SAMPLE QUESTION PAPER

BLUE PRINT

Time Allowed : 3 hours **Maximum Marks :** 70

S. No.	Chapter	VSA/ AR/ Case Based (1 mark)	SA-I (2 marks)	SA-II (3 marks)	LA (5 marks)	Total
1.	Electrostatics	2(2)	1(2)	–	1(5)	**7(16)**
2.	Current Electricity	1(1)	–	2(6)	–	
3.	Magnetic Effects of Current and Magnetism	2(2)	2(4)	–	–	**8(17)**
4.	Electromagnetic Induction and Alternating Current	1(1)	1(2)	1(3)	1(5)	
5.	Electromagnetic Waves	2(2)	1(2)	–	–	**8(18)**
6.	Optics	2(5)	2(4)	–	1(5)	
7.	Dual Nature of Radiation and Matter	2(5)	–	1(3)	–	**5(12)**
8.	Atoms and Nuclei	1(1)	–	1(3)	–	
9.	Electronic Devices	3(3)	2(4)	–	–	**5(7)**
	Total	**16(22)**	**9(18)**	**5(15)**	**3(15)**	**33(70)**

Subject Code : **042**

PHYSICS

Time allowed : 3 hours ***Maximum marks : 70***

(i) All questions are compulsory. There are 33 questions in all.

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

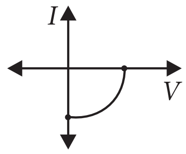
(iii) Section A contains ten very short answer questions and four assertion reasoning MCQs of 1 mark each. Section B has two case based questions of 4 marks each, Section C contains nine short answer questions of 2 marks each, Section D contains five short answer questions of 3 marks each and Section E contains three long answer questions of 5 marks each.

(iv) There is no overall choice. However internal choice is provided. You have to attempt only one of the choices in such questions.

SECTION - A

All questions are compulsory. In case of internal choices, attempt any one of them.

1. Name the junction diode whose *I*-*V* characteristics are drawn below :



2 . Write the following radiations in ascending order in respect of their frequencies :

X-rays, Microwaves, UV rays and Radio waves.

OR

Why does microwave oven heats up a food item containing water molecules most efficiently?

3. Is any work done by the magnetic field on a moving charge? Why?

4. A coil of inductance *L* is carrying a steady current *i*. What is the nature of its stored energy?

OR

A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason.

5. Draw a graph showing the variation of magnetic field with distance *r* from straight infinite current *I* carrying wire.

6. How does an intrinsic semiconductor behave at 0 K temperature?

OR

Which one among conductors, insulators and semiconductors, the forbidden gap is largest, based on the band theory

7. Why photoelectric emission is not possible at all frequencies?

8 . According to Rutherford's experiment what is the approximate size of the nucleus?

9. Show the variation of resistivity of Si with temperature in a graph.

10. Is the ratio of number of holes and number of conduction electrons in a *p*-type semiconductor more than, less than or equal to 1?

OR

Name the type of impurity required to be added to produce a *p*-type semiconductor.

For question numbers 11, 12, 13 and 14, two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

(a) Both A and R are true and R is the correct explanation of A
(b) Both A and R are true but R is NOT the correct explanation of A
(c) A is true but R is false
(d) A is false and R is also false

11. **Assertion (A) :** Lines of force are perpendicular to conductor surface.
Reason (R) : Generally electric field is perpendicular to equipotential surface.

12. **Assertion (A) :** The frequencies of incident, reflected and refracted beam of monochromatic light incident from one medium to another are same.
Reason (R) : The incident, reflected and refracted rays are coplanar.

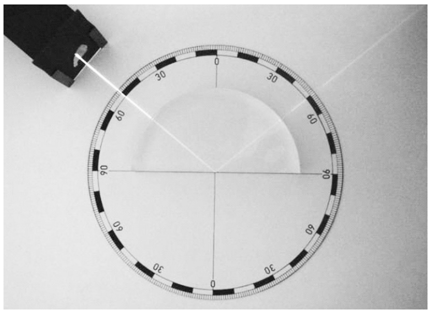
13. **Assertion (A) :** Electromagnetic radiations exert pressure.
Reason (R) : Electromagnetic waves carry both momentum and energy.

14. **Assertion (A) :** Gaussian surface is considered carefully.
Reason (R) : The point where electric field to be calculated should be with in the surface.

SECTION - B

Questions 15 and 16 are Case Study based questions and are compulsory. Attempt any 4 sub parts from each question. Each question carries 1 mark.

15. Total internal reflection, or TIR is the reflection of the total amount of incident light at the boundary between two media. Total internal reflection, in physics, complete reflection of a ray of light within a medium such as water or glass from the surrounding surfaces back into the medium. The phenomenon occurs if the angle of incidence is greater than a certain limiting angle, called the critical angle.



(i) Which of the following is the correct relation between critical angle and refractive index of the medium?

