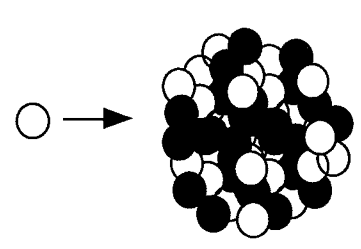
St Maurice's High School | Physics Department

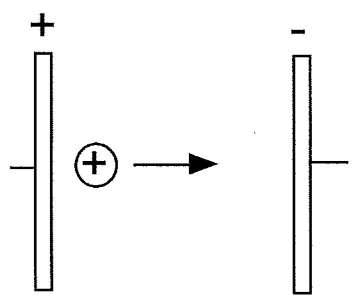
Higher Physics

Unit 2

Particles and Waves



up
down
charm
strange
top
bottom



Summary Notes

A. The Standard Model

1. Order of Magnitude

Physicist study objects from the very small - (atoms) up to the very large- (universe). We use x10^n notation to indicate the order of size or magnitude.

Order of magnitude (m)	Object
10^{-15}	width of a p_______
10^{-8}	width of an a________
10^{-7}	wavelength of visible________
10^{-4}	width of a grain of s_______
10^{0}	width of a do____
10^{3}	length of Forth Road _________
10^{7}	diameter of E________
10^{11}	distance to the S______
10^{17}	distance to nearest S_______
10^{26}	width of a observable ___________

10^2 = order of magnitude 2 10^7 = order of magnitude 7

10^{-8} = order of magnitude -8

So 1×10^{14} is an order of magnitude 7 bigger than 1×10^{7}.
ie it's 10,000,000 times bigger. It is not twice as big.

Ex 1 How many orders of magnitude bigger is 7.1×10^6 than 5.6×10^4

Divide biggest no by smallest = $\frac{7.1\times10^6}{5.6\times10^4}$ = 127 nearer ______ than 1000 therefore 7.1×10^6 is an order of ____ or 100 times bigger than 5.6×10^4

Ex 2 How many orders of magnitudes bigger is 1.7×10^{-3} than 2.4×10^{-7}?

Divide biggest o by smallest = $\frac{1.7\times10^{-3}}{2.4\times10^{-7}}$ = 7083 This is nearer 10,000 than ________ so 1.7×10^{-3} is an order of ___ magnitudes bigger than 2.4×10^{-7} or 10,000 times bigger

2. Fermions

Anything in the universe which is made from matter is called a _____________.

3. 1st Generation Fermions

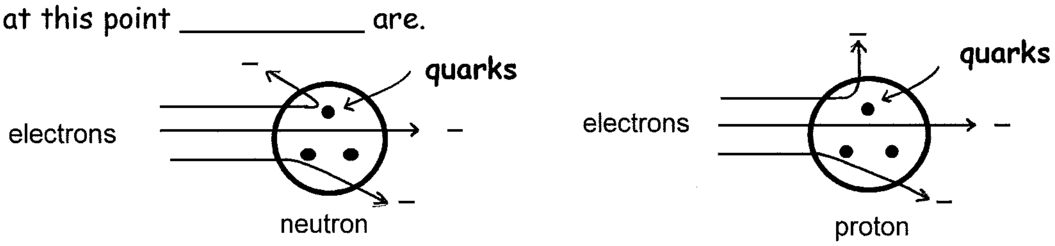
There are 4 fundamental fermion particles which make up all the matter in the universe we can see. We call these 4 fermions ___st generation fermions.
A fundamental particle cannot be ____________ down into anything simpler.

The electron

The electron is a fundamental particle. It cannot be broken __________ into anything simpler.

Neutrons and protons?

In 1909 Rutherford fired alpha particles at atoms and concluded that the nucleus was made up of smaller particles called _________. In 1963 American physicist Murray Gell-Mann fired electrons at neutrons and protons and found they were actually made from 3 tiny sub-nuclear particles called __________.
So protons and neutrons are ______ fundamental particles, but as far as we know at this point __________ are.



There are two different 1st generation quarks:

The _____ quark (u), with a charge of [ ] e

The ___________ (d) quark with a charge of [ ] e.

Proton **Up + Up + Down** $= \frac{2}{3} + \_\_ - \_\_ =$ [ ] (u u d)

Neutron **Down + Down + _____** $= -\frac{1}{3} - \frac{1}{3} + \_\_ =$ [ ] (d u d)

4. The final fundamental particle - The neutrino ν_e

In Nat 5 we said that Beta decay involved an unstable atom decaying and emitting an electron. Another particle is also released. This new particle has no mass and no ___________ and is called a __________________ or electron ______________. Wolfgang Pauli predicted mathematically their existence in 1931 but because they are such ghostly particles it was not until 1956 that they were finally detected.

In fact there are two types of Beta decay. One creates an electron neutrino ν and the other an anti-electron neutrinos ν. (More about anti-matter in a minute)

In big unstable atoms, protons change into neutrons and emit and an anti - electron or positron and a neutrino

$$\text{(p)} \longrightarrow \text{(n)} + \bar{e} + \nu_e$$

Or sometimes a neutron turns into a proton emitting an electron and an anti neutrino.

$$\text{(n)} \longrightarrow \text{(p)} + e + \bar{\nu}_e$$

Billions of neutrinos, emitted from the sun, pass through our bodies each _________ and are virtually undetectable.

5. Anti matter

Every matter particle has an anti-matter particle. An anti-matter particle has the same ___________ as the particle but an opposite _________________. We indicate an anti-matter particle with a _________ above the symbol for the matter particle

particle	anti-particle
proton p neutron n electron e	antiproton or $\bar{p}$ _______neutron or _____ anti ____________ or p_____________. $\bar{e}$ or e^+

proton $^{0}_{1}p$ anti proton $^{0}_{-1}\bar{p}$

electron $^{0}_{-1}e$ anti electron or positron $^{\square}_{\square}e$

up quark u charge = $+\frac{2}{3}$ anti-up quark = $\bar{u}$ charge = ☐

down quark d charge $-\frac{1}{3}$ anti-down quark = $\bar{d}$ charge = ☐

When a particle and anti particle meet they ____________________ each other.
Their masses are turned to energy in the form of ________________ waves.
We think most anti-matter was destroyed just after the big bang. But why does it appear that slightly more matter particles were made?

We sub divide fermions into different groups as summarised below

Fermions -
Particles made from m__________

Hadrons
Particles made from _________

Leptons
Particles not made from _________.
Ex - ______________ &
electron ___________

Baryons
Hadrons made from __ quarks. Ex
________ & ________

Mesons
Hadrons made from __ quarks: a quark and an anti quark.
Very unstable - don't last long.
Ex ___________

An example of a meson is a Pion. It is made from an up quark and an anti-down quark.

Pion $u\bar{d}$ charge $= +\frac{2}{3} +$ ☐ = ☐

The only stable Hadron is a proton. Even neutrons outside a nucleus decay to protons. Mesons decay very rapidly to leptons and photons. (ie energy).

So the 1st generation fermions (the stuff we see all around us) consist of up quarks, _______ quarks, electrons and electron _______________.

6. 2nd and 3rd generation fermions

In the last 80 years we have been building more powerful particle ______________.
The most powerful to date is at ___________ in Switzerland. As we smash protons and neutrons together at higher and higher velocities we find heavier and heavier versions of the 1st generation fundamental particles in the debris.
We find a heavier version of the up quark called the charm quark, then in even higher energy collisions an even heavier version called the ______quark appears.
We find heavier versions of the down quark called the strange and ________quark.

We also spot even more massive versions of the electrons and neutrinos whizzing about in the debris. The more massive electrons are called the _______ and the ____ . And the more massive neutrinos are called _______ neutrinos and _____ neutrinos.
Again each of these particles has an anti _____________________.

This table summarises all the fermions we know about at this moment.
Remember the physical universe is made up from the 1st generation fermions.
The 2nd and 3rd generation fermions are made inside particle accelerators and maybe black holes and exploding stars. But they are short lived and quickly decay back to their 1st generation versions.

1st generation	2nd generation	3rd generation
$+\frac{2}{3}$ up quark	$+\frac{2}{3}$ c________ quark	$+\frac{2}{3}$ top quark
$-\frac{1}{3}$ down quark	$-\frac{1}{3}$ strange quark	$-\frac{1}{3}$ ________ quark
– electron	– muon	– ______
electron neutrino	_______ neutrino	______ neutrino

7. Fundamental Forces

There are 4 fundamental forces in the universe which hold these fermions together.

1. Strong force.	The force which hold ___________ together and therefore protons and neutrons. It is the strongest of the 4 forces but operates over a very ___________ range. Less than_______m.
2. Electromagnetic.	This is the force which acts between ___________ particles. It has an ___________ range.
3. Weak force.	This is the force which makes protons turn to neutrons and neutrons to turn to protons. So therefore it is vital in _________ decay. It has a very __________ range. Less than _______m
4. Gravitational.	This is the attractive force between ___________. It is extremely weak but has an _______________ range.

8. Force carriers - Bosons

So how do these forces get from one quark to another to have an affect or from one electron to another?
Well, individual particles interact by exchanging force mediating or force carrier particles called _____________. The strong force requires ___________. The weak force has 2 mediating particles called the _____ and _____ bosons. The electromagnetic force requires particles called ____________ to carry the force. Gravity is weird - we still have not found the force mediating particle. But when it discovered we will call it a _______________.

