Class- XII
Physics

TIME ALLOWED: 3 hour **MAX MARKS:70**

General Instructions:

(i) All questions are compulsory. There are 26 questions in all

(ii) The question paper has five sections. Section A, Section B, Section C, Section D and Section E.

(iii) Section A contains five questions of one mark each, Section B contains five questions of two marks each, Section C contains twelve questions of three marks each, Section D contains one value based question of four marks and Section E contains three questions of five marks each.

(iv) There is no overall choice. However, an internal choice has been provided for one question of two marks, one question of three marks and all the three questions of five marks weightage. You have to attempt only one of the choices in such questions.

(v) You may use the following values of physical constants wherever necessary.

$c = 3\times10^{8}\,\text{m s}^{-1}$

$h = 6.63\times10^{-34}\ \text{J s}$

$e = 1.6\times10^{-19}\,\text{C}$

$\mu_0 = 4\pi\times10^{-7}\,\text{T m A}^{-1}$

$\varepsilon_0 = 8.854\times10^{-12}\,\text{C}^2\text{N}^{-1}\text{m}^{-2}$

$\dfrac{1}{4\pi\varepsilon_0} = 9\times10^{9}\,\text{Nm}^2\text{C}^{-2}$

$m_e = 9.1\times10^{-31}\,\text{kg}$

mass of neutron = 1.675×10^{-27}kg

mass of proton = 1.673×10^{-27}kg

Avogadro number = 6.023×10^{23} per gram mole

Boltzmann constant =$1.38\times10^{-23}\text{JK}^{-1}$

SECTION A

1. Where can electric field lines take the form of closed continuous curves?

2. Can a charged particle be accelerated in a magnetic field? What is the change in its kinetic energy?

3. Show graphically the variation of photo electric current with increase in stopping potential.

4. A substance with a forbidden energy gap of 4 eV is heated. Will its conductivity increase or decrease with the increase in temperature?

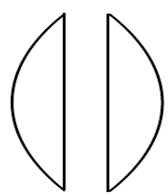
5. Many any two applications of internet**.**

SECTION B

6. In the circuit given below, a current of 4A flows initially. It then increases at a rate of 2.0A/s. Find the potential difference $V_A - V_B$ across the points A and B of the circuit.

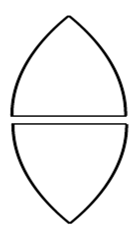
7. Define Q value of an LCR series circuit. If the temperature across the resistor is increased, will the Q value be affected? Justify your answer.

8. A Biconvex lens of focal length *f* and with equal radii of curvature is cut vertically into two halves as shown below.



Find the ratio of focal length of each half of the lens to that of the original lens.

How would the ratio change if the lens is cut horizontally?



9. What is an LED? What is the criterion to be kept in mind for selecting semiconductors for fabricating LED s that emit visible radiation? Name the semiconductor used to make infra-red LED.

OR

What is a photo diode? Draw the I-V characteristics for different illumination intensities. Why a photo diode is always operated in the reverse bias conditions?

10. Define the term *radio horizon.* A transmitting antenna has a length of 100 m. Calculate the maximum distance up to which the signal transmitted from the antenna can be received. Take the radius of the earth as 6400 km.

SECTION C

11. Two equal and opposite charges q and $-q$ are kept at a small distance $2a$ apart. What is the combination of these charges called? Find the electric field intensity at a point along its axis at a distance x from the midpoint of the line joining the two charges.

12. (a) Define the unit of capacitance.

(b) Three capacitors each of capacitance C are connected in series across a source of emf which maintains a potential difference V across the combination. They are then connected in parallel across the same source of emf. Find the ratio of the energy stored in the series combination to that stored in the parallel combination.

13. A potentiometer of length 100 cm has a battery of emf 5.0V with internal resistance 1Ω in its driver circuit. The secondary circuit has a cell of emf 2.0 V connected to a galvanometer through a high resistance of 10 kΩ. This setup gives a balance point at 85 cm. The cell in the secondary circuit is then replaced by another cell of emf E, which then gives the balance point at 60 cm.

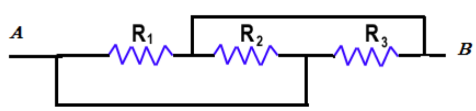
(i) Find the value of E.

(ii) If a cell of emf 1mV be connected in the secondary circuit, can this circuit arrangement be used to determine the balance point accurately? Explain.

(iii) If the high resistance in the circuit be changed to 5MΩ, will the balance point be affected? Justify.

OR

What is the equivalent resistance between points **A** and **B** in the circuit given below? Given $R_1 = R_2 = R_3 = 2\Omega$.



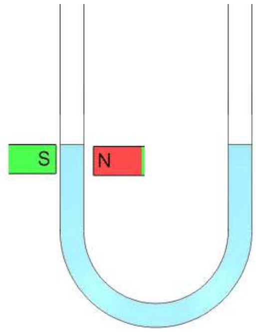
If the system of resistors is connected across a battery of emf 6.0V, find the current flowing through R_2. Also calculate the heat dissipated in the circuit in 2 s.

14. Sodium Chloride is taken in a U-tube manometer and a magnetic field is applied across on of the limbs of the manometer as shown.

(i) Predict what would happen to the liquid levels in the limbs. Justify your answer.

(ii) Draw a graph to show the variation of *Magnetisation (M)* of sodium chloride when the *applied magnetic field intensity (H)* is increased.

(iii) If the temperature of the liquid in the manometer is increased, how will its magnetic susceptibility vary?



15. A pure inductor of self inductance L is connected across an ac source. The voltage across the source is $v = v_m \sin \omega t$. Deduce an expression for the current flowing in the circuit. Represent the relationship between voltage and current flowing in the circuit by means of (i) a graph (ii) a phasor diagram. Hence define inductive reactance. If the ac source be replaced by a dc source of emf v, what will be the value of the inductive reactance?

16. The electric field in a plane electromagnetic wave oscillates in accordance to the equation $E_x = 48 \sin\left[0.5\times10^3 z + 2\times10^{10} t\right] \text{V m}^{-1}$.

