

IIT-JAM - 2019SECTION - AMULTIPLE CHOICE QUESTIONS (MCQ)

**Q1. – Q10. carry one mark each.**

Q1. The function  $f(x) = \frac{8x}{x^2 + 9}$  is continuous everywhere except at

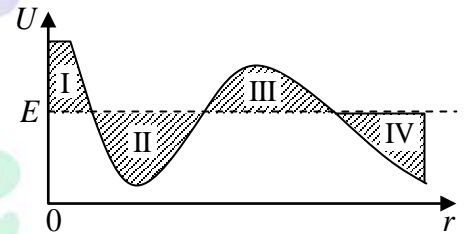
- (a)  $x = 0$                       (b)  $x = \pm 9$                       (c)  $x = \pm 9i$                       (d)  $x = \pm 3i$

Ans. : (d)

Solution: We know that a rational function is discontinuous at a point where the denominator is 0. Therefore,

$$x^2 + 9 = 0 \Rightarrow x = \pm 3i$$

Q2. A classical particle has total energy  $E$ . The plot of potential energy ( $U$ ) as a function of distance ( $r$ ) from the centre of force located at  $r = 0$  is shown in the figure. Which of the regions are forbidden for the particle?

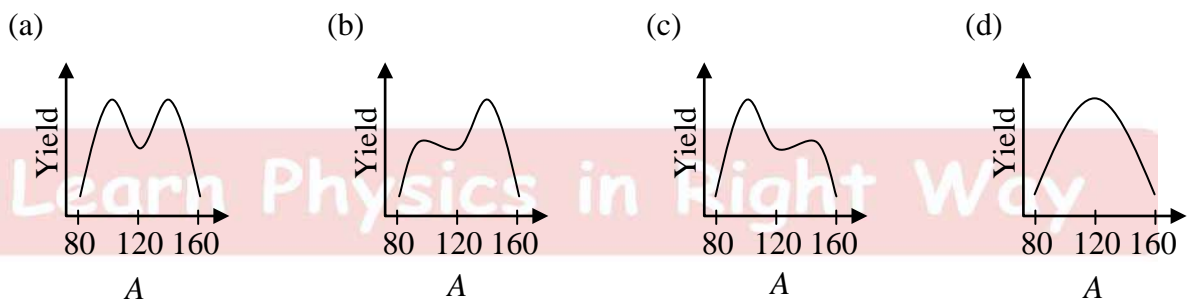


- (a) I and II    (b) II and IV  
(c) I and IV    (d) I and III

Ans. : (d)

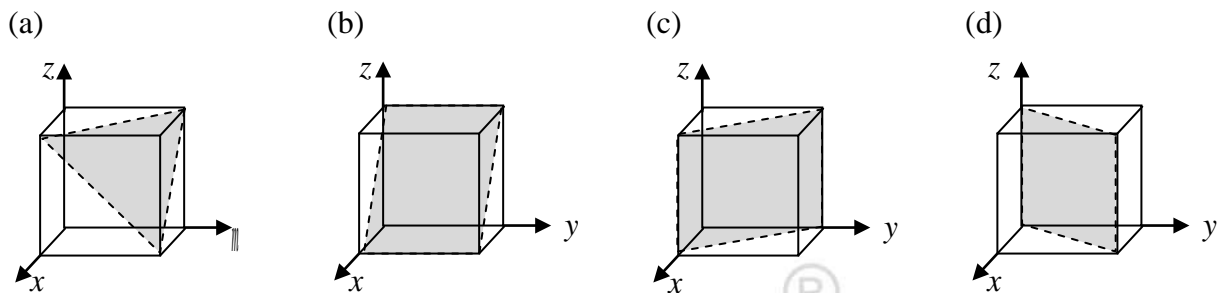
Solution: In the region I and III potential energy is more than total energy.

Q3. In the thermal neutron induced fission of  $^{235}\text{U}$ , the distribution of relative number of the observed fission fragments (Yield) versus mass number ( $A$ ) is given by



Ans. : (a)

Q4. Which one of the following crystallographic planes represent (101) Miller indices of a cubic unit cell?



Ans. : (b)

Solution: Plane intercepts

$$x : y : z = \frac{a}{h} : \frac{b}{k} : \frac{c}{l} = \frac{a}{1} : \frac{b}{0} : \frac{c}{1} = a : \infty : c$$

$$\therefore x = a, y = \infty, z = c$$

Plane is parallel to  $y$ -axis and intersecting  $x$  and  $z$ -axis at  $a$  and  $c$ . Thus, option (b) is correct.

Q5. The Fermi-Dirac distribution function  $[n(\varepsilon)]$  is

( $k_B$  is the Boltzmann constant,  $T$  is the temperature and  $\varepsilon_F$  is the Fermi energy)

(a)  $n(\varepsilon) = \frac{1}{e^{\frac{\varepsilon - \varepsilon_F}{k_B T}} - 1}$

(b)  $n(\varepsilon) = \frac{1}{e^{\frac{\varepsilon_F - \varepsilon}{k_B T}} - 1}$

(c)  $n(\varepsilon) = \frac{1}{e^{\frac{\varepsilon - \varepsilon_F}{k_B T}} + 1}$

(d)  $n(\varepsilon) = \frac{1}{e^{\frac{\varepsilon_F - \varepsilon}{k_B T}} + 1}$

Ans. : (c)

Q6. If  $\phi(x, y, z)$  is a scalar function which satisfies the Laplace equation, then the gradient of  $\phi$  is