Force	Acts on	Relative Strength	Range	Boson (force carrier)
Strong	Quarks	1	10^{-15}m	G________
electromagnetic	__________ particles	x 0.01		P________
Weak	Quarks and leptons	x0.00001	10^{-17}m	W and ____ Bosons
Strong	Anything with _______	$x10^{-40}$	∞	G____________

9. Summary - The Standard Model

	F________			B________
Q________	up $+\frac{2}{3}$	c______ $+\frac{2}{3}$	top ☐	P______
	down $-\frac{1}{3}$	strange ☐	b______ ☐	G______
Leptons	e electron	μ m______	τ t______	___ & Z
	ν_e electron neutrino	ν_μ muon ______		

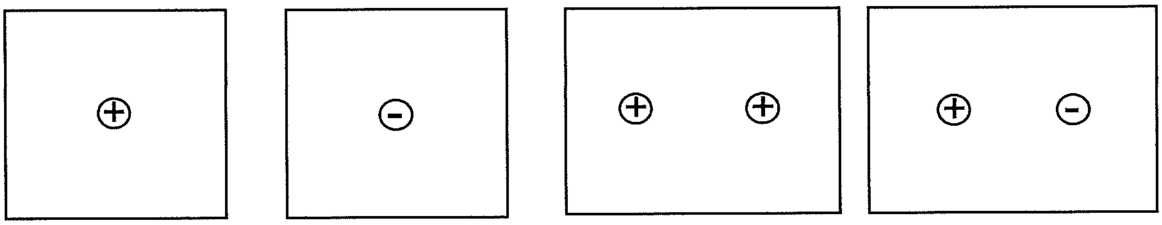
Recently we found another boson called the Higgs Boson. This Boson solved the puzzle of why things have _________. Each Boson is associated with a field - ie the photon is associated with the electromagnetic field. So the Higgs boson must have a field associated with it. This field is called the Higgs field. When a fermion moves through the Higgs field it finds it "sticky", it's this "stickiness" which we feel as mass. Things not made from mass are not affected and whizz through the field unaffected at the speed of light. ie the photon.
When we find the gravitational forces carrier particle, the graviton, it will be added.

B. Electric Fields

1. Field Patterns

Just as there is a gravitational field around a mass there is an electric field around ____________________ particles. The direction of the field is defined as the direction a ________________particle would move if place in the field.
Like charges ______________ each other. Unlike charges ___________ each other.

Field round a single particle (radial) Fields between bi-poles



The closer the lines are together the ___________________ the field.

Field between two parallel charged plates.

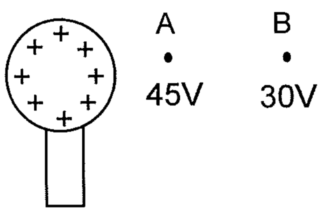
u___________ field

2. Charged Particles in fields

When a charged particle is placed in an electric field. A force acts on it which causes it to a________________ and therefore gain ________________energy.
This energy come from the ______________ field. We say the field has done work on the particle or work is done to the particle.

3. Potential Difference ( )

The potential difference between 2 points is the ______________ transferred when one coulomb of charge moves from one point to the other. ie $V = E/Q$



Voltage at A = ______V

Voltage at B = ______V

Potential difference (pd) =_____V

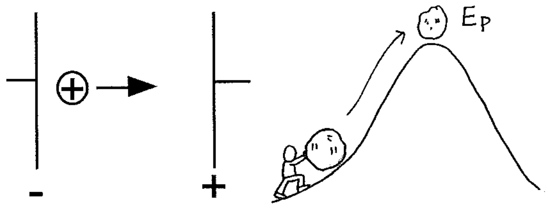
So energy required to move 1C of charge from A to B is ______J

So energy required to move any amount of charge between these two points is

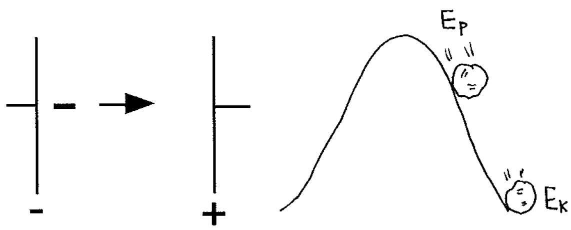
$$\text{Energy} = Q \times V \quad \text{or} \quad WD = QV$$

Quantity	Unit
WD	
Q	
V	

When you are moving against the field you are doing QV of work to the field, and the particle gains electrical ____________ energy.



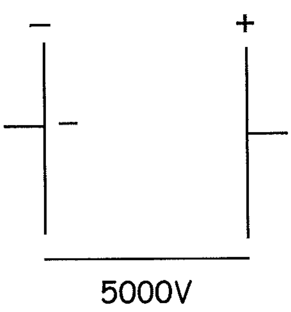
When a charge is moved by the field ie accelerates it loses ____________ potential energy and gains ______________ energy



In the second diagram the electron loses QV Joules of energy and gains $1/2mv^2$ of kinetic energy

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

Ex 1



(a) What type of energy does the electron have at the negative plate? ________________

(b) Do you have to (a) do work against the field or (b) does the field do work on the electron? ____________

(c) What does its electrical potential energy turn into as it accelelerates across field? ____________

(d) How much electrical potential energy is lost in crossing the field?

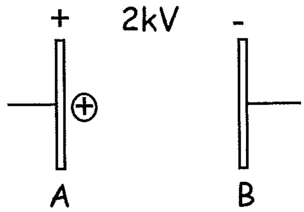
(e) Therefore how much kinetic energy does electron have at positive plate?

4. Speed of the charged particle.

$QV = \frac{1}{2}mv^2$ therefore $2QV = mv^2$ therefore $v^2 =$

so $v =$

Ex The pd between two parallel electric plates is 2kV. An proton is released from plate A



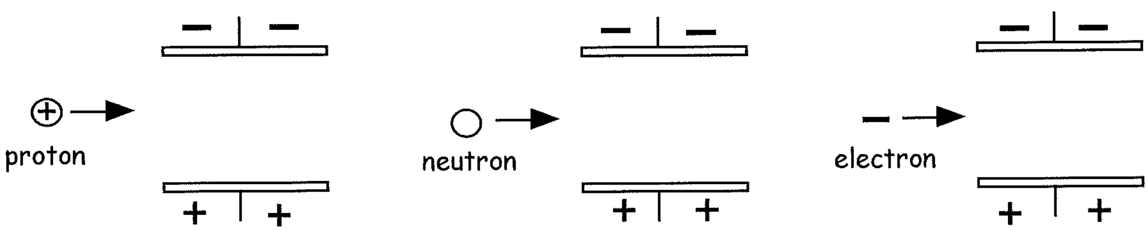
(a) Calculate electrical potential energy lost when the proton moves from plate A to B?

(b) What form does this electrical potential energy turn into? ____________________

(c) Calculate the speed of the particle as it hits plate B.

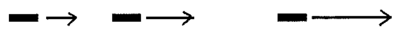
5. Charges moving perpendicular to electric field

These 3 diagrams show electric fields created by a negative plate at the top and a positive plate at the bottom. Sketch the path of the particle.



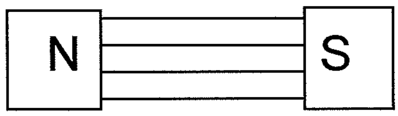
6. Electric charges and fields

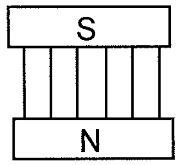
An electric charge can create 3 fields around it depending on its motion.

Stationary	Moving with constant speed	Accelerating
		
produces an_________ field	produces an____________ field and a _____________ field	Produces an____________ field a ______________ field and __________________waves

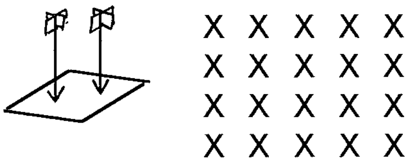
7. Showing magnetic fields

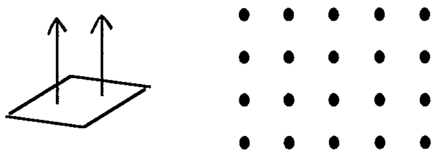
We can show magnetic fields as lines between North and South Poles. By convention magnetic field direction is from North to South





Or we can show it going into paper with and x or out of paper with a dot.

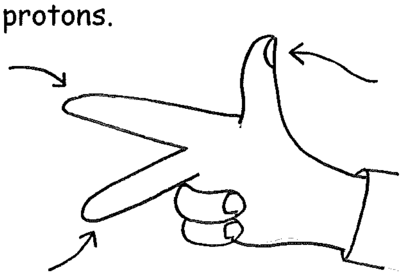




8. Charges moving in a magnetic field

Magnetic fields change the direction or d____________charged particles. The direction can be determined using the __________ hand rule for electrons. _________ hand rule for protons.