(i) What is the expression for the corresponding magnetic field?
(ii)What is the wavelength of this wave?
(iii) Write any two uses of this electromagnetic wave.

17. (a) Two waves of equal intensities I_0 each have a constant phase difference of ϕ between them. They superpose on each other and produce an interference pattern. What would be the expression for the intensity of the resultant wave?
(b) If the phase difference between the waves varies continuously with time, what changes can be observed in the interference pattern?

18. (a) The de Broglie wavelength of a particle of mass m moving with a velocity v is λ . What is the effect of temperature on the de Broglie wavelength?
(b) Represent graphically, the variation of de Broglie wavelength with temperature.

19. Obtain a general expression for the energy of an electron in an orbit using Bohr's postulates.

20. (a) Define Q value of a nuclear reaction.
(b) Can a nucleus of iron $^{56}_{26}Fe$ split into two $^{28}_{13}Al$ nuclei? Given mass of $^{56}_{26}Fe$ =55.9349404 u and mass of $^{28}_{13}Al$ = 7.981914u? Explain.

21. An NPN transistor is connected in common emitter configuration. Draw its transfer characteristics. Explain the regions of the curve. What is the region that cannot be used if transistor has to work as a switch.

22. Why is modulation essential? Derive an expression for amplitude modulated wave. Explain its components.

SECTION D

23. Geetha was doing her homework and her grandmother was helping her. She observed that her grandmother was holding the book far away from her eyes to read. Geetha asked her grandmother why she was holding the book so far from her face, to which her grandmother replied that she could not read clearly if the book was held closer to her face. Geetha realized that her grandmother had some defect in her eye and insisted that she go for an eye check up.

(a) What kind of defect was Geetha's grandmother suffering from?

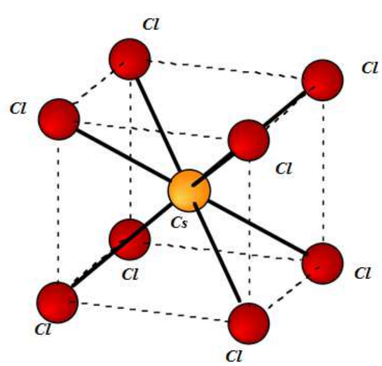
(b) If the closest distance at which she could read clearly was 40 cm, what power of reading lenses could help her to read comfortably at the distance which the people with normal vision are able to?

(c) What values did Geetha display?

SECTION E

24. (a) Derive an expression for the potential energy of a system of charges.

(b) A molecule of CsCl has a body centered cubic structure with the Cs^+ ion in the centre surrounded by 8 Cl^- ions.



If the distance between the Cs^+ ion and each of the chloride ions is 0.3571 nm, what is the magnitude of the force experienced by the Cs^+ ion?

What is the work done in bringing the Cs^+ ion from infinity to the centre of the cubic lattice?

OR

(a) State Gauss's law. Use this law to derive an expression for the electric field at a point due to an infinitely long line of charge having uniform charge density λ C/m.

(b) Represent the variation of the electric field with distance from the wire graphically. How does this graph differ from the variation of electric field with distance due to a point charge?

25. (a) A circular coil of radius *R* carries a current *I*. Deduce an expression for the magnetic field at a point *P* located at a distance x from the centre of the coil, along its axis.

(b) Express graphically, the variation of magnetic field *B* with distance *x*.

(c) Use this expression to prove that a circular loop acts as a magnetic dipole.

OR

(a) Two long conductors are separated by a distance *d*. They carry currents I_1 and I_2 in the same direction. Derive an expression for the force between them. What is the direction of the force if the current in one conductor is reversed?

(b) If $I_1 = I_2 = I$, What is the value of the magnetic field at a distance $\frac{d}{2}$ when the currents in both the conductors flow (i) in the same direction (ii) in the opposite direction?

26. Derive a relationship between object distance *u*, image distance *v* and the radius of curvature *R* of a convex spherical refracting surface when the refraction takes place from an optically rarer medium of refractive index n_1 to an optically denser medium of refractive index n_2

OR

Explain the phenomenon of total internal reflection.

Explain using ray diagrams to show how a right angled isosceles prism can be used to deviate the incident rays through (i) 90^o (ii) 180^o.

(Solution)
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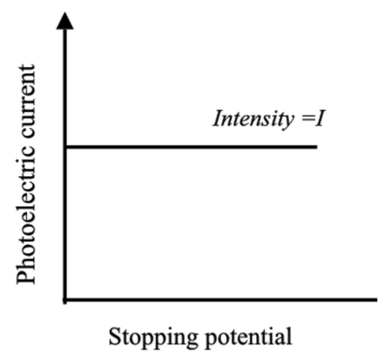
Section A

1. In charge free region.

2. Yes. A charged particle is under the action of Lorentz force in a Magnetic field; Change in KE is Zero, as the force acts perpendicular to the direction of motion of the charge, there is no change in its velocity.

3. Photo electric current is independent of stopping potential for a constant intensity.

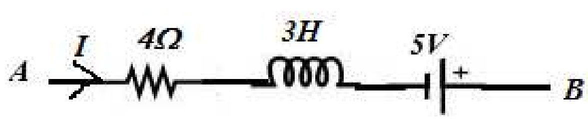


4. Any substance with energy gap > 3 eV is an insulator. It has negative temperature coefficient of resistance. Its resistance decreases with increase in temperature. Its conductivity increases.

5. Email, e commerce, FTTP, WWW, Chat etc any two applications.

Section B

6. In the circuit



The voltage across the inductor is $\varepsilon = -L\frac{dI}{dt} = -3(2) = -6V$. Using Kirchhoff's laws,

$4\times4-6=(V_A-V_B)-5;(V_A-V_B)=15V$

7. Q value is also called quality factor of the circuit. It determines the sharpness of resonance.

$Q = \frac{\omega_0 L}{R} = \frac{1}{\omega_0 CR}; \because \left(\omega_0 = \frac{1}{\sqrt{LC}}\right); Q \propto \frac{1}{R}$. Resistors are conductors which have positive temperature coefficient of resistance. If the temperature increases, R increases. Q decreases.