(a) Solenoidal and irrotational

(b) Solenoidal but not irrotational

(c) Irrotational but not solenoid

(d) Neither Solenoidal nor irrotational

Ans. : (a)

Solution:  $\nabla^2 \phi = 0 \Rightarrow \vec{\nabla} \phi = \text{const} \Rightarrow \vec{\nabla} \cdot \vec{\nabla} \phi = 0, \vec{\nabla} \times \vec{\nabla} \phi = 0$

Q7. In a heat engine based on the Carnot cycle, heat is added to the working substance at constant

(a) Entropy

(b) Pressure

(c) Temperature

(d) Volume

Ans. : (c)

Q8. Isothermal compressibility is given by

(a)  $\frac{1}{V} \left( \frac{\partial V}{\partial P} \right)_T$       (b)  $\frac{1}{P} \left( \frac{\partial P}{\partial V} \right)_T$       (c)  $-\frac{1}{V} \left( \frac{\partial V}{\partial P} \right)_T$       (d)  $-\frac{1}{P} \left( \frac{\partial P}{\partial V} \right)_T$

Ans. : (c)

Q9. For using a transistor as an amplifier, choose the correct option regarding the resistances of base-emitter ( $R_{BE}$ ) and base-collector ( $R_{BC}$ ) junctions

- (a) Both  $R_{BE}$  and  $R_{BC}$  are very low      (b) Very low  $R_{BE}$  and very high  $R_{BC}$   
 (c) Very high  $R_{BE}$  and very low  $R_{BC}$       (d) Both  $R_{BE}$  and  $R_{BC}$  are very high

Ans. : (b)

Q10. A unit vector perpendicular to the plane containing  $\vec{A} = \hat{i} + \hat{j} - 2\hat{k}$  and  $\vec{B} = 2\hat{i} - \hat{j} + \hat{k}$  is

(a)  $\frac{1}{\sqrt{26}}(-\hat{i} + 3\hat{j} - 4\hat{k})$       (b)  $\frac{1}{\sqrt{19}}(-\hat{i} + 3\hat{j} - 3\hat{k})$   
 (c)  $\frac{1}{\sqrt{35}}(-\hat{i} + 5\hat{j} - 3\hat{k})$       (d)  $\frac{1}{\sqrt{35}}(-\hat{i} - 5\hat{j} - 3\hat{k})$

Ans. : (d)

Solution:  $\vec{A} \cdot \hat{n} = 0$  and  $\vec{B} \cdot \hat{n} = 0$

Verify option (d):  $\vec{A} \cdot \hat{n} = \frac{1}{\sqrt{35}}(-1 - 5 - 6) = 0$

$$\vec{B} \cdot \hat{n} = \frac{1}{\sqrt{35}}(-2 + 5 - 3) = 0$$

Q11. – Q30. carry two marks each.

Q11. A thin lens of refractive index  $\frac{3}{2}$  is kept inside a liquid of refractive index  $\frac{4}{3}$ . If the focal

length of the lens in air is 10 cm, then the focal length inside the liquid is

- (a) 10 cm      (b) 30 cm      (c) 40 cm      (d) 50 cm

Ans. : (c)

Solution:  $\frac{1}{f_a} = \left( \frac{3}{2} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right)$

$$\frac{1}{f_l} = \left( \frac{3/2}{4/3} - 1 \right) \left( \frac{1}{R_1} - \frac{1}{R_2} \right) \Rightarrow \frac{f_l}{f_a} = \frac{\left( \frac{3}{2} - 1 \right)}{\left( \frac{9}{8} - 1 \right)} = 4$$

$$f_l = 4f_a = 4 \times 10 = 40 \text{ cm}$$

Q12. The eigenvalues of  $\begin{pmatrix} 3 & i & 0 \\ -i & 3 & 0 \\ 0 & 0 & 6 \end{pmatrix}$  are

- (a) 2, 4 and 6      (b)  $2i, 4i$  and 6      (c)  $2i, 4$  and 8      (d) 0, 4 and 8

Ans. : (a)

Solution: For calculation of eigenvalues

$$\begin{vmatrix} 3-\lambda & i & 0 \\ -i & 3-\lambda & 0 \\ 0 & 0 & 6-\lambda \end{vmatrix} = 0$$

$$\Rightarrow (3-\lambda)[(3-\lambda)(6-\lambda)] - i[-i(6-\lambda)] = 0$$

$$\Rightarrow (3-\lambda)(3-\lambda)(6-\lambda) - (6-\lambda) = 0$$

$$\text{or } (6-\lambda)[(\lambda-3)^2 - 1] = 0$$

$$\text{or } (6-\lambda)[(\lambda^2 - 6\lambda + 8)] = 0$$

$$\text{or } (6-\lambda)(\lambda-2)(\lambda-4) = 0. \text{ Therefore, } \lambda = 6 \text{ or } 2 \text{ or } 4.$$

Q13. For a quantum particle confined inside a cubic box of side  $L$ , the ground state energy is given by  $E_0$ . The energy of the first excited state is