(a) $\mu = \frac{1}{\tan C}$ (b) $\mu = \frac{1}{\cos C}$ (c) $\mu = \frac{1}{\sin C}$ (d) $\mu = \sin C$

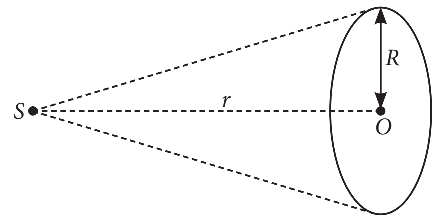
(ii) Which among the following is the necessary condition for TIR?
(a) light must travel from a denser medium to a rarer medium
(b) the angle of incidence inside the denser medium must be greater than the critical angle, *i.e.*, $i > C$.
(c) Both (a) and (b)
(d) none of these.

(iii) Which one of the following is an example of the principle of total internal reflection?
(a) Optical fibres
(b) Brilliance of a diamond
(c) Mirage
(d) All of these

(iv) If the speed of light in two mediums are $\sqrt{3}\times10^8$ m/s and 2×10^8 m/s, then the critical angle above which total internal reflection takes place between two surfaces.
(a) 60°
(b) 30°
(c) 45°
(d) 33.3°

(v) What is the critical angle for light travelling from glass to water? ($\mu_{glass} = 1.5$ and $\mu_{water} = 1.33$)
(a) 41.4°
(b) 41.8°
(c) 60.5°
(d) 62.5°

16. A point source S of power 6.4×10^{-3} W emits monoenergetic photons each of energy 6.0 eV. The source is located at a distance of 0.8 m from the centre of a stationary metallic sphere of work function 3.0 eV and of radius 1.6×10^{-3} m as shown in figure. The sphere is isolated and initially neutral and photoelectrons are instantly taken away from sphere after emission. The efficiency of photoelectric emission is one for every 10^5 incident photons.



(i) The power received by the sphere through radiations is
(a) 6.4×10^{-9} J s^{-1}
(b) 3.2×10^{-9} J s^{-1}
(c) 6.4×10^{-8} J s^{-1}
(d) 3.2×10^{-8} J s^{-1}

(ii) Number of photons striking the metal sphere per second is
(a) 26.7×10^9
(b) 3.3×10^9
(c) 26.7×10^{10}
(d) 3.3×10^{10}

(iii) The number of photoelectrons emitted per second is about
(a) 3.3×10^4
(b) 26.7×10^4
(c) 26.7×10^{15}
(d) 3.3×10^{15}

(iv) The photoelectric emission stops when the sphere acquires a potential of about
(a) 2 V
(b) 3 V
(c) 4 V
(d) 6 V

(v) The linear momentum of the emitted photons is
(a) 10^{-6} eV s/m
(b) 10^{-4} eV s/m
(c) 10^{-8} eV s/m
(d) 10^{-2} eV s/m

SECTION - C

All questions are compulsory. In case of internal choices, attempt anyone.

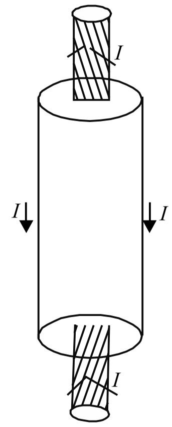
17. About 10% of the power of a 100W light bulb is converted to visible radiation. What is the average intensity of visible radiation, at a distance of 1 m from the bulb?

Assume that the radiation is emitted isotropically and neglect reflection.

OR

How do you convince yourself that electromagnetic waves carry energy and momentum?

18. A current I flows upwards along the inner conductor of a co-axial cable and returns down along external shell of the cable. What is the magnetic field at a point inside the cable?



19. Write two characteristic features to distinguish between n-type and p-type semiconductors.

20. What is the shape of the wavefront on earth for sunlight?

21. State Gauss's law for magnetism. Explain its significance.

OR

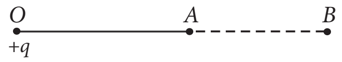
(i) Name the three elements of the Earth's magnetic field.

(ii) Where on the surface of the Earth is the vertical component of the Earth's magnetic field zero?

22. What is the area of the plates of 2 F parallel plate capacitor having separation between the plates is 0.5 cm?

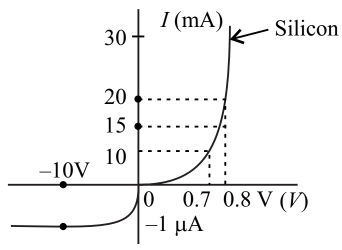
OR

A point charge 'q' is placed at O as shown in figure. Is $V_A - V_B$ positive, negative or zero, if 'q' is a (i) positive ($q > 0$) (ii) negative ($q < 0$) charge?



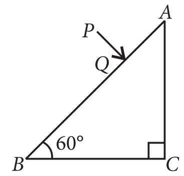
23. A wire in the form of a tightly wound solenoid is connected to a DC source and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease ? Explain.

24. The V-I characteristic of a silicon diode is shown in figure. Find the resistance of the diode at $I_D = 15$ mA.



25. A ray *PQ* incident normally on the refracting face *BA* is refracted in the prism *BAC* made of material of refractive index 1.5. Complete the path of ray through the prism.

From which face will the ray emerge? Justify your answer.



SECTION - D

All questions are compulsory. In case of internal choices, attempt any one.

26. Why are de Broglie waves associated with a moving football not visible? The wavelength λ, of a photon and the de Broglie wavelength of an electron have the same value. Show that the energy of the photon is $\frac{2\lambda mc}{h}$ times the kinetic energy of the electron, where *m*, *c* and *h* have their usual meanings.