8. The focal length of the uncut lens is given by

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For a biconvex lens of equal radii of curvature, $R_1 = R; R_2 = -R$

$$\frac{1}{f} = (n-1)\left(\frac{1}{R} - \left(-\frac{1}{R}\right)\right) = \frac{2}{R}(n-1)$$

When the lens is cut vertically, for each half of the lens, $R_1 = R; R_2 = \infty$. The focal length f_1 is given by

$$\frac{1}{f_1} = (n-1)\left(\frac{1}{R} - \frac{1}{\infty}\right) = \frac{1}{R}(n-1)$$

Therefore, $\frac{f_1}{f} = 2$.

When the lens is cut horizontally, there is no change in the radii of curvatures. So, each half of the lens has the same focal length *f*.

$$\frac{f_2}{f} = 1$$

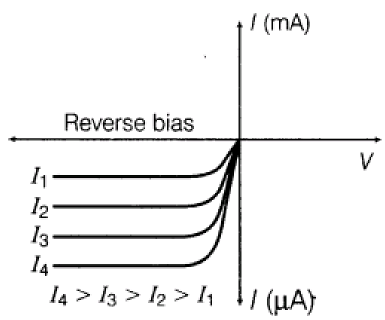
9. An LED is a heavily doped p-n junction which under forward bias emits spontaneous radiation.

A semi conductor that can be fabricated into visible LED must have a band gap of 1.8eV .

Gallium Arsenide

OR

Photodiodes are optoelectronic devices which is operated under reverse bias conditions and are used for detecting optical signals.



Reverse bias currents through a photodiode

It is always operated in reverse bias conditions since it is easy to detect the change in current with change in the light intensity.

10. Radio horizon is the maximum distance a signal can travel due to a transmitting antenna of height h_T

$$d_T = \sqrt{2Rh_T}$$
$$d_T = \sqrt{2Rh_T} = \sqrt{2\times6400\times0.1} = 35.78\text{km}$$

SECTION C

11. Dipole

Consider an electric dipole *AB* made up of charges –*q* and +*q* separated by a small distance 2*a*. P is a point on the axis of the dipole at a distance *x* from the centre of the dipole *O*. This is shown in the figure.

Point *P* is under the action of two electric fields- one due to the positive charge at *B* and the second due to the charge –*q* at *A*. The net electric field at point *P* is the resultant of these two fields. The electric field at P due to charge +q at B is

$$E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(BP)^2} \text{ along } \overrightarrow{\text{BP}}; E_1 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(x-a)^2}$$

And the electric field at P due to charge –q at A is

$$E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(PA)^2} \text{ along } \overrightarrow{\text{PA}}; E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(x+a)^2}$$

These two fields are opposite in direction acting parallel to the axis of the dipole and the resultant of these two fields is along BP, the direction of dipole moment.

$$E_{axial} = E_1 - E_2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{(x-a)^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{(x+a)^2} = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{(x-a)^2} - \frac{1}{(x+a)^2}\right)$$

$$E_{axial} = \frac{q}{4\pi\varepsilon_0}\frac{4ra}{(x^2-a^2)^2} = \frac{1}{4\pi\varepsilon_0}\frac{2px}{(x^2-a^2)^2}; \because p = 2qa$$

If the point *P* is at a very large distance when compared to the length of the dipole, $x \gg a$ the value of *a* can be neglected in the denominator. When *x*>>*a*

$$\vec{E}_{axial} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{x^3}$$

12. (a) The unit of capacitance is farad (F). One farad is defined as the capacitance of a capacitor which stores a charge of 1 coulomb when a potential of 1 V is 1F = 1C/V applied across it.

(b) When the capacitors are connected n series, the equivalent capacitance

$$\frac{1}{C_s}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}$$

$$C_1=C_2=C_3=C$$

$$C_s=\frac{C}{3}$$

The energy stored in the series combination is

$$U_S=\frac{1}{2}C_sV^2=\frac{1}{2}\frac{C}{3}V^2=\frac{CV^2}{6}$$

When the capacitors are connected in parallel,

$$C_P=C_1+C_2+C_3; C_P=3C$$

The energy stored in the parallel combination

$$U_P=\frac{1}{2}C_PV^2=\frac{3}{2}CV^2$$

The ratio of energies in series to that in parallel

$$\frac{U_S}{U_P}=\frac{CV^2/6}{3CV^2/2}=\frac{1}{9}$$

13. (i) From the principle of potentiometer,

$$\frac{E_2}{E_1}=\frac{l_2}{l_1}$$

$$\frac{E}{2.0}=\frac{60}{85}; E=1.41\text{ V}$$

(ii) The balancing length for 1 mV cell would be,

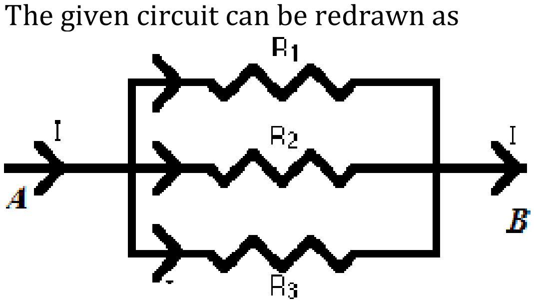
$$\frac{1\times10^{-3}}{2.0}=\frac{l}{85}; l=0.0425\text{ cm } =0.425\text{ mm}$$

It is is very small length which cannot be measured using this potentiometer, as the smallest length that can be measured is only 1 mm.

(iii) No. The balance point will not be affected .As no current flows through the galvanometer and hence the high resistance, any change in the value of the high resistance will not affect the balance point.