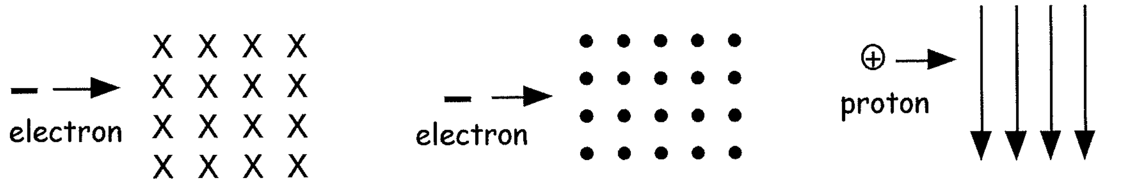
First finger - direction of the magnetic f_________



Thumb - Direction of f__________ or direction charge is d_______________

Middle finger - direction of e__________ flow

Ex Predict the path of this electron in the magnetic field.



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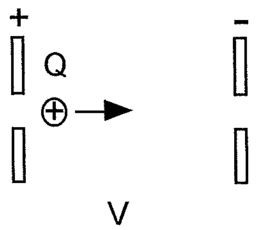
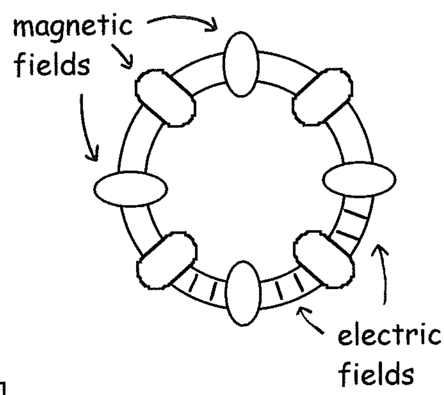
9. Particle accelerators

CERN - The Large Hadron Collider - Synchrotron

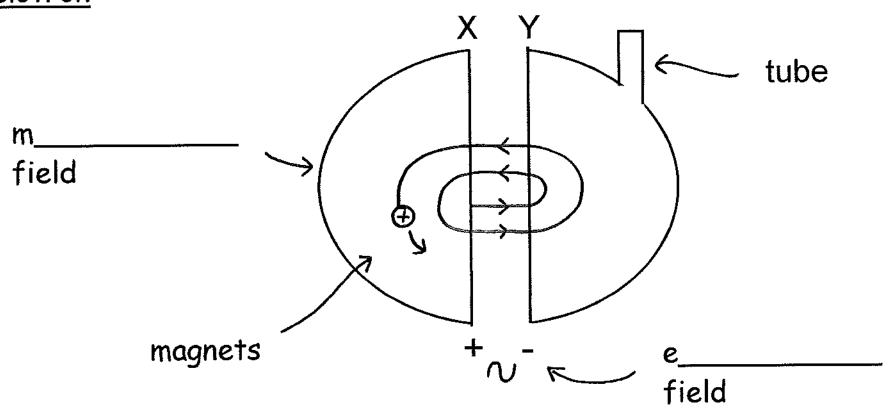
Particle accelerators accelerate charged particle to close to the speed of __________. In many applications the particles are made to collide. The debris of collisions help us to understand the composition of matter and the Big __________. At CERN, electric fields are used to ________________ particles to speeds close to the speed of _______. Magnetic fields are used to ________ the particles in a circle.



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



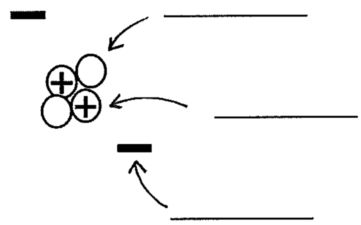
Cyclotron



Charged particles are accelerated across electric field XY set up between two semi circular magnets, The magnets ______________ the particles so they re enter electric field and are further accelerated. When the charged particle has achieved a sufficient speed the magnets are switched ______ and the particle beam travels down a tube in a straight line to be used in further experiments.

C. Nuclear Reactions

1. Structure of the atom



An atom is made of a tiny central nucleus comprising positive ____________ and ____________ which have ___charge. Surrounding the nucleus orbit negative ____________.

Electrically neutral atoms have the same number of ____________ and electrons. If it gains an electron it becomes a ______________ ion. If it loses an electron it becomes a ________________ ion. Atoms with the same number of protons but different numbers of neutrons are called ________________.

2. Describing a nucleus

$$^{A}_{Z}X$$

X = Chemical symbol
A = Mass number = Number of ___________ + ___________
Z = Atomic number = Number of ___________.

Ex

$$^{7}_{3}Li$$

Element = Li = ____________
No of protons = Z = ___
No of protons + neutrons = ___
No of neutrons = 7 - ___ = ___

3. Stable and Unstable nuclei

In small atoms the electrostatic force trying to blow the nucleus apart is balanced by the __________ force gluing nucleons together. However with very big nuclei (Uranium) the number of positive ____________ increases and so the electrostatic force increases to the point where it is gets much bigger then the ________ force. These atoms are called unstable or radioactive atoms.

To become stable the nucleus attempts to become stable by emitting alpha α, Beta ____ and gamma _____ radiation.

Radiation	Symbol	Charge	Nature
Alpha			Helium ___________
Beta			Fast moving __________
Gamma			____________________ wave

Alpha particles are Helium nuclei so can be represented as follows

$^{4}_{2}He$

A Beta particle is an electron and can be represented as follows

$^{0}_{-1}e$

A Gamma wave is represented as follows

γ

When an unstable nucleus emits a radioactive particle we say it has ___________.
We can show these decays with decay equations

Alpha Decay

$^{208}_{84}Po \rightarrow ^{4}_{2}He + ^{\square}_{\square}\square$

Beta Decay

$^{199}_{78}Pt \rightarrow ^{0}_{-1}e + ^{\square}_{\square}\square$

Gamma radiation is usually a by-product of the above decays. Gamma emission does _______ change the structure of the nucleus. But does make it more stable by reducing the ___________ in the nucleus.

4. Decay and Energy

In all these decays a little mass is lost. This mass is converted to ___________.

5. Fission

In a fission reaction a large nuclei ________ into two smaller _________ with the release of energy.
In a stimulated fission reaction an unstable nucleus (Uranium) absorbs a ____________. This causes it to split into 2 fission fragments, some ____________ and kinetic energy, which turns to __________as the particles __________ down.
The emitted neutrons travel on an cause more fission reactions. This is creates a ________________ reaction.

$$^{1}_{0}n + ^{235}_{92}U \longrightarrow ^{134}_{52}Te + ^{98}_{40}Kr + 4\,^{1}_{0}n + \text{energy}$$

The mass of the particles after the reaction is __________ than the mass of the particles before the reaction. This lost mass is converted to __________.
The amount of energy created is calculated using

E = ____ ____

where E = Energy ____________ m = ________ mass c = speed of ________

Ex Use the following information to calculate the energy released in the above fission reaction

Particle	Mass
neutron	1.675×10^{-27}kg
Uranium 235	3.901×10^{-25}kg
Tellurium 134	2.221×10^{-25}kg
Zirconium 98	1.626×10^{-25}kg

Mass of particles before reaction

__________________ + __________________ = ________________

Mass of particles after reaction

_____________ + ___________ + 4 (_____________) = ___________

Lost mass = ______________ - ________________ = ___________

Therefore **energy created** by this lost mass =

$E = mc^2$ = ______________ x ____________ = _____________

6. Fusion Reaction

In a fusion reaction ______ smaller nuclei combine to create a __________ nuclei with the release of energy. This is the reaction which powers the _________.

$$^{2}_{1}H + ^{2}_{1}H \longrightarrow ^{3}_{2}He + ^{1}_{0}n + \text{energy}$$

Once again the mass of the particles after the reaction is _______ than the mass of the particles before the reaction. This lost mass is converted to _________. The amount of energy created is calculated using

E = __ __

Fission is the process by which e________________ is generated in our nuclear reactors. Fusion will only be viable when we can fuse the hydrogen atoms at a low enough _________________ to make the process economical.

Ex Use the following information to calculate the energy created in the above fusion reaction

Particle	Mass
hydrogen 2	3.342×10^{-27}kg
Helium 3	5.004×10^{-27}kg
neutron	1.675×10^{-27}kg

Mass before reaction = ______________ + ______________ = _____________

Mass after reaction = ______________ + _______________ = _____________

Mass Lost in reaction = ______________ - ______________ = ________________

Energy created by reaction = $E = mc^2$ = _________ x _________

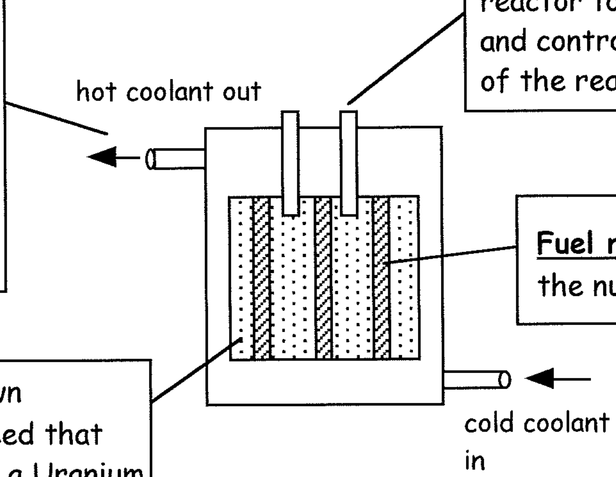
= _____________________

7. Parts of a nuclear Reactor

A nuclear reactor produces heat which is used to turn water into a jet of________ which spins a magnet inside a coil of ________ to create ____________________.

