NEWTON'S LAWS OF MOTION

Date. No.

FIRST LAW

A body continues in its state of rest or uniform motion in a straight line, unless a resultant external force acts on it.

implies: state of rest and uniform velocity requires no resultant force to maintain.

THIRD LAW

If a body A exerts a force on body B, then body B exerts an equal but opposite force on body A.
→ forces act on different bodies. i.e. not weight & normal

SECOND LAW

The rate of change of momentum of a body is proportional to the resultant force acting on it and occurs in the direction of the force.

$F = \frac{\Delta p}{\Delta t} = \frac{\Delta (mv)}{\Delta t}$. when m is constant, $F = m\frac{\Delta v}{\Delta t} = ma$.

when v is constant, $F = v\frac{\Delta m}{\Delta t}$

Impulse = Δmomentum = Δp = $F\Delta t$ = area under force-time graph

use $m\Delta v = F\Delta t$!!

CONSERVATION OF MOMENTUM

conservation of momentum : $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ ①

conservation of KE : $\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$ ②

relative speed of approach = " of separation : $u_1 - u_2 = v_2 - v_1$ ③

elastic : ①, ②, ③

inelastic : ①

completely inelastic : ①, final velocities are same, i.e. $m_1u_1 + m_2u_2 = (m_1+m_2)v$

The principle of conservation of linear momentum states that the total momentum of bodies interacting in a system remains constant, provided no net external force acts on it.

$s = \frac{1}{2}(u+v)t$

$v = u + at$

$s = ut + \frac{1}{2}at^2$

$v^2 = u^2 + 2as$

U-GRADE

FORCES

very very very tired

Date. No.

Upthrust

Upward force experienced by object immersed in fluid, equal to weight of fluid displaced by object.

$U = V\rho g$, when floating in equilibrium, it displaces a weight of fluid equal to its own weight,

i.e. U = weight of object.

Hooke's Law – extension of spring proportional to applied force if limit of proportionality is not exceeded

springs in parallel: $k_{effective} = k_1 + k_2 + \dots$

" in series: $\frac{1}{k_{effect}} = \frac{1}{k_1} + \frac{1}{k_2} + \dots$

area under F-x graph, area above x-F graph, $E.P.E = \text{work done} = \frac{1}{2}kx^2$

A **COUPLE** consists of a pair of equal and opposite parallel forces whose lines of action do not coincide

conditions for equilibrium

1. zero resultant force (translational eqm)
2. zero resultant torque (rotational eqm)

definition of moment: force multiplied by perpendicular distance from the axis of rotation / pivot to the line of action of force.

WORK ENERGY POWER

work done = force x distance = energy, units: Nm or J

for gas: Work done = $Fd = pA \times d = p \times \text{volume}$ (p is pressure)

$KE = \frac{1}{2}mv^2$, $GPE = mgh$, $EPE = \frac{1}{2}kx^2$, electric PE, U, is $F = -\frac{dU}{dx}$

Law of conservation of Energy w Wd on system: $(E_p + E_k)_{initial} + W_F = (E_p + E_k)_{final}$

power: $\frac{\text{work done}}{\text{time}} = \frac{F \times d}{t} = FV = \frac{mgh}{t}$

$\text{Energy}_i + WD = \text{Energy}_f$

Archimedes Principle: upthrust acting on an object in a fluid equals to the weight of water displaced by object.

Principle of floatation: A body floating at equilibrium in a fluid displaces a weight of fluid equal to its own weight.

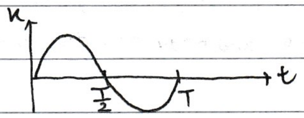
OSCILLATIONS

Date. No.

simple harmonic motion is defined as the oscillatory motion of a body whose acceleration is directly proportional to its displacement from a fixed displacement position and is always directed towards that fixed position.

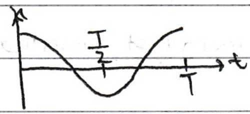
If $x = 0$ at $t = 0$,

$x = x_0 \sin \omega t$

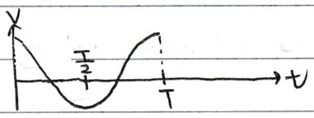


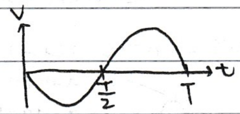
If $x = x_0$ at $t = 0$

$x = x_0 \cos \omega t$

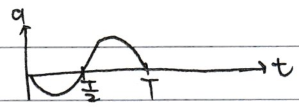


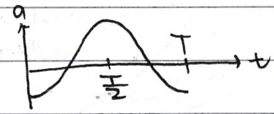
$v = \omega x_0 \cos \omega t = \omega \sqrt{x_0^2 - x^2} \longrightarrow v_{max} = \pm \omega x \longleftarrow v = -\omega x_0 \sin \omega t = -\omega \sqrt{x_0^2 - x^2}$



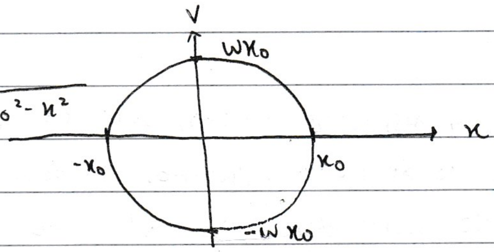


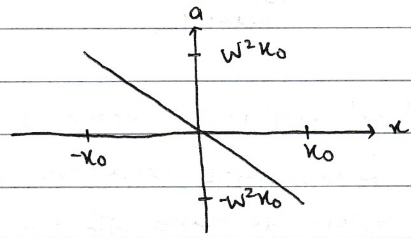
$a = -\omega^2 x_0 \sin \omega t \longrightarrow a_{max} = \pm \omega^2 x \longleftarrow a = -\omega^2 x_0 \cos \omega t$





$v = \pm \omega \sqrt{x_0^2 - x^2}$



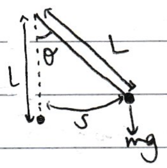


$a = -\omega^2 x$

spring system :

$mg = ke$ (vertical), or $ma = -kx \implies \omega = \sqrt{\frac{k}{m}}$

pendulum system:

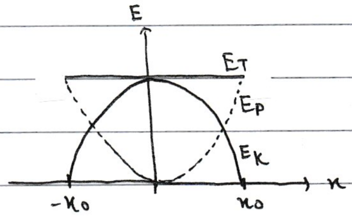


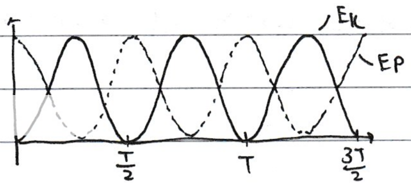
$F_{restoring} = -mg\sin\theta = -mg\sin\frac{s}{L} \approx -mg\frac{s}{L}$

$\implies \omega = \sqrt{\frac{g}{L}}$

* f of energy is twice that of motion

when $x = x_0$ at $t = 0$,





$E_T = \frac{1}{2} m x_0^2$, $E_k = \frac{1}{2} m (x_0^2 - x^2)$, $E_p = \frac{1}{2} m x^2$

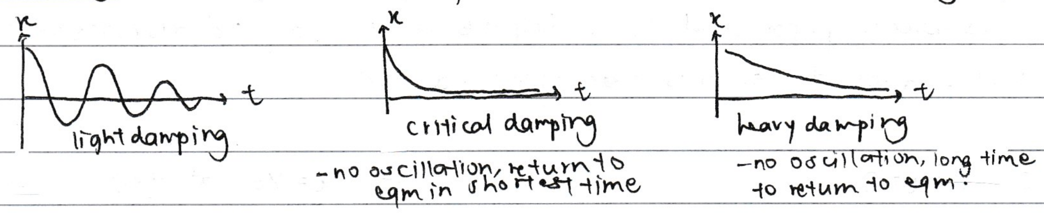
Recycle

U-GRADE

cont.

