Date: 20/02/2026

Question Paper Code

55/2/2

Series: R2SQP
SET-2

Corporate Office: Aakash Educational Services Limited,
3rd Floor, Incuspaze Campus-2, Plot No. 13, Sector-18, Udyog Vihar, Gurugram, Haryana - 122018

Time: 3 hrs.

Class-XII

Max. Marks: 70

PHYSICS (Theory)

(CBSE 2026)

GENERAL INSTRUCTIONS

Read the following instructions very carefully and strictly follow them:

(i) This question paper contains **33** questions. **All** questions are **compulsory**.

(ii) Question paper is divided into **FIVE** sections – Sections **A**, **B**, **C**, **D** and **E**.

(iii) **In Section A :** Question Nos. **1** to **16** are Multiple Choice (MCQ) type questions, carrying **1** mark each.

(iv) **In Section B :** Question Nos. **17** to **21** are Very Short Answer (VSA) type questions, carrying **2** marks each.

(v) **In Section C :** Question Nos. **22** to **28** are Short Answer (SA) type questions, carrying **3** marks each.

(vi) **In Section D :** Question Nos. **29** and **30** are Case Study-Based questions, carrying **4** marks each.

(vii) **In Section E :** Question Nos. **31** to **33** are Long Answer (LA) type questions, carrying **5** marks each.

(viii) There is no overall choice given in the question paper. However, an internal choice has been provided in few questions in all the Sections except **Section A**.

You have to attempt only one of the choices in such questions.

(ix) Use of calculator is **NOT** allowed.

SECTION-A

1. Three point charges $+q$, $-2q$ and $+q$ are placed along x-axis at points $x = -1$ m, $x = 0$ m and $x = 2$ m respectively. The potential energy of the system is

(A) $-\dfrac{q^2}{\pi\varepsilon_0}$

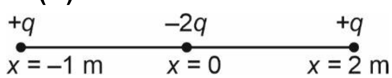
(B) $-\dfrac{2q^2}{3\pi\varepsilon_0}$

(C) $\dfrac{q^2}{4\pi\varepsilon_0}$

(D) $\dfrac{-5q^2}{4\pi\varepsilon_0}$

Answer (B)

Sol.



PE of system = $\dfrac{1}{4\pi\varepsilon_0}\dfrac{(-2q^2)}{1}+\dfrac{1}{4\pi\varepsilon_0}\dfrac{(-2q^2)}{2}+\dfrac{1}{4\pi\varepsilon_0}\dfrac{q^2}{3}$

$=\dfrac{1}{4\pi\varepsilon_0}q^2\left[-2-1+\dfrac{1}{3}\right]$

$=\dfrac{1}{4\pi\varepsilon_0}q^2\times\dfrac{-8}{3}=-\dfrac{2q^2}{3\pi\varepsilon_0}$

2. A photosensitive surface is illuminated by radiations of wavelength λ_1, λ_2 ($>\lambda_1$) and λ_3 one by one and photoemission is observed in each case. λ_1, λ_2 lies in UV range and λ_3 in visible range. If V_1, V_2 and V_3 are stopping potential in these cases respectively, then

(A) $V_1 = V_2 = V_3$

(B) $V_2 > V_1 > V_3$

(C) $V_1 > V_2 > V_3$

(D) $V_3 > V_1 > V_2$

Answer (C)

Sol. From the question

$\lambda_1 < \lambda_2 < \lambda_3$

Now using equation

$eV_0 = \dfrac{hC}{\lambda} - \phi_0$ ...(1)

From this equation it is clear for higher λ, V_0 will be lesser

$V_1 > V_2 > V_3$

3. In Bohr model of hydrogen atom, the value of potential energy of an electron in n^{th} orbit varies with 'n' as

(A) $\dfrac{1}{n^2}$

(B) $\dfrac{1}{n}$

(C) n

(D) n^2

Answer (A)

Sol. In Bohr model of hydrogen atom

TE = $\dfrac{-13.6}{n^2}eV$

As we know PE is double of TE

$\Rightarrow$ PE = $\dfrac{-27.2}{n^2}eV$

$\Rightarrow$ PE varies as $\dfrac{1}{n^2}$

4. Two metal spheres of radii r_1 and $r_2 (> r_1)$ having charges q_1 and q_2 respectively kept in air, are brought in contact. Which of the following statements is not correct?

(A) The total charge of the two spheres is conserved.

(B) Both spheres attain the same potential.

(C) The final potential of the system equals $\frac{1}{4\pi\varepsilon_0}\frac{(q_1+q_2)}{(r_1+r_2)}$

(D) The final potential of the system equals $\frac{1}{4\pi\varepsilon_0}\frac{(q_1+q_2)(r_1+r_2)}{r_1 r_2}$

Answer (D)

Sol. 1. Total charge of an isolated system (sphere (1) plus sphere (2) remain conserved.

2. After redistribution they will attain same potential, accordance with property of metallic body.

3. Final potential of system

$$V_c = \frac{\text{Total charge}}{\text{Total capacitance}} = \frac{q_1+q_2}{c_1+c_2}$$

$$= \frac{q_1+q_2}{4\pi\varepsilon_0 r_1 + 4\pi\varepsilon_0 r_2} = \frac{q_1+q_2}{4\pi\varepsilon_0 (r_1+r_2)}$$

5. In Bohr model of hydrogen atom, an electron makes a transition from n = 4 state to n = 1 state and a photon of frequency ν is emitted. The frequency of photon emitted when an electron makes a transition from n = 4 state to n = 2 state in the same model is

(A) $\frac{\nu}{3}$

(B) $\frac{\nu}{4}$

(C) $\frac{\nu}{5}$

(D) $\frac{\nu}{6}$

Answer (C)

Sol. Using Bohr model, we have

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \qquad [\because C = \nu\lambda]$$

$$\Rightarrow \quad \frac{\nu}{C} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$$\Rightarrow \quad \nu = RC\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

for transition

n_2 = 4 to n_1 = 1

$$\nu = RC\left[\frac{1}{1^2} - \frac{1}{4^2}\right] = \frac{15}{16}RC \qquad \ldots\text{(i)}$$

For transition

n_2 = 4 to n_1 = 2

$$\nu' = RC\left[\frac{1}{4} - \frac{1}{16}\right] = RC \times \frac{12}{64}$$

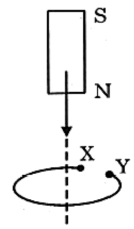
$$\nu' = \frac{3RC}{16} \qquad \ldots\text{(ii)}$$

From eq. (i) and (ii)

$$\frac{\nu'}{\nu} = \frac{\frac{3RC}{16}}{\frac{15RC}{16}} = \frac{1}{5}$$

$$\nu' = \frac{\nu}{5}$$

6. Figure shows a magnet dropped through a small loop with a small cut. Which of the following statements is correct?



(A) The speed of the falling magnet increases as it approaches the loop and starts decreasing as it crosses the loop.