OR

The given circuit can be redrawn as



The equivalent resistance of the combination is

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{3}{R}$$

$$R_P = \frac{R}{3} = \frac{2}{3}$$

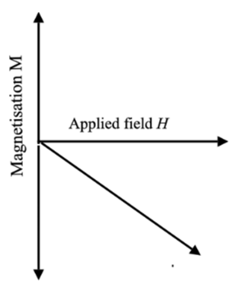
Using Ohm's law,

$$I = \frac{V}{R} = \frac{6}{2} = 3 \text{ A}$$

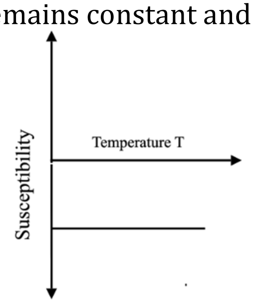
14. (i) Sodium chloride is a diamagnetic substance. It moves away from the stronger part of the field towards the weaker part. The liquid level in the left arm will move down while that in the right arm will move up.

(ii) Diamagnetic substances develop a magnetic moment opposite to the direction of the applied field.

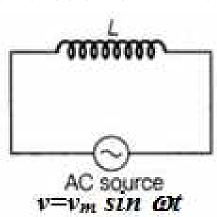
$M = \chi H$



(iii) Susceptibility of Diamagnetic substance is independent of temperature. It remains constant and negative.



15. An ideal inductor has no resistance. When a c voltage is applied across the inductor a back e mf if developed across it.The circuit diagram is shown below.



Applying Kirchhoff's loop rule to the circuit,

$$v - L\frac{di}{dt} = 0$$

$$\frac{di}{dt} = \frac{v}{L} = \frac{v_m \sin \omega t}{L}$$

Integrating the above equation,

$$\int \frac{di}{dt} dt = \int \frac{v_m \sin \omega t}{L}$$

$$i = -\frac{v_m \cos \omega t}{\omega L} = \frac{v_m}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$i = i_m \sin\left(\omega t - \frac{\pi}{2}\right)$$

Where,

$$i_m = \frac{v_m}{\omega L}$$

This is called the amplitude of current.

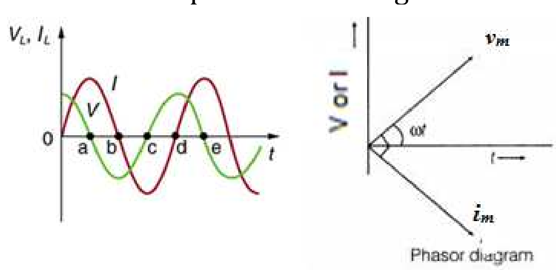
The voltage in an ac circuit containing an ideal inductor leads the current by a phase angle of $\pi/2$.

The quantity ωL has a similar function as the resistance in a dc circuit and is called inductive reactance. X_L

$$X_L = L\omega$$

Inductive reactance limits the current in an ac circuit.

The relationship between voltage and current is represented graphically



If the inductor is connected to a dc circuit, the inductive reactance is zero, since the frequency of dc circuit is zero.

16. The equation of the oscillating electric field in an e m wave is $E_x = E_0 \sin[kz + \omega t]$

Here, The electric field oscillates in the *x* direction and the propagation is along the *z* direction.

(i) Comparing the given equation with the above,

$$E_x = 48 \sin\left[0.5 \times 10^3 z + 2 \times 10^{10} t\right] \text{V m}^{-1}$$

$$E_0 = 48 \text{V m}^{-1}$$

$$B_0 = \frac{E_0}{c} = \frac{48}{3\times10^8} = 16\times10^{-8}T$$

The corresponding magnetic field will oscillate along the y direction.

$$B_y = B_0 \sin\left[kz+\omega t\right] = 16\times10^{-8}\sin\left[0.5\times10^3 z + 2\times10^{10} t\right]T$$

(ii) from the equation,

$$k = 0.5\times10^3 = \frac{2\pi}{\lambda}$$

$$\lambda = \frac{2\pi}{0.5\times10^3} = 12.6\times10^{-3}m = 12\text{ mm}$$

(iii) The wavelength falls in the microwave region of the electromagnetic spectrum.

Uses: Radar systems used in aircraft navigation

Microwave ovens

17. (a) Let the equations for the displacement of the two waves be

$y_1 = a\cos\omega t$ and $y_2 = a\cos(\omega t+\phi)$

The resultant displacement is given by

$$y = y_1 + y_2$$
$$= a\cos\omega t + a\cos(\omega t+\phi)$$
$$= 2a\cos\left(\frac{\phi}{2}\right)\cos\left(\omega t+\frac{\phi}{2}\right)$$

The amplitude of the resultant wave is

$$A = 2a\cos\left(\frac{\phi}{2}\right)$$

Since intensity is related to amplitude as,

$$I = A^2 = 4a^2\cos^2\left(\frac{\phi}{2}\right)$$

$$\because I_0 = a^2;$$

$$\boxed{I = 4I_0\cos^2\left(\frac{\phi}{2}\right)}$$

(b) If the phase difference between the two waves varies continuously, then an average intensity would be observed. Averaging the expression for intensity over time,

$$\langle I\rangle = \left\langle 4I_0\cos^2\left(\frac{\phi}{2}\right)\right\rangle = 4I_0\left\langle\cos^2\left(\frac{\phi}{2}\right)\right\rangle$$

$$\left\langle\cos^2\left(\frac{\phi}{2}\right)\right\rangle = \frac{1}{2}$$

Therefore

$I = 2I_0$

The interference pattern changes with time and the intensities add up to give a constant illumination.

18. (a)The average kinetic energy of a particle of mass m moving with a speed v *is* related to temperature as,

$$\frac{1}{2}mv^2 = \frac{3}{2}kT$$

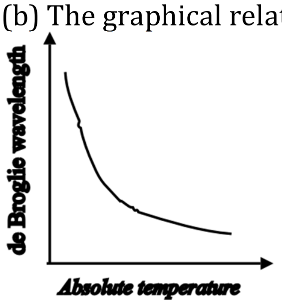
Where, k is the Boltzmann's constant and T its absolute temperature.

$$v = \sqrt{\frac{3kT}{m}}; mv = \sqrt{3mkT}$$

$$\lambda = \frac{h}{mv} = \frac{h}{\sqrt{3mkT}}$$

$$\lambda \propto \frac{1}{\sqrt{T}}$$

(b) The graphical relationship between λ and T



19. B ohr's postulates:

(i) An electron in a an atom could revolve in certain stable orbits without the emission of radiant energy.