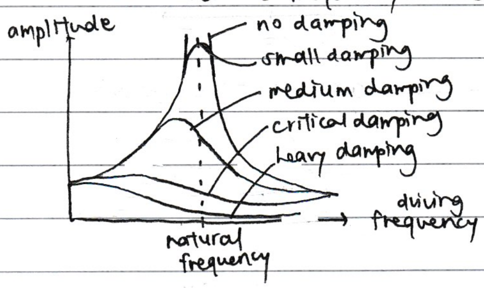
Date. No.

Damping is the process whereby energy is taken from the oscillating system.



car suspension system: when car goes over dump, the car suspension, being critically damped, absorbs the energy of the vertically accelerated wheel, allowing the frame and body to ride undisturbed.

Resonance occurs when a system responds at maximum amplitude to an external driving force. This occurs when the frequency of the driving force is equal to the natural frequency of the driven system.



A real oscillating system is opposed by dissipative forces, such as friction and viscous forces, which causes the amplitude to decrease with time. The total energy of the system decreases with time due to work done against these forces.

A forced oscillation is produced when a body is subjected to an oscillatory external force. The force is usually called the driving force/driver, and is a means of supplying energy to the system.

Free oscillations are oscillations that occur without an external driving force, with no change in total energy of the system and a constant amplitude.

CIRCULAR MOTION

Date No.

$\theta = \frac{s}{r}$, $v = r\omega$, $\omega = \frac{2\pi}{T} = 2\pi f$ $F = \frac{mv^2}{r} = m\omega^2 r$

centripetal force = resultant force.

Why must the object experience a force?

Although moving at constant speed, velocity changing as direction of motion is changing. Hence, object experiences acceleration. leads to force acting on object as F=ma.

OR

By Newton's First Law of Motion, object will continue to move at constant speed in the same direction unless there is a resultant force acting on it. Hence there must be a force acting on object to constantly change its direction of motion.

Why is the force directed to centre of circle/perpendicular to direction of motion of object?

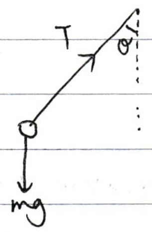
constantly changing direction → v is vector, v changes with time.

since there is rate of Δv: → $a \neq 0$, $p = mv$, $dp/dt \neq 0$ ⇒ net force = $F = ma \neq 0$

→ no change in speed, no component of a in direction of motion of object, or else speed will Δ.

→ so direction of a and F ⊥ v, direction of motion, always acts towards centre.

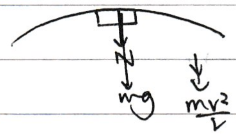
∴ constant speed, constant KE.



$T\cos\theta = mg$

$T\sin\theta = \frac{mv^2}{r}$

$\tan\theta = \frac{v^2}{rg}$



apparent weight = N

$N + mg = \frac{mv^2}{r}$

feel heaviest at bottom, lightest on top.

At top, minimum contact, N=0 ⇒ $rg = v^2$ at top.

$$\frac{1}{2}mv_{bottom}^2 + mgh_{bottom} = \frac{1}{2}mv_{top}^2 + mgh_{top}$$

$$\frac{1}{2}mv_b^2 + 0 = \frac{1}{2}m(rg) + mg(2r)$$

$$v_{bottom} = \sqrt{5gr}$$

Geostationary orbital: 24h orbital period, rotates west to east, lies in same plane as Equator/above equator

Advantages: constant surveillance of region below it, easy for ground station to communicate, receive signals over large area

Disadvantages: high altitude – loss of signal strength, poorer resolution in imaging satellites, time lag.

A'ZONE

GRAVITATION

$F = -\frac{GMm}{r^2}$, units N, '(−)' sign represents force is attractive

GPE = $F \times d = U = \frac{-GMm}{r}$, units Nm

definition: GPE of a mass in a gravitational field is defined as the work done by an external force in bringing the mass from infinity to that point without a change in kinetic energy.

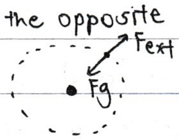
Gravitational potential = $\phi = \frac{V}{m} = -\frac{GM}{r}$, units $Nmkg^{-1}$

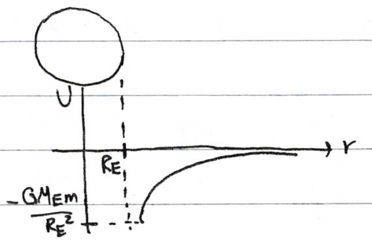
definition: ϕ at a point in a gravitational field is defined as the work done by an external force in bringing a unit mass from infinity to that point without a change in KE.

why is there a '(−)' sign?

① potential energy at infinity is defined as 0.

② GPE is defined as work done by an external force in bringing an object from infinity to that point without ΔKE, so this external force acts in the opposite direction as gravitational force, as well as the direction of motion.





as radius tends to infinity, GPE tends to 0.

gravitational field strength = $g = -\frac{GM}{r^2}$, units Nkg^{-1}, i.e. g, acceleration of free fall.

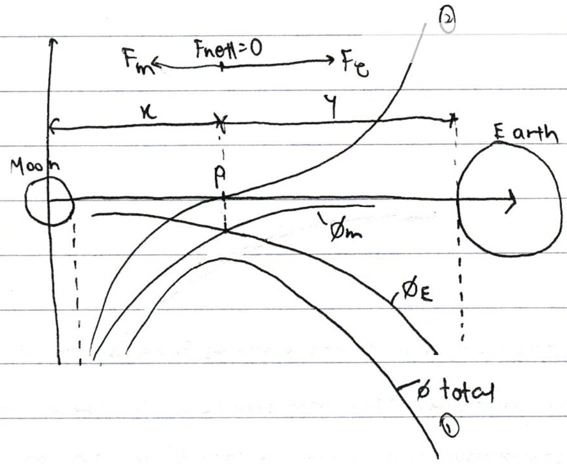
definition: g at a point in space is defined as the gravitational force experienced per unit mass at that point.

ESCAPE VELOCITY!!!

at infinity, total energy = KE + GPE = $\frac{1}{2}mv^2 - \frac{GMm}{r} = 0$

$\frac{1}{2}mv^2 = \frac{GMm}{r}$ => escape velocity, $v = \sqrt{\frac{2GM}{r}}$ *escape v is independent of mass, m

*when objects have '(−)' sign, they are still bounded to the planet.