(B) Acceleration of magnet increases as it approaches the loop and starts decreasing as it crosses the loop.

(C) Speed of magnet remains uniform as it moves through the loop.

(D) Acceleration of the magnet remains uniform as it moves through the loop.

Answer (D)

Sol. Using Faraday's law of EMI, there will be induced emf in loop but it is cut so effective resistance of path be infinite, hence using Ohm's law no current in loop, hence loop will not have any magnetic moment, *i.e.*, no force on bar magnet due to loop. Hence acceleration of magnet remain constant *i.e.*, of *g*.

7. The expression of magnetic fields associated with four electromagnetic waves are given below :

I. $B_1 = (4 \times 10^{-6}\ \text{T}) \sin [0.7 \times 10^3 x + 1.4 \times 10^{11}\ t]$

II. $B_2 = (2 \times 10^{-7}\ \text{T}) \sin [0.6 \times 10^3 x + 1.5 \times 10^{11}\ t]$

III. $B_3 = (3 \times 10^{-5}\ \text{T}) \sin [0.5 \times 10^3 x + 1.5 \times 10^{11}\ t]$

IV. $B_4 = (5 \times 10^{-4}\ \text{T}) \sin [0.2 \times 10^4 x + 4.8 \times 10^{11}\ t]$

Which wave is travelling in free space?

(A) I
(B) II
(C) III
(D) IV

Answer (C)

Sol. The wave, which is moving in free space must have speed 3×10^8 m/s. Wave (**III**) has speed

$$v = \frac{\omega}{K} = \frac{1.5 \times 10^{11}}{0.5 \times 10^3} = 3 \times 10^8 \text{ SI unit}$$

Other waves have speed less than 3×10^8 m/s

8. Which of the following substance has relative magnetic permeability $\mu_r >> 1$?

(A) Aluminium
(B) Copper
(C) Lead
(D) Nickel

Answer (D)

Sol. Nickel is ferromagnetic.

For ferromagnetic materials, $\mu_r >> 1$.

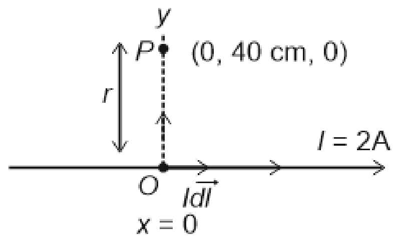
9. A straight conductor lies along x-axis and carries a current of 2 A along $+x$ direction. The magnetic field at a point (0, 40 cm, 0) due to 1 cm length of conductor centered at the origin points along.

(A) y-axis (B) $-y$-axis

(C) z-axis (D) $-z$-axis

Answer (C)

Sol.



Using cross product of vectors, direction of $d\vec{B}$ at given point P(0, 40 cm, 0) will be along $(\hat{I}dl \times \hat{r})$ i.e., along $(\hat{i} \times \hat{j})$ i.e. along $+\hat{k}$. That is along $+z$ axis

10. A galvanometer of resistance 27 Ω is converted into an ammeter of range (0–10 mA) using a resistance of 3 Ω. The galvanometer will show full scale deflection for a current of about

(A) 10 mA

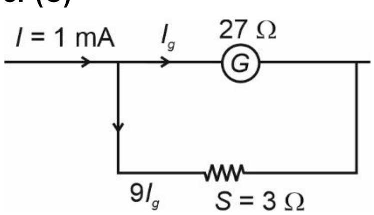
(B) 100 mA

(C) 1 mA

(D) 3 mA

Answer (C)

Sol.



Let Galvanometer gives full deflection at current I_g.

From circuit diagram, $I_g + 9I_g = 10$ mA $\Rightarrow I_g = 1$ mA

11. The magnetic flux ϕ (in Wb) linked with a coil is related to time t (in s) as

$\phi = 5\,At^2 + Bt - 2C$

The SI units of A and B are respectively

(A) Wbs^2, Wbs

(B) Wbs^{-1}, Wb

(C) Wbs^{-2}, Wbs^{-1}

(D) Wbs^{-1}, Wbs^{-2}

Answer (C)

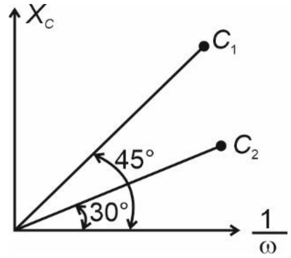
Sol. Using principle of dimensional homogeneity,

$[\phi] = [5At^2] \Rightarrow [A] = \dfrac{[\Phi]}{[t^2]} \Rightarrow$ SI unit of A is $\dfrac{Wb}{s^2}$

and

$[\phi] = [Bt] \Rightarrow [B] = \dfrac{[\Phi]}{[t]} \Rightarrow$ SI unit of B is $\dfrac{Wb}{s}$

12. The figure shows the variation of capacitive reactance (X_C) of two ideal capacitors of capacitances C_1 and C_2 with the reciprocal of angular frequency ($1/\omega$) of ac source. The value of C_1/C_2 is



(A) $\frac{1}{2}$ (B) 2

(C) $\sqrt{3}$ (D) $\frac{1}{\sqrt{3}}$

Answer (D)

Sol. $X_C = \frac{1}{\omega C}$

$\Rightarrow$ Graph X_C vs $\frac{1}{\omega}$ is a straight line passing through origin and its slope gives $\frac{1}{C}$

$\Rightarrow \tan 45° = \frac{1}{C_1}$ and $\tan 30° = \frac{1}{C_2}$

$\Rightarrow \frac{\tan 45°}{\tan 30} = \frac{C_2}{C_1} \Rightarrow \frac{C_1}{C_2} = \frac{\tan 30°}{\tan 45} = \frac{1}{\sqrt{3}}$

Note: For question numbers 13 to 16, two statements are given – one labelled as **Assertion (A)** and the other labelled as **Reason (R)**. Select the correct answer from the codes (A), (B), (C) and (D) as given below:

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

13. **Assertion (A):** Light added to light can produce darkness.