- (a)  $2E_0$       (b)  $\sqrt{2}E_0$       (c)  $3E_0$       (d)  $6E_0$

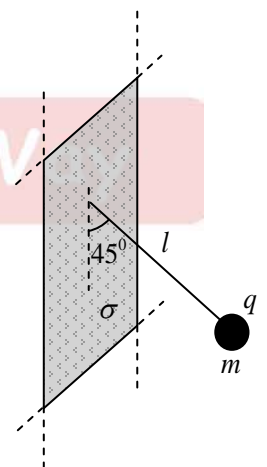
Ans. : (a)

$$\text{Solution: } E_{n_x, n_y, n_z} = \frac{(n_x^2 + n_y^2 + n_z^2)\pi^2\hbar^2}{2ma^2} \Rightarrow E_{1,1,1} = \frac{3\pi^2\hbar^2}{2ma^2} = E_0$$

$$E_{2,1,1} = E_{1,2,1} = E_{1,1,2} = \frac{(4+1+1)\pi^2\hbar^2}{2ma^2} = \frac{6\pi^2\hbar^2}{2ma^2} = 2E_0$$

Q14. A small spherical ball having charge  $q$  and mass  $m$ , is tied to a thin massless non-conducting string of length  $l$ . The other end of the string is fixed to an infinitely extended thin non-conducting sheet with uniform surface charge density  $\sigma$ . Under equilibrium the string makes an angle  $45^\circ$  with the sheet as shown in the figure. Then  $\sigma$  is given by ( $g$  is the acceleration due to gravity and  $\epsilon_0$  is the permittivity of free space)

- (a)  $\frac{mg\epsilon_0}{q}$       (b)  $\sqrt{2}\frac{mg\epsilon_0}{q}$   
 (c)  $2\frac{mg\epsilon_0}{q}$       (d)  $\frac{mg\epsilon_0}{q\sqrt{2}}$

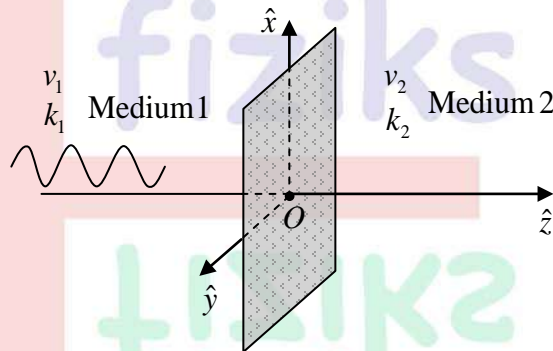


Ans. : (c)

$$\text{Solution: } \tan \theta = \frac{F}{mg} \Rightarrow \tan \theta = \frac{qE}{mg} = \frac{q\sigma}{2\varepsilon_0 mg} \Rightarrow \sigma = \frac{2mg\varepsilon_0}{q} \tan \theta$$

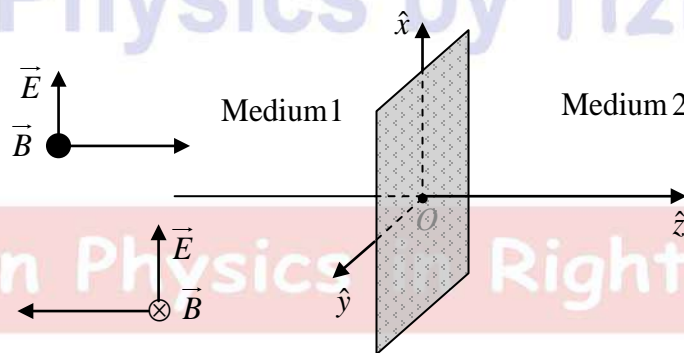
$$\Rightarrow \sigma = \frac{2mg\varepsilon_0}{q} \tan 45^\circ = \frac{2mg\varepsilon_0}{q}$$

- Q15. Consider the normal incidence of a plane electromagnetic wave with electric field given by  $\vec{E} = E_0 \exp[k_1 z - \omega t] \hat{x}$  over an interface at  $z=0$  separating two media [wave velocities  $v_1$  and  $v_2$  ( $v_2 > v_1$ ) and wave vectors  $k_1$  and  $k_2$ , respectively] as shown in figure. The magnetic field vector of the reflected wave is ( $\omega$  is the angular frequency)



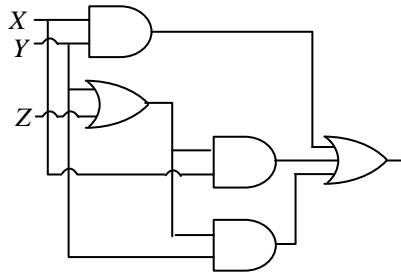
- (a)  $\frac{E_0}{v_1} \exp[i(k_1 z - \omega t)] \hat{y}$                       (b)  $\frac{E_0}{v_1} \exp[i(-k_1 z - \omega t)] \hat{y}$   
 (c)  $\frac{-E_0}{v_1} \exp[i(-k_1 z - \omega t)] \hat{y}$                       (d)  $\frac{-E_0}{v_1} \exp[i(k_1 z - \omega t)] \hat{y}$

Ans. : (c)



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Q16. The output of following logic circuit can be simplified to



- (a)  $X + YZ$                       (b)  $Y + XZ$                       (c)  $XYZ$                       (d)  $X + Y + Z$

Ans. : (b)

$$\begin{aligned} \text{Solution: Output} &= XY + X(Y+Z) + Y(Y+Z) = XY + XY + XZ + Y + YZ \\ &= XY + XZ + Y = Y(1+X) + XZ = Y + XZ \end{aligned}$$

Q17. A red star having radius  $r_R$  at a temperature  $T_R$  and a white star having radius  $r_w$  at a temperature  $T_w$ , radiate the same total power. If these stars radiate as perfect black bodies, then

