Physics - Component 3 - 3.1 / The Nature of Waves

Wave: a progressive wave transfers energy without any transfer of matter

Transverse wave: A wave in which the medium vibrates at right angles to its direction.

↳ eg. electromagnetic wave, water wave

Longitudinal wave: A wave in which the medium vibrates in the direction of propagation

↳ eg. sound

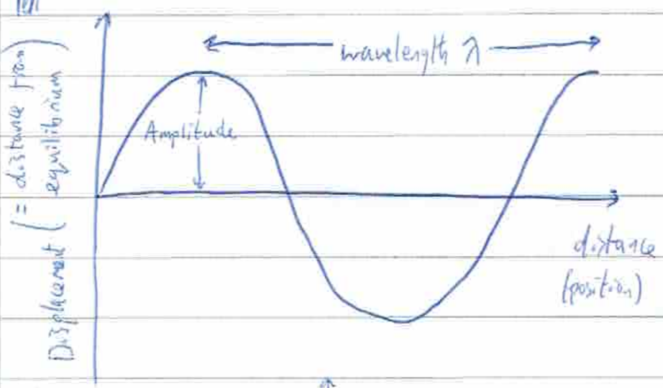
Polarisation: The restriction of the vibrations of transverse waves to one direction.

In Phase: When two+ waves or material is in the same stage of vibration.

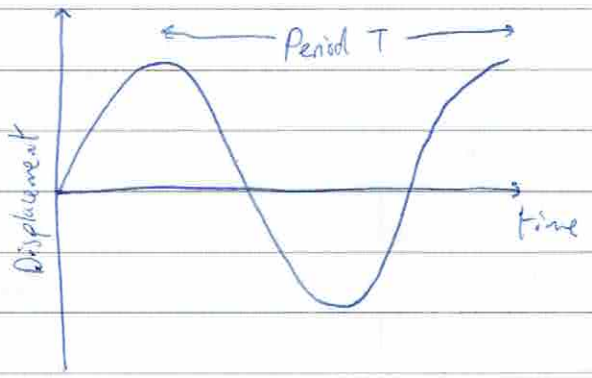
Out of Phase: When two+ waves or material is in different stages of vibration.

Coherent: When two wave have a constant phase difference and same frequency.

↳ usually means only one frequency is being emitted (i.e lasers)



this shows while wave



this is the graph of movement of a particl

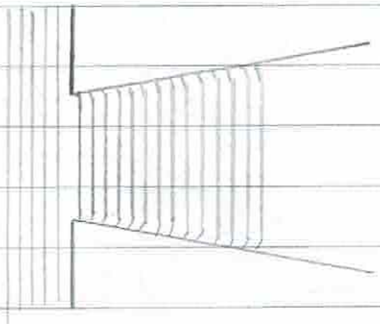
$$c = f\lambda$$

All points on wavefronts oscillate in phase (not necessarily polarised).

Wave propagation directions (rays) are at right angles to wavefronts.

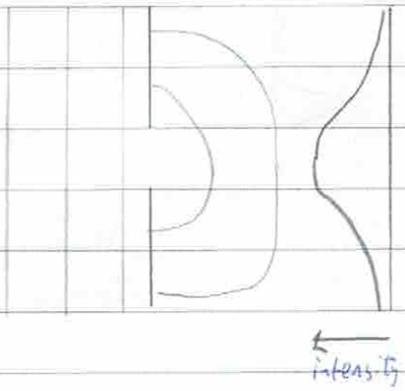
Physics - Component 3 - 3.2 / Wave Properties

Diffraction : the spreading of ~~obstacles~~ waves around obstacles in their way.
Diffraction occurs when waves encounter slits or obstacles.



if $\lambda <<$ than the width of a slit, waves ~~m~~ experience little diffraction

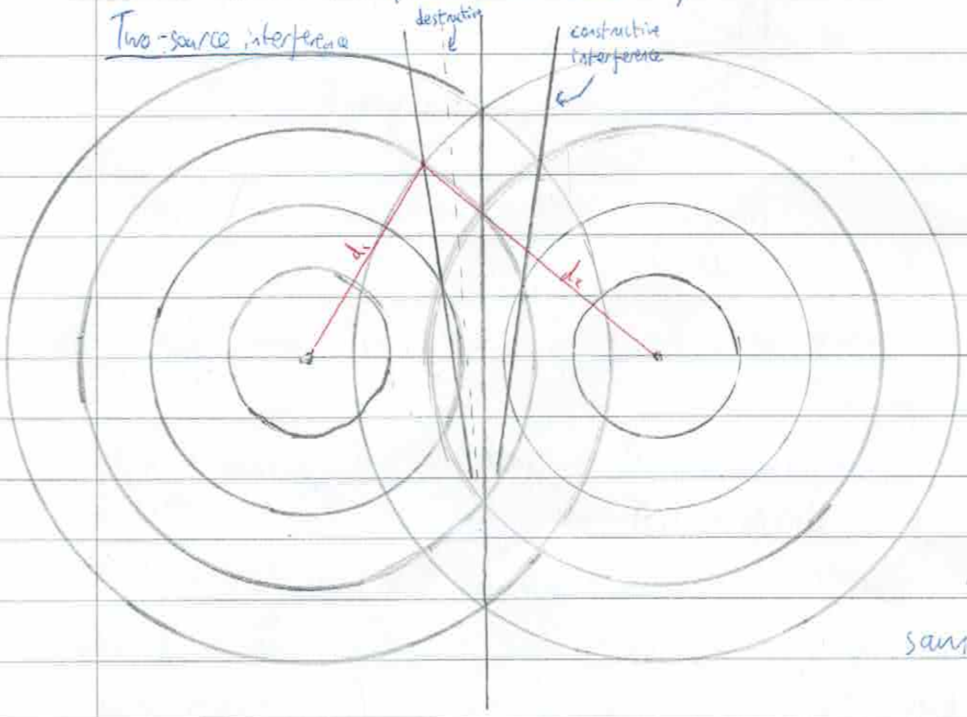
~~not nearly finished~~



if $\lambda \geq$ the slit width, waves spread as roughly semicircular wave fronts, but if $\lambda <$ slit width the main beam spreads through less than 180°

Interference : interference is what happens when waves from more than one source, or waves travelling by different paths from the same source, superpose or 'overlap' in the same region.

Two-source interference

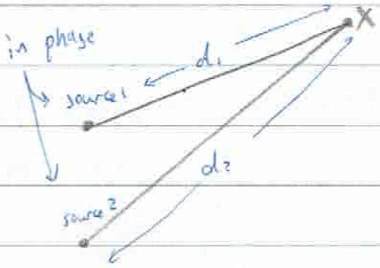


When constructive interference occurs you get peaks and this happens when two peaks of the waves meet.
For this to be observed, the sources must have a zero or constant phase difference and have oscillations in the same direction.

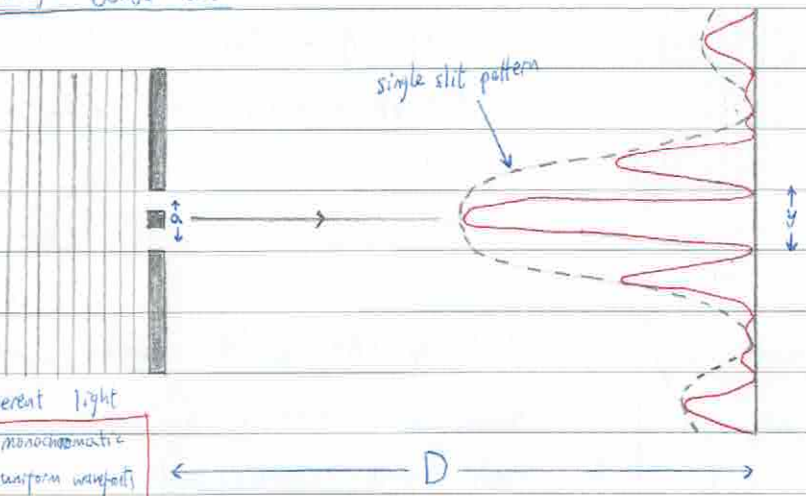
Path difference

constructive interference : $|d_1 - d_2| = n\lambda$

destructive interference : $|d_1 - d_2| = (n + \frac{1}{2})\lambda$



Young's Double Slit



$\lambda = \frac{ay}{D}$, given $a \ll D$, $y \ll D$

Historical importance: showed that light is a wave. Later showed the same for electrons and all other particles. This led to the concept of wave-particle duality. This can also be used to measure wavelength.

coherent light
↳ monochromatic uniform wavefronts
↳ can also apply to two or more sources if there is a constant phase difference.

coherent: eg. lasers
incoherent: eg. sunlight

Diffraction grating

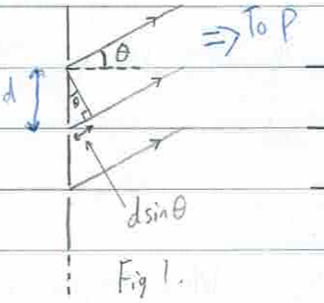
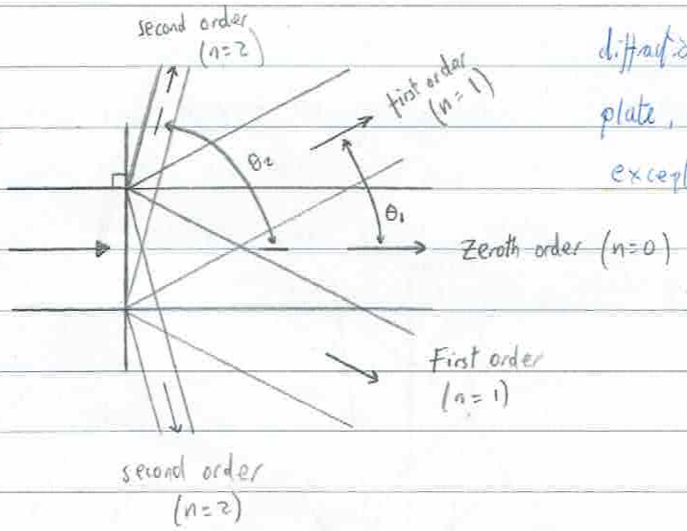


Fig 1.



diffraction grating: a flat plate, which is opaque except for thousands of straig parallel, equally-spac slits.