① same slope { ϕ-distance graph / U-distance graph } as $U = m\phi$

② same slope { $g = -\frac{d\phi}{dr}$ / $F = mg$ }

At one point, g field strength cancels out, =0

=> max point of ϕ-distance or U-distance graph

*SUBTRACT VECTORS, ADD SCALAR VALUES.

moon about earth: one month
sun about earth: one day
earth about sun: one year

WAVE MOTION

Date. No.

phase difference

either $\frac{t}{T} \times 2\pi$ for distance-time graph (one particle over time)

OR $\frac{x}{\lambda} \times 2\pi$ for displacement-distance graph (wave at one moment of time)

progressive wave: a disturbance that travels through a medium from one location to another. It transports its energy without transporting matter. Particles do not move along wave, they oscillate about their equilibrium positions.

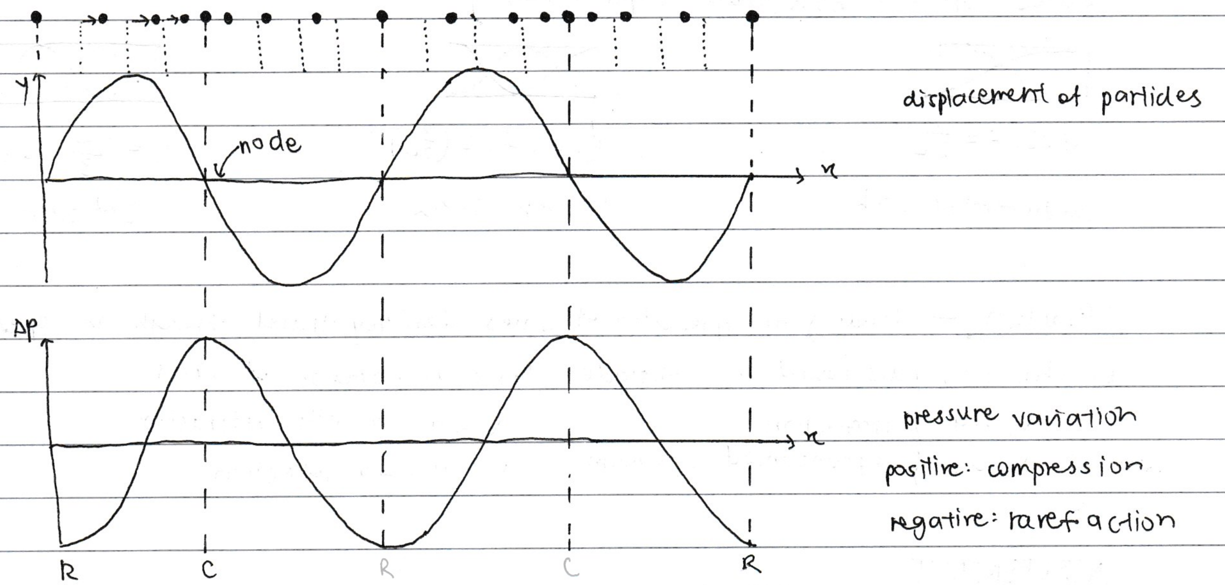
* transverse waves

	radio	microwave	infrared	visible	UV	x-ray	Gamma-ray
λ/m	10^3	10^{-2}	10^{-5}	0.5×10^{-6}	10^{-8}	10^{-10}	10^{-12}
f/Hz	10^4	10^8	10^{12}	10^{15}	10^{16}	10^{18}	10^{20}

speed of EM waves: $3.00\times10^8 \text{ ms}^{-1}$

- do not require medium, can move through vacuum.

longitudinal waves



e.g. soundwaves (can be referred to as soundwaves)

polarisation is a phenomenon whereby the oscillations of transverse waves are restricted to a single plane

resultant amplitude $A = A_0\cos\theta$, resultant amplitude $I = I_0\cos^2\theta$

$I = \frac{\text{power}}{\text{surface area}} \Rightarrow I = \frac{P}{4\pi r^2}$ for sphere, $I = \frac{P}{2\pi r}$ for flat circle.

$I \propto A^2$, $I \propto \frac{1}{r^2}$ (for sphere), $I \propto \frac{1}{r}$ (for flat circle)

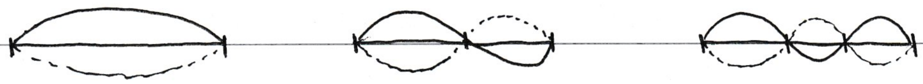
SUPERPOSITION

Date. No.

stationary wave (→ does not propagate): resultant wave of two waves with same amplitude, frequency and wavelength moving toward each other. every particle of the wave oscillates about their respective equilibrium positions with same frequency but fixed different amplitudes

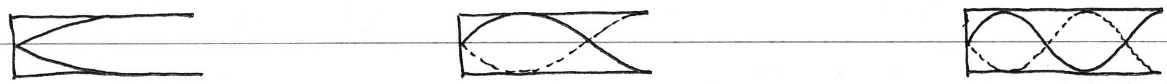
* particles at nodes are at rest

waves fixed at both ends (e.g. plucked string)



fundamental (1st harmonic) | 1st overtone (2nd) | 2nd overtone (3rd)

waves fixed at one end (closed tube)

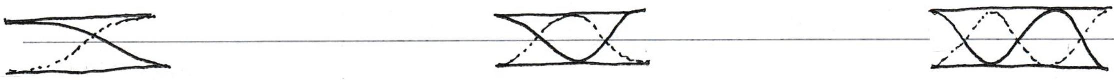


$\lambda = 4L$, $f = \frac{v}{4L}$ — fundamental, 1st harmonic

$\lambda = \frac{4}{3}L$, $f = 3\left(\frac{v}{4L}\right)$ — 1st over, 3rd harmonic

$\lambda = \frac{4}{5}L$, $f = 5\left(\frac{v}{4L}\right)$ — 2nd overtone, 5th harmonic

waves open at both ends (open tube)



$\lambda = 2L$, $f = \frac{v}{2L}$ — fundamental, 1st h

$\lambda = L$, $f = 2\left(\frac{v}{2L}\right)$ — 1st over, 2nd h

$\lambda = \frac{2L}{3}$, $f = 3\left(\frac{v}{2L}\right)$ — 2nd over, 3rd h

Diffraction — bending or spreading of waves when they travel through an aperture or when they pass round an obstacle. It is a phenomenon of waves.

$\lambda < a$, $\lambda \sim a$ } diffraction is pronounced, maximum

$\lambda < a \rightarrow$ little diffraction

$\lambda > a \rightarrow$ reflection

INTERFERENCE

when same A: constant phase difference ⟹ coherence ⟹ same f & λ. same frequency ⇏ coherent!!

add ⟹ 2A: constructive interference – when 2 waves arrive at the same point in phase. max is obtained.

subtract ⟹ 0: destructive interference – when 2 waves arrive " π rad out of phase/in anti-phase. min "

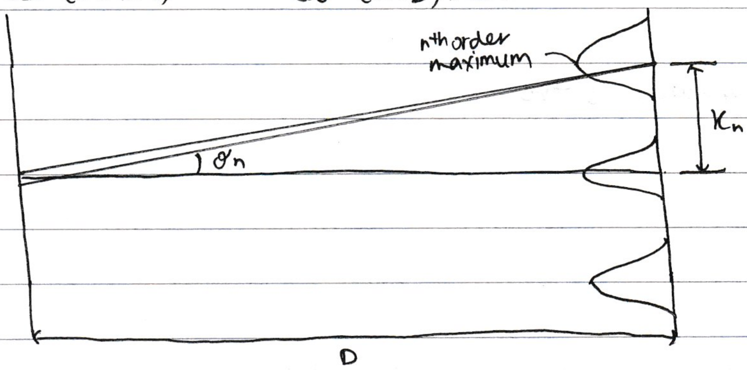
cont.