(ii) The electron revolves around the nucleus only in those orbits for which the angular momentum is an integral multiple of $h/2\pi$.

(iii)When an electron makes a transition from one of its higher specified non radiating orbits to another of lower energy, a photon is emitted with energy equal to the difference in energy between the two states.

Consider an electron of mass m revolving around a nucleus of charge Ze with a velocity v in an orbit of radius r. The electrostatic force between the nucleus and the electron provides the centripetal force for its circular motion.

$$F_e = F_c$$

$$\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r^2} = \frac{mv^2}{r}$$

The kinetic energy K is given by

$$K = \frac{1}{2}mv^2 = \frac{1}{8\pi\varepsilon_0}\frac{Ze^2}{r}$$

The potential energy U is given by

$$U=\frac{1}{4\pi\varepsilon_0}\frac{Ze(-e)}{r}=-\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}$$

The total energy E is the sum of kinetic and potential energies.

$$E=K+U=\frac{1}{8\pi\varepsilon_0}\frac{Ze^2}{r}-\frac{1}{4\pi\varepsilon_0}\frac{Ze^2}{r}=-\frac{1}{8\pi\varepsilon_0}\frac{Ze^2}{r}$$

20. (a) The Q value of a nuclear reaction is the disintegration energy. It is the difference between initial mass energy and the total mass energy of the disintegration products.

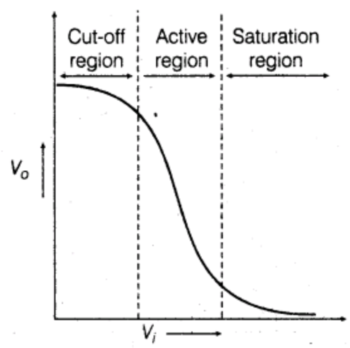
(b) The reaction is written as

$${}^{56}_{26}Fe \rightarrow 2\left({}^{28}_{13}Al\right)+Q$$

$$Q=m_{Fe}-2m_{Al}=\left(55.9349\text{u}-2\times 27.98191\text{u}\right)\left(931.5\text{ MeV/u}\right)=-26.94MeV$$

Since the Q value is negative, the reaction is not possible.

21. The transfer charcteristics of a based biased transistor is as below.



(i) Cut off region: If the input voltage is less than the cut in voltage, the transistor does not conduct. Both the emitter- base and the collector base junctions are reverse biased.

(ii) Active region: Linear relationship exists between I_C and V_i. The outpour voltage V_0 decreases linearly. The emitter- base junction is forward biased and the collector base junction is reverse biased.

(iii) Saturation region: With further increase in V_i, the relationship between V_o and V_i becomes non linear and the transistor goes into saturation. Both the emitter- base and the collector base junctions are forward biased and the collector current is independent of the base current.

If a transistor has to operate as a switch, it cannot be operated in the active region.

22. Modulation is essential because,

(i) A large size of antenna is required to transmit low frequency waves.

(ii) Radiating power of an antenna increases with increasing frequency.
(iii) To avoid mixing up of signals.
A sinusoidal carrier wave is

$c(t) = A_c \sin \omega_c t$

The modulating signal is written as

$m(t) = A_m \sin \omega_m t$

The modulated signal is given by

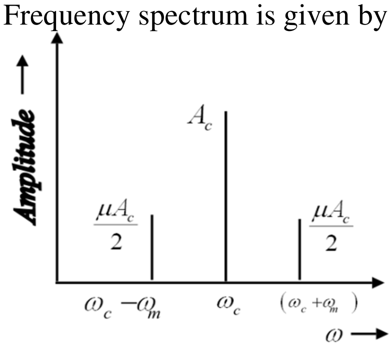
$$c_m(t) = (A_c + A_m \sin \omega_m t)\sin \omega_c t = A_c \left(1 + \frac{A_m}{A_c} \sin \omega_m t\right) \sin \omega_c t$$

$$c_m(t) = A_c \sin \omega_c t + \mu A_c \sin \omega_m t \sin \omega_c t; \because \mu = \frac{A_m}{A_c} (\text{modulation index})$$

$$c_m(t) = A_c \sin \omega_c t + \frac{\mu A_c}{2} \cos(\omega_c - \omega_m)t - \frac{\mu A_c}{2} \cos(\omega_c + \omega_m)t$$

upper side band frequency $= (\omega_c + \omega_m)$; lower side band frequency $= (\omega_c - \omega_m)$

Frequency spectrum is given by



SECTION D

23. (a) Hypermetropia

(b) The near point of the eye has shifted to 40 cm. The object distance is 25 cm. The lens is to be so chosen that the image of the object at 25 cm is to be formed at 40 cm.

$$P = \frac{1}{f} = \frac{1}{v} - \frac{1}{u} = -\frac{5}{2} - (-4) = 4 - \frac{5}{2} = +\frac{3}{2} = +1.5D$$

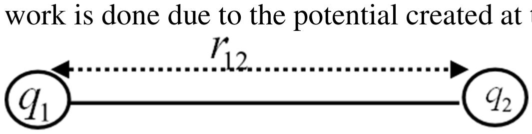
A convex lens of +1.5D is needed.

(c) Keen observation, responsible, scientific approach, compassion,

SECTION E

24. (a) Potential energy of a system of charges is the work done in building up the required configuration of charges.

When a charge q_1 is brought from infinity to a point in the absence of external electric field, no work is done. When a second charge $q_2$is placed at a distance r_{12} from q_1, work is done due to the potential created at that point due to q_1.