Consider the light arriving at a distant point, P, from each slit.

path difference = $d \sin\theta$

constructive interference at P => depends on path difference = $n\lambda$

$$d \sin\theta_n = n\lambda$$

The slit separation is much less than that used in Young's double slit ($d \ll a$), as a result the beams orders further apart than in Young's. Also the large number of slits makes the beams much sharper and brighter [∴ much better at measuring wavelength].

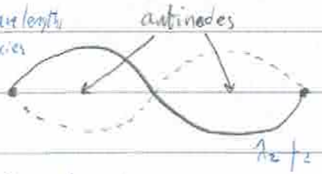
Standing Waves

Standing waves behave more like an oscillation than a wave. The wave (or oscillation) arises when two waves of the same frequency travel in opposite directions. The superposition of the two waves produces a stationary wave pattern.

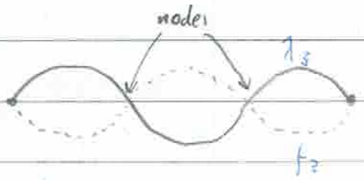
internodal distance = $\frac{\lambda}{2}$

just use your loaf to figure out wavelength and frequencies

First/fundamental harmonic



second harmonic

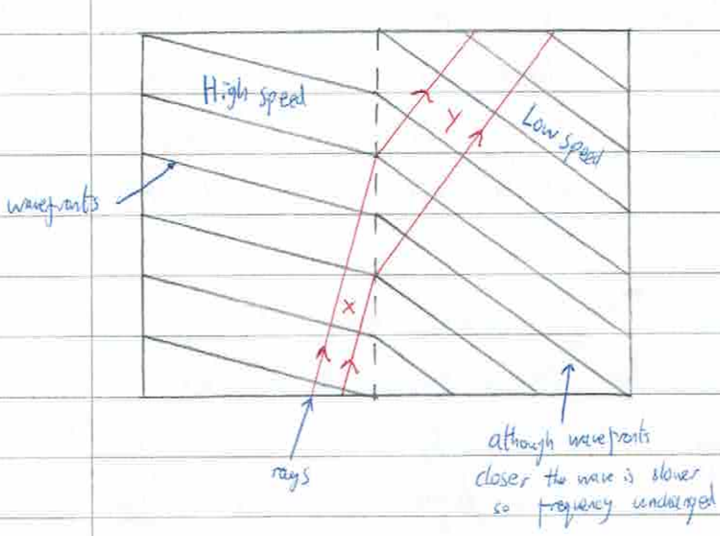


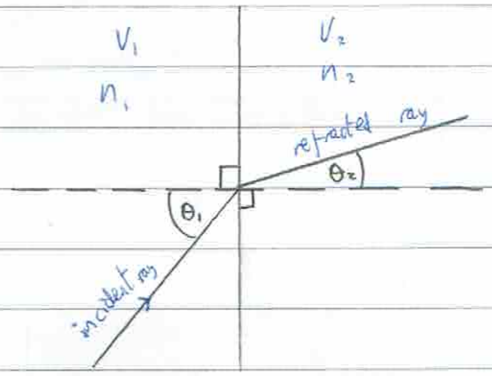
third harmonic

Physics Component 3 - 3.3 / Refraction of light

Refractive index: $n = \frac{c}{v}$ ← speed of light in a vacuum, ← speed of light in medium

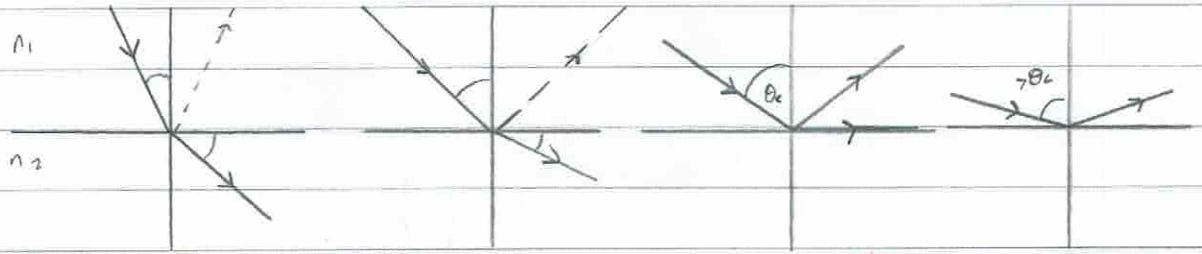
Snell's Law: $n_1 v_1 = n_2 v_2$ and $n_1 \sin\theta_1 = n_2 \sin\theta_2$





Total internal reflection

conditions:
- The light ray is incident upon a boundary with a material of lower refractive index
- The angle of incidence is greater than the critical angle



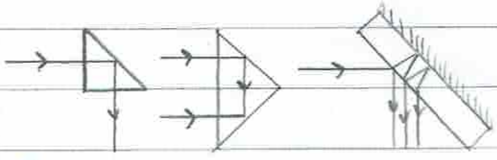
$n_1 \sin\theta_c = n_2$ or $\sin\theta_c = \frac{n_2}{n_1}$

↳ this comes from $n_1 \sin\theta_1 = n_2 \sin\theta_2$ $(\sin\theta_2 = 1$ as $\theta_2 = 90°)$

Optical fibres and other consequences

$\lambda = 1.5mm$

Totally reflecting prisms



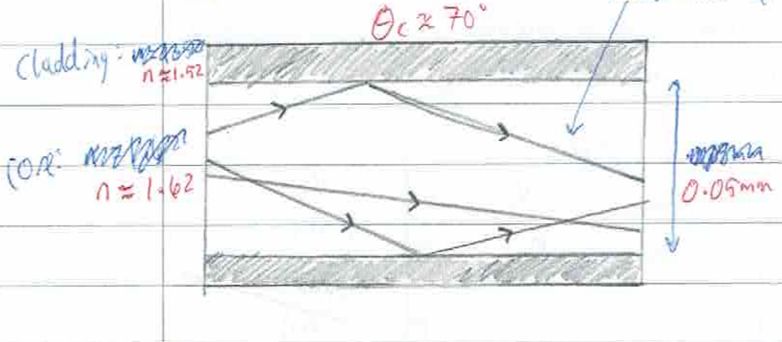
These prisms are used ~~to~~ in binoculars microscopes and periscopes. They don't have the multiple reflections like the mirror as these affect the image. They have $1.5 < n < 1.7$ so $\theta_c < 45°$

Optical fibres are used for data transmition in local, regional and intercontinental networks. They are also used in remote imaging systems (eg. ~~[illegible]~~ endoscopy).

A typical optical fibre consists of a single glass thread, the central part of which (the core) carries the light signal and the outer part (the cladding) keeps the signal in the core. Then there is a protective layer of plastic (the coating). External coating diameter = 0.25

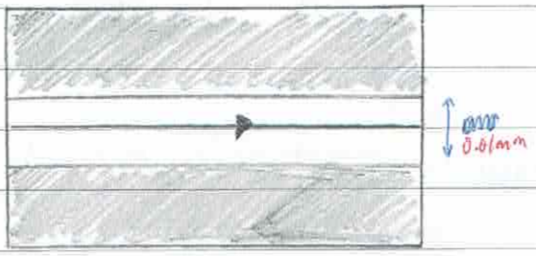
Multimode

multimode dispersion: data degredation because of the path difference



This kind is fine for short-distance communication and endoscopy but it can't handle longer distances, because the path difference causes the signal to overlap. This limits rate of data transfer and transmission distance

Monomode



The light waves are effectively restricted to traveling parallel to the axis of the fibe. Only downside is that its not as bright. This fibre allows for much greater transmission rates and distances