Coolant - Carbon ___________ or water. Circulated round core to remove ________ and take it to heat exchangers. Keeps he core at a safe _________________.

Control rods - lowered into reactor to absorb neutrons and control the ______ of the reaction.



Fuel rods - Contains the nuclear________

Moderator - slows down ____________ to a speed that makes their capture by a Uranium nucleus __________likely.

As the coolant passes through the core it becomes very ________________. Therefore it is very important to contain it and not let it _______________ into the environment. The core is surrounded by thick ________________ walls to prevent the escape of radioactive material into the environment

D. Wave Particle Duality

1. Photoelectric Effect

In some situations waves can act like ________________ and particles like ____________. An example of a wave acting like a particle is the ____________________________ effect.

Extremely bright white light could not eject electrons from a negatively charged metal plate. However a very dim UV source would see electrons being emitted. Why?

Einstein postulated that light did not travel as continuous waves like water waves but as individual packets of wave energy called ________________.
The energy of these photons was not dependent on their amplitude but on their ________________________.

Energy of a photon = Planks constant x frequency of photon

$$E = hf$$

Energy ( ) → E; h ← 6.63×10^{-34}Js; f ← frequency ( )

Ex A photon of X-rays has a frequency of 7.2×10^{17}Hz. What is the energy of the photon?

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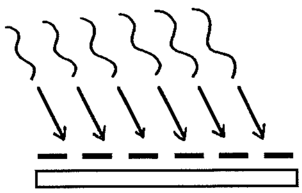
1 So extremely bright white light would not eject an electron because although a huge amount of energy in total is hitting the surface, because the frequency of white light is l_________ the energy of each photon is s__________.
So none of the photons has sufficient energy to release a photon.

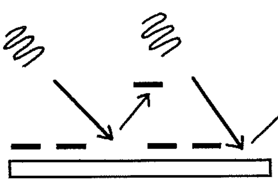
2. The dim UV light will eject electrons because UV light has a _____________ frequency than white light so each individual photon has sufficient energy to release a photon. One photon interacts with one electron.

low energy photons



very intense white light

high energy photons



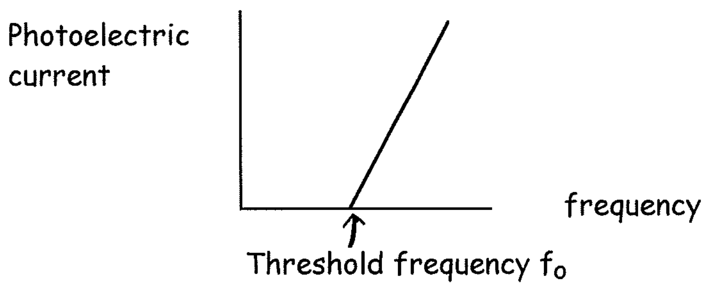
very dim UV light

2. Threshold frequency f_0

The threshold frequency of a metal is the minimum ____________ of incident photon which will cause an _____________ to be emitted. If the frequency of the photons in the irradiating light is higher than the threshold frequency electrons will be ________________.

Ex The threshold frequency of a metal plate is 4.6×10^{15}Hz. Circle the photons from the following options that will emit electrons from the plate?

A. 2.1×10^{15}Hz B. 7.2×10^{15}Hz C. 9.8×10^{14}Hz D. 1.1×10^{17}Hz



From the graph, as freq of photons increases above fo the electrons come off faster so more charge passes a point each second & photoelectric current increases.

3. Work function

Therefore the minimum energy of photon required to remove a photon is called the _____________ function.

$$W = hf_0$$

A photon with energy Ep which is greater than the work function Wo hits a plate. Electrons will be _____________. The bigger the gap between Ep and W the greater the ____________ energy of the emitted photon

Ex The threshold frequency of a metal plate is 2.6×10^{14}Hz

(a) Calculate the work function

(b) Will a photon of energy 3×10^{-19}J be able to eject an electron?

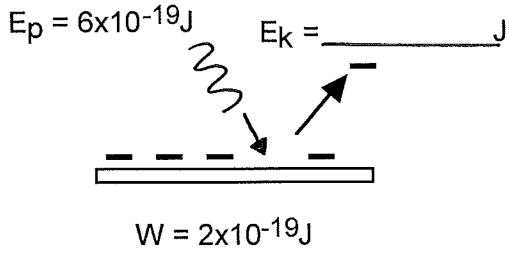
4. Kinetic energy of emitted electrons

A photon with 4J of energy hits a plate with a work function of 3J. So it takes ____J to remove the photon, so __J is left over, this is transferred to the kinetic energy of the ejected electron.*

Kinetic energy of ejected electron = Energy of photon - Work function

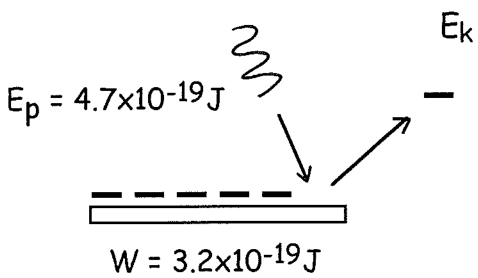
$$E_k = E_p - W$$

$$\frac{1}{2}mv^2 = hf - hf_0$$



* The only difference between reality and the example above is that the numbers involved will be smaller.

Ex From diagram Ep is greater than W therefore electrons _______ be ejected.



The kinetic energy E_k of an ejected electron $E_k = E_p - W$

E_k = _________ - __________

= ______________

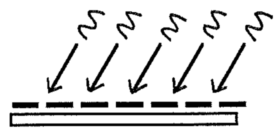
If the frequency of photons is increased each photon has more __________.
Therefore the kinetic energy of emitted electrons will _____________.

Ex A beam of red light is incident on a metal plate with $W = 4.3\times10^{-19}$J.
The energy of each photon is 2.2×10^{-19}J

(a) Will electrons be emitted?

(b) How would you change the frequency of photons to eject electrons?

Ex A metal plate has a work function of 2.2×10^{-19} J. Light of frequency 5.9×10^{14} Hz is incident on it.



(a) What is the energy of an incident photon?

(b) Will electrons be released? ________

(c) If so calculate the kinetic energy of the emitted electrons

(d) Calculate the speed of an emitted electron.

5. Changing Irradiance & Frequency

Increasing the irradiance increases the ______________ of photons in the beam.
Increasing the frequency of photons increases the _____________ of each photon.

Ex Light of frequency 5×10^{15} Hz is incident on a plate which has a threshold frequency of 2×10^{15} Hz.

(a) Will electrons be released? ________

(b) The irradiance is increased. How does this affect the

(i) number of electrons being released? ______________

(ii) the kinetic energy of released electrons? ______________

(c) The frequency of the photons is now increased. How does this affect the

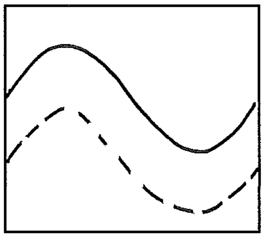
(i) number of electrons being released? ______________

(ii) the kinetic energy of released electrons? ______________

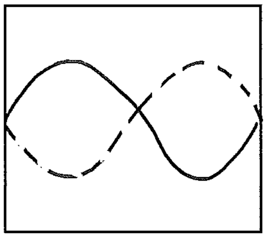
E Interference and diffraction

1. In phase.

Waves which are in phase are in step. The same point on both waves occurs at the same time . ie peaks and peaks in step



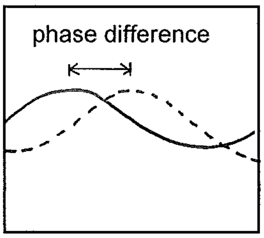
2 waves in phase (in step)



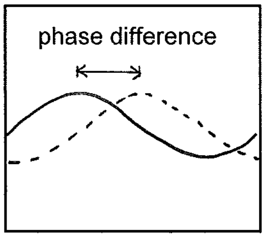
2 waves 180^{o} out of phase (out of step)

2. Coherent waves

Coherent waves have a constant phase difference and to keep this constant phase difference all the time they require to have the same frequency, ________________ and _______________.



10mins later



2 coherent waves

3. Interference Patterns.

To create interference patterns we require 2 coherent wavefronts to meet.
It is easy to create two coherent wave fronts with sound and water waves because the wavelengths are very large. Two people clapping __________ at the same time or two stones being dropped into a pool of ____________ at the same time will create two sufficiently coherent wave fronts.

When water waves and sound waves from two coherent sources meet they ___________________ with each other. They can interfere constructively or ________________________.

4. Constructive interference

When peaks from one source meet with peaks from the other source they a______ together to form a ______________ wave. .

+ =

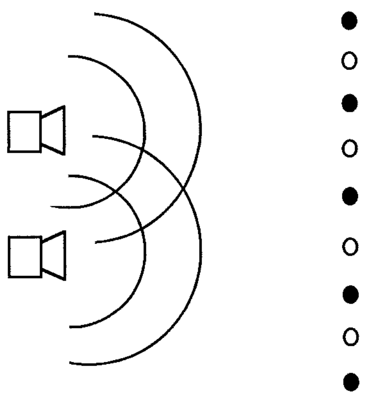
5. Destructive interference

When peaks from one source meet troughs from the other source they _____________ each other out resulting in ____ wave motion.