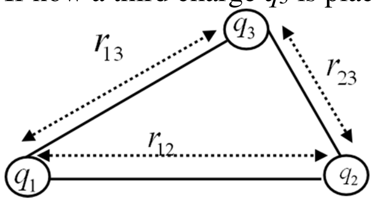
The potential at the point due to q_1 is

$$V_{12}=\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{12}}$$

The work done in bringing q_2 to the point is

$$U_{12}=q_2V_{12}=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}}$$

If now a third charge q_3 is placed as shown,



Work is done due to the potentials created by both the charges q_1 and q_2 .
Work done by q_3 due to the potential V_{13} due to q_1 is

$$V_{13}=\frac{1}{4\pi\varepsilon_0}\frac{q_1}{r_{13}};U_{13}=q_3V_{13}=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_3}{r_{13}}$$

Work done by q_3 due to the potential V_{23} due to q_2 is

$$V_{23}=\frac{1}{4\pi\varepsilon_0}\frac{q_2}{r_{23}};U_{23}=q_3V_{23}=\frac{1}{4\pi\varepsilon_0}\frac{q_2q_3}{r_{23}}$$

The total work done in assembling the three charges is

$$U=U_{12}+U_{13}+U_{23}=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r_{12}}+\frac{1}{4\pi\varepsilon_0}\frac{q_1q_3}{r_{13}}+\frac{1}{4\pi\varepsilon_0}\frac{q_2q_3}{r_{23}}$$

(b) The Cs ion is symmetrically placed with respect to all chloride ions. Hence the total force on the Cs ion is zero.
Both Cs and Cl are singly ionized, the work done is

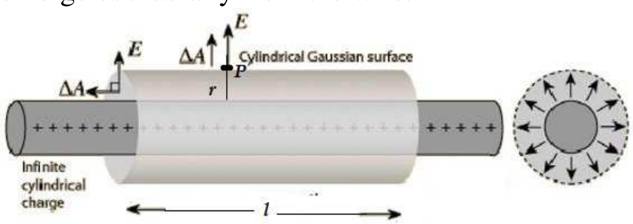
$$W=8\times\frac{1}{4\pi\varepsilon_0}\frac{e(-e)}{r}=-\frac{8\times9\times10^9\times\left(1.6\times10^{-19}\right)^2}{0.3571\times10^{-9}}=-5.162\times10^{-18}\,\mathrm{J}$$

OR

(a) Gauss law states that the total electric flux through any closed surface is $1/\varepsilon_0$ times the net charge enclosed by the surface**.**

$$\phi=\frac{q}{\varepsilon_0}$$

Consider an infinitely long uniformly charged wire with a linear charge density λ . Looking through a plane perpendicular to its length, the electric field lines are seen to emerge out radially from the wire.



Let the electric field intensity at a point *P*, distance *r* from the wire be *E.* Since the electric flux around the conductor has a radial symmetry, the preferred Gaussian surface is a cylinder. This cylindrical Gaussian surface has a radius *r* and length *l.*

Point *P* lies on its curved surface as shown in the figure. The cylindrical Gaussian surface is bounded by the curved surface and sealed on both ends by plane caps. Therefore, the total flux through the Gaussian surface is the sum of flux through the plane caps and that through the curved surface.

Electric flux ϕ through a small area $d\vec{A}$ and the electric field intensity $\vec{E}$ are related as follows:

$\phi = \vec{E} \bullet d\vec{A} = EdA\cos\theta$, where, θ is the angle between $\vec{E}$ and $d\vec{A}$.

Since the electric lines of force emerge radially from the wire, they are normal to the curved surface of the Gaussian cylinder. It follows therefore that the electric field intensity is also normal to the curved surface of the cylinder under consideration.

Consider a small area *dA* on the plane caps. At the plane caps, the angle between the area vector $d\vec{A}$ and the electric field vector $\vec{E}$ is 90º. The flux through the area considered on the plane caps

$$d\phi_{\text{plane caps}} = EdA\cos\theta = EdA\cos 90$$
$$= 0$$

The total flux through the plane caps is also equal to zero.

At the curved surface, the electric field is along the area vector and the angle between the vectors becomes zero. The flux through the small area on the curved surface is

$$d\phi_{\text{curved}} = EdA\cos\theta = EdA\cos 0$$
$$= EdA$$

The total flux through the curved surface is

$$\phi_{\text{curved}} = \int d\phi_{\text{curved}}$$
$$= \int EdA$$

The total area of the curved surface of the cylindrical Gaussian surface of length *l* and radius *r* is $2\pi rl$.

Therefore, $\phi_{\text{curved}} = E \cdot 2\pi rl$.

The total flux through the Gaussian surface is

$$\phi = \phi_{\text{plane caps}} + \phi_{\text{curved}}$$
$$= E \cdot 2\pi rl$$

By Gauss's law,

$$\phi = \frac{q}{\varepsilon_0}$$

Where the total charge contained by the Gaussian surface is *q*. If the wire has a linear charge density λ, then, $\lambda = \frac{q}{l}$ and $q = \lambda l$

Therefore, $\phi = \frac{q}{\varepsilon_0} = \frac{\lambda l}{\varepsilon_0}$.

Since $\phi = E \cdot 2\pi rl$,

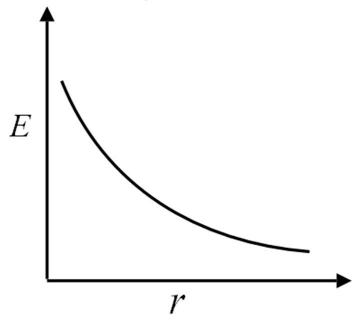
$$E \cdot 2\pi rl = \frac{\lambda l}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi r\varepsilon_0}$$

The direction of the field is along the normal to the curved surface. $\vec{E} = \frac{\lambda}{2\pi r \varepsilon_0} \hat{n}$