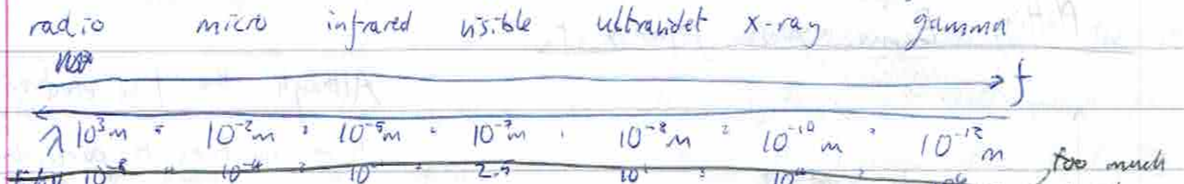
Physics - Component 3 - 3.4 / Photons

Light can be shown to consist of discrete packets of energy called photons. $E_{photon} = hf$ $c = f\lambda$ $h = 6.63 \times 10^{-34} Js$ $f = \frac{c}{\lambda}$

$E_{photon} = h\frac{c}{\lambda}$ $1eV = 1.60 \times 10^{-19} J$

A diffraction grating splits 'white light' ~~[illegible]~~ into a continuous spectrum of colours. The colours range from dark red: $\lambda \sim 700nm$ to ~~[illegible]~~ violet: $\lambda \sim 400nm$. Our eyes are only sensitive to this tiny slice of the whole ~~em~~ e-m spectrum. Diffraction gratings can also be ~~was~~ used to measure wavelength

Retarded men inject viagra until extreme growth



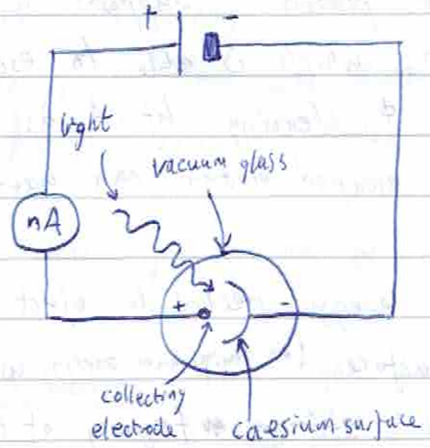
~~E/eV 10^{-8} : 10^{-4} : 10 : 2.5 : 10^1 : 10^4 : 10^6~~ too much to learn

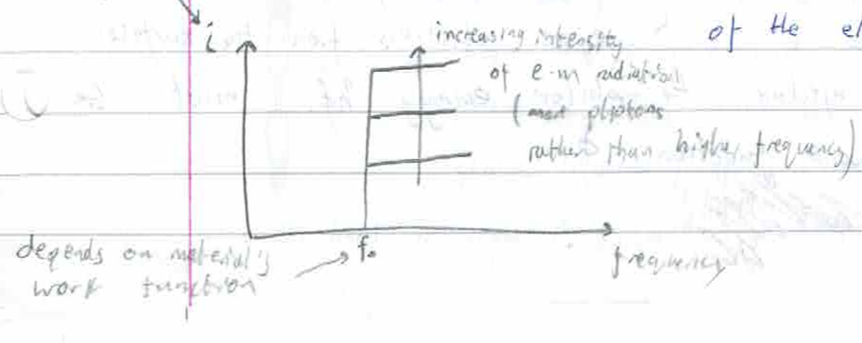
The Photoelectric Effect

When e-m radiation of a high enough frequency falls on a metal surface, electrons are ~~em~~ emitted from the surface. For most metals ultraviolet radiation is needed. For caesium, visible light (but not far red) will release electrons. This effect can be demonstrated with a vacuum photocell. There is still a current with very low intensity → evidence for photons

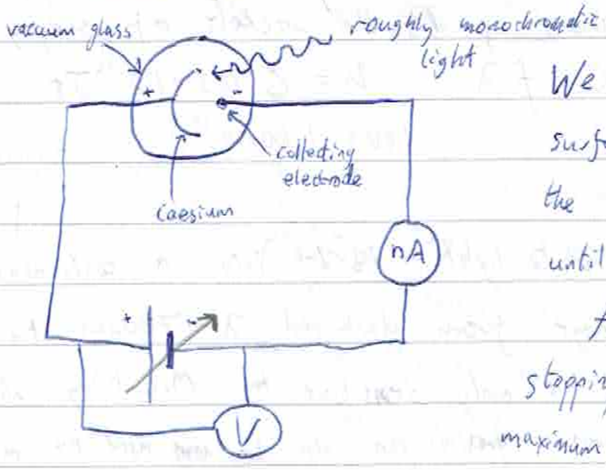
Vaccum Photocell - demonstration of photoelectric effect

When light falls on the caesium surface the very sensitive (nano-) ammeter registers a current. Electrons emitted from the surface into the vacuum are attracted to the collecting electrode (made positive by the battery). The electrons flow through the ammeter and the battery back into the caesium surface. There is even a current if there is no battery as some of the electrons have enough KE to reach the electrode alone.





Measuring $E_{k\,max}$

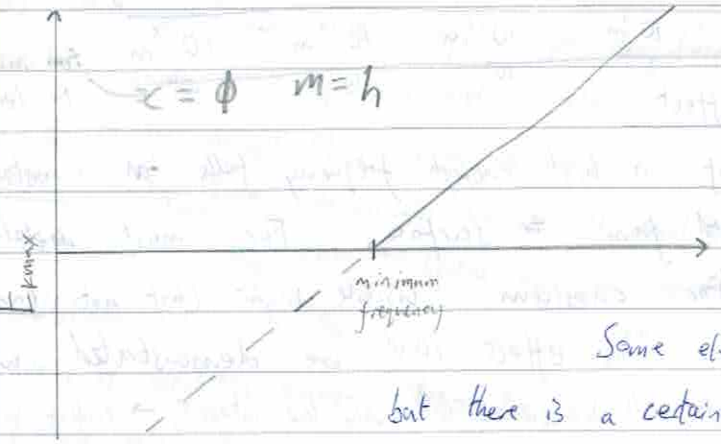


We increase the p.d between the caesium surface and the collecting ~~surface~~ electrode, making the ~~collect~~ collecting ~~ele~~ electrode more negative until the current just drops to zero.

At this point the pd is called the stopping voltage (Vstop). Those electrons with the maximum KE almost reach the collecting electrode before being stopped so $E_{kmax} = eV_{stop}$

$E_{kmax} = eV_{stop}$

Plotting E_{kmax} against frequency, f



Although the free electrons in a metal have no ties to particular atoms, there are forces holding them to the lattice of ~~ions~~ ions as a whole. To escape from the metal an electron has to do work against these forces. Some electrons have to do less work than others, but there is a certain minimum amount ~~of~~ needed called the work function, Φ. Any electron that leaves the surface is ejected by a single photon. Suppose a photon gives its energy, hf, to an electron, which is able to escape. The minimum energy used in escaping is ϕ, leaving $hf - \phi$ as the maximum kinetic energy (E_{kmax}) that the escaped electron can have. $E_{kmax} = hf - \phi$

The work function = the minimum energy needed to eject an electron from its surface (or minimum energy used in escaping)

~~I'M INCOMPLETE FYI~~

The photoelectric threshold frequency = minimum ~~fr~~ frequency of e-m radiation needed to eject electrons from the surface

For any electrons to be ejected, the photon energy, hf, must be at least as big as the work function ϕ

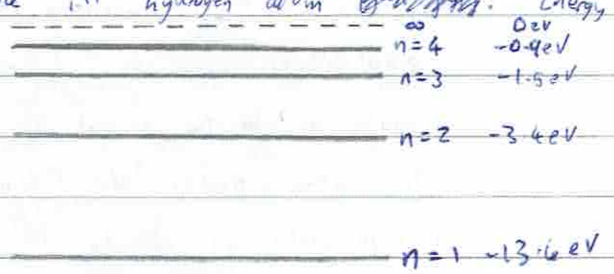
$hf_{threshold} = \phi$ ~~$f_{threshold}$~~

Radiation Intensity

We can relate the intensity of a radiation beam to the number of photons passing an area per second. Consider a monochromatic beam of radiation, of frequency f, crossing a surface. Let N be the number of photons crossing the surface per second. Then the Power in the radiation, $P = N E_{ph}$ or $P = Nhf = Nh\frac{c}{\lambda}$. We can relate this to the I·S·L to get the formula $I = \frac{Nhf}{4\pi r^2}$. Most radiation sources aren't monochromatic but the I·S·L still applies (although we can't use Nhf).

Atomic Spectra

Atoms have spectra [AKA line spectra] which consist of a series of wavelengths. Atomic gases both absorb and emit radiation at characteristic wavelengths. The reason atomic gases have line spectra as atomic systems can only posses particular levels of energy. The simplest atom is the ^1_1H hydrogen atom. Its Energy levels are as on the right.



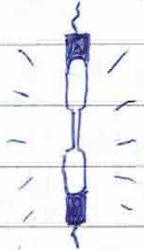
Virtually all of the energy shown is the sum of the kinetic and potential energies of the electron in motion around the nucleus.

An atom is excited if it is in an energy state above the ground state (with $n=2$ being the first 'excited state').

