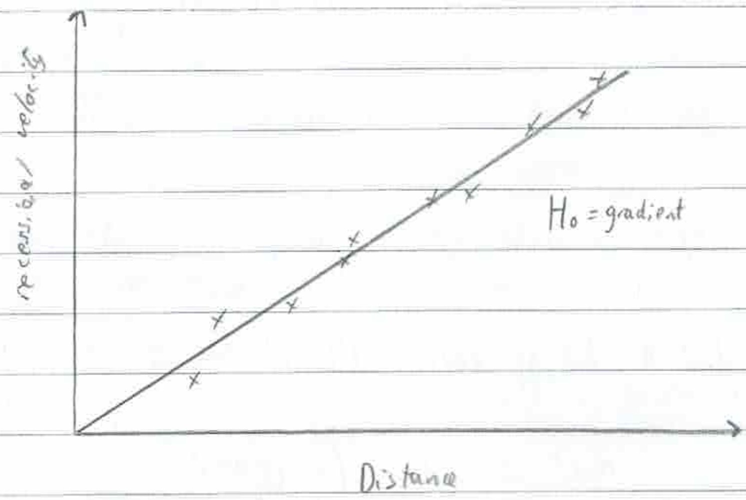
If it is approaching/receeding: $V_{orbital} = \frac{1}{2}\left(|V_{max}| + |V_{min}|\right)$

just kinda have to think - don't get caught out

$$V_{recessional/towards} = \frac{1}{2}\Big|\,|V_{max}| - |V_{min}|\,\Big|$$

Deep Space and Hubble's Law

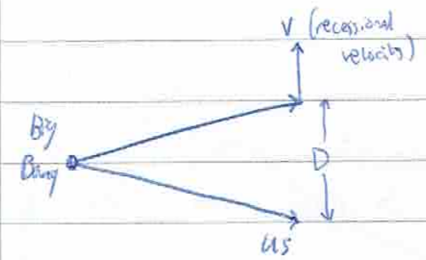
Stars orbit within galaxies. Galaxies themselves are clustered and orbit within the clusters. However, ~~the~~ superimposed over these 'local' movements there is a motion away from us. The greater its distance D, the greater its red shift and the greater its velocity away from us (known as radial velocity of ~~recess~~ recession)



Hubble's Law: Each object has a superimposed radial velocity $v = H_0 D$

(H_0 = Hubble constant) $\quad H_0 = 2.20 \times 10^{-18}$

The age of the Universe



~~at t after~~

~~(at time (t) after the Big Bang) D = vt~~

At time (t) after the Big Bang: $D = vt$ $\qquad$ Hubble's Law: $v = H_0 D$

$$D = \frac{v}{H_0}$$

Age of Universe $= \frac{1}{H_0}$ (derivation)

$$vt = \frac{v}{H_0} \Rightarrow t = \frac{1}{H_0}$$

$\therefore \frac{1}{H_0}$ = age of the universe

$$\frac{1}{2.20 \times 10^{-18}} = 14.4 \times 10^9 \text{ years}$$

Critical Density of Universe

Imagine a sphere of radius r drawn around our galaxy, large enough to contain millions of other galaxies. Treating it as a homogenous sphere its mass M will be: $\boxed{M = \text{Volume} \times \text{density} = \frac{4}{3}\pi r^3 \rho}$

Now consider a thin shell (mass m) of universe surrounding the sphere. This shell, moving away from us has $\boxed{v = H_0 r.}$ Will this velocity be great enough to keep moving backwards?

For the escape velocity of a body of mass m to infinity: with no spare KE

Initial KE of body = PE at infinity − Initial PE (at r)

So $$\frac{1}{2}mv^2 = 0 - \left(-\frac{GmM}{r}\right)$$

$$v^2 r = 2GM$$
$$(H_0 r)^2 r = 2G\left(\frac{4}{3}\pi r^3 \rho_c\right)$$

critical density $\longrightarrow$ $$\boxed{\rho_c = \frac{3H_0^2}{8\pi G}}$$

if $\rho_{actual} > \rho_c$: expansion slows to zero, then contraction at a growing rate

if $\rho_{actual} = \rho_c$: expansion will slow to zero but only at infinite size

if $\rho_{actual} < \rho_c$: expansion will continue for ever

Actual evidence suggests (including dark matter) $\rho_{actual} \approx \rho_c$. Yet we appear to be in an era of accelerating expansion. → Dark energy