Date No.

Conditions for 2-source interference:

1. The waves must be coherent.
2. The waves must have approximately same amplitude
3. The waves must be unpolarised or polarised in the same plane.
4. The waves must interfere to give regions of maxima (CI) and minima (DI)

	2 sources in phase	2 sources π rad out of phase
CI (maxima)	path diff, $\Delta x = n\lambda$	$\Delta x = (n+\frac{1}{2})\lambda$
DI (minima)	$\Delta x = (n+\frac{1}{2})\lambda$	$\Delta x = n\lambda$



x_n = distance of n^{th} bright fringe from central fringe

a = slit separation ≈ 0.5mm
D = distance between slits and screen ≲ 1m
λ of light ≈ 500nm

slit width ≈ 0.2mm

$\Delta x = a\sin\theta_n$ => since source is coherent, at CI: $\Delta x = a\sin\theta_n = n\lambda$

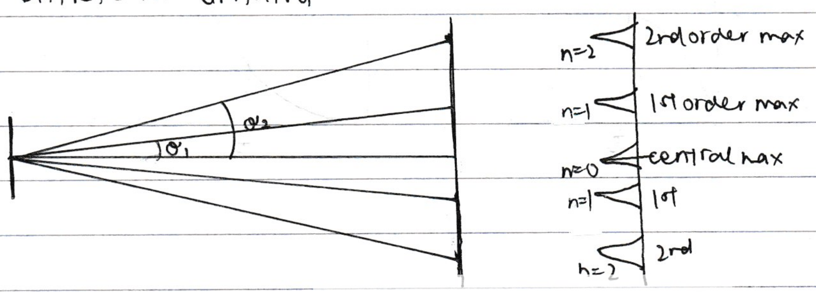
$\therefore \sin\theta_n = \frac{n\lambda}{a}$

CI takes place at these positions: $x_n = \frac{n\lambda D}{a}$, $n = 0, 1, 2 \ldots$

spacing between successive bright fringes: $x = \frac{\lambda D}{a}$. (fringe separation)

can use $x = \frac{\lambda D}{a}$ only when $a \ll D$, $\theta < 10°$

DIFFRACTION GRATING



*d usually 10^{-6} m

$\Delta x = d\sin\theta_n$, where d = slit separation $= \frac{1}{N}$ (N usually per mm)

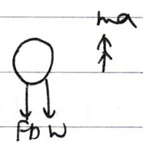
since source is coherent, in phase. for CI., $\Delta x = d\sin\theta_n = n\lambda$

$\therefore \sin\theta_n = \frac{n\lambda}{d}$

since $\theta_n < 90°$, $\sin\theta_n < 1$ => $\frac{n\lambda}{d} < 1$ => max order $n < \frac{d}{\lambda}$

KINEMATICS

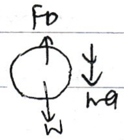
With air resistance:



- drag force acts as retarding force to motion
- decelerates faster, velocity reduces to zero faster
- less time taken, lower max height

$ma = F_D + mg$

$a_{up} > g$

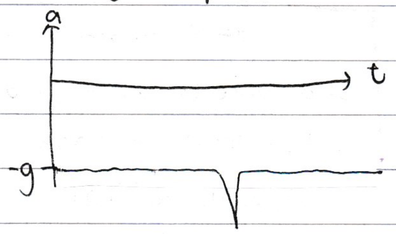


- drag force opposes motion
- velocity increases at a slower rate
- longer time taken to reach initial position.

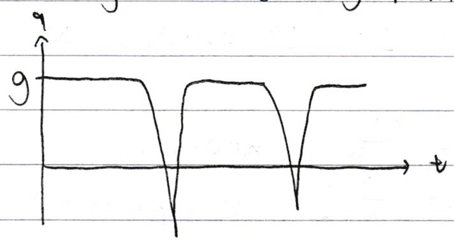
$ma = W - F_D$

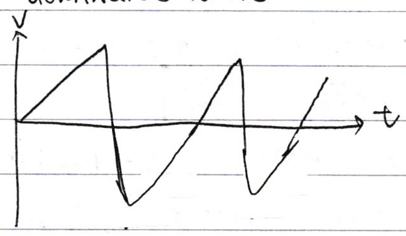
$a_{up} < g$

Throwing ball upwards — upwards is +ve

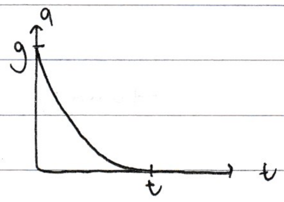


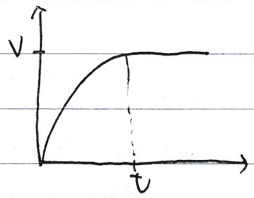
Bouncing ball — starting from height, downwards is +ve

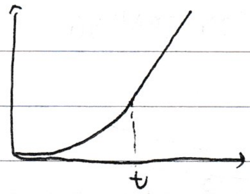




Free fall with air resistance => reaches terminal velocity.





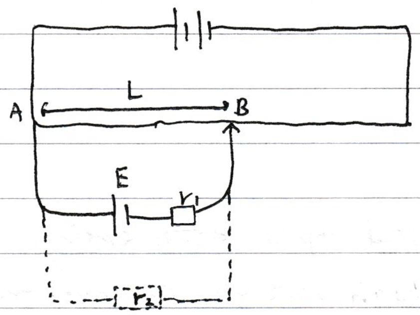


D.C. CIRCUITS

Date No.

potential difference between two points is the amount of electrical energy per unit charge that is converted to other forms of energy when a charge is passed from one point to another.

volt – one Joule of electrical energy converted to other forms of energy when one collumb of charge passes from one point to the other.



p.d across AB = p.d across |¹

when r_1 is added, balance length L remains the same as there is no current flowing through, so p.d. remains the same.

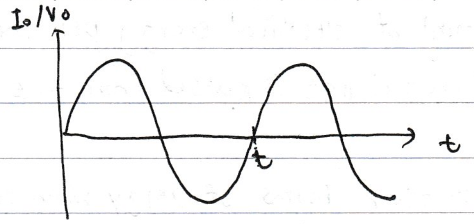
when r_2 is added, p.d. across AB = p.d across |¹ = p.d. across r_2.

p.d across r_2 is less than E, so p.d across AB < E, since length ∝ p.d, balance length is shorter.

$E = V + Ir$

- emf of a source is defined as the amount of electrical energy per unit charge that is converted from other forms of energy to drive a charge around a complete circuit.
- resistance is the ratio of p.d across the conductor to the current flowing through it.
- one ohm is when a p.d of one volt causes 1A of current to flow through
- resistivity of a material is the constant of proportionality relating electrical resistance to the dimensions of the material.
- resistance depends on dimensions, resistivity is a characteristic of a material.

A.C.