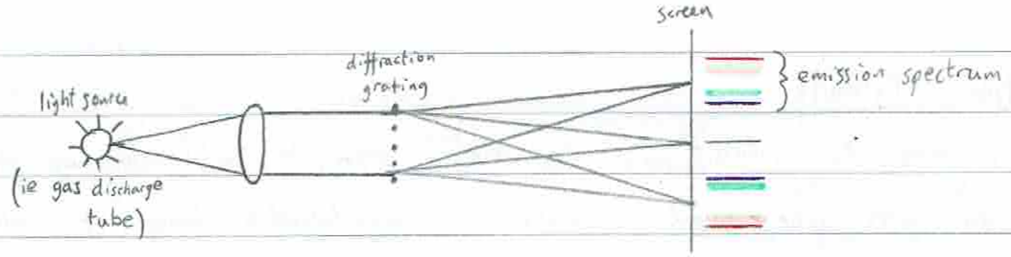
An electron trapped inside an atom must be given energy in order to escape, so its total energy must be negative (that's why the energies shown are negative). The energy to release an electron from an atom is the energy of its state (the negative of one), this is known as the atom's IONISATION ENERGY (need to kno this & how y find it

Atoms' line spectra can be shown in line emission spectra or line absorption spectra.

Emission Spectra: Use a gas discharge tube. This is a sealed glass tube containing a low pressure gas and two high electrical terminals. When a high voltage is applied, the gas is partially ionised, allowing electrons to pass through it. These collide with gas atoms and raise them to a range of excited states (electrical pumping) Then they drop down and emit photons (spontaneous emissio



When this light is viewed through a diffraction grating its spectrum is visible. (pto for diagram)



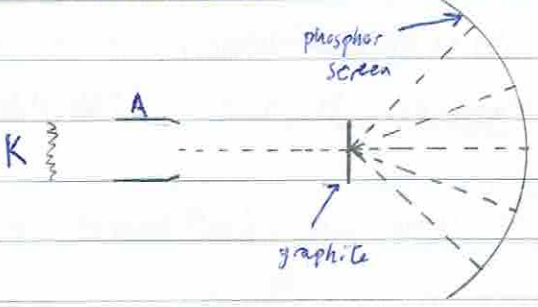
Absorption Spectra: A suitably shielded bright white light source with a continuous spectrum (eg. a filament lamp) is used and a tube of the gas is placed between the light source and a screen. The spectrum can then be displayed as above (it will look like a continuous spectrum with black bars). The absorption spectra of metals can also be displayed with this method by shining the light source through a vapourised sample of the metal in a bunsen flame.

Wave - particle Duality

Objects that we usually think of as particles (electrons, protons, etc.) have wave-like properties such as diffraction and interference. All objects have wave-like properties leading us to the concept of wave-particle duality.

The electron diffraction tube = demonstrates wave-particle duality (Note: each electron interferes with itself not othe

- A metal-coil cathode (K) is heated up, causing it to emit electrons by thermionic emissio
- The electrons are accelerated to the anode (A)
- A beam of electrons emerges from the hole in the anode and hits the graphite target.
- The graphite acts like a diffraction grating (all them layers) diffracting the beam
- The electron beam shows circular rings on the phosphor.



The Wavelength of Particle's

All particles have a wavelength such that: $p = \frac{h}{\lambda}$ ← de Broglie wavelength
(includes matter and photons)
momentum

Momentum and pressure of photons:

$\therefore\ p = \frac{h}{\lambda} = hf/c = E_{ph}/c = P\Delta t/c = \frac{IA\Delta t}{c}$ ∴ Momentum of photons in $\Delta t = \frac{IA\Delta t}{c}$

if all momentum is absorbed (totally black surface) then $\frac{dP}{dt} = -\frac{IA\Delta t}{c\Delta t} = -\frac{IA}{c}$ ∴ $\frac{dP}{dt}$ of surface $= +\frac{IA}{c}$

∴ F on surface $= +\frac{IA}{c}$ => F on surface $= \frac{IA}{c}$, $\boxed{\text{Pressure} = \frac{I}{c}}$,

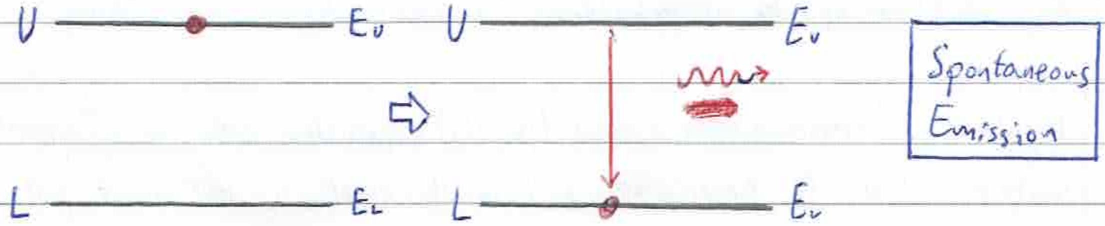
Physics - Component 3 - 3.5 / Lasers

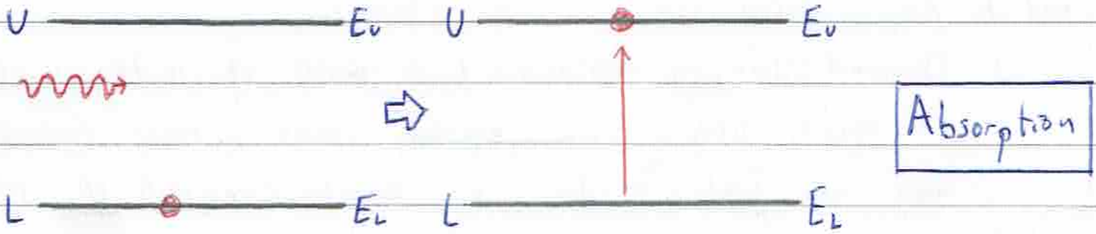
Atomic and molecular systems exist in a series of discrete energy states. For the moment we will consider just two states, U and L (Upper and Lower) of a system with energies E_U and E_L. An atom or molecule can change its state:

- From U to L by spontaneously by emitting a photon of frequency f where

$$hf = E_U - E_L$$

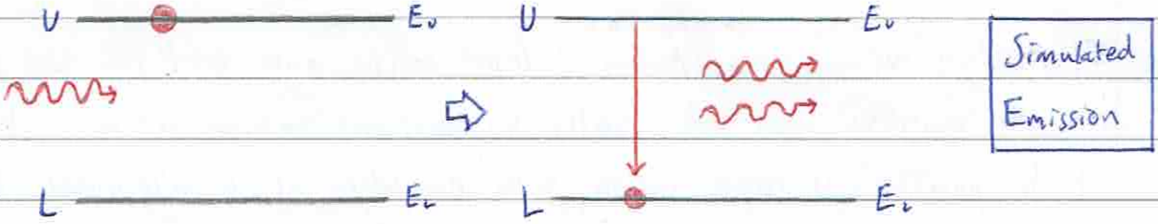
- From L to U by absorbing the energy of a photon of the same frequency f as above.





There is a second process of emission known a 'stimulated emission'. In this process, an atom in the upper state (U) is stimulated into moving down into the lower energy state by another photon of the same energy: $hf = E_U - E_L$. In doing so it emits a second photon which is in phase with the first one and travelling in the same direction. If each of these photons now interacts with an atom in the upper state, there will be four photons: the light is progressively amplified as it passes through the medium leading to the name;

Light **A**mplification by the **S**imulated **E**mission of **R**adiation.



ie. a population inversion is necessary for a laser to work

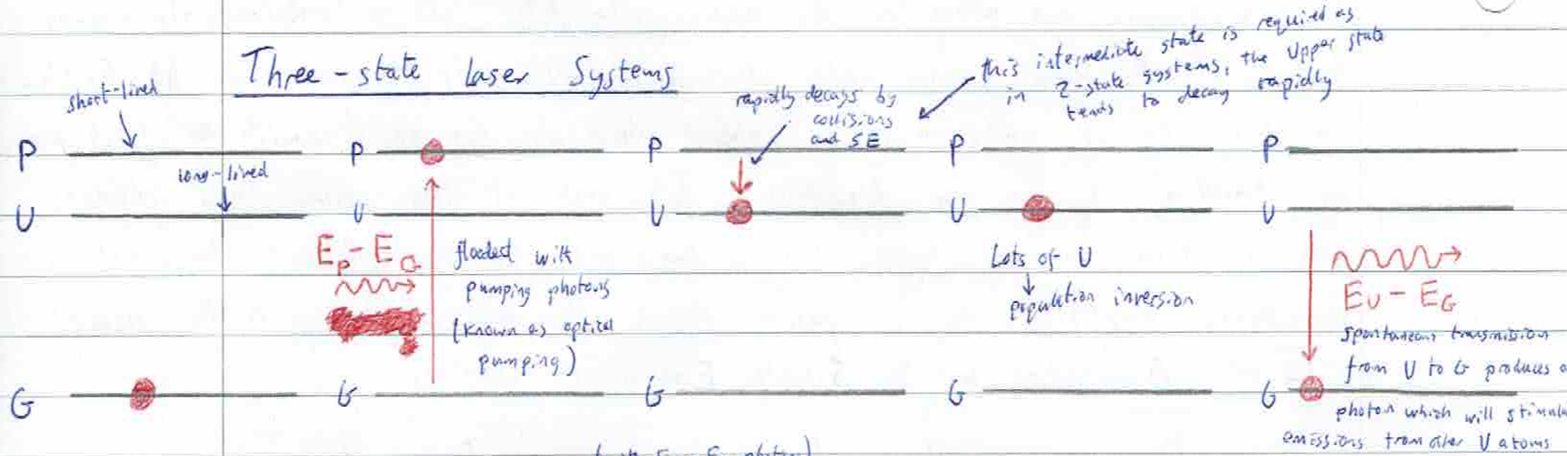
This is known as a 'population inversion' (a good thing)

Clearly, for the light to be amplified in this way, the photons have to carry on meeting atoms, all of which are in the upper state. This is not likely to occur naturally, as for the laser to work, the population of atoms of high-energy has outnumber the low-energy population and in normal temperature ranges the high-energy population is vastly outnumbered by the low-energy population. A laser can only work if the populations are the other way around, (ie. if $N_U > N_L$). Therefore we need some non-thermal means of boosting the population of the upper state. This is known as 'pumping'.