(b) For a line of charge,

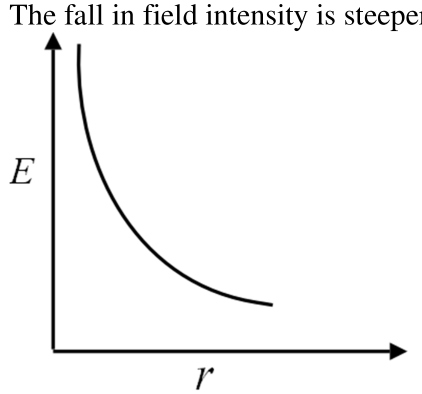
Since $E \propto \frac{1}{r}$



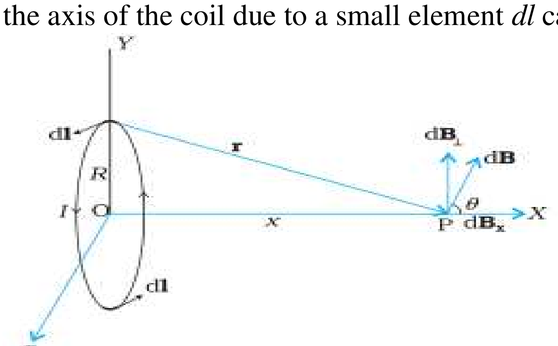
For a point charge,

$E \propto \frac{1}{r^2}$

The fall in field intensity is steeper.



25. (a) Field due to current carrying coil: Consider a coil of radius *R* carrying a current *I*. The loop is placed in the *y-z* plane. The magnetic field at a point *P* at a distance *x* on the axis of the coil due to a small element *dl* carrying current is



$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \vec{r}}{r^3}$.

The direction of the field vector **dB** is perpendicular to the plane containing the vectors **dl** and **r**

Since the angle between the vectors **dl** and **r** is 90º,

$$\left|d\vec{l}\times\vec{r}\right| = rdl$$

Therefore,

$$dB = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}.$$

$$\because r^2 = x^2 + R^2; dB = \frac{\mu_0}{4\pi}\frac{Idl}{x^2+R^2}$$

Resolving **dB** into horizontal and vertical components, the vertical component cancels out for every diametrically opposite current element. The horizontal components add along the *x* direction. The net magnetic field is along the axis of the coil.

$$dB_x = dB\cos\theta$$

$$dB_x = \frac{\mu_0}{4\pi}\frac{IdlR}{\left(x^2+R^2\right)^{3/2}}$$

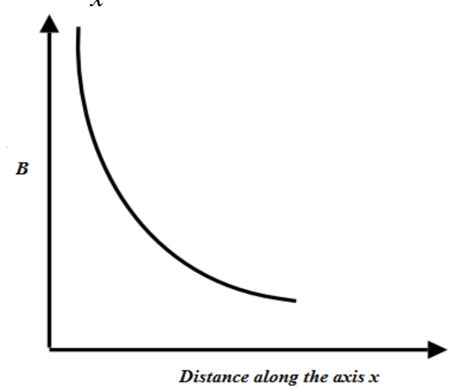
Integrating over the loop,

$$\vec{B} = \int dB_x\hat{i} = \int\frac{\mu_0}{4\pi}\frac{IdlR}{\left(x^2+R^2\right)^{3/2}}\hat{i}$$

$$= \frac{\mu_0}{4\pi}\frac{IR}{\left(x^2+R^2\right)^{3/2}}\int dl\hat{i} = \frac{\mu_0}{4\pi}\frac{IR}{\left(x^2+R^2\right)^{3/2}}2\pi R\hat{i}$$

$$= \frac{\mu_0 IR^2}{2\left(x^2+R^2\right)^{3/2}}\hat{i}$$

(b) $B \propto \frac{1}{x^3}$



(c) $B = \frac{\mu_0 IR^2}{2\left(x^2+R^2\right)^{3/2}}$

$for\ x >> R$

$$B = \frac{\mu_0 IR^2}{2x^3} = \frac{\mu_0}{4\pi}\frac{2I\left(\pi R^2\right)}{x^3}$$

$$= \frac{\mu_0}{4\pi}\frac{2IA}{x^3}$$

Where, A is the area of the coil.

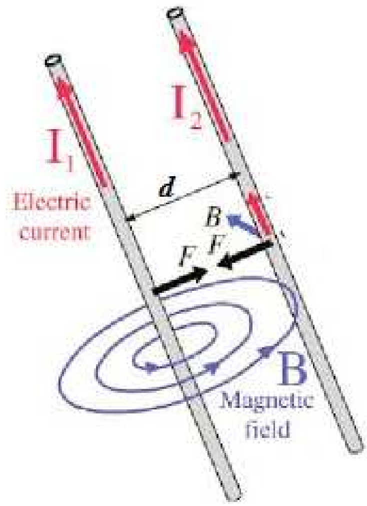
Since $I\vec{A} = \vec{m}$, the magnetic moment

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{2\vec{m}}{x^3}$$

The coil carrying current behaves as a magnetic dipole.

OR

Consider two parallel infinitely long conductors carrying currents I_1 and I_2 placed at a distance d in air or vacuum.



The conductor 2 is placed in the magnetic field B_1 due to the current in conductor 1.

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

The conductor 2 experiences a force F_{21} since it carries a current I_2.

$$F_{21} = B_1 I_2 l = \frac{\mu_0 I_1 I_2 l}{2\pi d}$$

where l is the length of the conductors. This force acts towards the conductor 1according to Fleming's left hand rule.

Similarly, the conductor 1 experiences a force F_{12} since it lies in the magnetic field

$B_2 = \frac{\mu_0 I_2}{2\pi d}$ due to the conductor 2.

$$F_{12} = B_2 I_1 l = \frac{\mu_0 I_1 I_2 l}{2\pi d}$$

According to Fleming's left hand rule this is directed towards the conductor 2.

$$\vec{F}_{21} = -\vec{F}_{12}$$

The conductors carrying current in the same directions attract each other.

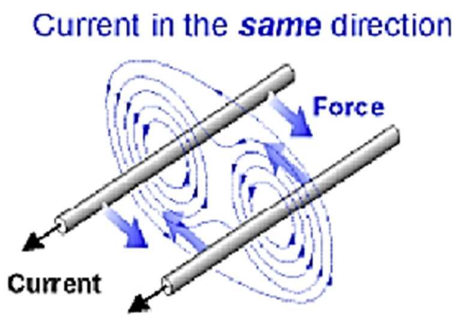
If the currents are in the opposite directions, the conductors repel each other.