OR

A source of light of frequency $\upsilon > \upsilon_0$ is placed at 2 m from the cathode of a photocell. The stopping potential is found to be V_0. If the distance of the light source is halved, state with reason changes occur in

(a) stopping potential

(b) photoelectric current, and

(c) maximum velocity of photoelectrons emitted.

27. How does the mutual inductance of a pair of coils change when

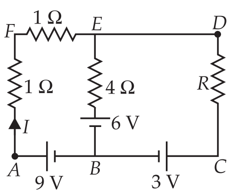
(a) the distance between the coil is increased?

(b) the number of turns in each coil is decreased?

(c) a thin iron sheet is placed between the two coils, other factors remaining the same?

Justify your answer in each case.

28. Using Kirchhoff's rules determine the value of unknown resistance *R* in the circuit so that no current flows through 4 Ω resistance. Also find the potential difference between *A* and *D*.



OR

An *n* number of identical cells, each of emf ε and internal resistance *r* connected in series are charged by a d.c. source of emf ε′, using a resistor *R*. Draw the circuit arrangement. Deduce the expression for the potential difference across the combination of the cells.

29. Using Rutherford's model of the atom, derive the expression for the total energy of the electron in hydrogen atom. What is the significance of total negative energy possessed by the electron?

30. A conductor of length *l* is connected to a dc source of potential *V*. If the length of the conductor is tripled by stretching it, keeping *V* constant, explain how do the following factors vary in the conductor.

(a) Drift speed of electrons

(b) Resistance

(c) Resistivity.

SECTION - E

All questions are compulsory. In case of internal choices, attempt any one.

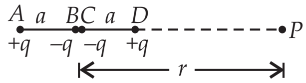
31. Consider a sphere of radius R with charge density distributed as

$$\rho(r) = kr \quad \text{for} \quad r \le R$$
$$= 0 \quad \text{for} \quad r > R.$$

Suppose the total charge on the sphere is $2e$ where e is the electron charge. Where can two protons be embedded such that the force on each of them is zero ? Assume that the introduction of the proton does not alter the negative charge distribution.

OR

Figure shows a charge array known as an electric quadrupole. For a point on the axis of quadrupole, obtain the dependence of potential on r for $r/a >> 1$, and contrast your results with that due to an electric dipole, and an electric monopole (*i.e.*, a single charge).



32. **(a)** Derive an expression for the impedance of a series LCR circuit connected to an AC supply of variable frequency.

(b) Plot a graph showing variation of current with the frequency of the applied voltage.

OR

(a) Derive an expression for the average power consumed in a series LCR circuit connected to a.c. source in which the phase difference between the voltage and the current in the circuit is ϕ.

(b) Define the quality factor in an a.c. circuit. Why should the quality factor have high value in receiving circuits? Name the factors on which it depends.

33. **(a)** Use Huygen's geometrical construction to show how a plane wave-front at $t = 0$ propagates and produces a wave-front at a later time.

(b) Verify, using Huygen's principle, Snell's law of refraction of a plane wave propagating from a denser to a rarer medium.

(c) When monochromatic light is incident on a surface separating two media, the reflected and refracted light both have the same frequency. Explain why.

OR

(a) Consider two coherent sources S_1 and S_2 producing monochromatic waves to produce interference pattern. Let the displacement of the wave produced by S_1 be given by $y_1 = a \cos\omega t$ and the displacement by S_2 be $y_2 = a \cos(\omega t + \phi)$.

Find out the expression for the amplitude of the resultant displacement at a point and show that the intensity at that point will be

$I = 4a^2 \cos^2\phi/2$.

Hence establish the conditions for constructive and destructive interference.

(b) What is the effect on the interference fringes in Young's double slit experiment when (i) the width of the source slit is increased ; (ii) the monochromatic source is replaced by a source of white light?

SOLUTIONS

1. The junction diode is solar cell.

2. The ascending order of the frequencies of the radiations are :
Radio waves < Microwaves < UV rays < X-rays.

OR

Resonant frequency of water molecules matches the frequency of microwaves generated by the microwave oven.

3. No work done, as magnetic force is perpendicular to displacement.

4. Energy stored $=\frac{1}{2}Li^2$

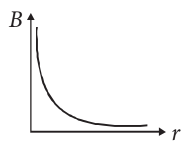
where Li is magnetic flux.

OR

As the electric current is switched on, the increasing magnetic flux sets up eddy current in the disc and convert it into a small magnet. This disc has same polarity as that on the top of the electromagnet and hence it is thrown up due to repulsion.

5. $B=\frac{\mu_0}{4\pi}\frac{2I}{r}$

$\therefore\ B \propto \frac{1}{r}$



6. An intrinsic semiconductor at 0 K temperature behaves like an insulator.

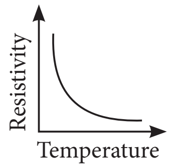
OR

According to band theory, the forbidden gap in conductors is $E_g \approx 0$, in insulators $E_g > 3$ eV and in semiconductors $E_g < 3$ eV. Thus, the forbidden gap is largest in insulators.

7. Photoelectric emission is not possible at all frequencies because below the threshold frequency for photosensitive surface of different atoms, emission is not possible.