Population inversions are not (usually) possible with a 2-level energy system, as the upper state will usually empty as fast as it fills.
To understand how a population inversion is achieved in multiple-state systems, you need to know that:

1. Downward transitions can occur by a variety of routes, not all of which are equally likely. Laser engineers choose systems in which P is much more likely to decay via the intermediate state U, rather than direct to G.
2. Some energy states are very short-lived - ie. they decay very quickly. These are different to ones that last much longer, known as metastable states. Engineers choose systems in which P is short-lived but U is long-lived.

Three-state laser Systems



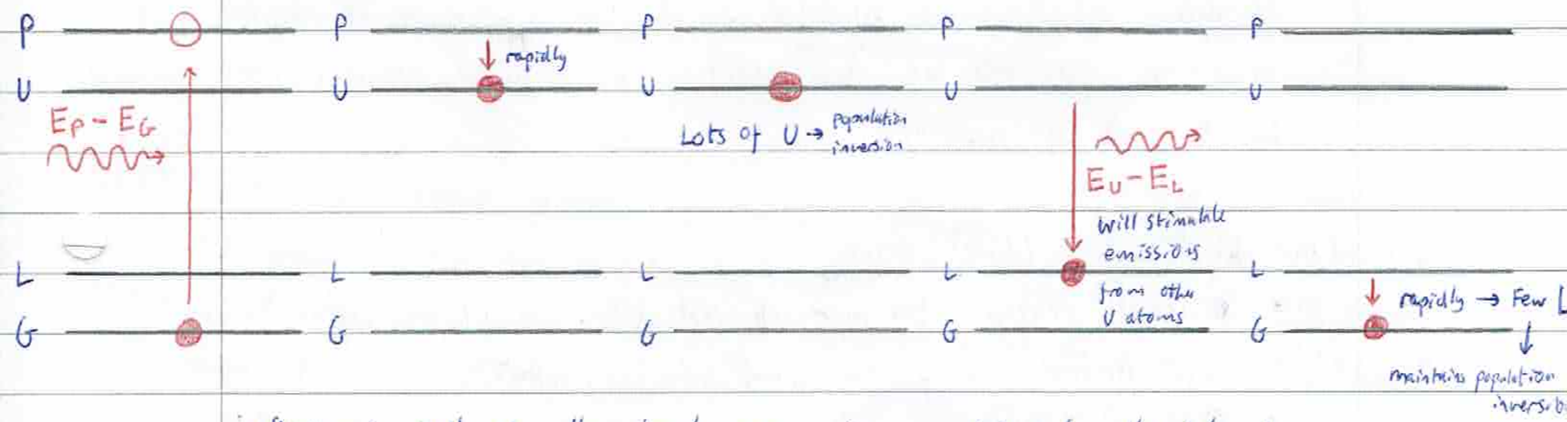
If the laser medium is pumped (with $E_p - E_G$ photons) atoms in G state will be raised to P state and rapidly decay into the metastable upper state (partly by spontaneous emission but mainly by collisions).
If the pumping is rapid enough, the population of U will exceed that of G (population inversion achieved), any spontaneous transition from U to G will produce a photon which will stimulate emissions from other atoms in state U (producing coheren light).

Because over half of the atoms in the ground state must be pumped to achieve laser operation, three-state systems are energy-hungry and inefficient. In practice, most lasers use four-state systems.

Four-state laser Systems

The characteristics of the pumped and upper states in a four-state laser system are the same as in a three-state laser. The additional, lower, state (L) is between the upper and ground states. L is short-lived and rapidly decays, mainly by collisions to G.

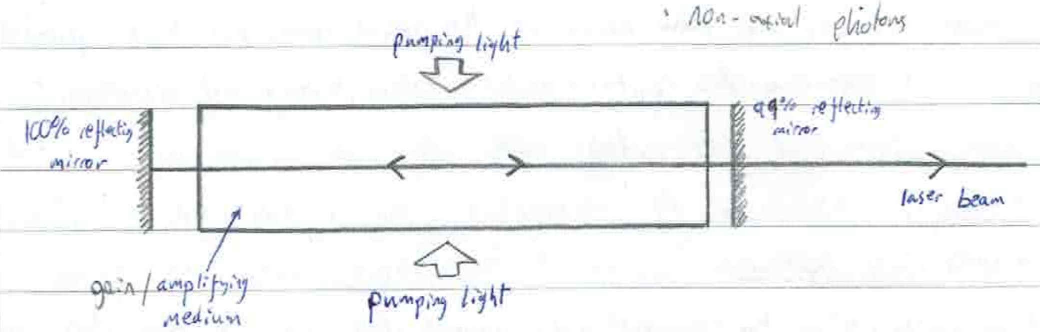
The advantage of this system over the three-state laser is that L is initially empty, so a population inversion between L and U is present from the first few electrons in U. The short-lived nature of L ensures that a population inversion is maintained with much lower level pumping, and hence requires less energy input, than the three-state laser. This means that lasing is possible at a much lower power input.



inefficiency: most of the input energy is converted into the internal energy of the atoms rather than raising the atoms' energy state. Even for successful pumping events the input ($E_P - E_G$) is more than the output ($E_U - E_L$ for 4-state: $E_U - E_G$ for 3-state).

not all absorbed
inefficiency: • imperfect pumping (not all the right absorbtion)
• transitions are not all wanted (non-lasing transitions)
• non-axial photons

Typical Laser Structure



- The pumping radiation creates a population inversion in the amplifying medium ($E_P - E_G$)
- Photons of energy $E_U - E_L$ or $E_U - E_G$ (4/3 state respectively) are produced by spontaneous emission in the amplifying medium.
- These photons ~~travelling parallel to the axis of the medium~~ pass through the amplifying medium and produce coherent photons travelling in the same direction by stimulated emission in an exponential increase.
- The photons tavelling parallel to the axis of the medium are reflected backwards and forwards stimulating more photons and eventually escaping through the partly transmitting mirror in the laser beam. (non-axial photons are lost)
- A dynamic equilibrium is established when the rate of escape of photons is equal to the rate of their production by stimulated emission (itself controlled by the rate of pumping.

The Semiconductor [diode] Laser

- small, cheap, far more efficient than other types (up to 70%)
- use electrical pumping and operate at low voltage
- used for DVD and CD reading and writing, blu-ray reading, optical fibre data transfer, computer scanners, and printers.

Physics component 3 - 3.6 / Nuclear decay

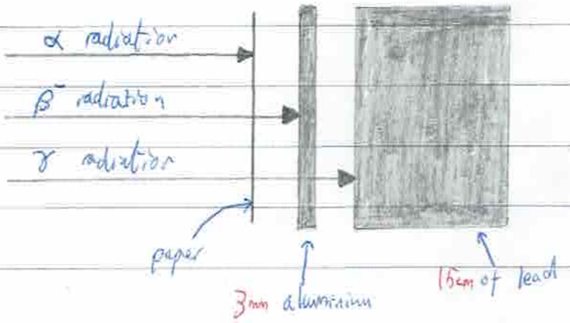
Alpha (α), beta (β), and gamma (γ) radiation are all types of ionising radiation because they knock electrons from atoms or molecules. The ionised particles that are produced are highly reactive and will react with other nearby molecules. In living tissue this can lead to all sorts of damage at the cellular level including damage to DNA, possibly leading to cancer. Nuclear decay (source of radiation) occurs spontaneously.

roughly all ionise to produce 10^5 ions per particle

α particle : ${}^{4}_{2}He^{2+}$ or ${}^{4}_{2}\alpha$ = helium nucleus (fast moving) : highest ionising, lowest penetration

β^- particle : ${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$ = fast-moving electron : intermediate ionising, intermediate penetration

γ radiation : high-energy, low-wavelength e.m wave / photon : arises from an excited nucleus



You may have to deal with equations representing the nuclear transformations using the ${}^{A}_{Z}X$ notation (A = nucleon no. Z = proton no.)