+ =

6. Maximum and Minimums.

In this example 2 loudspeakers create 2 coherent semicircular wavefronts which meet and interfere. Areas of loud sound (maximum) ● and no sound (minimum) o are detected. Areas of max wave disturbance are caused by waves _____________________ interfering. Areas of no wave disturbance are created by waves ______________________ interfering.
The path difference Δ is the difference between the number of ___________ arriving from source A and B at a fringe. Or the difference in distance



__________ order maximum. Δ = ___λ

first order maximum. Δ = ___λ

zero order maximum. Δ = ___λ

first order minimum. Δ = ___λ

__________*order minimum.* Δ = ___λ

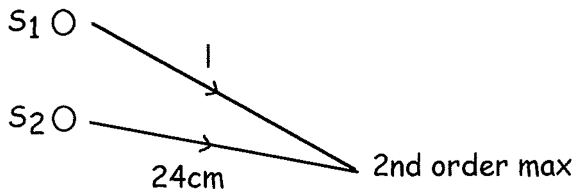
For constructive interference the path difference of waves arriving from the two sources have to be a full number of waves apart. ie 1λ, 2λ 3λ ......

so path difference = $m\lambda$ where m = order ie 0,1,2,3....

For destructive interference the path difference from waves coming from the two sources has to be a half number of waves apart. ie $\frac{1\lambda}{2}, \frac{3\lambda}{2}\ \frac{5\lambda}{2}$ ......

so path difference = $(m + \frac{1}{2})\lambda$ where m = order ie 0,1,2,3...

Ex 1. Find length l. Wavelength of sound = 2cm



It's a 2nd order max therefore

Δ in terms of waves = __λ

Δ in terms of distance = l -24

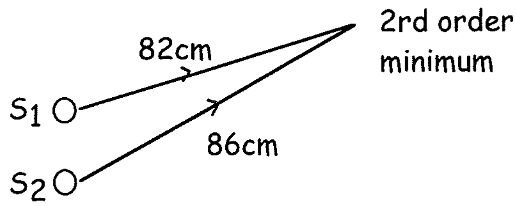
2λ = l - 24

l = 24cm + __λ

l = 24 + _____

l = _________

Ex 2. Finding the wavelength.



It's a 3rd order minimum therefore

Δ in terms of waves = ____λ

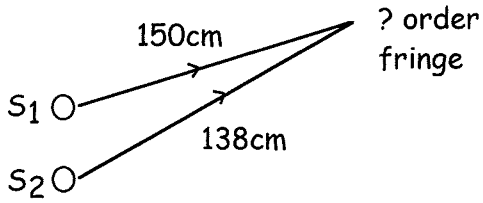
Δ in terms of distance = 86 - 82

So 2.5λ = 86 -82

2.5λ =

λ =

Ex3 Find the order. Wavelength is 3cm.



Path difference in terms of distance = 150-138cm. So path difference in terms of waves

nλ = 150 - 138

n x 3 = ______

n = —

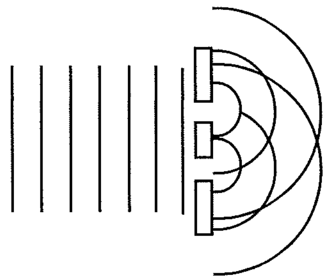
n = _____

Therefore it is a ______ order _______________.

7. Is light a wave or particle?

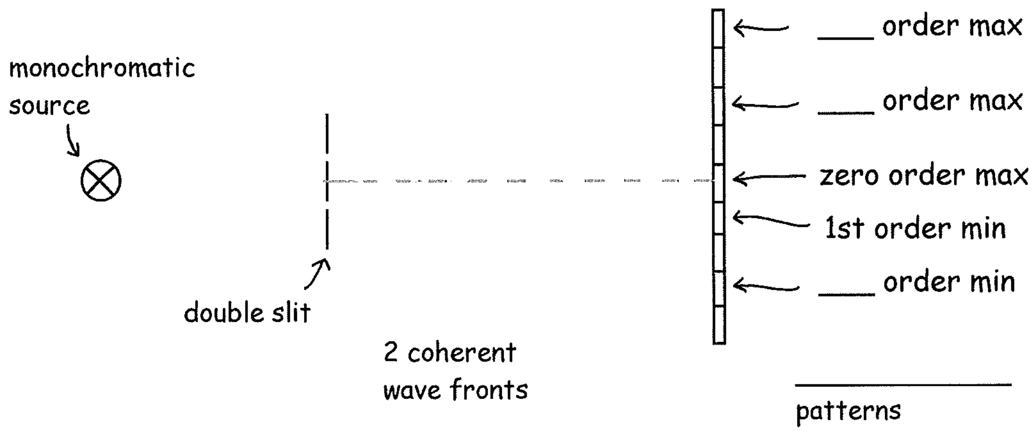
Water and sound create interference patterns because they are w__________.
So if we could get light to interfere then we could say light was a __________.
In 1801 Thomas Young created two coherent source of light by firing a beam of monochromatic light (______ frequency) through 2 narrow slits.

The light d______________ as it passed through the slits creating 2 semi circular coherent wave fronts.



Slit width has to be approx same length as the wavelength of light to create two semi circular coherent wavefronts

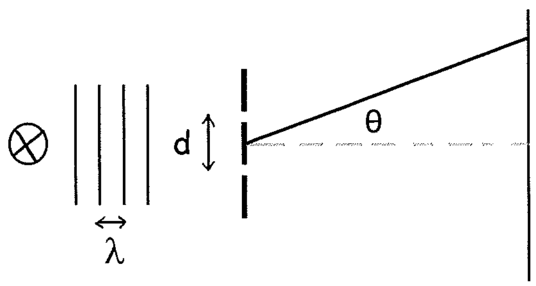
On a screen he saw an interference pattern proving that light travels as a _______.



8. Grating Equation

If a wave of wavelength λ is shone through a grating where the distance between slits is d then the nth fringe is seen at angle of θ from the centre line and the relationship between these terms is.

$$\sin\theta = \frac{n\lambda}{d}$$



Ex A ray of red light of wavelength 650nm is incident on a grating with slit separation 2.1×10^{-6}m.
Calculate the angle the 2nd order maximum fringe would be found?

9. Grating Spacing d

If the grating is defined as No of lines per cm or mm or m Then we have to calculate the separation d.

Ex 1 200lines /mm = 200 x1000 line per m = 200,000line /m therefore the

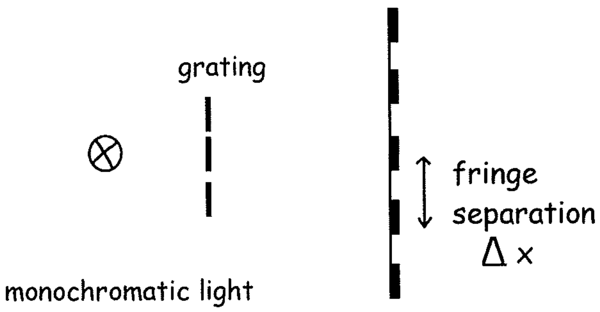
slit separation $d = \frac{1}{200{,}000}$ = ______________m

Ex 2 5000lines/cm = 5000 x100 lines per m = ______________line/m

therefore $d = \frac{1}{\square}$ = ______________m

10. Changing fringe separation

The fringe separation Δx is the distance between interference fringes.



Fringe separation can be increased by

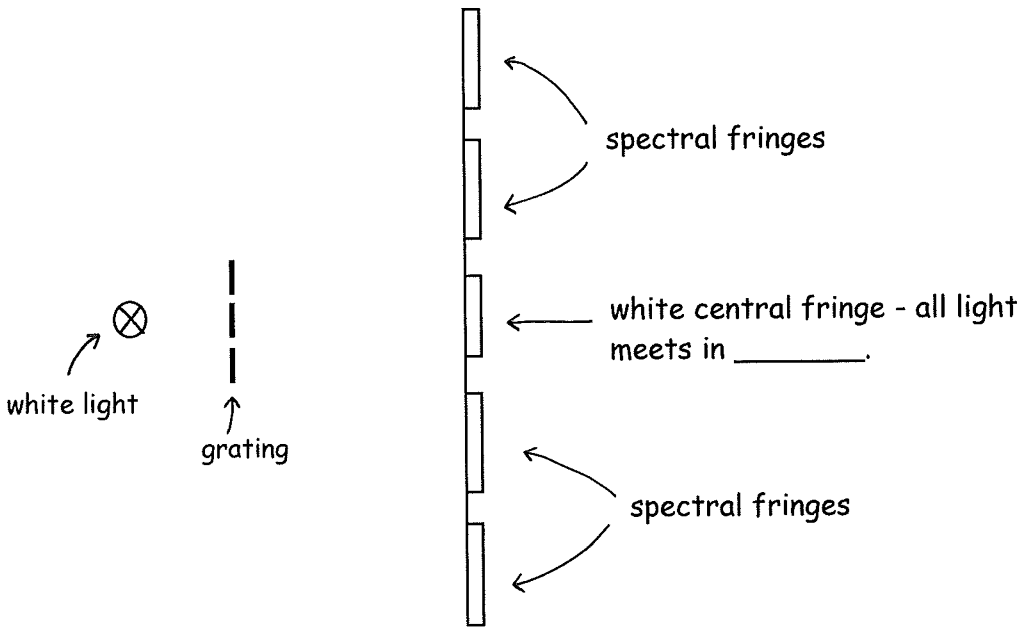
(a) Moving screen further from the grating
(b) Decrease d (slit width)
(c) Increase λ (wavelength)