8. Size of nucleus = 10^{-15} m to 10^{-14} m

9. The variation of resistivity of Silicon (Si) with temperature is shown.



10. The ratio of number of holes and number of conduction electrons in a p-type semiconductor is more than 1.

OR

A trivalent impurities such as Boron (B), Gallium (Ga), Indium (In) etc, are added to an instrinsic or pure semiconductor (Silicon or germanium) to produce p-type semiconductor.

11. (a)

12. (b) : Frequency of light depends upon the energy levels of the source which produces light. It does not vary with medium.

13. (b) : Electromagnetic wave transport energy, momentum and information. Electromagnetic waves exert radiation pressure on surface.

14. (a)

15. (i) (c) : From Snell's law, $\frac{\sin i}{\sin r} = {}^1\mu_2$

For total internal reflection, $r = 90°$, $i = C$ (critical angle)

$\therefore\ \sin C = \frac{\mu_{air}}{\mu_1}$ or $\mu_1 = \frac{1}{\sin C}$

(ii) (c) : For TIR (Total internal reflection), the light must travel from denser medium to rarer medium. Also, the angle of incidence, i should be greater than the critical angle C.

(iii) (d)

(iv) (a) : Given that speed of light in medium 2 is $\sqrt{3}\times 10^8$ m/s and speed of light in medium is 2×10^8 m/s.

$\therefore\ \frac{\sin C}{\sin 90°} = \frac{\mu_2}{\mu_1} = \frac{\sqrt{3}}{2} \qquad \left(\because \mu = \frac{C}{v}\right)$

$\Rightarrow C = \sin^{-1}\left(\frac{\sqrt{3}}{2}\right) = 60°$

(v) (d) : $\sin C = \frac{\mu_{water}}{\mu_{glass}} = \frac{1.33}{1.5}$

or $C = \sin^{-1}\left(\frac{1.33}{1.5}\right) = 62.5°$

16. (i) (a) : Here $P = 6.4\times 10^{-3}$,
Energy of the photon, $E = 6.0$ eV $= 6.0\times 1.6\times 10^{-19}$ J
Let R be the radius of the metallic sphere and r be its distance from the source. So, the power received at the sphere is

$P' = \frac{P\times \pi R^2}{4\pi r^2} = \frac{PR^2}{4r^2} = \frac{(6.4\times 10^{-3})\times(1.6\times 10^{-3})^2}{1\times(0.8)^2}$

$= 25.6\times 10^{-9}$ J s^{-1}

(ii) (a) : Number of photons striking the metal sphere per second is

$$n' = \frac{P'}{E} = \frac{25.6\times10^{-9}}{6.0\times1.6\times10^{-19}} = 26.7\times10^{9}\,s^{-1}$$

(iii) (b) : Number of photoelectrons emitted from metal sphere, $\frac{n'}{10^5} = \frac{26.7\times10^9}{10^5} = 26.7\times10^4$

(iv) (b) : Kinetic energy of the fastest photoelectron is $K_{max} = 6.0 - 3.0 = 3.0$ eV

$\therefore$ Stopping potential, $V_s = \frac{K_{max}}{e} = \frac{3.0\text{ eV}}{e} = 3.0$ V

(v) (c) : Energy of photon, $E = 3.0$ eV

Linear momentum of the photon, $p = \frac{E}{c}$

where c is the speed of light.

$$\therefore\ p = \frac{3.0\text{ eV}}{3\times10^8\text{ m s}^{-1}} = 10^{-8}\text{ eV s/m}$$

17. $I = \frac{\text{Power}}{\text{Area}} = \frac{10\%\text{ of }100\text{ W}}{4\pi r^2}$

$$= \frac{10}{4\times3.14\times1^2} = 0.8\text{W/m}^2$$

OR

Electromagnetic waves or photons transport energy and momentum. When an electromagnetic wave interacts with a small particle, it can exchange energy and momentum with the particle. The force exerted on the particle is equal to the momentum transferred per unit time. Optical tweezers use this force to provide a non-invasive technique for manipulating microscopic-sized particles with light.

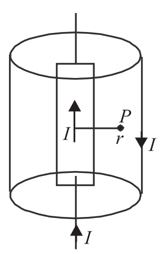
18. Due to inner wire current

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I}{r}\otimes$$

Due to current at outer surface,

$B_2 = 0$

Hence net magnetic field is only due to current in the inner wire.



19.

	n-type Semiconductor	p-type Semiconductor
(i)	It is formed by doping pentavalent impurities.	It is formed by doping trivalent impurities.
(ii)	The electrons are majority carriers and holes are minority carriers. ($n_e >> n_h$)	The holes are majority carriers and electrons are minority carriers. ($n_h >> n_e$)

20. There would be spherical wavefront on earth for sunlight which is treated as point source, but radius is very large as compared to radius of earth, so it is almost a plane wavefront.

21. Gauss's law for magnetism : Gauss's law for magnetism states that the net magnetic flux through any closed surface is zero.

$$\phi = \sum_{\substack{\text{All area}\\ \text{elements}}} \vec{B}\cdot\Delta\vec{S} = 0$$

Physical significance : This law establishes that isolated magnetic poles do not exist.

OR

(i) Elements of earth's magnetic field :

(a) Angle of declination (θ)

(b) Angle of dip (δ)

(c) Horizontal component of earth's magnetic field (B_H)

(ii) At equator.