Reason (R): When two coherent light waves interfere, there is darkness at position of destructive interference.

Answer (A)

Sol. When two light waves coming from coherent surface superimpose, they can produce complete darkness if they have same amplitudes. According to superposition principle, when they meet in opposite phase, there is darkness, this is called destructive interference.

14. **Assertion (A):** Two electric heaters of power P_1 and P_2 (> P_1) are joined in series across a *dc* source of voltage V. The power consumed by the combination will be less than that consumed by P_1 when connected across the same source.

Reason (R): The power consumed by a electric device when connected to a *dc* source of voltage V is proportional to its resistance.

Answer (C)

Sol. Here $P_2 > P_1$

Using combination of heaters in series,

We have $\frac{1}{P_s} = \frac{1}{P_1} + \frac{1}{P_2}$

$\Rightarrow$ power consumed by combination, $P_s = \frac{P_1P_2}{P_2 + P_1}$

and thus P_s is less than both P_1

as well as P_2

So, assertion is true

Power of electric device, $P = \frac{V^2}{R} \Rightarrow P \propto \frac{1}{R}$

So, reason is false.

15. **Assertion (A):** On increasing the intensity of incident light of frequency $\nu(> \nu_0)$ on a photosensitive surface, the photocurrent increases.

Reason (R): The stopping potential for a photosensitive surface increase with increase of frequency v ($>v_0$) of incident light.

Answer (B)

Sol. For $\nu(> \nu_0)$ with the increase of intensity of light, there is increases in the no. of incident photons. For each photon, there will be only one electron emission. Hence with the increase of intensity, photo-current increases. So assertion is true.

Using photoelectric equation,

$eV_0 = h\nu - \phi_0$

with $\nu\uparrow$, V_0 increases.

So, reason is correct but it is not the correct explanation of assertion.

16. **Assertion (A):** On forward biasing a *p-n* junction diode, the height of the barrier potential increases.

Reason (R): In forward biasing of a *p-n* junction diode, the direction of the applied voltage is in the same direction as the built-in potential.

Answer (D)

Sol. On forward biasing a *p-n* junction diode, the height of barrier potential decreases, so assertion is false. In forward biasing of *p-n* junction diode, the direction of applied voltage is in opposite direction as the built is potential across junction. Hence reason is also false.

SECTION-B

17. A 5 cm long pencil is placed along the principal axis of a concave mirror of focal length 20 cm such that its nearest end is at a distance of 25 cm from the mirror. Calculate the length of the image of the pencil.

OR

In a Young's double-slit experiment, a beam of light consisting of two wavelengths 500 nm and 600 nm is used. The interference fringes are observed at a screen placed 1.8 m away from the plane of slits (slit separation 0.3 mm). Calculate the least distance from the central maximum where the bright fringes due to both the wavelengths coincide.

Sol. Concave mirror (pencil along axis)

u_1 = –25 cm

u_2 = –30 cm

f = –20 cm

From mirror formula we have

$$v_1 = \frac{f \times u}{u - f} = \frac{(-20)(-25)}{-25+20}$$

= –100 cm

$$v_2 = \frac{(-20)(-30)}{-30+20} = -60 \text{ cm}$$

Image length = $|v_1 - v_2|$ = 40 cm

OR

For YDSE coincidence

$n\lambda_1 = M\lambda 2$

LCM (500, 600) = 3000 nm

for n = 6, M = 5

$$y = m\frac{\lambda D}{d}$$

$$= 6\left(500 \times 10^{-9}\right) \times \frac{1.8}{0.3 \times 10^{-3}}$$

= 0.018 m

= 1.8 cm

18. Calculate the temperature at which the resistance of a conductor becomes 20% more than its resistance at 27 °C. The value of the temperature coefficient of resistance of the material of conductor is 2.0×10^{-4} °C^{-1}.

Sol. Resistance increases 20% from its value (R) at 27 °C

$$\Rightarrow \quad R' = R\left(1 + \frac{20}{100}\right) = 1.2R$$

Now, $R' = R\left[1 + \alpha(T - 27)\right]$

$1.2 = 1 + \alpha(T - 27)$

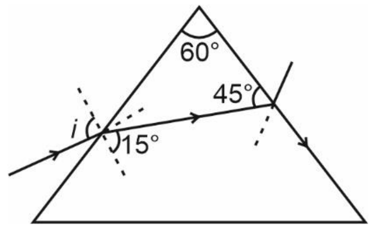
$\alpha = 2 \times 10^{-4}$ °C^{-1}

$$\therefore \quad T - 27 = \frac{0.2}{2 \times 10^{-4}} = 1000$$

$\Rightarrow T$ = 1027 °C

19. A ray of light is incident on the face of a triangular prism of refracting angle 60° and it just suffers total internal reflection at the other face. Find the angle of incidence for the ray if the refractive index of the material of the prism is $\sqrt{2}$.

Sol. $\mu = \sqrt{2}$



$\sin i_C = \frac{1}{\mu}$

$i_C = 45°$

For prism

$r_1 + r_2 = A = 60°$

$r_2 = 45°$

So, $r_1 = 15°$

By Snell's law

$\sin(i) = \mu \sin r_1$

$\Rightarrow \sin i = \sqrt{2}\sin(15°)$

$\Rightarrow \sin i = \sqrt{2} \times \frac{\sqrt{3}-1}{2\sqrt{2}}$

$i = \sin^{-1}\left(\frac{\sqrt{3}-1}{2}\right)$

20. Write two points of difference between intrinsic and extrinsic semiconductors.

Sol.

Intrinsic semiconductor		**Extrinsic semiconductor**	
(1)	Pure semiconductor	(1)	It is formed by doping intrinsic semiconductor with impurity atoms
(2)	It has equal number of electrons and holes	(2)	Majority and minority charge carriers exist in it.
(3)	It has low conductivity	(3)	It has higher conductivity

21. Find ratio (λ_α/λ_p) of the de Broglie wavelength λ_α and λ_p associated respectively with an alpha particle and a proton,

(i) if they are moving with the same kinetic energy.

(ii) just after they are accelerated through the same potential difference.