The 2nd two methods are summarised by the equation. $\sin\theta = \frac{n\lambda}{d}$

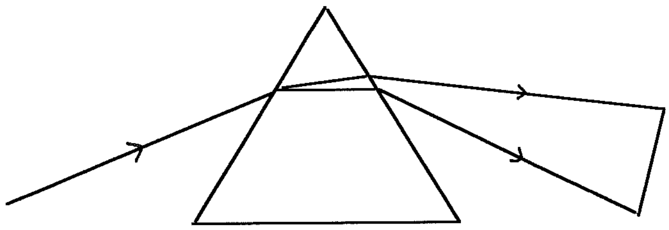
For θ to ↑ then d or λ

11. Interference with white light

White light is made from all the colours of the spectrum and each colour has a different w________________, so each colour will diffract by a different amount through grating. The longer the wavelength the more it diffracts.
So ________ light will be deviated the most at each fringe



12. Compare with refraction of white light



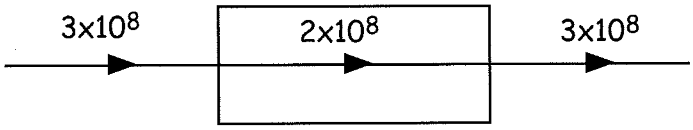
Differences

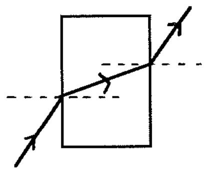
1. No central white ________________
2. Only __________ spectral fringe is created.
2. __________ light is deviated more than _______ light in this spectrum.

F Refraction

1. Absolute refractive index

Refraction is the process whereby the ____________ of a wave changes as it travels from one medium into another. If the wave travels from one medium into another at an angle to the normal the ______________ of the wave also changes.





The absolute refractive index n of a material is the ratio of the speed of light in a ____________ to the speed of light in the ____________. Now because air has approximately the same density as a vacuum we can calculate the approximate n by measuring the speeds of light as it travels from air into the material

$$n = \frac{v \text{ light in vacuum}}{v \text{ light in material}} = \frac{v_v}{v_m}$$

which is approximately $n = \frac{v_a}{v_m}$

The larger the value of n the more the material will slow down or change the direction of a beam of light. If n= 2 the speed of light decreases by ________.

Ex A beam of light travels into a glass prism with a refractive index 1.6.

(a) What is the speed of the light in the prism?

$$n = \frac{v_a}{v_m} \qquad \text{So} \quad v_m = \frac{v_a}{n} = \frac{3x10^8}{\square} = \_\_\_\_\_\_\_\_$$

(b) If another prism of refractive index 1.9 was used would the light in the new prism be faster slower or the same as in part (a) Explain

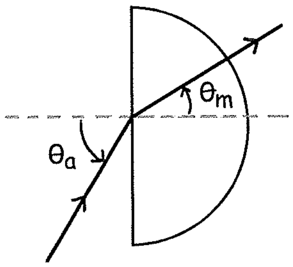
It would be ____________.The new prism has a larger refractive index so will refract or change the speed by a greater amount. Or from above equation as n increases v_m will ______________.

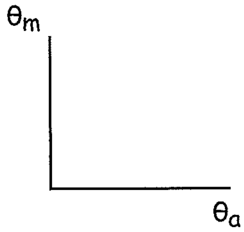
2. Snell's Law

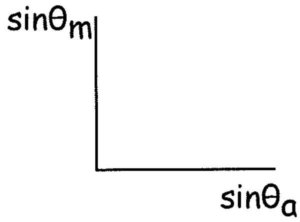
In the following experiment the angle of incidence is increased and the angle of refraction measured. The following graphs are drawn.

θ_a = angle on air side

θ_m = angle on material side





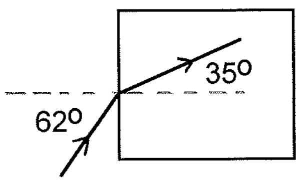


As the graph of $\sin\theta_a$ vs $\sin\theta_m$ is a straight ________ passing through the ________ we can say that $\sin\theta_a$ is ________________ proportional to $\sin\theta_m$.
Therefore $\sin\theta_a / \sin\theta_m$ = a constant = the ________________ index of the material.

$$n = \frac{\sin\theta_a}{\sin\theta_m}$$

As the beam is unidirectional is does not matter which direction the light is travelling as long as the angle on the air side of the boundary is on the _______ of the fraction.

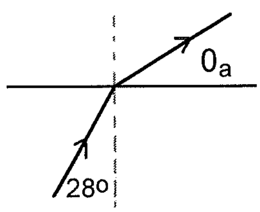
Ex 1 Look at this beam of light travelling from air into a glass block. Calculate the refractive index of the glass.



$$n = \frac{\sin\theta_a}{\sin\theta_m} = \frac{\sin \_\_\_\_}{\sin \_\_\_\_} = \_\_\_\_\_\_\_\_$$

Example 2

Ex 2 This beam of light is emerging from water (n=1.33) into air. Calculate 0_a.



$$n = \frac{\sin\theta_a}{\sin\theta_m}$$

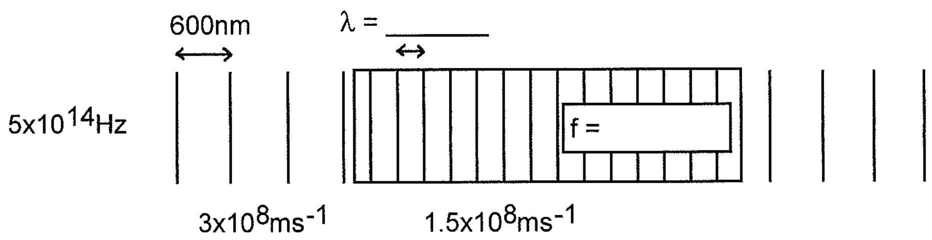
$\sin\theta_a = n \times \sin\theta_m$

$\sin\theta_a$ = 1.33 x sin____

$\theta_a = \sin^{-1}$ ______ = _______

3. Refraction and frequency, wavelength and speed of light

As a light wave travels from one medium into a more optically dense material its speed and ____________________ decrease but the frequency remains _____________.



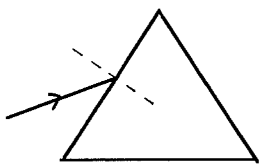
So as light travels from material 1 into 2 we can say $f_1 = \frac{v_1}{\lambda_1} = f_2 = \frac{v_2}{\lambda_2}$

$$n = \frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$$

Again, because n_{air} a_{vac} we can write above equation as

$$n = \frac{\sin\theta_a}{\sin\theta_m} = \frac{v_a}{v_m} = \frac{\lambda_a}{\lambda_m}$$

Ex A beam of light of frequency 4.8×10^{14} Hz travels from air into this prism of refractive index 1.54 as shown.



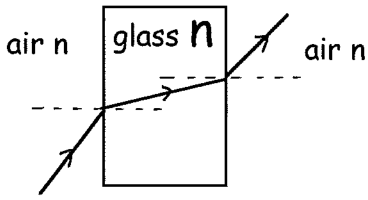
(a) Calculate the wavelength of the light in air

(b) Calculate the wavelength of the light in the prism

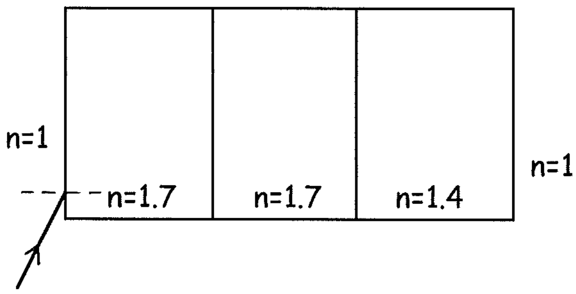
(c) Calculate the speed of the light in the prism.