22. Here : $C = 2$ F, $d = 0.5$ cm $= 0.5\times10^{-2}$ m

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

$$\therefore\ C = \frac{\varepsilon_0 A}{d} \Rightarrow A = \frac{Cd}{\varepsilon_0} = \frac{2\times0.5\times10^{-2}}{8.854\times10^{-12}}$$

$A = 1.13\times10^9\text{ m}^2$

OR

The potential at a point is given by,

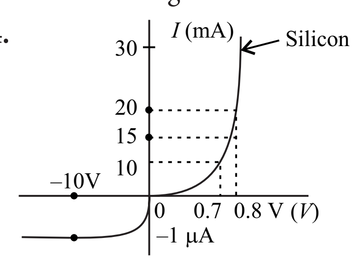
$V = \frac{kq}{r}$ *i.e.,* $V \propto \frac{1}{r}$

So, (i) $V_A - V_B$ is positive.

(ii) $V_A - V_B$ is negative.

23. When the coil is stretched, current will increase because magnetic flux decreases as it leaks through the gaps created in coil, decrease in flux is resisted by emf induced according to Lenz's law.

24.

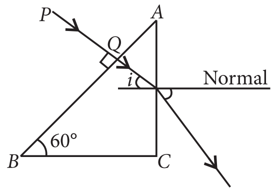


In diagram, At $I = 20$ mA, $V = 0.8$ V and

At $I = 10$ mA, $V = 0.7$ V

$$r_{fb} = \frac{\Delta V}{\Delta I} = \frac{0.1\text{ V}}{10\text{ mA}} = 10\ \Omega$$

25. Ray will emerge from the face AC.



As $\sin i_c = 1/\mu$

Here $\sin i_c = 1/1.5 = 0.67$, $i_c = 42°$

$\angle i$ on face AC is 30° which is less than $\angle i_c$. Hence the ray will get refracted at the face AC.

26. de Broglie wavelength, $\lambda = \dfrac{h}{mv}$

Due to large mass of a football, the de Broglie wavelength associated with the moving football is very small, so its wave character is not visible.

de Broglie wavelength of an electron is

$$\lambda = \frac{h}{p} \text{ or } p = \frac{h}{\lambda}$$

Kinetic energy of an electron, $K = \dfrac{p^2}{2m}$

$$\therefore \; K = \frac{h^2}{2m\lambda^2} \quad \text{...(i)}$$

Energy of the photon, $E = h\upsilon = \dfrac{hc}{\lambda}$ ($\because \lambda$ is same) ...(ii)

Divide (ii) by (i), we get

$$\frac{E}{K} = \frac{hc}{\lambda} \times \frac{2m\lambda^2}{h^2} = \frac{2\lambda mc}{h}$$

or Energy of the photon

$$= \left(\frac{2\lambda mc}{h}\right) \times \text{Kinetic energy of the electron}$$

OR

Given that the source of frequency $\upsilon > \upsilon_0$.

Distance of source from cathode of photocell = 2 m.

Stopping potential = V_0

If distance of light source from cathode of photocell is halved, intensity of light increases.

(a) Stopping potential will remain the same as it is independent of the intensity of the source of light.

(b) Photoelectric current is directly proportional to the intensity of incident light. So it will increase.

(c) Maximum velocity of photoelectrons emitted, remains unchanged, because it depends upon the frequency of incident light, which is not changing.

27. (a) The mutual inductance of two coils, decreases when the distance between them is increased. This is because the flux passing from one coil to another decreases.

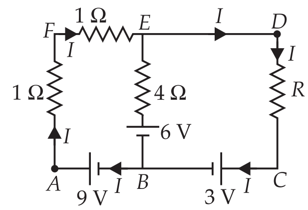
(b) Mutual inductance, $M = \dfrac{\mu_0 N_1 N_2 A}{l}$

i.e., $M \propto N_1 N_2$

Clearly, when the number of turns N_1 and N_2 in the two coils is decreased, the mutual inductance decreases.

(c) When an iron sheet is placed between the two coils, the mutual inductance increases, because $M \propto$ permeability (μ).

28. As no current flows through 4 Ω, the current in various branches as shown in the figure.



Applying Kirchhoff's loop rule to the closed loop $AFEBA$, we get

$$-I - I - 4 \times 0 - 6 + 9 = 0$$

or $9 - 6 - 2I = 0$ or $2I = 3$ or $I = \dfrac{3}{2}$ A ...(i)

Again, applying Kirchhoff's loop rule to the closed loop $BEDCB$, we get

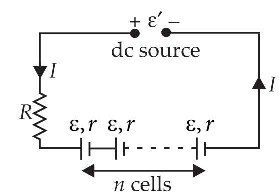
$$6 + 4 \times 0 - IR - 3 = 0 \text{ or } IR = 3$$

$$R = \frac{3}{I} = 3 \times \frac{2}{3} = 2\,\Omega \quad \text{(Using (i))}$$

Potential difference between A and D = Potential difference between A and E

$$\therefore \; V_{AD} = 2I = 2 \times \frac{3}{2} = 3\text{ V}$$

OR



Net emf of cells = $n\varepsilon$

Net internal resistance = nr

So, charging current in the circuit, is $I = \dfrac{\varepsilon' - n\varepsilon}{R + nr}$