$I = I_0 \sin \omega t \Rightarrow I_{rms} = \frac{I_0}{\sqrt{2}}$

$V = V_0 \sin \omega t \qquad V_{rms} = \frac{V_0}{\sqrt{2}}$

I_{rms} is the value of steady D.C. that would deliver the same power to a given resistance as the A.C.

$P_{rms} = V_{rms} \times I_{rms} = \frac{1}{2} V_0 I_0 = \frac{1}{2} P_0$

$= (I_{rms})^2 \times R = \frac{1}{2} I_0^2 R = \frac{1}{2} P_0$

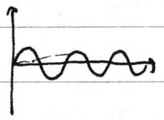
Transformers

since P is constant, $\frac{N_s}{N_p} = \frac{V_s}{V_p} = \frac{I_p}{I_s}$

Main advantage of a.c. is that it can be stepped up or down easily using a transformer compared to d.c. for high voltage transmission.

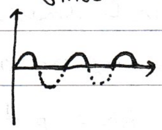
$P_{lost} = I^2 R = (\frac{P}{V})^2 R \Rightarrow$ higher voltage, lower power loss

$P_{loss} \propto \frac{1}{V^2}$

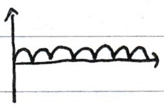


$I_{rms} = \frac{I_0}{\sqrt{2}}$

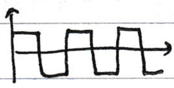
sinusoidal A.C.



$I_{rms} = \frac{I_0}{2}$



$I_{rms} = \frac{I_0}{\sqrt{2}}$



$I_{rms} = I_0$

principle of transformer:

When an AC flows through the primary coil, it sets up an alternating magnetic field in the core which links the p & s coils. By Faraday's Law, an alternating magnetic flux induces an alternating emf in the s coil.

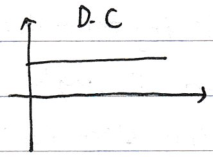
To generate:

D.C - use current rectifier or split rings (makes current change direction every half rotation)

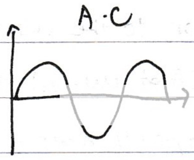
A.C - use slip rings (maintains the connection)

on CRO:

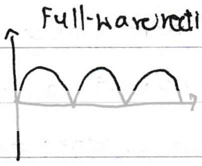
D.C



A.C



Full-wave rectified A.C. (using split rings on DC)



ELECTRIC FIELDS

Electric field strength at a point in an electric field is the force per unit charge acting on a small test charge placed at that point.

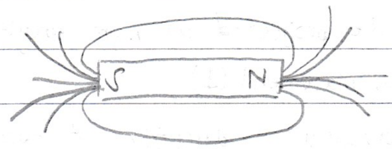
Electric potential at a point in an electric field is the work done by an external force in moving a unit positive charge from infinity to that point without a change in KE.

$F = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r^2} = qE = q\left\lvert\frac{V}{d}\right\rvert$	force	vector	N	$E = \frac{F}{q}$
$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$	(points away from +ve charge) high to low potential	vector	NC^{-1}	$E = \left\lvert\frac{\Delta V}{d}\right\rvert$
$U = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$	potential energy	scalar	J	$U = W = qV$
$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$	potential	scalar	V	

$E = -\frac{dV}{dr}$, $F = -\frac{dU}{dr}$

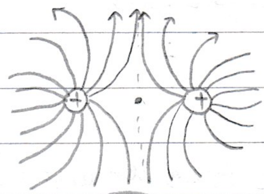
gain in KE = loss in PE.

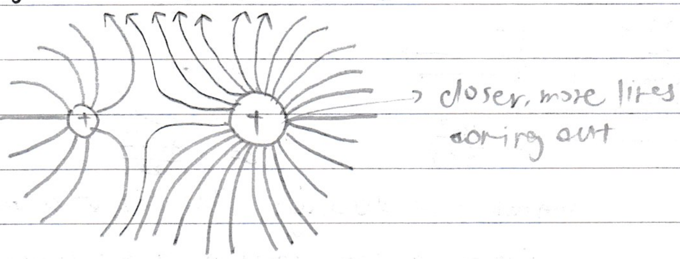
$\frac{1}{2}mv^2 - 0 = qV$

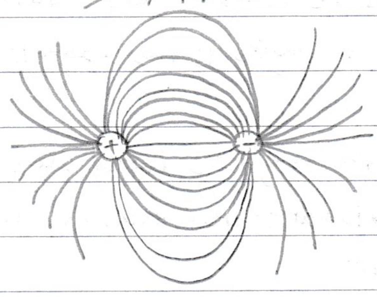


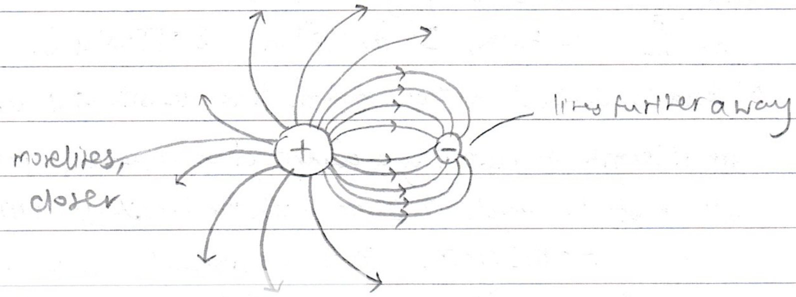
electric field lines originate from positive charges & terminate on -ve charges.

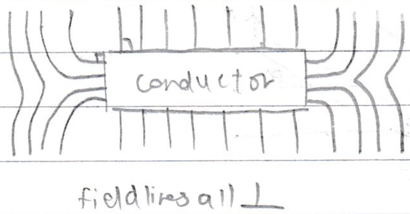
The closer the field lines, the stronger the field at that region.

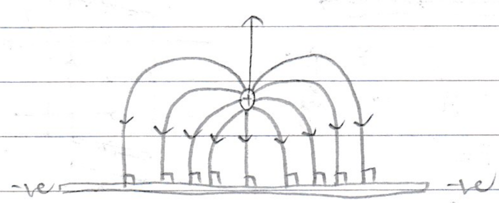












within a conductor, E=0. within a sphere, it varies linearly with r.

ELECTROMAGNETISM

Gravitational field – charge acts in direction of field

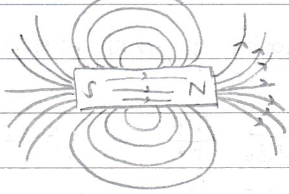
Electric field – charge acts in direction of field (stationary or moving, will experience force)

Magnetic field – charge acts perpendicular to field and current (direction of displacement)

↳ stationary or moving ∥ to field, no force experienced

velocity of charge gives current direction

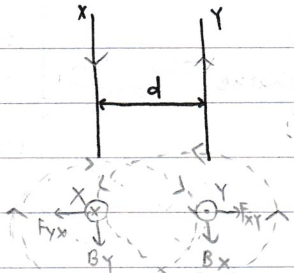
like currents attract, unlike currents repel

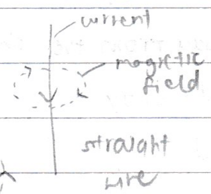


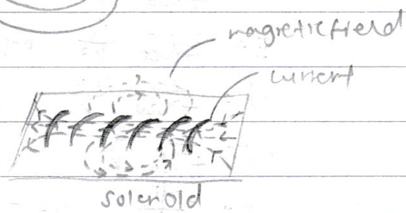
③ FORCES between 2 current-carrying conductors

$F_{XY} = B_X I_Y L_Y$

$= \frac{\mu_0 I_X}{2\pi d} I_Y L_Y$





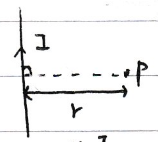


$F_B = Bqv = F_C = \frac{mv^2}{r}$

- charged particle projected at right angles into a magnetic field, F_M always ⊥ to direction of displacement (I)
- distance travelled in direction of force is zero
- no energy gained or lost by particle moving through magnetic field, speed always constant
- F has constant magnitude, always ⊥ to direction of displacement – circular motion.