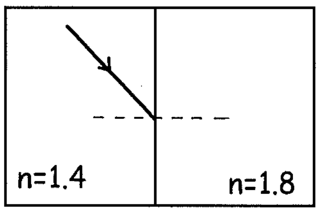
4. Predicting paths

When a wave travels from a less optically dense material (small n ie air) to a more dense material (larger n ie glass) its speed ______________ and the beam bends ___________________ the normal.
Moving from big n to small n the speed _____________ and the beam bends _____________ from the normal. This is summarised by remembering the following diagram:



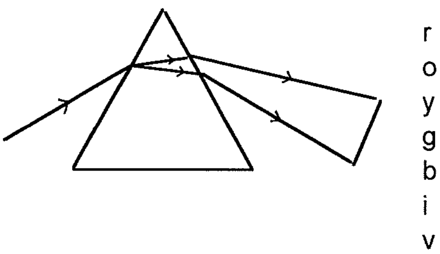
Predict the path of the ray through each of these diagrams:





5. Refractive index and frequency

We remember what happens when white light passes through a triangular prism



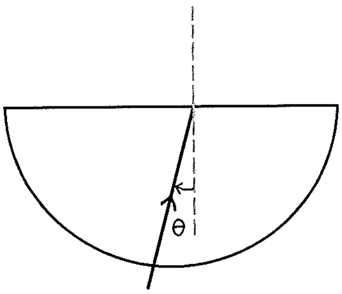
From the diagram we can see that for this prism the violet light (high freq) refracts more than the ______ light (low freq). So the refractive index n of the material for violet light is greater than n for red light. The refractive index of a material depends on the ______________ of the light passing through it.

The higher the frequency of the light the _______________ the material's refractive index.
So for this material n for red = 1.49 n for vioet = 1.51. because the prism refracts the violet light more The 1.5 we quote for the material is an average for all the colours.

6. Total Internal Reflection

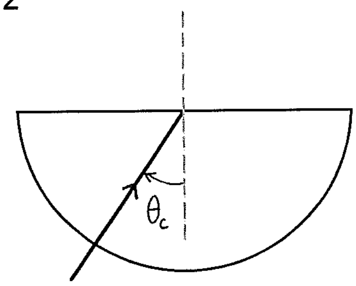
When a ray of light is travelling through a material. It soon hits the material / air boundary. What happens to this beam at this point depends on the ________ angle of the material.

1



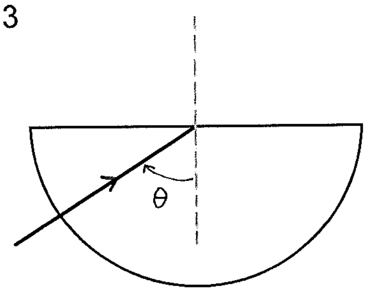
At a small angle of incidence most light refracts through to the ________ side, only some is reflected back

2



At a certain angle of incidence called the ________angle θ_c most of the light travels along the ________. Again some is ________ back

3

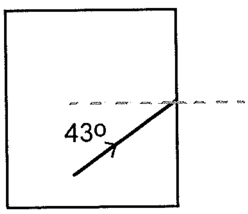


At an angle of incidence ________ than the critical angle **ALL** of the light is ________ internally ________

For diagram 2 $n = \dfrac{\sin\theta_a}{\sin\theta_m} = \dfrac{\sin \_\_\_\_}{\sin \_\_\_\_} = \_\_\_\_\_\_$

therefore sin____ = ______

Ex A beam of light hits the glass to air boundary at the following angle. n for glass is 1.52.



(a) Calculate the critical angle for the glass.

$\sin\theta c = \dfrac{1}{n} = \dfrac{1}{\square}$ so $\theta c = \sin^{-1}($ $)$ $\theta c =$ ______

(b) Predict the path of the beam after hitting the boundary

As the angle of incidence (43°) is ________ than the critical angle for the glass (41.7°) the light will totally ________ reflect at the boundary.

7. Critical angle and refractive index

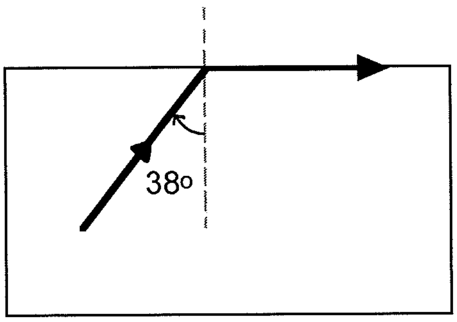
$$\sin\theta c = \frac{1}{n}$$

so as n increases the critical angle ____________________.

8. Critical angle and frequency of light

We know that the refractive index of a material depends upon the frequency of the light. So as the frequency of light increases the refractive index ______________. As refractive index increases, from above equation, the critical angle ________________

Ex A beam of light travels along the path shown



(a) What is the critical angle of the glass? ________

(b) If a beam of light of higher frequency was used describe the path of the bulb.

Higher frequency light - Therefore the refractive index of glass will be greater. As

$$\sin\theta_c = \frac{1}{n}$$

as n increases then 0c ________________. So 38° will bigger than the critical angle so the light will _____________ ______________ __________________.

G Spectra

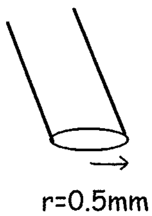
1. Irradiance

The irradiance (I) of light is defined as the __________ (P) of the light arriving at each unit ____________ (A).

$$I = \frac{Power}{Area} = \frac{P}{A}$$

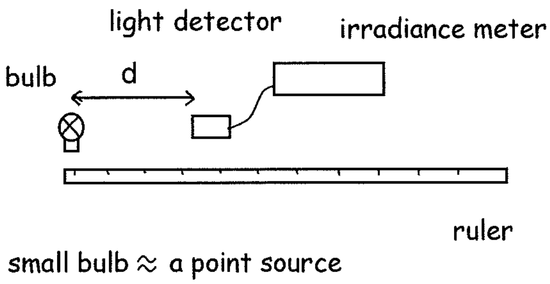
Quantity	Unit
Irradiance	
Power	
Area	

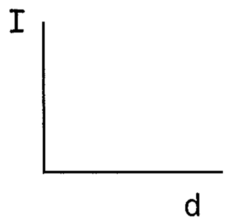
Ex What is the irradiance of a 0.1mW laser beam which creates a circular beam of radius 0.5mm?

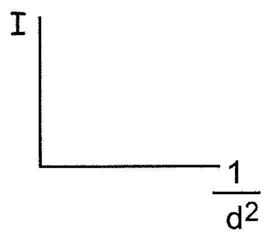


2. Irradiance and distance

Move the light meter gradually away from the bulb and note the irradiance.







From the second graph we see a _____________line passing through the origin so we can conclude that Irradiance is directly ____________________ to $1/d^2$

so $I \ / \ 1/d^2$ = constant so $Id^2 = k$

or $I_1 d_1^2 = I_2 d_2^2$

Ex A bulb is 50cm from a surface. The irradiance of light on the surface is $2.4Wm^{-2}$. What is the irradiance when the bulb is moved to a point 20cm from the surface?

3. Bhor's model of the atom.

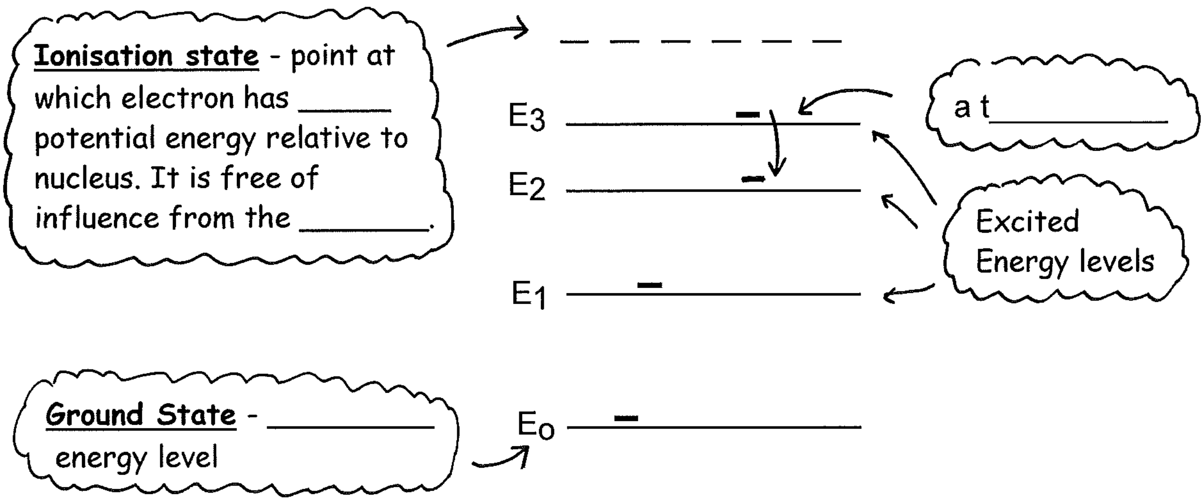
Two mysteries of 19th century classical physics were solved by Neil's Bhor:

(1) Why, when gaseous elements were heated did they give off a __________ spectrum and each line spectrum was unique for each element?

(2) According to classical physics, an orbiting electron should loose energy and spiral into the ___________. Therefore all atoms should collapse.

Bhor's atom consists of a very small positive ____________. The electrons exist in certain discrete ___________ levels. Electrons can "jump" between energy levels but cannot exist between them.

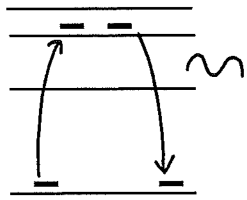
He showed these energy levels in energy level diagrams as shown below
The gaps between the levels indicate the amount of____________ transferred as an electron moves from one level to another.



An electron which moves up to a higher energy level is in an ______________ state. This can be done by heating the atom or passing ______________energy through it.

4.