Potential difference across the combination of cells is

$$V = n\varepsilon + Inr$$

$$\text{or } V = n\varepsilon + \left(\frac{\varepsilon' - n\varepsilon}{R + nr}\right) nr$$

$$\text{or } V = \frac{n\varepsilon(R + nr) + (\varepsilon' - n\varepsilon)nr}{R + nr}$$

$$\text{or } V = \frac{n\varepsilon R + n^2\varepsilon r + n\varepsilon' r - n^2\varepsilon r}{R + nr}$$

$$\text{or } V = \frac{n(\varepsilon R + \varepsilon' r)}{R + nr}$$

29. An electron revolving in an orbit of H-atom, has both kinetic energy and electrostatic potential energy. Kinetic energy of the electron revolving in a circular orbit of radius r is $E_K = \frac{1}{2}mv^2$

Since the electrostatic force of attraction between the revolving electrons and nucleus provides the necessary centripetal force to them in their orbits,

$$\therefore \quad \frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r^2}$$

$$\therefore \quad E_K = \frac{1}{2}\times\frac{1}{4\pi\varepsilon_0}\frac{e^2}{r} \quad \text{or} \quad E_K = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r} \qquad \text{... (i)}$$

Electrostatic potential energy of electron of charge $-e$ revolving around the nucleus of charge $+e$ in an orbit of radius r is

$$E_P = \frac{1}{4\pi\varepsilon_0}\frac{+e\times-e}{r} \quad \text{or} \quad E_P = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{r} \qquad \text{... (ii)}$$

So, total energy of electron in orbit of radius r is

$$E = E_K + E_P \quad \text{or} \quad E = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{2r} - \frac{1}{4\pi\varepsilon_0}\frac{e^2}{r}$$

$$\text{or} \quad E = \frac{-1}{4\pi\varepsilon_0}\frac{e^2}{2r}$$

The negative sign of the energy of electron indicates that the electron and nucleus together form a bound system *i.e.*, electron is bound to the nucleus.

30. The drift speed is given by

$$v_d = \frac{eE\tau}{m} = \frac{eV}{ml}\tau \qquad \text{...(i)}$$

(a) $v_d \propto \frac{1}{l}$ (Using (i))

Thus, if length is tripled, the drift speed will become one-third.

(b) Since volume remains constant,

$$A'l' = Al \quad \text{or} \quad A' = \frac{Al}{l'} = \frac{A}{3} \qquad [\because l' = 3l]$$

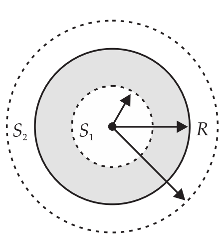
$$R = \frac{\rho l}{A}, \quad R' = \frac{\rho l'}{A'}$$

$$\Rightarrow \frac{R'}{R} = \left(\frac{l'}{A'}\right)\left(\frac{A}{l}\right) = \left(\frac{l'}{l}\right)\left(\frac{A}{A'}\right) = 3\times 3 = 9$$

(c) Resistivity remains unchanged.

31. The given charge density distribution of the sphere of radius R is

$$\rho(r) = kr \quad \text{for} \quad r \le R$$
$$= 0 \quad \text{for} \quad r > R$$



For point $r < R$, let us consider a spherical Gaussian surface S_1 of radius r.

Then on the surface,

$$\oint \vec{E}\cdot\vec{dS} = \frac{1}{\varepsilon_0}\int \rho\, dV$$

As $V = \frac{4}{3}\pi r^3$,

$dV = 4\pi r^2 dr$ and $\rho(r) = kr$

$$\therefore \quad \oint \vec{E}\cdot\vec{dS} = \frac{1}{\varepsilon_0}4\pi k\int_0^r r\, r^2\, dr$$

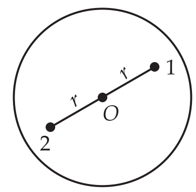
$$(E)4\pi r^2 = \frac{4\pi k}{\varepsilon_0}\frac{r^4}{4}$$

$$\vec{E} = \frac{1}{4\varepsilon_0}kr^2\hat{r} \qquad \text{...(i)}$$

From symmetry, we find that the two protons must be on the opposite sides of the centre, along a diameter of the sphere as shown in figure.

Proceeding as above, charge on the sphere,

$$q = \int_0^R \rho\, dV = \int_0^R (kr)\ 4\pi r^2\, dr$$



$$q = 4\pi k\frac{R^4}{4} = 2e$$

$$\therefore \quad k = \frac{2e}{\pi R^4} \qquad \text{... (ii)}$$

If protons 1 and 2 are embedded at distance r from the centre of the sphere as shown in figure, then attractive force on proton 1 due to charge distribution is

$$F_1 = -eE = -e\frac{kr^2}{4\varepsilon_0} \qquad \text{(Using (i))}$$

Repulsive force on proton 1 due to proton 2 is

$$F_2 = \frac{e^2}{4\pi\varepsilon_0(2r)^2} = \frac{e^2}{16\pi\varepsilon_0 r^2}$$

Net force on proton 1

$F = F_1 + F_2$

$$F = -e\frac{kr^2}{4\varepsilon_0} + \frac{e^2}{16\pi\varepsilon_0 r^2}$$

$$F = \left[-\frac{er^2}{4\varepsilon_0}\frac{2e}{\pi R^4} + \frac{e^2}{16\pi\varepsilon_0 r^2}\right] = 0 \qquad \text{(Using (ii))}$$

This force on proton 1 will be zero, when

$$\frac{er^2.2e}{4\varepsilon_0\pi R^4} = \frac{e^2}{16\pi\varepsilon_0 r^2}$$

$$\text{or} \quad r^4 = \frac{R^4}{8} \quad \text{or} \quad r = \frac{R}{(8)^{1/4}}$$

This is the distance of each of the two protons from the centre of the sphere.