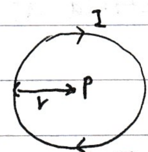
② FORCE on a current-carrying conductor

①



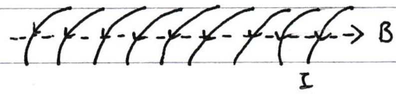
$B = \frac{\mu_0 I}{2\pi r}$

②



$B = \frac{\mu_0 N I}{2r}$

③



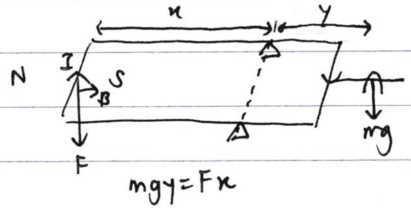
$B = \mu_0 n I$

magnetic flux density: The MFD of a magnetic field is the force per unit length acting on a wire carrying a unit current, lying at right angles to the magnetic field.

$B = \frac{F}{IL}$, if $F = 1N$, $I = 1A$, $L = 1m$, $B = 1$ Tesla (T)

*1 Tesla is defined as the magnetic flux density of a uniform magnetic field when a wire of length 1m, carrying a current of 1A, placed perpendicular to the field, experiences a force of 1N which is ⊥ to both the field & current.

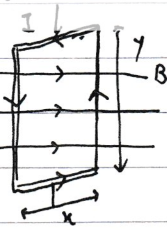
∴ $F = BIL\sin\theta$, θ is angle between I & B.

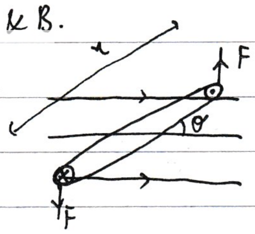


$mgy = Fx$

$mgy = BILx$

$B = \frac{mgy}{ILx}$





torque = force × ⊥ distance between lines of force

$= Fx\cos\theta$

$= BINyx\cos\theta$

$= NBIA\cos\theta$

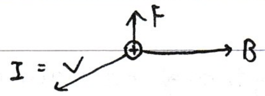
cont.

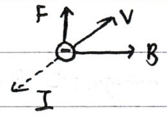
④ Force on a charge in a magnetic field

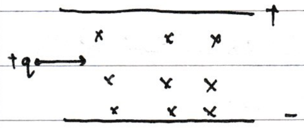
$F = Bqv\sin\theta$, θ is angle between velocity and field

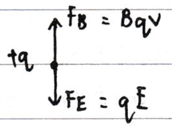
For a +ve charge, direction of current = direction of motion of charge

For a -ve charge, direction of current is opp. direction of motion of charge.









If $F_B > F_E$, particle deflected ↑.

If $F_B < F_E$, particle deflected ↓

$v = \frac{E}{B}$ => particles w this speed remain undeflected

EMF vs potential difference:

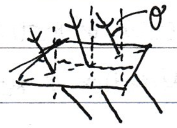
emf: Amount of electrical energy that is converted from other forms of energy when the source drives a unit charge through a complete circuit.

potential difference: Amount of electrical energy that is converted to other forms of energy when a unit charge is passed from one point to another.

ELECTROMAGNETIC INDUCTION

Magnetic flux through an area is the product of the area and the magnetic flux density that passes ⊥ through the area.

$\phi = BA\cos\theta$



Magnetic flux linkage of a coil is the magnetic flux passing through each turn of the coil multiplied by number of turns. => $\Phi = NBA\cos\theta$

SI unit: Wb: The flux, linking a circuit of one turn, that produces an Emf of 1V when the flux is reduced to zero at a uniform rate in 1s.

Faraday's law: When there is a Δ in magnetic flux linkage in circuit/coil, an emf is induced and its magnitude is directly proportional to rate of Δ of magnetic flux linkage of circuit/coil, i.e. $\text{emf} = -\frac{d\Phi}{dt}$ (emf — 1V, $d\Phi$ — 1Wb, dt — 1s)

Lenz's Law: Induced current always flows in a direction so as to oppose the change that produces it.

Moving rod	$\text{emf} = Blv$
Moving coil / Generator	$\text{emf} = NBA\omega\sin\omega t$
Rotating Disc	$\text{emf} = BAf = \frac{1}{2}Br^2\omega$

How to explain induced emf/current:

When the coil is rotating, there is a continuous change in the angle between the magnetic field and area / disc continuously cuts the magnetic flux within the solenoid, thus Φ is continuously changing. By Faraday's Law, emf is induced. Since the induced emf is formed in a closed circuit, induced current will flow.

For transformer: Δ in current in primary coil causes Δ in MFL in secondary coil, leads to induced emf.

Laminated core – to reduce eddy current losses.

Thick copper wires – to reduce heat loss due to high current.

Soft iron core – to reduce heat loss due to energy used in repeated magnetising & demagnetising (hysteresis loss)

Wind alternating primary and secondary coils on each limb of core-type transformer / move the coils closer – to reduce flux leakage

QUANTUM PHYSICS

Date No.

$hf = \Phi + E_{kmax}$

$\Phi = hf_0$, $E_{kmax} = \frac{1}{2}mv_{max}^2$, decrease in KE = increase in EPE , $\frac{1}{2}mv^2 = eV_s$

photoelectric effect: Electrons near the surface of a metal can absorb the energy of an incoming photon from a light source. When the photon has sufficient energy, larger than the work function (depending on wavelength / frequency of light source, i.e. $f > f_0$), electrons can be emitted with varying kinetic energy
→ some will reach the collector, generate electric field, current flows through circuit

current $= \frac{Ne}{t}$, intensity $I = \frac{NE}{tA} = \frac{Nhf}{tA}$.

rate of incidence $= \frac{N_e}{t} = \frac{\text{current}}{e}$

rate of emission $= \frac{N_p}{t} = \frac{\text{intensity} \times A}{E}$

observations of photoelectric effect:

1. Electrons emitted only if $f \geq f_0$, existence of threshold frequency. Intensity of light does not affect emission of electrons as energy of each photon remains the same, only rate of incidence of photons changes.
2. Almost immediate emission of electrons even though intensity is low.
3. Max E_k of electrons depends on frequency of light, not intensity.

WAVE PARTICLE DUALITY.

particle like a wave has $\lambda = \frac{h}{p} = \frac{h}{mv}$

wave like a particle has $p = \frac{h}{\lambda} = \frac{hf}{c}$

if particles behave like electrons, bright central spot observed.
If they behave like waves, pattern of concentric circles with increasing distance.
This is called electron diffraction.