(c) If $I_1 = I_2 = I$, $B_1 = B_2 = \frac{\mu_0 I}{2\pi d}$.

At a distance $\frac{d}{2}$, $B_1 = B_2 = \frac{\mu_0 I}{\pi d}$

(i) When the currents are in the same direction, the magnetic field directions at $\frac{d}{2}$ are opposite in direction. They cancel each other. $B = B_1 - B_2 = 0$

(ii) When the currents are in the opposite direction, the magnetic field directions at $\frac{d}{2}$ are in the same direction. $B = B_1 + B_2 = \frac{2\mu_0 I}{\pi d}$



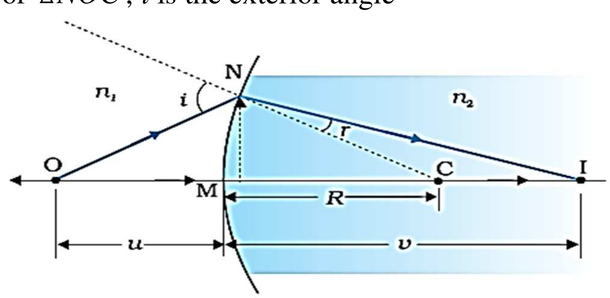
26. The incident rays from a point object *O* from a medium of refractive index n_1 is refracted at the convex surface of centre of curvature at C, with a radius of curvature *R*, separating it from a denser medium of refractive index n_2. The image of the object is formed at *I*. Assuming that the rays are very close to the principal axis,

$$\tan \angle NOM = \angle NOM = \frac{MN}{OM}$$

$$\tan \angle NCM = \angle NCM = \frac{MN}{MC}$$

$$\tan \angle NIM = \angle NIM = \frac{MN}{MI}$$

For $\triangle NOC$, i is the exterior angle



Refraction at a spherical surface separating two media.

$$i = \angle NOM + \angle NCM = \frac{MN}{OM} + \frac{MN}{MC}$$

Similarly, $r = \angle NCM - \angle NIM = \dfrac{MN}{MC} - \dfrac{MN}{MI}$

From snell's law, $n_1 \sin i = n_2 \sin r$ and for small angles, $n_1 i = n_2 r$.

$$\frac{n_1}{OM} + \frac{n_2}{MI} = \frac{n_2 - n_1}{MC}$$

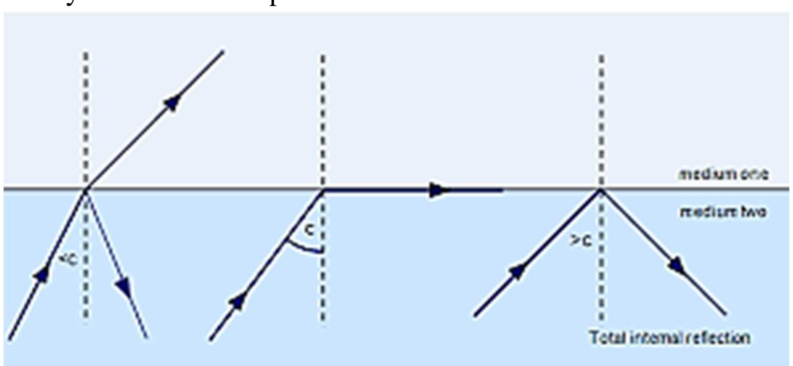
Applying sign conventions, for object distance *u*, image distance *v* and the radius of curvature *R*,

$OM = -u, MI = +v, MC = +R$

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

OR

When a ray of light enters a rarer medium from a denser medium, it bends away from the normal. The angle of refraction $r > i$, the angle of incidence. As the angle of incidence increases, the angle of refraction also increases. At a particular value of the angle of incidence, the refracted ray is found to graze the boundary of separation between the two media. The angle of incidence in the denser medium for which the angle of refraction is 90^0, is called the critical angle. If the ray strikes the boundary of separation at an angle greater than 90^0,refraction is not possible, hence the ray is totally reflected. This phenomenon is called total internal reflection.



The refractive index of the rarer medium with respect to the denser medium is

$$n_{21} = \frac{\sin i}{\sin r}$$

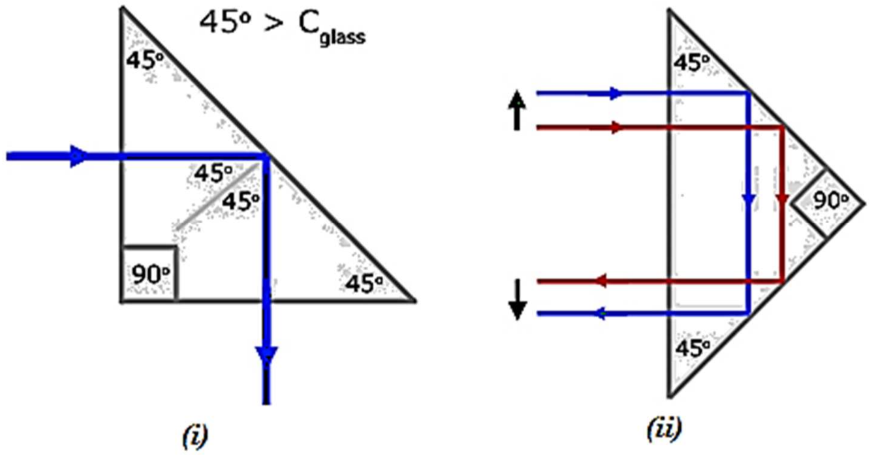
At critical angle, $i = i_c ; r = 90°$

$$n_{21} = \frac{\sin i_c}{\sin 90°} = \sin i_c$$

The refractive index of the rarer medium with respect to the denser medium is

$$n_{12} = \frac{1}{n_{21}} = \frac{1}{\sin i_c}$$

Total reflecting prisms are right angle prisms and are used to deviate the incident rays by 90^0 or by 180^0



If the critical angle of the material of the prism is less than 45°, the ray undergoes total internal reflection in the prism.