The electron moving from a lower to a higher energy level must absorb a quanta of __________.

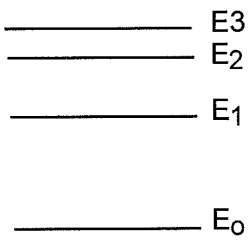


When the electrons falls from a higher to a lower energy level it __________ the quanta of energy in the form of a ______________ of light.

A jump is some times called a ______________________. The bigger the transition the more _______________ is involved.

By convention we take the ionisation level as __J of energy. Energy levels of atoms are given as -ve.

Ex This diagram shows the energy levels in an atom



(a) ___ is the highest energy level

(b) ___ is the lowest energy level

(c) There are ____ possible electron transitions in this atom

(d) For an electron to move "up", energy has to be a______________ by the electron

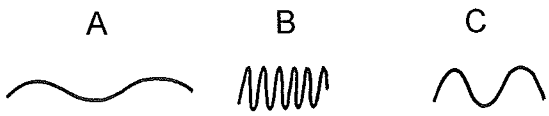
(e) When an electron "falls down" energy levels it emits a quanta of energy in the form of a p__________ of light

(f) Transition ____ to ____ will result in the emission of the highest energy photon

(g) Transition ____ to ____ will result in the emission of the lowest energy photon.

Ex This diagram shows the energy levels in an atom

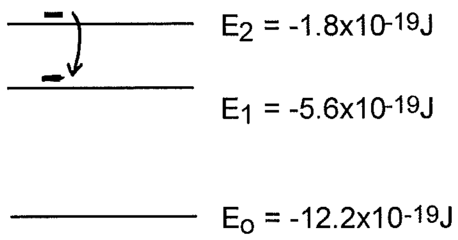
(a) Match 3 possible transitions with the following emitted photons



(b) ___ to ____ emits the lowest energy photon?

(c) ___ to ____ emits the highest frequency photon

Ex Energy Calculations



An electron makes transition E2 to E1

(a) What is energy involved = $E_2 - E_1$

$-1.8x10^{-19}$ - ( )

= ______________

(b) What is the frequency of emitted photon?

$E = hf \qquad f = \frac{E}{f}$ = __________ = __________

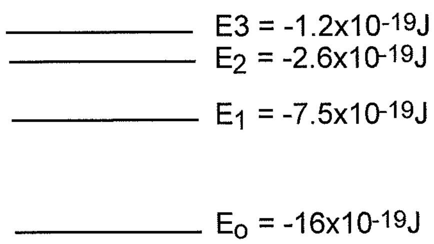
(c) What is the wavelength of the emitted photon

$v = f\lambda \qquad \lambda = \frac{v}{f}$ = __________ = __________

(d) Which part of the electromagnetic spectrum is it from?

A large energy transition is associated with a __________ frequency photon which is associated with a __________ wavelength.

Ex Here are the energy levels in an atom



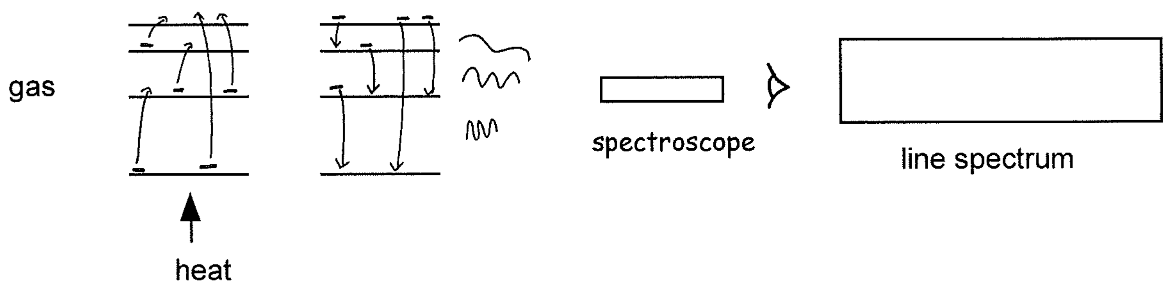
(a) An electron absorbs a photon of energy $8.5x10^{-19}J$. Which transition does the electron make?

(b) When the electron falls back down how much energy does it emit?

(c) Calculate the frequency of the emitted photon

5. Line emission spectra

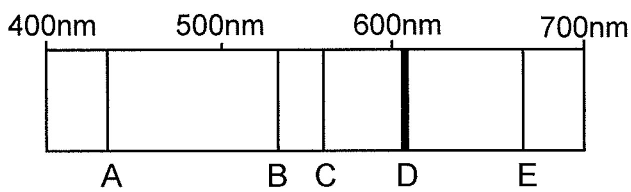
The atoms in a gas are ______ apart so do not interfere with each other.
When a gas is heated electrons absorb discrete quanta of ________ and jump up to ____________ energy levels. When they fall back down they emit the quanta of energy in the form of a _____________ of light, As each atom has only a discrete number of possible transitions they produce a discrete number of ___________
If we view these photons using a spectroscope we see a _________ spectrum



Some of the electron transitions are so large they emit invisible high energy UV photons which cannot be _________ on the line spectra. Some transitions are so small they emit invisible low energy _____ red photons which again will not show up on the spectra.

Some lines are brighter than others indicating that more electrons will make this _________________ compared to others so more photons of the same frequency are emitted.

Ex A line spectra for a certain gas is shown below.



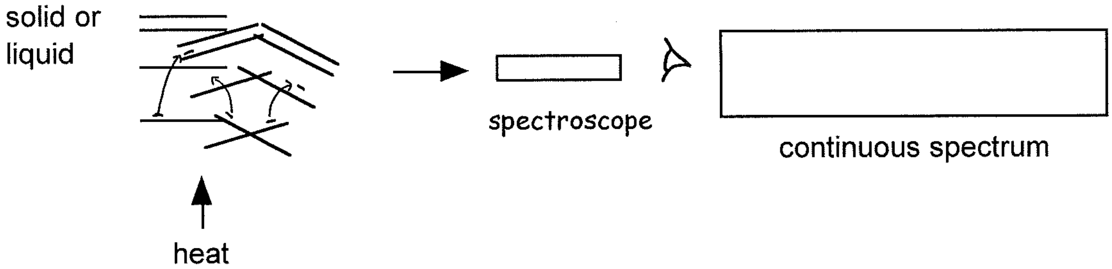
The shorter the wavelength of the emitted photon the higher its ____________ and the larger the energy the photon has.

Line ___ is associated with a large energy transition
Line ___ is associated with a small energy transition
Line ___ is associated with a popular energy transition

The atom produces 6 different photons. The 6th photon cannot be seen on the spectra because it is _______________ and cannot be seen on the visible spectrum

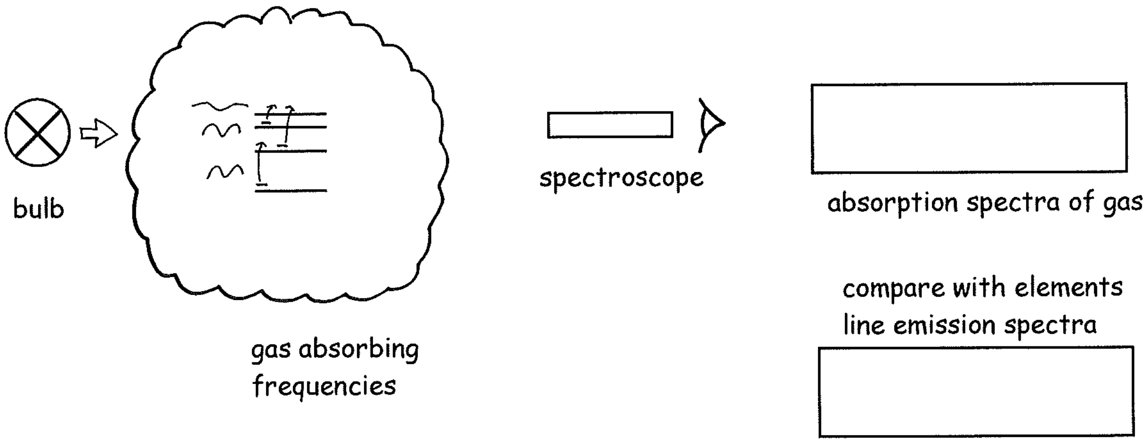
6. Continuous emission spectra

In a solid or liquid, atoms overlap, so when electrons are heated they can jump up to an infinity of different ____________ levels and when they fall back down they emit an _______________ of different frequencies resulting in a _____________________ spectrum.



7. Absorption Spectra

If you view the light from a filament bulb, using a spectroscope, you see the light from a solid wire so you will see a ______________________ spectra.
If you place a gas between the bulb and your spectroscope, electrons in the gas absorb discrete frequencies according to the possible transitions in the gas atoms.



This results in certain frequencies being removed from the white light. What you see is the continuous spectra but with ___________ lines corresponding to the absorbed frequencies. These lines are in the exact same position as the gases ________ emission spectrum

The sun emits a continuous spectra (white light) .When these gases pass through the sun's upper atmosphere the gases in the atmosphere ____________ certain frequencies. We can use the absorption spectra produced to _____________ the gases which make up the upper atmosphere. We call these lines ______________ lines.