Electron like wave	Electron diffraction (concentric circles of particles, increasing dist. from centre) → use de Broglie
Light like wave	Interference / diffraction (2 source interference / diffraction grating)
Electrons like particles	Undergo collision, have mass, charge (central bright spot)
Light like particles	Photoelectric effect

EMISSION LINE SPECTRUM – coloured lines on black background

hf, energy of emitted photon $= E_i - E_f$. $K\alpha \Rightarrow n=2$ to $n=1$, $K\beta \Rightarrow n=3$ to $n=1$

continuous spectrum: As electrons approach the nucleus, they slow down due to interaction with nucleus. When they decelerate, they lose KE by emitting X-ray photons of equal EM energy. These electrons with lower KE continue to collide with other target atoms, generating X-ray photons of various energies & frequencies.

characteristic peaks: Incoming electrons can also knock out electron orbiting in K-shell. Electron from an outer shell can fill this vacancy, emitting an X-ray photon with energy corresponding to this energy gap.

Absorption line spectrum – black lines on coloured background.

- electrons excited to higher level only if they absorb energy equal to the energy gap
- when excited atoms move down lower energy levels, they lose energy by emitting photons
- these photons have energy which correspond to energy gap.
- By Bohr's theory, since electrons can only occupy discrete energy levels, only photons of certain energies are produced.

$$eV = \frac{1}{2}mv_{max}^2 = hf_{max} = h\frac{c}{\lambda_{min}}$$

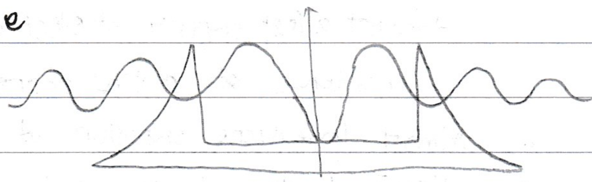
energy of electron ↳ energy of photon.

$$\Delta x \Delta p \geq \frac{h}{4\pi} , \quad \Delta E \Delta t \geq \frac{h}{4\pi}$$

$$T \propto e^{-2kd} , \quad k = \frac{\sqrt{2m(U-E)}}{\hbar} , \quad R+T=1$$

If electron is like wave, can tunnel through potential barrier even if insufficient KE.

- between barriers, wave has large amplitude
- decays exponentially outside barriers
- smaller amplitude outside atom.



STM:

- Region between tip and surface constitutes a potential barrier as electrons are bounded to surface by electrostatic forces.
- Electrons can still tunnel through even though KE not enough.
- Probability is higher when tip is nearer surface, current produced depends on distance between tip & surface (height of potential barrier)
  → keep height of tip constant, current measured when tip moves across gives image of surface
- → keep distance between tip and surface constant, current constant, diff in height of tip gives image of surface.

LASERS

Date No.

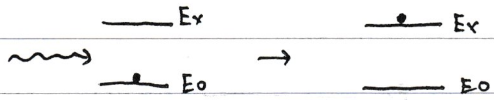
coherent – light waves have the same phase difference

collinated – light emitted travels in the same direction (highly directional). Focused into a tiny spot, achieving high intensity.

monochromatic – light consists of one wavelength only

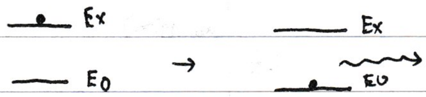
Absorption :

When an atom / electron at ground state E_0 absorbs a photon of energy $(E_x - E_0)$, the atom is excited to higher energy state E_x



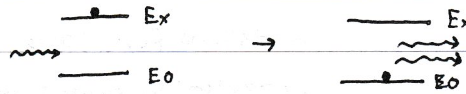
Spontaneous Emission :

When an atom at excited state Ex de-excites randomly & spontaneously (without any external influence) to ground state E_0, emitting a photon of energy $(E_x - E_0)$. This happens in a short time $(\sim 10^{-8} s)$



Stimulated Emission:

An excited atom at state Ex interacts with an incoming photon of energy $(E_x - E_0)$, and de-excites to its ground state E_0, emitting an identical photon in the process (same energy (& f & λ), polarisation & direction of travel)

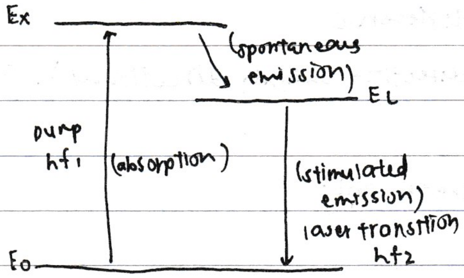


optical pumping: excitation of atom / electron from a lower to higher energy state using light of correct frequency f, such that the energy difference is f.

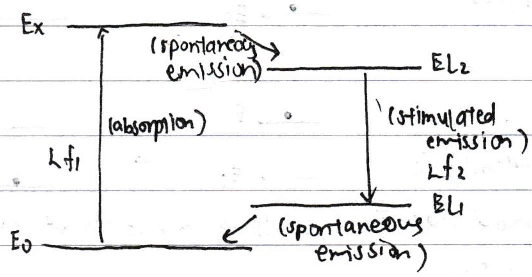
population inversion is achieved only when more atoms are in the excited state rather than ground state. This is only possible when atoms are excited to a metastable state, where they remain excited for $\sim 10^{-3} s$, much longer than the usual lifetime of $10^{-8} s$. Hence stimulated emission can take place to emit photons, rather than just spontaneous emission.

Why population inversion doesn't work for two-level laser system:

- equal probability of incoming photon causing absorption or stimulated + spontaneous emission.
- initially more atoms at ground state, so rate of absorption is higher
- as more atoms get excited, rate of stimulated emission increases till it equals that of absorption. Hence, no. of excited atoms = no. of ground state atoms => no population inversion.



- atoms excited to normal excited level Ex
- atoms spontaneously & quickly decay to metastable state EL. important for Ex to have short lifetime ($\sim 10^{-8}$s) for spontaneous emission compared to EL.
- atoms remain long enough at EL ($\sim 10^{-3}$s) to undergo stimulated emission & contribute to photon gain required for production of laser light.



- lower laser level EL1 introduced.
- atoms in EL1 move back to Eo quickly by spontaneous emission, so very few atoms are found in EL1.
- This greatly decreases loss of photons of energy hf_2 by absorption from EL1 to EL2 (too few atoms at EL1 to go through absorption, so less loss of photons)

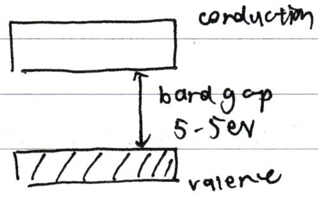
conditions for laser light:

1. population inversion
2. metastable state as excited state
3. photons must be confined in system long enough to stimulate further emission of photons from atoms. One end of the system is reflecting mirrors to accumulate triggering photons, other end is partially reflecting to allow laser light to escape.

SEMICONDUCTORS

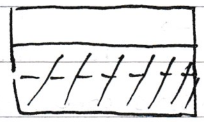
Date No.