OR

$V_P = V_{PA} + V_{PB} + V_{PC} + V_{PD}$

or $V_P = \frac{1}{4\pi\varepsilon_0}\left[\frac{+q}{r+a} - \frac{q}{r} - \frac{q}{r} + \frac{q}{r-a}\right]$

or $V_P = \frac{q}{4\pi\varepsilon_0}\left[\frac{r(r-a)-2(r^2-a^2)+r(r+a)}{r(r^2-a^2)}\right]$

or $V_P = \frac{q}{4\pi\varepsilon_0}\left[\frac{r^2-ra-2r^2+2a^2+r^2+ra}{r(r^2-a^2)}\right]$

or $V_P = \frac{1}{4\pi\varepsilon_0}\frac{q\cdot 2a^2}{r(r^2-a^2)} = \frac{1}{4\pi\varepsilon_0}\frac{p\cdot a}{r(r^2-a^2)}$

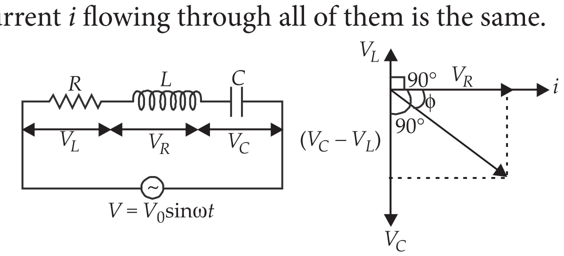
For $r >> a$

$V_P \approx \frac{1}{4\pi\varepsilon_0}\frac{pa}{r^3}$ or $V_P \propto \frac{1}{r^3}$.

However, electric potential at any point on axis of electric dipole is $V = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}$ or $V \propto \frac{1}{r^2}$ and due to point charge is

$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ or $V \propto \frac{1}{r}$

32. (a) : Expression for impedance in *LCR* series circuit : Suppose resistance *R*, inductance *L* and capacitance *C* are connected in series and an alternating source of voltage $V = V_0 \sin\omega t$ is applied across it as shown in figure. On account of being in series, the current *i* flowing through all of them is the same.



Consider the voltage across resistance *R* is V_R, voltage across inductance *L* is V_L and voltage across capacitance *C* is V_C. The voltage V_R and current *i* are in the same phase, the voltage V_L will lead the current by angle 90° while the voltage V_C will lag behind the current by angle 90° (figure). Clearly V_C and V_L are in opposite directions, therefore their resultant potential difference = $V_C - V_L$ (if $V_C > V_L$).

Thus V_R and $(V_C - V_L)$ are mutually perpendicular and the phase difference between them is 90°. As applied voltage across the circuit is *V*, the resultant of V_R and $(V_C - V_L)$ will also be *V*. From figure,

$V^2 = V_R^2 + (V_C - V_L)^2$

$V = \sqrt{V_R^2 + (V_C - V_L)^2}$

But $V_R = Ri$, $V_C = X_C\, i$ and $V_L = X_L\, i$

where $X_C = \frac{1}{\omega C} =$ capacitive reactance and

$X_L = \omega L =$ inductive reactance

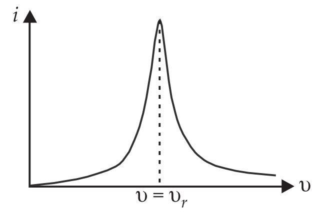
$\therefore\ V = \sqrt{(Ri)^2 + (X_C i - X_L i)^2}$

$\therefore$ Impedance of circuit,

$Z = \frac{V}{i} = \sqrt{R^2 + (X_C - X_L)^2}$

$Z = \sqrt{R^2 + (X_C - X_L)^2} = \sqrt{R^2 + \left(\frac{1}{\omega C} - \omega L\right)^2}$

(b)



OR

(a) If the applied voltage across series *LCR* circuit is $V = V_0 \sin \omega t$, then let current in the circuit be

$I = I_0 \sin(\omega t + \phi)$.