Sol. (i) $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2\,mK}} = \frac{h}{\sqrt{2mqV}}$

$\lambda \propto \frac{1}{\sqrt{m}}$ (*K*-same)

$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p}{m_\alpha}} \Rightarrow \sqrt{\frac{1}{4}} = \frac{1}{2}$

$\because m_\alpha = 4\, m_p$

(ii) For same V

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

$q_\alpha = 2e$, $q_p = e$

$$\frac{\lambda_\alpha}{\lambda_p} = \sqrt{\frac{m_p e}{4m_p.2e}}$$

$$= \frac{1}{2\sqrt{2}}$$

SECTION-C

22. (i) Define mutual inductance of a pair of coils. Write its SI unit.

(ii) A long solenoid of radius R and length L has n turns per unit length. A circular loop of radius $r(<R)$ is placed inside at the centre of the solenoid such that its axis coincides with the axis of the solenoid. Obtain the mutual inductance of the solenoid and the loop.

OR

Two long straight parallel conductors A and B carrying steady currents I_a and I_b in the same direction are separated by a distance d. Deduce the expressions for the force acting on length L of conductor B due to conductor A and show it in figure. Write the expression for the force acting on length L of conductor A due to conductor B and show that it follows Newton's third law.

Sol. (i) Mutual inductance of two coils is the magnetic flux linked with one coil per unit current flowing in other.

Current $M = \frac{\phi}{I}$

SI unit: Henly (H)

(ii) Magnetic field inside long solenoid

$B = \mu_0 nI$

Flux through loop

$$\phi = B(\pi r^2)$$

$$= \mu_0 nI(\pi r^2)$$

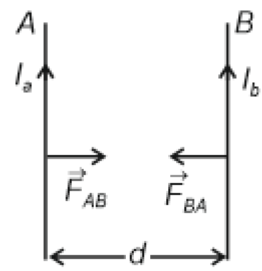
$$M = \frac{\phi}{I} = \mu_0 \pi r^2 n$$

$$M = \mu_0 n \pi r^2$$

OR

Let B_a be the magnetic field due to conductor A at distance d

$$B_a = \frac{\mu_0 I_a}{2\pi d}$$



Force on a section of length L for conductor B is

$$F_{BA} = \left|I_b\left(\vec{L} \times \vec{B}_a\right)\right| = I_b L B_a \sin 90^\circ$$

$$= I_b L \frac{\mu_0 I_a}{2\pi d} = \frac{\mu_0 I_a I_b \times L}{2\pi d}$$

Similarly force on a section of length L for conductor A due to field of B

$F_{AB} = \left|I_a\left(\vec{L} \times \vec{B}_b\right)\right| = I_a L B_b \sin 90°$

$$= \frac{\mu_0 I_a I_b L}{2\pi d}$$

$\left|\vec{F}_{AB}\right| = \left|\vec{F}_{BA}\right|$

But $\vec{F}_{AB} = -\vec{F}_{BA}$

This is consistent with Newton Third Law.

23. Calculate the de Broglie wavelength associated with an electron revolving in the second excited state of hydrogen atom. The ground state energy of the hydrogen atom is –13.6 eV. Take $m_e = 9 \times 10^{-31}$ kg, $h = 6.6 \times 10^{-34}$ J.s.

Sol. $E_n = -\frac{13.6}{n^2}$ eV

For second excited state n = 3

$E_3 = -\frac{13.6}{3^2} = -1.51$ eV

Kinetic energy (E) = 1.51 eV

= 1.51 × 1.6 × 10^{-19} J

using momentum $P = \sqrt{2mE}$

$= \sqrt{2 \times 9 \times 10^{-31} \times 1.51 \times 1.6 \times 10^{-19}}$

$= \sqrt{43.488 \times 10^{-50}} = 6.59 \times 10^{-25}$

$\therefore \quad \lambda = \frac{h}{P} = \frac{6.6 \times 10^{-34}}{6.6 \times 10^{-25}} = 10^{-9}$ m

24. Name the electromagnetic waves which are used

(i) as a diagnostic tool in medicine

(ii) in remote switches for TV sets

(iii) in water purifiers

Also write their wavelength range.

Sol. (i) X-rays are used as a diagnostic tool in medicine.

Range (0.01 nm to 10 nm)

(ii) Infrared waves are used in remote switches for TV sets

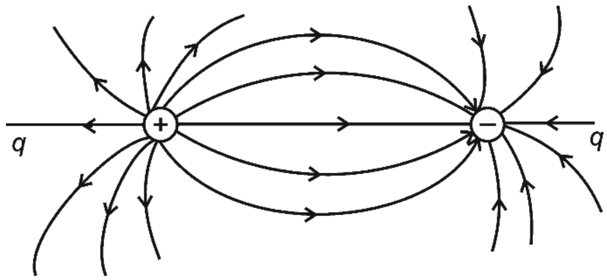
Range (700 nm to 1 μm)

(iii) UV rays (range 200-280 nm) are used to purify water.

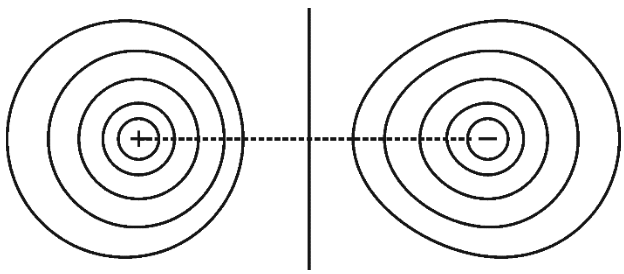
25. (i) Draw electric field lines and equipotential surfaces for a system of two equal and opposite point charges separated by some distance.

(ii) Why electric field $\vec{E}$ at a point on an equipotential surface must be perpendicular to the surface at that point?

Sol. (i) Electric field



Equipotential surfaces



(ii) If the field had a component parallel to the equipotential surface, work would be done. But at the surface of an equipotential, surface where potential is constant and no work is done in moving a charge along such a surface. Hence electric field must be perpendicular to equipotential surface.

26. (a) Consider the following nuclides:

$^{12}_{6}C, ^{198}_{80}Hg, ^{14}_{6}C, ^{197}_{79}Au$

Group them into isotopes and isotones.

(b) How does the size of a nucleus depend on its mass number A? Hence prove that the density of nucleus is a constant, independent of A, for all nuclei.

Sol. (a) $^{12}_{6}C$ and $^{14}_{6}C$ are isotopes having same number of protons (atomic number) but a different number of neutrons, resulting in different atomic masses.

So, $^{198}_{80}Hg$ and $^{197}_{79}Au$ are isotones having the same number of neutrons ($n = A - Z$) i.e. 118 but different number of protons (atomic number).