- (a)  $r_R > r_w$  and  $T_R > T_w$                       (b)  $r_R < r_w$  and  $T_R > T_w$   
(c)  $r_R > r_w$  and  $T_R < T_w$                       (d)  $r_R < r_w$  and  $T_R < T_w$

Ans. : (c)

$$\text{Solution: } E = \sigma AT^4 (\epsilon=1) \Rightarrow \sigma \times 4\pi r_w^2 T_w^4 = \sigma \times 4\pi \times r_R^2 \times T_R^4 \text{ as } r_w < r_R$$

$$T_w = T_R \times \left(\frac{r_R}{r_w}\right)^2 \quad T_w > T_R$$

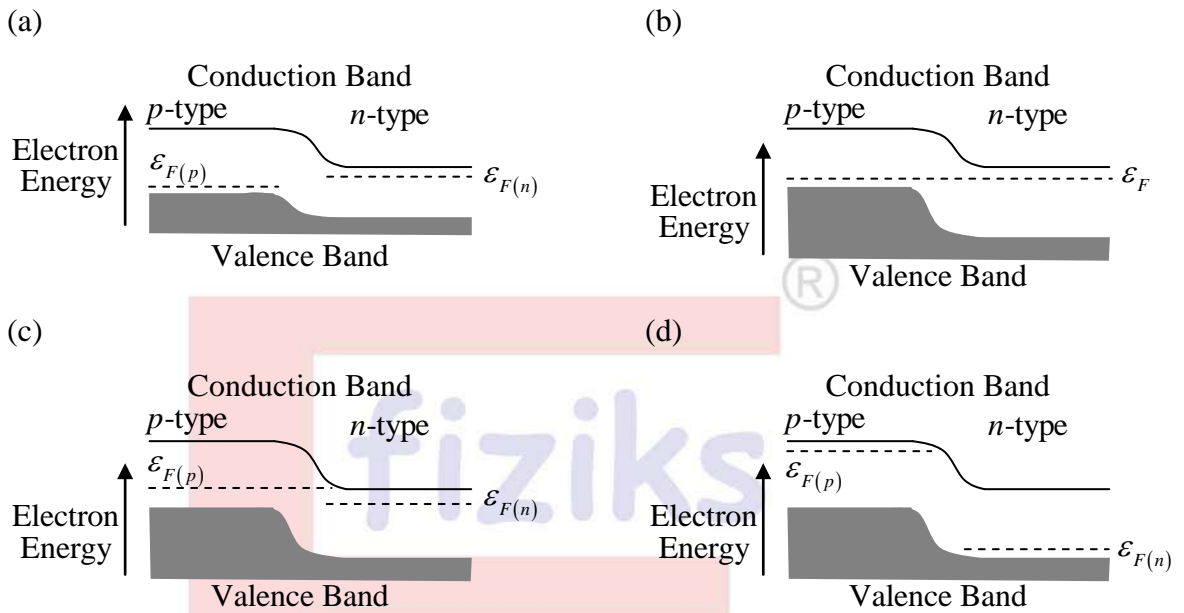
Q18. The mass per unit length of a rod (length 2m) varies as  $\rho = 3x$  kg/m. The moment of inertia (in  $\text{kg m}^2$ ) of the rod about a perpendicular-axis passing through the tip of the rod (at  $x=0$ )

- (a) 10                      (b) 12                      (c) 14                      (d) 16

Ans. : (b)

$$\text{Solution: } I = \int_0^l x^2 \rho dx = \int_0^2 x^2 3x dx = \frac{3x^4}{4} \Big|_0^2 = 12$$

Q19. For a forward biased p-n junction diode, which one of the following energy-band diagrams is correct ( $\epsilon_F$  is the Fermi energy)



Ans. : (a)

Q20. The amount of work done to increase the speed of an electron from  $c/3$  to  $2c/3$  is ( $c = 3 \times 10^8$  m/s and rest mass of electron is 0.511 MeV)

- (a) 56.50 keV      (b) 143.58 keV      (c) 168.20 keV      (d) 511.00 keV

Ans. : (b)

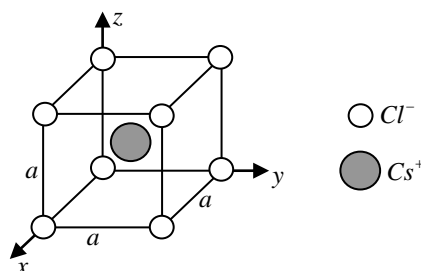
Solution: Change in kinetic energy is equal to work done

$$W = \left( \frac{m_0 c^2}{\sqrt{1 - \frac{v_2^2}{c^2}}} - m_0 c^2 \right) - \left( \frac{m_0 c^2}{\sqrt{1 - \frac{v_1^2}{c^2}}} - m_0 c^2 \right) = \frac{m_0 c^2}{\sqrt{1 - \frac{v_2^2}{c^2}}} - \frac{m_0 c^2}{\sqrt{1 - \frac{v_1^2}{c^2}}}$$

put  $v_1 = c/3, v_2 = 2c/3, m_0 c^2 = 0.511$

$$W = 143.58 \text{ keV}$$

Q21. The location of  $\text{Cs}^+$  and  $\text{Cl}^-$  ions inside the unit cell of  $\text{CsCl}$  crystal is shown in the figure. The Bravais lattice of  $\text{CsCl}$  is





- (a) Simple cubic (b) Body centred orthorhombic  
(c) Face centred cubic (d) Base centred orthorhombic

Ans. : (a)

Solution: Cesium-Chloride is made of two interpenetrating simple cubic lattices are displaced diagonally by half of the diagonal length. Thus, Bravais lattice of  $CsCl$  is simple cubic. The correct option is (a).