INSULATOR



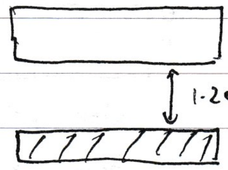
- valence band fully occupied
- large Eg, so at r.t., e⁻ don't have enough energy to move into conduction band

CONDUCTOR



- conduction band already partially filled with e⁻

SEMICONDUCTOR



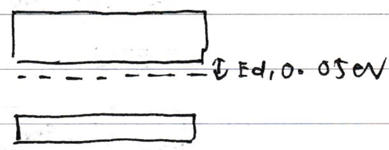
- valence band fully occupied
- lower Eg, so e⁻ can jump into conduction band at r.t.

INTRINSIC SEMICONDUCTOR

- smaller band gap, e⁻ from valence band can jump to conduction band by thermal agitation, e⁻ leaves behind a hole in valence band.
- e⁻ in neighbouring atom can fill in first hole, leaving behind second hole. Hence there is movement of holes in valence band, and also movement of e⁻ in conduction band
- Hence both e⁻ & holes are charge carriers as their movement contributes to flow of current.

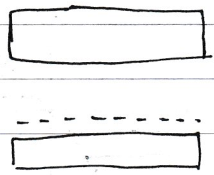
EXTRINSIC - n-type

- doping of Group V atom, extra electrons occupy higher energy state, can be excited to conduction band much more easily.



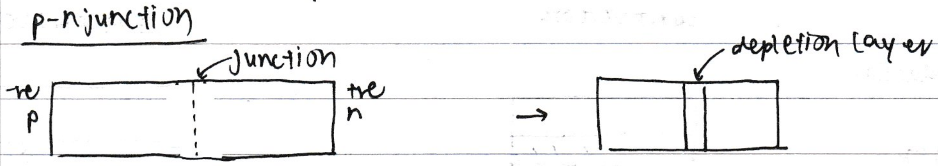
p-type

- doping of Group III atom, extra vacancy, electron from neighbouring bond can be torn to fill up hole with small amount of energy.
- e⁻ occupies acceptor energy level, e⁻ are easily bumped up to acceptor level from valence band leaving behind holes.



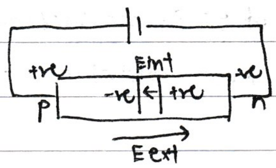
A'ZONE

p-n junction



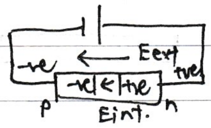
- when p-type & n-type semiconductors come into contact, e^- diffuse through the junction, from n to p, holes from p to n.
- e^- recombine with holes when they meet while moving across junction, forming depletion layer where there are no free charge-carriers. (~100m)
- since e^- moves to p, p-side becomes -ve, and n side comes +ve. Absence of free charge carriers in depletion layer exposes fixed -ve charged donor ions on p side & fixed +ve charged acceptor ions on n-side
- sets up contact potential diff/ potential barrier V_0 pointing from n to p-side, limiting further diffusion of e^- & holes across junction.

FORWARD BIAS

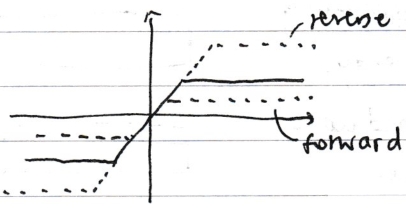


- when +ve charge applied to p-side & -ve to n-side, external e field Ext opposes Eint, lowering the height of potential barrier, depletion layer reduced in size (bc holes from p and e^- from n are pushing into layer). Since Eext>Eint, net e field allows flow of majority charge carriers across junction, and current flows.

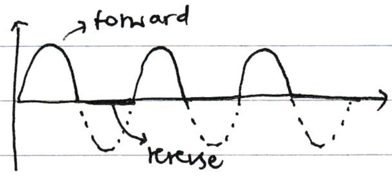
REVERSE



- p side more -ve, n side more +ve, increases height of barrier, size of depletion layer (holes in p & e in n pulled away from layer). Eext reinforces Eint, no flow of majority charge carriers, no current.



- when sinusoidal pd applied, forward for half a cycle, reverse for other half ∴ current only flows for half a cycle ⇒ half wave rectification of AC voltage.



NUCLEAR PHYSICS

Date No.

α particle scattering:

- most particles experienced little or no deflection	- small fraction indicates that the nucleus is very small ($10^{-14} \sim 10^{-15}$ m)
- a small fraction of α-particles experienced large deflection; a few deflected at angles ~180° (depends on impact parameter)	- large deflection possible only is nucleus is massive (99.99% mass of atom)

$^{12}_{6}C$

- 12 → protons + neutrons, also means 1mol is 12g.
- 6 → protons

If asked no. of nuclei / atoms of $^{12}_{6}C$ in 1kg:

→ $\frac{1}{0.012} \times 6.02 \times 10^{23}$

Δm, mass defect = $m_p + m_e + m_n - m_{atom}$ (rmb to multiply by no.)

to find energy released:

① mass defect ⇒ $E = (m_{reactants} - m_{products}) c^2$

② binding energy ⇒ E = B.E. products − B.E. reactants

∴ mass defect is the mass difference between rest mass of an atom and its constituent particles

∴ binding energy is the minimum energy required to break a nucleus into its constituent particles (protons, neutrons i.e. nucleons) completely.

α-particle scattering	V.S. neutron bombardment (nuclear fission)
- interact through electrostatic force	- strong nuclear force
- elastic	- inelastic
- no nuclear transformation, α-particle & nucleus remain intact.	- nuclear transformation: highly unstable nucleus decays to smaller daughter nucleus which is different from the parent nucleus.

RADIOACTIVE DECAY V.S. NUCLEAR FISSION

similarities:	differences:
- release of energy	- nuclear fission releases ~100MeV, radioactive decay only a few MeV
- production of smaller nuclides	- radioactive decay is spontaneous, nuclear fission is induced
- mass-energy & momentum conserved	- rate of decay depends on no. of undecayed radioactive nuclei (N) and decay constant / half life ($\lambda = \frac{\ln 2}{t_{1/2}}$); rate of fission depends on no. of slow neutrons captured.

stopped by: air/paper, Al, thick lead

speed: 0.05c, 0.9c, c

ionisation power ↑ / penetrating power ↓

α-decay (stopped by air ~3cm)	$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}X + ^{4}_{2}He$	Nucleus too large (too many nucleons)
β^- decay	$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{-1}e + \bar{\nu}$	Nucleus has too many neutrons (neutron → proton, emits e)
β^+ decay	$^{A}_{Z}X \rightarrow ^{A}_{Z+1}Y + ^{0}_{1}e + \bar{\nu}$	Too many protons (neutron → positron, emits e)
γ decay	$^{A}_{Z}X^* \rightarrow ^{A}_{Z}X + \gamma$	Daughter nucleus still in excited state after α or β decays, emits γ-ray photon.

A'ZONE

☺

λ, decay constant — probability that a radioactive nucleus will decay per unit time.

unit: s^{-1} $\frac{dN}{dt} = -\lambda N$

activity, A — rate of radioactive decay unit: Bq, 1 decay s^{-1}

$A = -\frac{dN}{dt} = \lambda N$.

$N = N_0 e^{-\lambda t}$, $A = A_0 e^{-\lambda t}$, $t_{1/2} = \frac{\ln 2}{\lambda}$

molar mass = mass of 1 mole of substance in g.