You can distinguish the radiation using different absorbers and a radioactivity detector or using direction of deflection in mag-field a cloud chamber (gives vapour trail where ionising radiation

Theory of Radioactivity

All of this depends on : disintegrations per second $\propto$ N (no. of nuclei)

A = rate of decay of a sample of radioactive nuclei (units Bq)

disintegrations per second = A (Activity) $\propto$ N $A = \lambda N$

$A = \lambda N$ (λ is a constant = decay constant

disintegrations per sec → $-\frac{\Delta N}{\Delta t} = \lambda N$

$\frac{\Delta N}{\Delta t} = -\lambda N$

↳ exponential decay : gradient always decreasing

x = no. half lives elapsed (not necessarily an integer)

$\left(\text{or} \quad N = \frac{N_0}{2^x} \quad A = \frac{A_0}{2^x} \right)$ $N = N_0 e^{-\lambda t}$

$A = A_0 e^{-\lambda t}$

Becquerel (Bq) = One disintegration per second

Half-life : time taken for the number of radioactive nuclei N (or the activity A) to reduce to half the initial value

$A = A_0 e^{-\lambda t}$

when $t = T_{1/2}$, $A = \frac{1}{2} A_0$

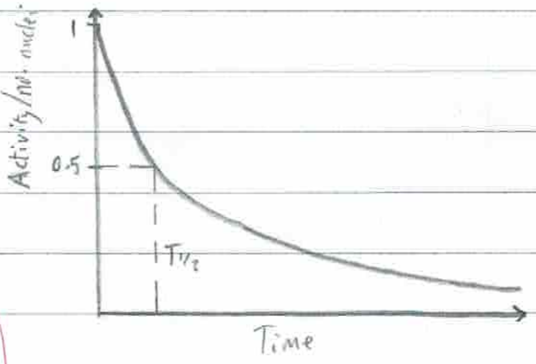
$\frac{1}{2} A_0 = A_0 e^{-\lambda T_{1/2}}$

$\frac{1}{2} = e^{-\lambda T_{1/2}}$

$2 = e^{\lambda T_{1/2}}$

$\ln 2 = \lambda T_{1/2}$

$\lambda = \frac{\ln 2}{T_{1/2}}$ $\left(\lambda = \frac{\ln k}{T_{1/k}} \right)$



Physics Component 3 - 3.7 Particles and Nuclear Structure

In 1904 Thomson proposed the Plum Pudding model. This was ~~disproven~~ disproved in 1911 by Rutherford when he found the nucleus in his alpha particle scattering experiment. This led to the conclusions:

1. Most of the space in the atom is empty (most α-particles were undeflected)
2. The positive charge occupies very little space, in the nucleus (very few were deflected
3. All the positive charge and mass of the atom are concentrated ~~all~~ in a very small volume within the atom (in the nucleus).

Matter is composed of quarks and leptons. There are three generations of quarks and leptons (no questions will be set on second or third generations).

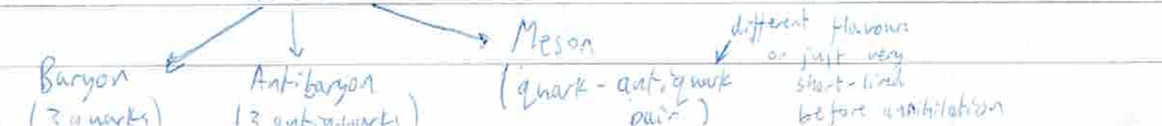
Generation	Leptons		Quarks	
	electron	electron neutrino	up	down
1st	symbol: e^-	symbol: ν_e	symbol: u	symbol: d
	charge: $-e$	charge: 0	charge: $\frac{2}{3}e$	charge $-\frac{1}{3}e$
	muon	muon neutrino	charm	strange
2nd	symbol: μ^-	symbol: ν_μ	symbol: c	symbol: s
	charge: $-e$	charge: 0	charge: $\frac{2}{3}e$	charge: $-\frac{1}{3}e$
	tauon	tauon neutrino	top	bottom
3rd	symbol: τ^-	symbol: ν_τ	symbol: t	symbol: b
	charge: $-e$	charge: 0	charge: $\frac{2}{3}e$	charge: $-\frac{1}{3}e$

different quark 'flavours'
↳ eg. top/bottom

Proton = uud
Neutron = udd

antiparticles exist for the particles in the table above. The properties of an antiparticle are identical to those of its corresponding particle apart from having opposite charge, (and color and stuff but not on spec). When antiparticles and particles meet, they annihilate. (Anti particles are often written as: anti-proton = $\bar{p}$ or positron = e^+).

Quarks and anti-quarks are never observed in isolation, but are bound into composite particles called hadrons, which have 3 types: Baryon (combination of 3 quarks), antibaryons (combination of 3 antiquarks), or mesons (quark-antiquark pairs).



Interaction	Experienced by	Range	Comments
Gravitational	all matter	infinite	very weak - negligible except between large objects such as planets
Weak	all leptons, all quarks (so all hadrons also)	very short	Only significant when the e.m and strong interactions don't operate
Electromagnetic (e.m)	all charged particles	infinite	Also experienced by neutral hadron as there are composed of quarks
Strong	all quarks (so all hadrons also)	Short	

What is conserved? Laws of conservation

↳ charge, lepton no., baryon number ~~(or quark number)~~

Neutrino involvement and quark flavour changes are exclusive to weak interactions.

γ = electromagnetic interaction

Physics Component 3 - 3.8 / Nuclear Energy

$E = mc^2$: gives us a relationship between mass and energy

Unified atomic mass unit ≈ mass of a nucleon (proton/neutron)

$1u = 1.66 \times 10^{-27}$ kg $\qquad 1eV = 1.60 \times 10^{-19}$ J

$1u = 931$ MeV/c^2 = 931 MeV

There is an attractive force between the nucleus and the electrons of an atom, which holds the electrons in place. The nucleons in the nucleus are held together by the strong nuclear force. Whenever an attractive force exists, as the particles come closer together they lose potential energy and this is the energy that is given out. In a chemical reaction, the electrons are more stable in the final products so they've lost potential energy and energy has been given out.

It is very similar in nuclear reactions, when the nuclei become more stable they lose PE and give out energy (about 10^6 times more than in chemical reactions). As the particles become closer together, their PEs and masses decrease. The name given to this change in PE as nucleons are brought together to form the nucleus is binding energy. When you divide the binding energy by the number of nucleons its an excellent measure of an individual nucleus' stability.

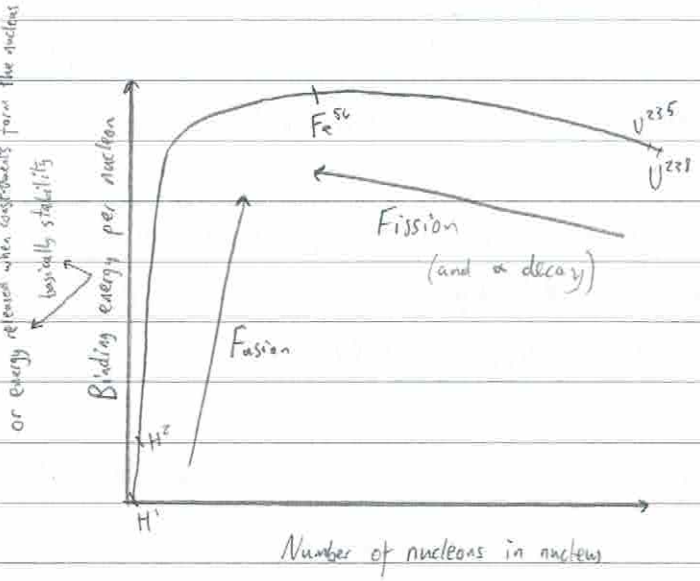
> More stable : lower PE (think closer together), lower mass, energy released
> ↳ Think of two of those magnet thingies coming together and releasing energy (that nice sound), their magnetic PE is lower, and pretend they get lighter.

Binding Energy :
- The energy that has to be supplied in order to separate a nucleus into its constituent components.
- Alternatively its the energy released (or the decrease in PE [which really is mass]) when the constituents form the nucleus.

To calculate Binding Energy : Add up the total mass of the constituents and find the differe between that and the mass when they are together. Then just conver to energy. (If 'per nucleon' just divide by no. nucleons)

↳ If given a weird synaptic example like a spring, just find the energy and convert as needed.

cons. of mass/energy is important for calculations

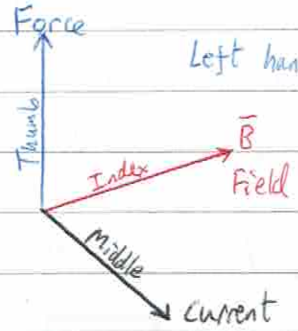


In both fission and fusion the binding energy is increased. Therefore the mass in the products is lower. Therefore energy is released.

Fusion releases much more energy as the change in the binding energy is much greater.