- Q22. A  $\gamma$ -ray photon emitted from a  $^{137}\text{Cs}$  source collides with an electron at rest. If the Compton shift of the photon is  $3.25 \times 10^{-13} \text{ m}$ , then the scattering angle is closest to (Planck's constant  $h = 6.626 \times 10^{-34} \text{ Js}$ , electron mass  $m_e = 9.109 \times 10^{-31} \text{ kg}$  and velocity of light in free space  $c = 3 \times 10^8 \text{ m/s}$ )

- (a)  $45^\circ$  (b)  $60^\circ$  (c)  $30^\circ$  (d)  $90^\circ$

Ans. : (c)

$$\text{Solution: } \Delta\lambda = \frac{h}{m_e c} (1 - \cos\theta) \Rightarrow \cos\theta = 1 - \frac{\Delta\lambda \cdot m_e c}{h}$$

$$= 1 - \frac{3.25 \times 10^{-13} \times 9.109 \times 10^{-31} \times 3 \times 10^8}{6.6 \times 10^{-34}} = 0.866 = \frac{\sqrt{3}}{2}$$

$$\theta = 30^\circ$$

- Q23. During free expansion of an ideal gas under adiabatic condition, the internal energy of the gas.
- (a) Decreases (b) Initially decreases and then increases  
(c) Increases (d) Remains constant

Ans. : (d)

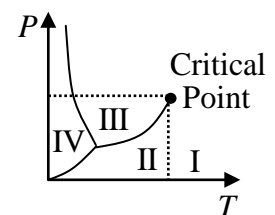
Solution: As  $W = \Delta U + Q$

$$Q = 0 \Rightarrow W = \Delta U$$

Work is done at the expense of internal energy.

- Q24. In the given phase diagram for a pure substance regions I, II, III, IV, respectively represent

- (a) Vapour, Gas, Solid, Liquid  
(b) Gas, Vapour, Liquid, solid  
(c) Gas, Liquid, Vapour, solid  
(d) Vapour, Gas, Liquid, Solid





Ans. : (b)

Solution: IV – Solid

III – Liquid

II – Vapour

I – Gas (superheated dry vapour)

Q25. Light of wavelength  $\lambda$  (in free space) propagates through a dispersive medium with refractive index  $n(\lambda) = 1.5 + 0.6\lambda$ . The group velocity of a wave travelling inside this medium in units of  $10^8$  m/s is

- (a) 1.5                      (b) 2.0                      (c) 3.0                      (d) 4.0

Ans. : (b)

$$\text{Solution: } v_g = \frac{d\omega}{dk} = \frac{d\omega}{d\lambda} \frac{d\lambda}{dk} \quad \because k = \frac{2\pi}{\lambda} \Rightarrow \frac{dk}{d\lambda} = -\frac{2\pi}{\lambda^2}$$

$$\Rightarrow v_g = -\frac{\lambda^2}{2\pi} \frac{d\omega}{d\lambda} = -\frac{\lambda^2}{2\pi} \frac{d}{d\lambda} \left( \frac{c 2\pi}{n\lambda} \right) \quad \because n = \frac{c}{v_p} = \frac{ck}{\omega} \Rightarrow \omega = \frac{c}{n} \frac{2\pi}{\lambda}$$

$$\Rightarrow v_g = -c\lambda^2 \frac{d}{d\lambda} \left( \frac{1}{n\lambda} \right)$$

$$\Rightarrow v_g = c\lambda^2 \frac{d}{d\lambda} (n\lambda) = c\lambda^2 \frac{d}{d\lambda} \left[ \frac{1 \cdot n + \lambda \frac{d}{d\lambda} n}{n^2 \lambda^2} \right] = c \frac{n + \lambda(0.6)}{n^2} = c \frac{1.5 + 1.2\lambda}{(1.5 + 0.6\lambda)^2} \approx \frac{c}{1.5}$$

$$\because \lambda \sim 10^{-7} \text{ m}$$

$$\Rightarrow v_g \approx \frac{2}{3} c \approx 2 \times 10^8$$

Q26. The maximum number of intensity minima that can be observed in the Fraunhofer diffraction pattern of a single slit (width  $10 \mu\text{m}$ ) illuminated by a laser beam (wavelength  $0.630 \mu\text{m}$ ) will be

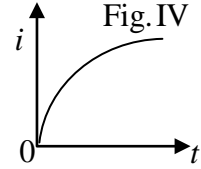
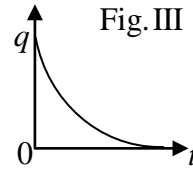
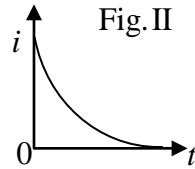
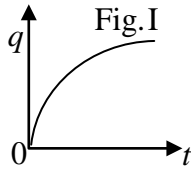
- (a) 4                      (b) 7                      (c) 12                      (d) 15

Ans. : (d)

$$\text{Solution: } e \sin \theta = n\lambda$$

$$n_{\text{max}} = \frac{e}{\lambda} = \frac{10 \mu\text{m}}{0.63 \mu\text{m}} = 15.87 \approx 15$$

- Q27. During the charging of a capacitor  $C$  in a series RC circuit, the typical variations in the magnitude of the charge  $q(t)$  deposited on one of the capacitor plates, and the current  $i(t)$  in the circuit, respectively are best represented by



- (a) Figure I and figure II                      (b) Figure I and Figure IV  
(c) Figure III and figure II                    (d) Figure III and figure IV

Ans. : (a)

- Q28. Which one of the following is an impossible magnetic field  $\vec{B}$  ?