(b) The size (radius R) of a nucleus is related to its mass number A as $R = R_0A^{1/3}$

where $R_0 \approx 1.2\ fm$

(f) Density of nuclear consists $= \dfrac{\text{Mass}}{\text{Volume}}$

Assume the nucleus consists of A nucleons with mass m_n

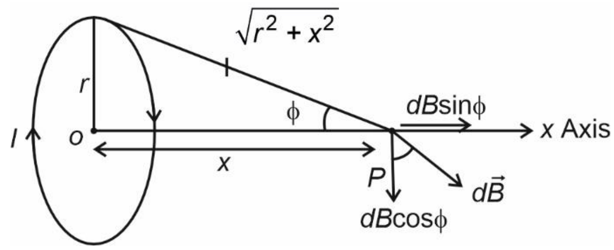
$$\therefore\ \rho = \frac{Am_n}{\frac{4}{3}\pi R^3} = \frac{Am_n}{\frac{4}{3}\pi R_b^3 A}$$

$$\rho = \frac{3m_n}{4\pi R_0^3} = \text{constant}$$

So, ρ is independent of A and same for all nuclei

27. Derive an expression for the magnetic field $\vec{B}$, due to a circular coil of N turns, each of radius r carrying current I, at a distance 'x' from the centre along its axis.

Sol.



Consider a circular loop of radius r in yz plane, carrying current I

Let dl be small element of coil at a distance $\sqrt{r^2+x^2}$ from P.

Small magnetic field due to the element dl is perpendicular to plane containing dl and radius vector r.

$$d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{dl\sin 90^\circ}{(r^2+x^2)} = \frac{\mu_0 I dl}{4\pi(r^2+x^2)}$$

Resolve $d\vec{B}$ into $dB\cos\phi$ ($\perp$ to axis) and $dB\sin\phi$ along axis

Due to symmetry for every element dl there is an opposite element producing $dB\cos\phi$ in opposite direction. These cancel out

$$\vec{B} = \int dB\sin\phi = \frac{\mu_0}{4\pi}\frac{I\,dl}{(r^2+x^2)}\sin\phi$$

$$\sin\phi = \frac{r}{\sqrt{r^2+x^2}}$$

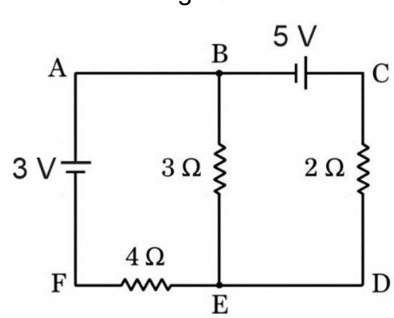
$$B = \frac{\mu_0 Ir}{4\pi(r^2+x^2)^{3/2}}\int_0^{2\pi r} dl = \frac{\mu_0 Ir}{4\pi(r^2+x^2)^{3/2}}2\pi r$$

For N turns, total magnetic field

$$B = \frac{N\mu_0 Ir^2}{2(r^2+x^2)^{3/2}}$$

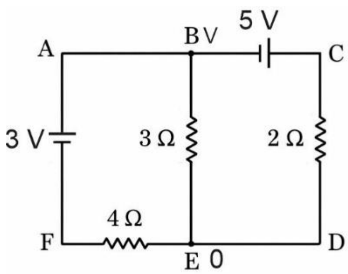
28. (a) Explain the statement: "Current is a scalar although we represent current with an arrow".

(b) Use Kirchhoff's rules to find the current through 3 Ω resistor in the circuit shown in the figure:



Sol. (a) Electric current is a scalar quantity because it has both magnitude and a defined conventional direction from positive to negative terminal of battery, but it does not obey the vector addition laws. The arrow indicates only direction of flow along a conductor.

(b)



Let node $E = 0$

node $B = V$

From batteries

$V_C = V + 5$ and $V_F = V - 3$

KCL at node E

$$\left[\frac{V}{3} + \frac{V+5}{2} + \frac{V-3}{4} = 0\right] \times 12$$

$4V + 6(V + 5) + 3(V - 3) = 0$

$$13V + 21 = 0\,;\, V = \frac{-21}{13}$$

$$\text{Current through } 3\ \Omega = \frac{V}{3} = \frac{-7}{13}\text{A}$$

Negative sign means $\Rightarrow$ direction is $E \rightarrow B$

$$\therefore\ I = \frac{7}{13}\text{A} \text{ through } 3\ \Omega$$

SECTION-D

Question numbers **29** and **30** are case study based questions. Read the following paragraphs and answer the questions that follow.

In an experiment with convex lens of focal length f, the screen is fixed at a distance D from the object. A student slowly moves the lens away from the object towards the screen and finds that she is able to form sharp image of the object for two positions of the lens. The distance between these two positions of the lens is d.

29. (i) The value of d is

(A) $\sqrt{D(D-4f)}$ (B) $\sqrt{D(D-2f)}$

(C) $2\sqrt{Df}$ (D) $\sqrt{D(D-f)}$

(ii) Compared to the size of the object, the images formed in the two positions of the lens are respectively

(A) reduced, enlarged (B) reduced, reduced

(C) enlarged, enlarged (D) enlarged, reduced

(iii) If the distance between object and screen is 80.00 cm and the lens forms sharp images at two positions separated by 20.00 cm, the focal length of convex lens is

(A) 15.50 cm (B) 18.75 cm

(C) 20.50 cm (D) 22.75 cm

(iv) Consider a convex lens of focal length 15 cms. For which of the following values of object-screen distance, two positions of the object can be found to obtain sharp image on the screen?

(A) 45 cm (B) 50 cm

(C) 55 cm (D) 65 cm

OR

(iv) A thin convex lens of focal length 10 cm and another thin lens of focal length '*f*' are placed coaxially in contact. If the power of their combination is $\frac{10}{3}D$, the value of 'f' is

(A) –15 cm (B) –10 cm

(C) –20 cm (D) –30 cm

Sol. (i) **Answer (A)**

From the experiment of lens displacement method we know that, $\frac{1}{f}=\frac{2}{D-d}+\frac{2}{D+d} \Rightarrow f=\frac{D^2-d^2}{4D}$

$\Rightarrow \ d=\sqrt{D^2-4Df}=\sqrt{D(D-4f)}$

(ii) **Answer (D)**

The magnification in the first position in the lens-displacement method is given by, $m_1=\frac{D+d}{D-d}$

While the magnification in the second position is given by, $m_2=\frac{D-d}{D+d}$

$\Rightarrow$ In first position image is magnified while in second position image is reduced.