Then average power consumed in series *LCR* circuit is given by

$P = \int_0^T \frac{VIdt}{T}$

or $P = \frac{1}{T}\int_0^T V_0 \sin\omega t\, I_0 \sin(\omega t + \phi)\, dt$

or $P = \frac{V_0 I_0}{T}\int_0^T \sin\omega t\,[\sin\omega t\cos\phi + \cos\omega t\sin\phi]\, dt$

or $P = \frac{V_0 I_0}{T}\left[\cos\phi\int_0^T \sin^2\omega t dt + \sin\phi\int_0^T \sin\omega t\cos\omega t\, dt\right]$

Solving the integration, we get

or $P = \frac{V_0 I_0}{2}\cos\phi = \frac{V_0}{\sqrt{2}}\cdot\frac{I_0}{\sqrt{2}}\cos\phi$

or $P = V_{rms}\, I_{rms}\cos\phi$

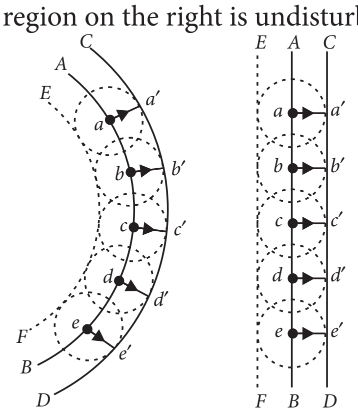
(b) The *Q*-factor or quality factor of a resonant a.c. series *LCR* circuit is defined as the ratio of voltage drop across inductor (or capacitor) to the applied voltage.

i.e., $Q\text{-factor} = \frac{V_L}{V} = \frac{IX_L}{IR} = \frac{\omega_r L}{R} = \frac{1}{\sqrt{LC}}\cdot\frac{L}{R}$

or $Q\text{-factor} = \frac{1}{R}\sqrt{\frac{L}{C}}$

So, *Q*-factor of a circuit depends on resistance *R*, capacitance *C* and inductance *L* of circuit. Quality factor measures the sharpeness of a resonant a.c. series *LCR* circuit. Thus if the ohmic resistance *R* of series *LCR* circuit is low, then its *Q*-factor is large due to which at resonance, large current flows in series *LCR* a.c. circuit.

33. (a) Consider a spherical or plane wavefront moving towards right. Let *AB* be its position at any instant of time. The region on its left has received the wave while region on the right is undisturbed.



(a) (b)

Huygens' geometrical construction for the propagation of (a) spherical, (b) plane wavefront.

According to Huygens' principle, each point on *AB* becomes a source of secondary disturbance, which takes with the same speed *c*. To find the new wavefront after time *t*, we draw spheres of radii *ct*, from each point on *AB*.

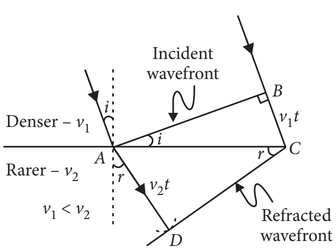
The forward envelope or the tangential surface *CD* of the secondary wavelets gives the new wavefront after time *t*.

The lines *aa*′, *bb*′, *cc*′, etc., are perpendicular to both *AB* and *CD*. Along these lines, the energy flows from *AB* to *CD*. So these lines represent the rays. Rays are always normal to wavefronts.

(b) A source of light sends the disturbance in all the directions and continuous locus of all the particles vibrating in same phase at any instant is called as wavefront.

Given figure shows the refraction of a plane wavefront at a rarer medium *i.e.*, $v_2 > v_1$

The incident and refracted waveforms are shown in figure.



Let the angles of incidence and refraction be *i* and *r* respectively.

From right ΔABC, we have,

$$\sin \angle BAC = \sin i = \frac{BC}{AC}$$

From right ΔADC, we have,

$$\sin \angle DCA = \sin r = \frac{AD}{AC}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{BC}{AD} = \frac{v_1 t}{v_2 t} \text{ or } \frac{\sin i}{\sin r} = \frac{v_1}{v_2} = {}^1\mu_2$$

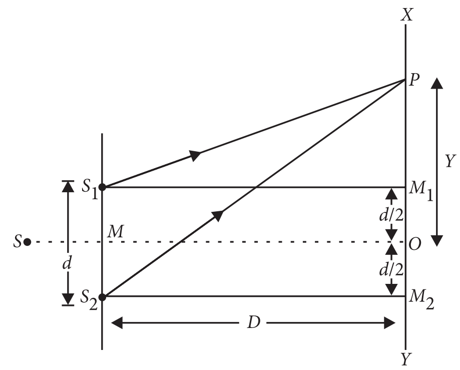
(a constant)

This verifies Snell's law of refraction. The constant ${}^1\mu_2$ is called the refractive index of the second medium with respect to first medium.

(c) Reflection and refraction arise through interaction of incident light with atomic constituents of matter which vibrate with the same frequency as that of the incident light. Hence frequency remains unchanged.

OR

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



where ϕ is phase difference between them. Resultant displacement at point *P* will be,

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

$= a [\cos \omega t + \cos (\omega t + \phi)]$

$$= a\left[2\cos\frac{(\omega t + \omega t + \phi)}{2}\cos\frac{(\omega t - \omega t - \phi)}{2}\right]$$

$$y = 2a\cos\left(\omega t + \frac{\phi}{2}\right)\cos\left(\frac{\phi}{2}\right) \quad \text{...(i)}$$

Let $y = 2a\cos\left(\frac{\phi}{2}\right) = A$, the equation (i) becomes

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

where *A* is amplitude of resultant wave,

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

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

Hence, resultant intensity,

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

(b) Since fringe width is give by $\beta = \frac{\lambda D}{d}$

(i) On increasing the width of slit *d*, the fringe width decreases.

(ii) On replacing monochromatic light with white light, the fringes of all colours will be overlapping in interference pattern.