- (a)  $\vec{B} = 3x^2z^2\hat{x} - 2xz^3\hat{z}$                       (b)  $\vec{B} = -2xy\hat{x} + yz^2\hat{y} + \left(2yz - \frac{z^3}{3}\right)\hat{z}$   
(c)  $\vec{B} = (xz + 4y)\hat{x} - yx^3\hat{y} + \left(x^3z - \frac{z^2}{2}\right)\hat{z}$                       (d)  $\vec{B} = -6xz\hat{x} + 3yz^2\hat{y}$

Ans. : (d)

Solution: Check that  $\vec{\nabla} \cdot \vec{B} \neq 0$

- (a)  $\vec{\nabla} \cdot \vec{B} = 6xz^2 - 6xz^2 = 0$   
(b)  $\vec{\nabla} \cdot \vec{B} = -2y + z^2 + (2y - z^2) = 0$   
(c)  $\vec{\nabla} \cdot \vec{B} = z - x^3 + (x^3 - z) = 0$   
(d)  $\vec{\nabla} \cdot \vec{B} = -6z + 3z^2 \neq 0$

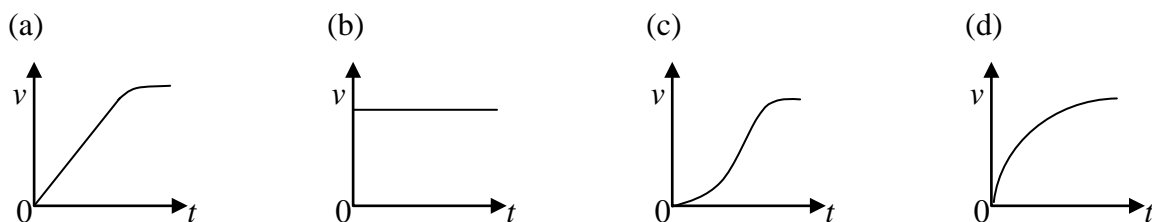
- Q29. If the motion of a particle is described by  $x = 5 \cos(8\pi t)$ ,  $y = 5 \sin(8\pi t)$  and  $z = 5t$ , then the trajectory of the particle is

- (a) Circular                      (b) Elliptical                      (c) Helical                      (d) Spiral

Ans. : (c)

Solution:  $x = 5 \cos(8\pi t)$ ,  $y = 5 \sin(8\pi t)$  and  $z = 5t$ ,  $\Rightarrow x^2 + y^2 = 5^2$ ,  $z = 5t$  motion is Helical

- Q30. A ball of mass  $m$  is falling freely under gravity through a viscous medium in which the drag force is proportional to the instantaneous velocity  $v$  of the ball. Neglecting the buoyancy force of the medium, which one of the following figures best describes the variation of  $v$  as a function of time  $t$  ?



Ans. : (d)

Solution:  $F \propto v$

$$ma = Kv$$

$$\frac{mdv}{dt} = Kv \Rightarrow v \propto t^2$$

### SECTION - B

#### MULTIPLE SELECT QUESTIONS (MSQ)

**Q31. – Q40. carry two marks each.**

Q31. The relation between the nuclear radius ( $R$ ) and the mass number ( $A$ ), given by  $R = 1.2 A^{1/3}$  fm, implies that

- (a) The central density of nuclei is independent of  $A$
- (b) The volume energy per nucleon is a constant
- (c) The attractive part of the nuclear force has a long range
- (d) The nuclear force is charge dependent

Ans. : (a), (b)

Q32. Consider an object moving with a velocity  $\vec{v}$  in a frame which rotates with a constant angular velocity  $\vec{\omega}$ . The Coriolis force experienced by the object is

- (a) Along  $\vec{v}$
- (b) Along  $\vec{\omega}$
- (c) Perpendicular to both  $\vec{v}$  and  $\vec{\omega}$
- (d) always directed towards the axis of rotation

Ans. : (c)

$$\text{Solution: } F_c = -2m(\vec{\omega} \times \vec{v})$$

Q33. The gradient of scalar field  $S(x, y, z)$  has the following characteristic(s)

- (a) Line integral of a gradient is path-independent
- (b) Closed line integral of a gradient is zero
- (c) Gradient of  $S$  is a measure of the maximum rate of change in the field  $S$
- (d) Gradient of  $S$  is a scalar quantity

Ans.: (a), (b), (c)

Q34. A thermodynamic system is described by the  $P, V, T$  coordinates. Choose the valid expression(s) for the system.

$$(a) \left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P = -\left(\frac{\partial P}{\partial T}\right)_V$$

$$(b) \left(\frac{\partial P}{\partial V}\right)_T \left(\frac{\partial V}{\partial T}\right)_P = \left(\frac{\partial P}{\partial T}\right)_V$$

$$(c) \left(\frac{\partial V}{\partial T}\right)_P \left(\frac{\partial T}{\partial P}\right)_V = -\left(\frac{\partial V}{\partial P}\right)_T$$

$$(d) \left(\frac{\partial V}{\partial T}\right)_P \left(\frac{\partial T}{\partial P}\right)_V = \left(\frac{\partial V}{\partial P}\right)_T$$

Ans. : (a), (c)

Q35. Which of the following statement(s) is/are true?