Hence, answer will be enlarged, reduced.

(iii) **Answer (B)**

From the experimental setup of lens displacement method we know that, $d=\sqrt{D(D-4F)}$

According to question, D = 80 cm, d = 20 cm

As, $d=\sqrt{D(D-4f)} \ \Rightarrow f=\frac{D^2-d^2}{4D}$

$\Rightarrow \ f=\frac{(80)^2-(20)^2}{4\times 80}=18.75 \text{ cm}$

(iv) **Answer (D)**

From the experimental setup of lens-displacement method, we know that two positions of object can be found to obtain a sharp image on the screen if, the required condition, is

$D > 4f$

$\Rightarrow D > 4(15)$ $\Rightarrow D > 60$ cm

$\Rightarrow$ 65 cm

OR

(iv) **Answer (A)**

As the two lens are placed coaxially in contact,

$\Rightarrow \ P_{eq}=P_1+P_2=\frac{10}{3}=\frac{100}{30}$ D

$\Rightarrow \frac{1}{f_{eq}} = \frac{1}{F_1} + \frac{1}{F_2} \Rightarrow \frac{100}{30} = \frac{100}{10} + \frac{100}{f}$

$\Rightarrow \frac{1}{f} = \frac{1}{30} - \frac{1}{10} = \frac{1-3}{30} = \frac{-2}{30} = \frac{-1}{15}$

$\Rightarrow f = -15$ cm

30. A *p*-type or *n*-type semiconductor can be converted into a *p*-*n* junction by doping it with suitable impurity. The motion of majority charge carriers causes diffusion current across the junction while the barrier electric field causes motion of minority carriers for drift current. In case of unbiased diode, the diffusion and drift currents are equal. This equilibrium is disturbed by the biasing batteries. Diodes, therefore, allow currents in one direction. This property of diode is used in making rectifiers.

(i) Silicon is doped with which of the following to obtain *p*-type semiconductor?

(A) Phosphorus (B) Arsenic

(C) Boron (D) Antimony

(ii) A semiconductor has an electron concentration of 5×10^{22} m^{-3}. The concentration of holes is (given $n_i = 1.5 \times 10^{16}$ m^{-3})

(A) 5×10^{22} m^{-3} (B) 1.5×10^{6} m^{-3}

(C) 9×10^{8} m^{-3} (D) 4.5×10^{9} m^{-3}

(iii) During forward biasing of a *p*-*n* junction diode, the

(A) Current is mainly due to drifting of majority carriers.

(B) Current is mainly due to drifting of minority carriers.

(C) Diffusion and drift currents are equal.

(D) Current is of the order of 1 A .

(iv) The threshold voltage for silicon diode is about

(A) 0.2 V

(B) 0.5 V

(C) 0.7 V

(D) 1.5 V

OR

(iv) When we dope Ge with a pentavalent element, four of its electrons bond with four germanium neighbours but fifth electron remains weakly bound. The ionisation energy for this electron is about

(A) 0.01 eV

(B) 0.05 eV

(C) 0.1 eV

(D) 0.15 eV

Sol. (i) **Answer (C)**

Silicon is doped with trivalent impurities (elements from Group 13 of the periodic table) such as Boron, Aluminium, Gallium or Indium to obtain a *p*-type semiconductor.

(ii) **Answer (D)**

Using law of mass-action in semiconductor: $n_e n_h = n_i^2$

$\therefore$ Concentration of holes = $n_h = \frac{n_i^2}{n_e} = \frac{(1.5 \times 10^{16})^2}{5 \times 10^{22}}$

$\Rightarrow n_h = \frac{2.25 \times 10}{5} \times 10^9 = 4.5 \times 10^9$ m^{-3}

(iii) **Answer (A)**

During forward biasing of a *p-n* junction diode:

- The current is of the order of milliamperes.
- The diffusion current becomes significantly greater than the drift current.
- The current is primarily due to the diffusion of majority carriers across the junction, not the drifting of minority carriers.

$\Rightarrow$ Hence the most appropriate answer would be option (A).

(iv) **Answer (C)**

The threshold voltage of a silicon diode is typically 0.7 V.

OR

(iv) **Answer (A)**

When Ge is doped with a pentavalent element (such as arsenic, phosphorus or antimony), the ionization energy for the extra weakly bound fifth electron is typically around 0.01 eV.

SECTION-E

31. (a) A series combination of *L*, *C* and *R* is connected to an a.c. source. Using a phasor diagram, derive an expression for the impedance of the circuit and phase difference between *V* and *I*.

(b) Under what conditions the

(i) Impedance of the circuit is minimum?

(ii) Wattless current flows in the circuit?

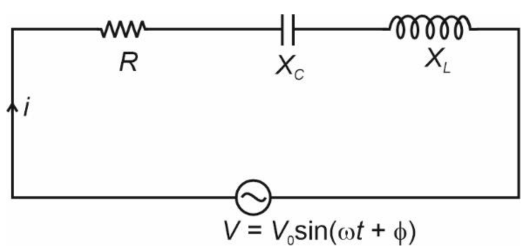
OR

(i) With the help of a labelled diagram, explain the principle, construction and working of an a.c. generator.

(ii) Deduce an expression for the induced emf in the coil of the generator.

(iii) If T is the time period of the rotation of the coil, at what values of T in a cycle, the emf generator is maximum?