Physics - Component 3 - 3.9 / Magnetic Fields

Fleming's Left Hand Rule: direction of force on a current in a $\bar{B}$ field



Left hand: F·B·I

Force on a current carrying conductor:

$F = BIL\sin\theta$ ← between I and $\bar{B}$

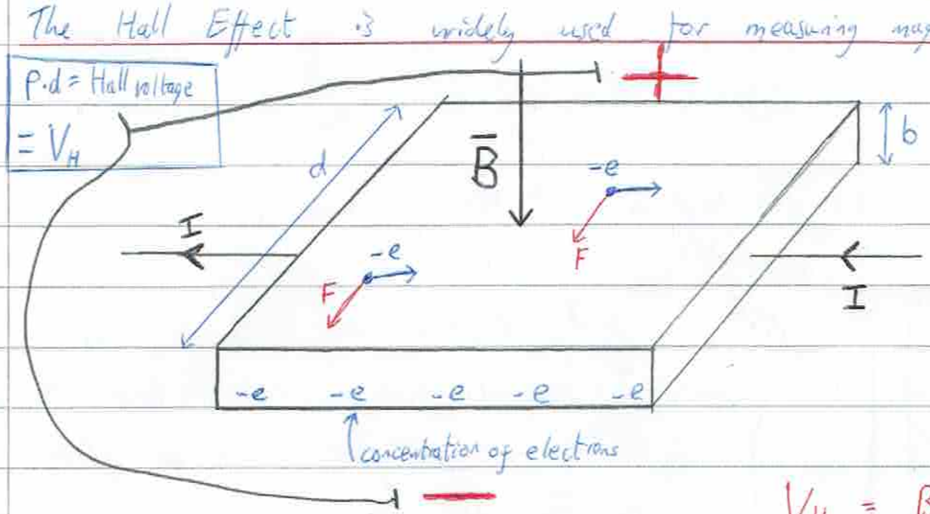
Force on a moving charge:

$F = Bqv\sin\theta$

The Hall Effect

This is when a current is flowing in a conductor, with a magnetic field at right angles to the current, there is a small potential difference across the conductor. This can be increased by using a semiconductor.

The Hall Effect is widely used for measuring magnetic fields.



once enough electrons have built up to repel new ones

$F_{el} = F_{mag}$

$Eq = Bqv$

$\frac{V_H}{d}\cancel{q} = B\cancel{q}v$

$I = nqva$

$\frac{V_H}{d} = \frac{BI}{qnA} = \frac{BI}{qnbd}$

$V_H = \frac{BI}{qnb}$ ← thickness

charge of charge carriers ↗ ↖ no. charge carries per volume

$\therefore V_H \propto B$ (constant I)

Don't need in this much detail but comes up often

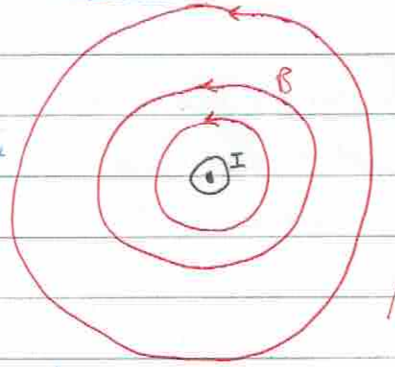
Magnetic Fields

Permeability

$B = \frac{\mu_0 I}{2\pi a}$

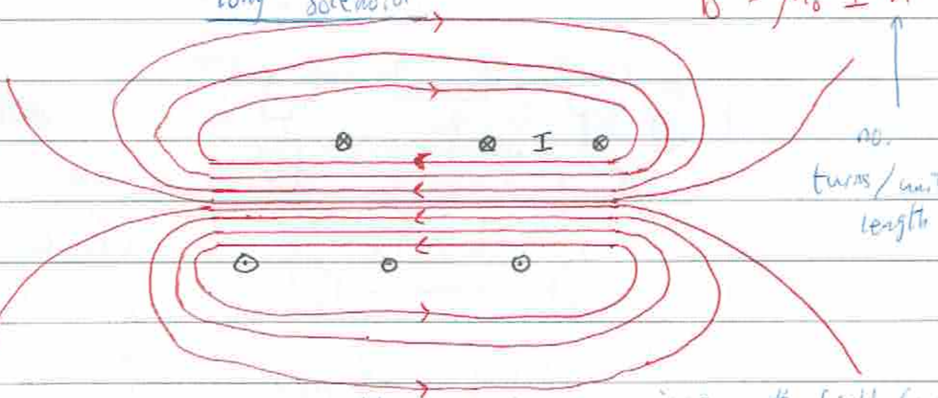
distance (radius)

long straight wire



Corkscrew Rule

long solenoid



At center:

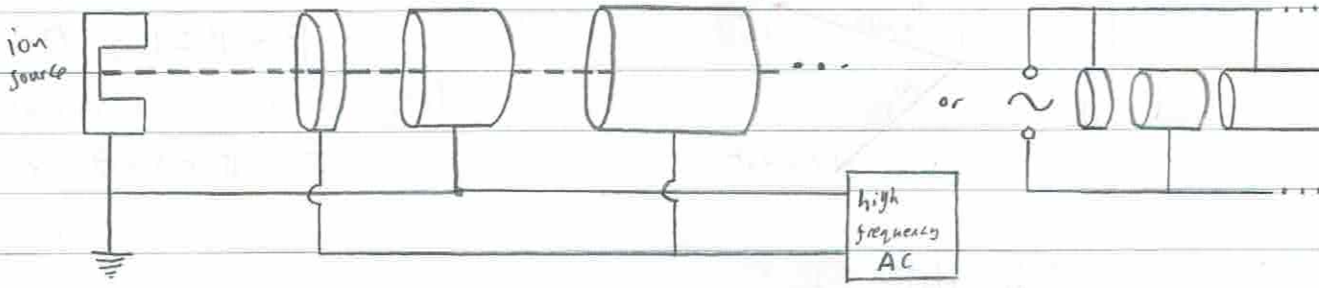
$B = \mu_0 I n$

no. turns / unit length

adding an iron core increases the field stre

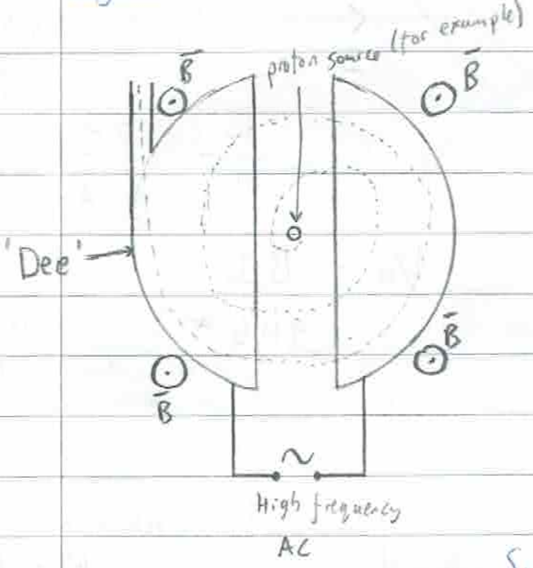
Particle Accelerators

LinAc: linear Accelerator = works using electric fields



The electric fields only exist in the gaps, not in the drift tubes. The AC means the polarity of the electric fields swaps at the right times to push/pull the particles. The particles are increasing in speed, and the drift tubes get longer to account for this so that the time spent in each tube is constant, so that the AC frequency can remain constant.

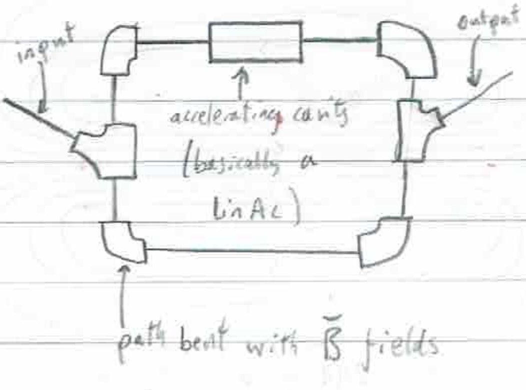
Cyclotron: particles' path bent using $\bar{B}$ fields, speed increased using electric fields



(To do calculations and stuff do $F_{cent} = F_{mag}$)

The magnetic field is there to bend the path of the charged particles, so that repeatedly cross the gap. The magnetic field is applied by electromagnet
There is an electric field in the gap of a constant frequency of change to polarization to increase the particles speed.

Synchrotron: same concept as Cyclotron, on a larger scale



In reality, there is a more circular shape, and probably more accelerating cavities.