- (a) Newton's laws of motion and Maxwell's equations are both invariant under Lorentz transformations
- (b) Newton's laws of motion and Maxwell's equations are both invariant under Galilean transformations
- (c) Newton's laws of motion are invariant under Galilean transformations and Maxwell's equations are invariant under Lorentz transformations
- (d) Newton's laws of motion are invariant under Lorentz transformations and Maxwell's equations are invariant under Galilean transformations

Ans. : (c)

Q36. For an under damped harmonic oscillator with velocity  $v(t)$

- (a) Rate of energy dissipation varies linearly with  $v(t)$
- (b) Rate of energy dissipation varies as square of  $v(t)$
- (c) The reduction in the oscillator frequency, compared to the undamped case, is independent of  $v(t)$
- (d) For weak damping, the amplitude decays exponentially to zero

Ans. : (b), (c), (d)

Solution: Displacement  $x = Ae^{-rt} \sin(\omega t + \phi)$

$$\text{Velocity } v = \frac{dx}{dt} \cong A\omega e^{-rt} \cos(\omega t + \phi)$$

$$\text{Energy } E = \frac{1}{2}mv^2 + \frac{1}{2}m\omega^2 x^2 = \frac{1}{2}\omega^2 A^2 e^{-2rt}$$

$$\text{Power dissipation, } P = \frac{dE}{dt} = \frac{1}{2}m\omega^2 A^2 e^{-2rt} (-2r)$$

$$P \propto v^2$$

Power dissipation is proportional to  $v^2$ , thus option (a) is wrong and option (b) is correct. Also, displacement  $x = Ae^{-rt} \sin(\omega t + \phi)$  decays exponentially to zero, thus option (d) is also correct.

The damped oscillation frequency is

$$\omega = \sqrt{\omega_0^2 - r^2}$$

It is independent of  $v(t)$ . Thus option (c) is also correct.

Q37. Out of the following statements, choose the correct option(s) about a perfect conductor.

- (a) The conductor has an equipotential surface
- (b) Net charge, if any, resides only on the surface of conductor
- (c) Electric field cannot exist inside the conductor
- (d) Just outside the conductor, the electric field is always perpendicular to its surface

Ans.: (a), (b), (c), (d)

Q38. In the  $X$ -ray diffraction pattern recorded for a simple cubic solid (lattice parameter  $a = 1 \text{ \AA}$ ) using  $X$ -rays of wavelength  $1 \text{ \AA}$ , the first order diffraction peak(s) would appear for the

- (a) (100) planes
- (b) (112) planes
- (c) (210) planes
- (d) (220) planes

Ans. : (a)

Solution: In simple cubic cell, planes are present. The first order diffraction peak would appear for the first plane (100).

$$2d \sin \theta = n\lambda \Rightarrow \sin \theta = \frac{\lambda}{2a} \sqrt{h^2 + k^2 + l^2} = \frac{\lambda}{2} \sqrt{h^2 + k^2 + l^2}$$

$$\Rightarrow \sin \theta = \frac{1}{2} \text{ for (100), } \sin \theta = \frac{\sqrt{6}}{2} \text{ for (112), } \sin \theta = \frac{\sqrt{5}}{2} \text{ for (210) and}$$

$$\sin \theta = \frac{\sqrt{8}}{2} \text{ for (220).}$$

Q39. Consider a classical particle subjected to an attractive inverse-square force field. The total energy of the particle is  $E$  and the eccentricity is  $\varepsilon$ . The particle will follow a parabolic orbit if

- (a)  $E > 0$  and  $\varepsilon = 1$
- (b)  $E < 0$  and  $\varepsilon < 1$
- (c)  $E = 0$  and  $\varepsilon = 1$
- (d)  $E < 0$  and  $\varepsilon = 1$

Ans. : (c)

Solution:  $\varepsilon = \sqrt{1 + \frac{2EJ^2}{mk^2}}$  for parabolic orbit  $E = 0$  and  $\varepsilon = 1$

Q40. An atomic nucleus  $X$  with half-life  $T_X$  decays to a nucleus  $Y$ , which has half-life  $T_Y$ .

The condition (s) for secular equilibrium is (are)

- (a)  $T_X \approx T_Y$                       (b)  $T_X < T_Y$                       (c)  $T_X \ll T_Y$                       (d)  $T_X \gg T_Y$

Ans. : (d)

### SECTION - C

#### NUMERICAL ANSWER TYPE (NAT)

Q41. – Q50. carry one mark each.

Q41. In a typical human body, the amount of radioactive  $^{40}\text{K}$  is  $3.24 \times 10^{-5}$  percent of its mass. The activity due to  $^{40}\text{K}$  in a human body of mass 70 kg is \_\_\_\_\_ kBq.

(Round off to 2 decimal places)

(Half-life of  $^{40}\text{K} = 3.942 \times 10^{16}$  S, Avogadro's number  $N_A = 6.022 \times 10^{23}$  mol $^{-1}$ )

Ans. : 6.0

Solution:  $\left| \frac{dN}{dt} \right| = \lambda N$

$$= \frac{0.693}{3.942 \times 10^{16} \text{ (s)}} \times \frac{(70 \times 10^3)}{40} \times \frac{3.24 \times 10^{-5}}{100} \times 6.022 \times 10^{23}$$

$$= 6.0 \times 10^3 \text{ disintegrations/s} = 6.0 \times 10^3 \text{ Bq}$$

$$= 6.0 \text{ kBq}$$

Q42. Sodium ( $\text{Na}$ ) exhibits body-centred cubic (BCC) crystal structure with atomic radius 0.186 nm. The lattice parameter of  $\text{Na}$  unit cell is \_\_\_\_\_ nm.