Sol. (a) A series combination of *L*, *C* and *R* is connected to an a.c. source



Let current $i = i_0\sin(\omega t)$

Potential drop:

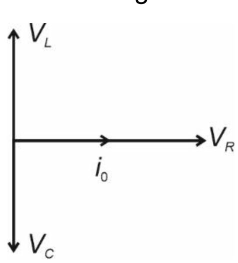
across resistance = $V_R = i_0R$

across inductor = $V_L = i_0X_L = i_0\omega L$

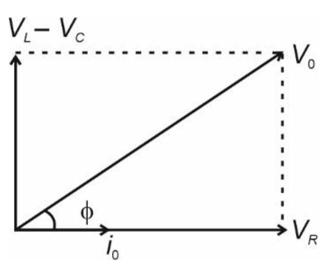
across capacitor = $V_C = i_0X_C = \dfrac{i_0}{\omega C}$

We assume, $V_L \geq V_C \Rightarrow X_L \geq X_C \Rightarrow \omega L \geq \dfrac{1}{\omega C} \Rightarrow \omega^2 \geq \dfrac{1}{LC}$

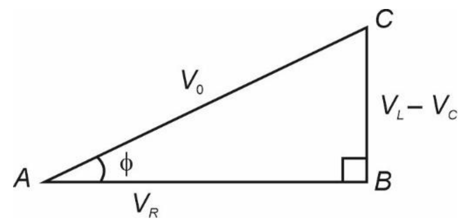
Phasor diagram of the same is



becomes



Using Pythagoras theorem in ΔABC,



$AC^2 = AB^2 + BC^2$

$$V_0^2 = (V_R)^2 + (V_L - V_C)^2$$

$$\Rightarrow V_0^2 = i_0^2 R^2 + i_0^2 (X_L - X_C)^2$$

$$\Rightarrow V_0 = i_0 \sqrt{R^2 + (X_L - X_C)^2}$$

Impedance of circuit, $Z = \dfrac{V_0}{i_0} = \sqrt{R^2 + (X_L - X_C)^2}$

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

In ΔABC, $\tan\phi = \dfrac{BC}{AB} = \dfrac{V_L - V_C}{V_R} = \dfrac{i_0(X_L - X_C)}{i_0 R} = \dfrac{X_L - X_C}{R}$

$\therefore$ Phase difference between V and $I = \phi = \tan^{-1}\left(\dfrac{X_L - X_C}{R}\right)$

$$\Rightarrow \phi = \tan^{-1}\left(\frac{\omega L - \frac{1}{\omega C}}{R}\right)$$

(b) (i) Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2} \ge R$

$Z_{min} = R$ at $X_L = X_C$

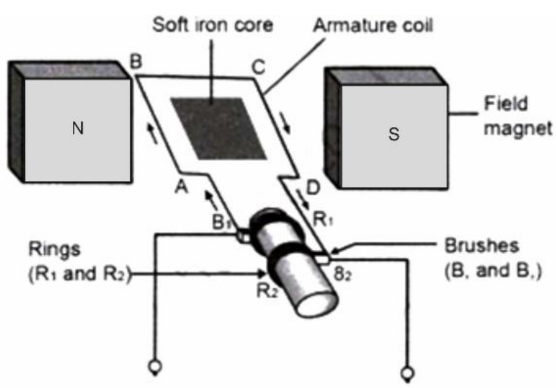
This condition exists when circuit is at resonance.

(ii) Wattless current flows in purely reactive AC circuits without power dissipation.

$\therefore$ Phase difference between voltage and current = ϕ = 90° (as only pure inductor/pure capacitor is present)

OR

(i)



Principle : It is a based om Faraday's Law of electromagnetic induction. Where a coil in a uniform magnetic field is rotated along an axis perpendicular to the field, the magnetic flux linked with the coil changes, and an induced emf is produced across its ends.

Construction : A rotating armature (rectangular coil) inside a converts mechanical energy into AC electrical energy. Major components include field magnets, and armature coil, slip rings, and carbon brushes

Working: When the coil begins to rotate with the arm AB travelling up and the arm CD moving down, cutting the magnetic lines of force, the induced current is set up in these arms along the AB and CD directions, according to Fleming's right-hand rule. As a result, an effective induced current flows in the direction of ABCD.

If the coil has a big number of turns, the current created in each turn adds up to produce a large amount of current across the coil. After half a rotation of the coil, its arm CD begins to move upward and its arm AB begins to move downward. As a result, the induced currents in the coil are reversed in the direction of DCBA. As a result, the polarity of the current in each arm changes every half rotation.

(ii) **Emf induced :** Consider a coil of N turns and area A being rotated at constant angular velocity ω in a magnetic field of flux density B, its axis being perpendicular to field.

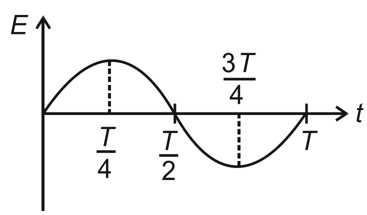
$\varphi = NBA\cos\theta = NBA\cos\omega t$

$$\varepsilon = \left|\frac{d\varphi}{dt}\right| = NBA\,\omega\sin\omega t$$

$\Rightarrow\ \varepsilon = \varepsilon_0\sin\omega t$

The maximum value of induced emf (ε_0) = NBA ω occurs when $\theta = \omega t = 90°$ (when the coil is in the plane of the field)

(iii) Induced emf, $\varepsilon = \varepsilon_0\sin\omega t$



Maximum emf occurs at $t = \frac{T}{4}$ and $t = \frac{3T}{4}$ in one cycle.

At $t = \frac{T}{4}$, $\varepsilon = \varepsilon_0$ = maximum positive value.

At $t = \frac{3T}{4}$, emf reaches maximum value in the opposite direction $\Rightarrow \varepsilon = -\varepsilon_0$

32. (a) What are coherent sources? Why are they necessary for observing a stable interference pattern? Draw a graph showing the variation of intensity of light with the position on the screen in Young's double-slit experiment.

(b) Find the intensity of light at a point on the screen when two interfering waves of the same intensity I_0 have a path difference of

(i) $\frac{\lambda}{4}$ and

(ii) $\frac{\lambda}{3}$

OR

(a) Draw a labelled ray diagram of a refracting telescope when it forms an image of a distant object at infinity. Derive the expression for its magnifying power.

(b) (i) In a telescope, the objective has a much larger aperture than the eyepiece. Why?

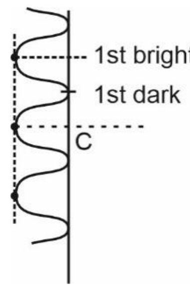
(ii) Write two advantages of a reflecting telescope over a refracting telescope.

Sol. (a) Coherent sources are two sources of light that emit waves of the same frequency (or wavelength) and maintain a constant phase difference

Interference fringes are formed due to superposition of waves.

If phase difference changes randomly, bright and dark fringes keep shifting.