Only major difference is that the frequency of the accelerator will have to increase as all of the distances are constant (this is different to LinAc and Cyclotron)

Physics - Component 3 - 3.10 / Electromagnetic Induction

Quick reminder on terms

B = Flux density = magnetic field strength = concentration of flux (through an area)

Φ = Magnetic Flux = Think of it as the stuff that makes up the field

$N\phi$ = Flux linkage = Flux 'linked' to a circuit (if a coil the flux is linked to each coil so flux linkage = $N\phi$ (N = no. turns))

$$\text{Flux} = \phi = \underset{\text{area}}{A}\ \underset{\text{flux density}}{B} \cos\theta \leftarrow \text{angle between area normal and field direction}$$

$$\text{Flux linkage} = \underset{\text{no. turns}}{N}\phi$$

V_ε = induced voltage

The voltage induced in a moving conductor

A voltage is induced in a conductor when it moves in such a way that it cuts lines of magnetic flux. The direction of the voltage is given by Fleming's right hand generator rule. $V_\varepsilon = BLv$ (velocity, current, and B are $\perp$)

actually learn this →

Faraday's Law: When the magnetic flux ϕ through a circuit changes, a voltage is induced in the circuit, proportional to the rate of change of flux linkage. $V_\varepsilon = -\dfrac{\Delta(N\phi)}{\Delta t}$ (often $= \dfrac{\Delta\Phi}{\Delta t}$) (pretty much always drop the −

↳ Gives the p.d induced in a ~~[illegible]~~ circuit in a general sense

↳ Applying to a rod moving in a $\bar{B}$ field:

$$\Delta\Phi = BA\cos\theta = BLv\Delta t \quad (\text{assuming } \theta = 0)$$

$$V_\varepsilon = \frac{\Delta N\phi}{\Delta t} = \frac{\Delta\Phi}{\Delta t} = BLv \qquad V_\varepsilon = BLv$$

often cannot use, so learn this properly

Lenz's Law: The direction of an induced voltage is such that its effects oppose the change ~~opposition~~ producing it.

a necessity to uphold the law of conservation of energy.

↳ the thing's movement will mean that there will be an induced voltage

↳ if there is a current the motor effect (LHR) will push it back

if there is a current its $\bar{B}$ field will oppose the original $\bar{B}$ field

↳ you can use these to find the current (might make things a lot simpler) or other things. If not a complete circuit, Lenz's Law still works imagining a complete circuit.

↳ if asked a question about something's movement being slowed by Lenz's Law, mention induced circular currents (eddy currents) that produce their own $\bar{B}$ fields cancelling some of the original $\bar{B}$ field/producing a counter force

The Simple Alternating Current Generator

This is a flat coil that is turned by some external means in a uniform magnetic field. As it rotates, the flux linkage changes, so a voltage is induced. For simplicity consider a rectangular coil with N turns.

Only need to know this qualitatively but learn the formula to solve time

When the normal to the coil is at angle ~~ϕ~~ θ to the field, the magnetic flux ϕ through the coil is $\phi = BA\cos\theta$

$$N\phi = NBA\cos\theta$$

To find out how the voltage varies with time, note that if the coil is being turned at angular speed ω, then at time t, $\theta = \omega t + \theta_0$ where θ_0 is the angle the normal makes with the field direction at time $t=0$.

$$\therefore N\phi = NBA\cos(\omega t + \theta_0)$$

$$V_\varepsilon = -\frac{d(N\phi)}{dt} = +\underbrace{\omega}_{\text{angular velocity}}\underbrace{N}_{\text{no. turns}}B\overset{\text{area of coil}}{A}\sin(\omega t + \underbrace{\theta_0}_{\text{angle between area normal and field at } t=0})$$

Physics - Option D / Energy and the Environment (Component 3)

The Earth's Rising Temperature

The Earth's equilibrium temperature is higher than it would be without an atmosphere due to the greenhouse effect (although the rate of energy loss is still equal to the net incoming power from the Sun. Burning of fossil fuels has increased the concentration of CO_2 in the atmosphere, leading to an enhanced greenhouse effect. Melting ice cover reducing albedo and melting permafrost releasing methane could become positive feedback loops.

Archimedes' Principle: The upthrust experienced by a body wholly or partially immersed in a fluid is equal to the weight of fluid displaced by the body.

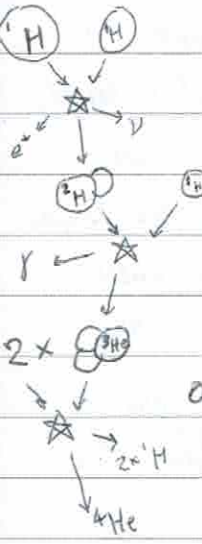
↳ The volume of water displaced by a floating iceberg therefore has a mass equal to the iceberg. Therefore if the iceberg were to melt, the mass of the meltwater = mass of water displaced. Therefore it won't cause sea water to rise.

Energy Sources

Solar Power

Without the Sun, the Earth would be a lifeless rock

- More massive stars produce energy by the CNO cycle
- The Sun produces it's energy (almost all of it) by the proton-proton chain



– 1. ${}^1_1H + {}^1_1H \rightarrow {}^2_1H + {}^0_1e^+ + \nu_e$

2. ${}^2_1H + {}^1_1H \rightarrow {}^3_2He + \gamma$

main branch

3. ppI: ${}^3_2He + {}^3_2He \rightarrow {}^4_2He + 2\,{}^1_1H$

⇓

overall: $4\,{}^1_1H + 2\,{}^0_{-1}e^- \rightarrow {}^4_2He$

ppII: ${}^3_2He + {}^4_2He \rightarrow {}^7_4Be + \gamma$

${}^7_4Be + {}^0_{-1}e^- \rightarrow {}^7_3Li + \nu_e$

${}^7_3Li + {}^1_1H \rightarrow 2\,{}^4_2He$

- $I = P/A = P/4\pi r^2$ (For a given planet/distance : I = 'solar constant')

Wind Power

- Power available from a flowing fluid: $P = \frac{1}{2}\rho A v^3$ (KE of air)
- Efficiency is affected by:
  - friction
  - KE of air cannot be reduced to zero
  - turbulent wake of one turbine interferes with the others downwind

(Tidal power stations work in the same way)

Hydroelectric, pumped-storage, and tidal-barrage power stations

- All work on the concept that the release of the gravitational potential energy of water as it flows downhill can be used to generate energy.
- Hydroelectric and pumped storage are obvious
- Tidal barrages are constructed with in-built turbines. As high tide approaches, the water level is higher outside than inside, so the sluice gates are opened allowing water to flow and its potential energy to be tapped. When the water levels are equal, the sluice gates are closed until the tide drops, then they are opened and the water flows back through the turbines the other way.

Nuclear fission

Enriching Uranium

Nearly all nuclear reactors operate by the fission of U235. The principles of operation of nuclear fission power stations, including moderators, control rods, and fission reactions themselves are not covered here. Natural uranium is >99% U238, and most reactors require 3-5% U235 so enrichment is needed. Historically this was done using gaseous diffusion but current technology uses gas centrifuges. This is based on the small mass differences of the two isotopes. The isotopes are chemically identical so a physical process (like the centrifuge) is needed. The Uranium is reacted with flourine to produce the gas uranium hexafluoride. This gas mixture is fed into a centrifuge. The heavier U238 molecules are spun to the outside and the enriched mixture is extracted along the central tube. This is repeated to achieve the desired levels of enrichment.

Breeding Nuclear Fuel

Although U238 is not fissile, it does capture neutrons, forming U239. This decays in two stages by β^- emission to give the fissile Pu239.

$$^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{92}U \xrightarrow{\beta^-} ^{239}_{93}Np \xrightarrow{\beta^-} ^{239}_{94}Pu$$

The fissile components of plutonium can be incorporated into fuel rods together with U235 in so-called MOX (mixed oxide) fuel.

Nuclear Fusion

In order to obtain fusion, three conditions have to be satisfied:

T : A high enough temperature, T, to enable the nuclei to come close enough for the electrostatic repulsion to be overcome by the strong nuclear interaction.

n : A high enough particle density, n, to allow a high enough collision rate

τ_E : A long enough confinement time, τ_E, which is how long the fuel maintains its internal energy.

Each of these conditions needs to be achieved separately. The aim of fusion engineers is to maximise the product, $nT\tau_E$, which is called the 'triple product'.

Fuel Cells

Fuel cell work through the combining of hydrogen and oxygen to produce energy.

1. Hydrogen is drawn into the anode
2. The hydrogen is oxidised by a catalyst (powdered platinum)
3. The H^+ ions diffuse into the electrolyte (through a non-conducting barrier) and the negatively charged electrons move through a circuit to a cathode. (ignore the cathode would repel) (I think the H^+ ions attract
4. Oxygen combines with the electrons and H^+ ions to produce water (the waste product).

↳ Anode: $H_2 \longrightarrow 2H^+ + 2e^-$

cathode: $\frac{1}{2}O_2 + 2H^+ + 2e^- \longrightarrow H_2O$

$\Rightarrow \quad 2H_2 + O_2 \rightarrow 2H_2O$

↳ Advantage: no fossil fuel emission (if hydrogen produced sustainably)

Disadvantage: hydrogen difficult and dangerous to transport and store.

Heat conduction

$$\frac{\Delta Q}{\Delta t} = \overset{\text{often dropped}}{-}\underset{\text{area}}{A}\,\overset{\text{coefficient of thermal conductivity }(W m^{-1} K^{-1})}{k}\,\frac{\Delta \theta}{\underset{\text{distance}}{\Delta x}} \longleftarrow \text{temperature}$$

Remember: If there are multiple layers involved, the rate of heat flow through the layers must be the same

U values

↳ $\frac{\Delta Q}{\Delta t} = UA\,\Delta\theta$ $\qquad U = \frac{k}{\Delta x}$

Thermal resistance = $R = U^{-1}$

↳ useful aspect is that the thermal resistance of a layered building is the sum of the individual thermal resistances.

↳ whereas $\frac{1}{U_T} = \frac{1}{U_1} + \frac{1}{U_2} \ldots$