Coherent sources ensure fixed positions of maxima and minima, producing stable interference pattern



(b) For two waves of equal intensity I_0

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

(i) $\Delta x = \frac{\lambda}{4}$

$$\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{4} = \frac{\pi}{2}$$

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

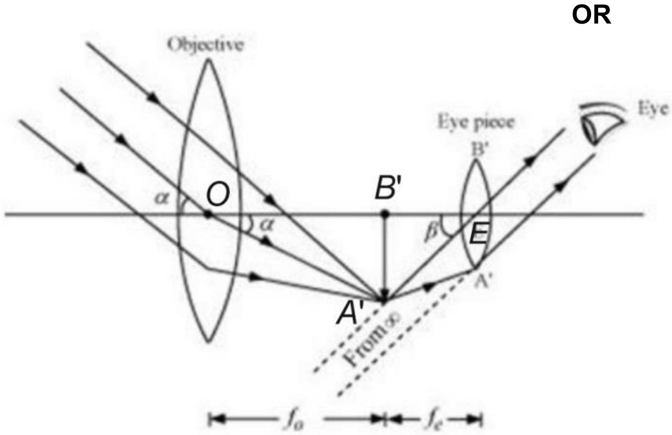
(ii) $\Delta x = \frac{\lambda}{3}$

$$\phi = \frac{2\pi}{\lambda} \times \frac{\lambda}{3} = \frac{2\pi}{3}$$

$$I = 4I_0 \cos^2\left(\frac{\pi}{3}\right) = 4I_0 \times \frac{1}{4} = I_0$$

OR

(a)



Let us assume that objective and eyepiece have focal lengths f_o and f_e respectively and object is situated at large distance u_0 from objective.

Let us assume object subtends an angle α on the objective. Since the object is far away, the angle it would subtend on eye, if there were no telescope is also essentially α.

From figure, $|\alpha| = |\tan\alpha| = \dfrac{B'A'}{OB'} = \dfrac{B'A'}{f_o}$

If telescope is set for normal adjustment then final image is formed at infinity. Hence first image.

$B'A'$ must be in focal plane of the eyepiece.

$\Rightarrow EB' = f_e$

$\Rightarrow |\beta| = |\tan\beta| = \dfrac{B'A'}{f_e}$

Magnification = $\left|\dfrac{\beta}{\alpha}\right| = \dfrac{\dfrac{B'A'}{f_e}}{\dfrac{B'A'}{f_o}} = \dfrac{f_o}{f_e} \Rightarrow m = -\left|\dfrac{\beta}{\alpha}\right| = -\dfrac{f_o}{f_e}$

(b) (i) The main considerations with an astronomical telescope are its light gathering power and its resolution or resolving power. The former clearly depends on area of the objective. With large diameters, fainter objects can be observed. The resolving power or ability to observe two objects distinctly also depends on diameter of objective. So, it is desired in telescopes to have objective of large diameter.

(ii) Following are the advantages of reflecting telescope over refracting telescope.

1. There is no chromatic aberration in reflecting telescope.

2. Mechanical support is much less of a problem since a mirror weighs much less than a lens of equivalent optical quality.

33. (a) Derive an expression for the capacitance of a parallel plate capacitor of plate area *A* and plate separation *d* with air present between the plates.

(b) Two air-filled capacitors of capacitances C_1 and C_2 are connected in parallel with a dc battery. After the capacitors are fully charged, a slab of dielectric constant *K* is inserted between the plates of each capacitor. How will the (i) charge on each capacitor and (ii) energy stored in the capacitor affected after the slab is introduced.

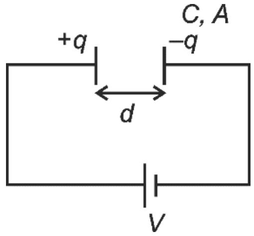
OR

(a) An electric field $\vec{E}$ is established across the ends of a cylindrical conductor of length *L* and area of cross-section *A*. Discuss how electrons attain an average velocity, independent of time. Hence, obtain a relation between current in the conductor and this 'average velocity' of electrons.

(b) (i) This 'average velocity' is found be few mm/s for currents in range of a few amperes. How then is current established almost the instant a circuit is closed?

(ii) Two copper wires having their radii in the ratio of 3 : 2 are connected in series across a battery. Find the ratio of the drift velocities of the electrons in the wires.

Sol. (a) For a capacitor of capacitance C



Let us assume the charge on the plate to be $+q$ and $-q$.

Electric field between plates

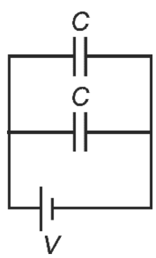
$$E = \frac{\sigma}{\varepsilon_0} = \frac{q}{A\varepsilon_0}$$

$$V = Ed = \frac{qd}{A\varepsilon_0}$$

Capacitance $C = \frac{q}{V}$

$$\Rightarrow \quad C = \frac{q}{V} = \frac{A\varepsilon_0}{d}$$

(b) (i)



Battery remains connected

$\Rightarrow$ Voltage constant [Initially $Q = CV$]

New capacitance $C' = KC$

$Q' = C'V = KCV$

$Q' = KQ$

Charge increase K times

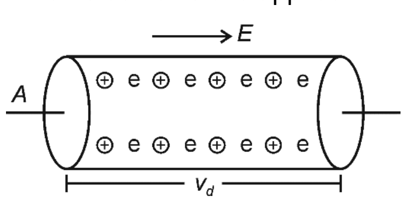
(ii) $U = \frac{1}{2}CV^2$

$$U' = \frac{1}{2}KCV^2 = KU$$

Energy increases K times

OR

(a) When electric field is applied



$F = eE$

$$a = \frac{eE}{m}$$

Due to collisions with lattice, electrons acquire constant average drift velocity.

$v_d = \frac{eE\tau_{av}}{m}$; τ_{av} = average relaxation time

n = number density of electrons

Now, $I = \frac{Q}{t} = \frac{\text{Volume} \times \text{No. density of electrons} \times e}{1\,\text{sec}}$

$= \frac{Av_d \times ne}{1} = neAv_d$

(b) (i) Drift velocity is small, but

- Electric field propagates through conductor with speed nearly equal to speed of light
- All electrons start drifting simultaneously. Hence, current appears almost instantly.

(ii) Current is same in series

$I = neAv_d$

$v_d \propto \frac{I}{A}$

and $A \propto r^2$

given $\frac{r_1}{r_2} = \frac{3}{2}$ $\quad\therefore\quad \frac{A_1}{A_2} = \frac{9}{4}$

So, $\frac{v_1}{v_2} = \frac{A_2}{A_1} = \frac{4}{9}$

Smaller wire means larger v_d.

❑ ❑ ❑