Ans. : 0.43

Solution: For BCC,  $\sqrt{3}a = 4r$

$$a = \frac{4r}{\sqrt{3}} = \frac{4 \times 0.186}{\sqrt{3}} \Rightarrow a = 0.43 \text{ nm}$$

Q43. Light of wavelength 680 nm is incident normally on a diffraction grating having 4000 lines/cm. The diffraction angle (in degrees) corresponding to the third-order maximum is \_\_\_\_\_

(Round off to 2 decimal places)

Ans. : 55 $^{\circ}$



Solution:  $(e + d)\sin\theta = n\lambda$

$$\frac{10^{-2}}{4000} \times \sin\theta = 3 \times 680 \times 10^{-9}$$

$$\theta = \sin^{-1}(0.82) \approx 55^\circ$$

- Q44. Two gases having molecular diameters  $D_1$  and  $D_2$  and mean free paths  $\lambda_1$  and  $\lambda_2$ , respectively, are trapped separately in identical containers. If  $D_2 = 2D_1$ , then

$$\frac{\lambda_1}{\lambda_2} = \text{_____}$$

(Assume there is no change in other thermodynamic parameters)

Ans. : 4

Solution:

$$\lambda = \frac{1}{\sqrt{2}\pi d^2 N/V} \Rightarrow \lambda \propto \frac{1}{d^2}$$

$$x \propto \frac{1}{d^2} \Rightarrow \frac{x_1}{x_2} = \left(\frac{d_2}{d_1}\right)^2 = 4$$

- Q45. An object of 2 cm height is placed at a distance of 30 cm in front of a concave mirror with radius of curvature 40 cm. The height of the image is \_\_\_\_\_ cm.

Ans. : 4

Solution:  $u = -30 \text{ cm}$

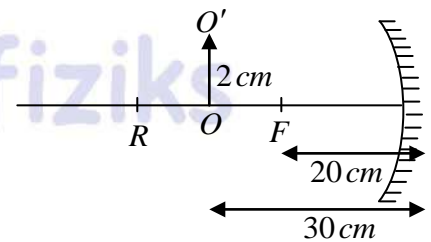
$$f = -20 \text{ cm}$$

$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \Rightarrow \frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-20} - \frac{1}{-30}$$

$$\frac{1}{v} = -\frac{1}{60} \Rightarrow v = -60 \text{ cm}$$

$$m = \frac{I}{O} = -\frac{v}{u}$$

$$I = -\frac{(-60)}{(-30)} \times 2 \text{ cm} = -4 \text{ cm}$$



Learn Physics in Right Way



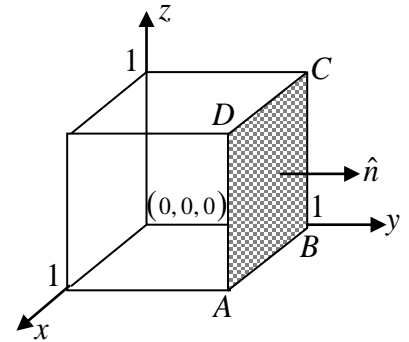
- Q46. The flux of the function  $\vec{F} = (y^2)\hat{x} + (3xy - z^2)\hat{y} + (4yz)\hat{z}$  passing through the surface  $ABCD$  along  $\hat{n}$  is \_\_\_\_\_

(Round off to 2 decimal places)

Ans. : 1.17

Solution:  $y = 1$  plane

$$\begin{aligned} \int_S \vec{F} \cdot d\vec{a} &= \iint \vec{F} \cdot (dx dz \hat{y}) = \iint (3xy - z^2) dx dz \\ &= \int_0^1 \int_0^1 (3x - z^2) dx dz = \int_0^1 \left[ 3xz - \frac{z^3}{3} \right]_{z=0}^1 dx = \int_0^1 \left[ 3z - \frac{1}{3} \right] dx \\ &= \left[ 3 \frac{x^2}{2} - \frac{x}{3} \right]_0^1 = \frac{3}{2} - \frac{1}{3} = \frac{9-2}{6} = \frac{7}{6} = 1.17 \end{aligned}$$



- Q47. The electrostatic energy (in units of  $\frac{1}{4\pi\epsilon_0} J$ ) of a uniformly charged spherical shell of total charge  $5C$  and radius  $4m$  is \_\_\_\_\_. (Round off to 3 decimal places)

Ans.: 3.125

$$\text{Solution: } W = \frac{q^2}{8\pi\epsilon_0 R} = \frac{1}{4\pi\epsilon_0} \frac{q^2}{2R}$$

$$W = \frac{1}{4\pi\epsilon_0} \frac{25}{2 \times 4} \text{ Joules} = \left( \frac{1}{4\pi\epsilon_0} \times 3.125 \right) \text{ Joules}$$

- Q48. An infinitely long very thin straight wire carries uniform line charge density  $8\pi \times 10^{-2} C/m$ . The magnitude of electric displacement vector at a point located 20 mm away from the axis of the wire is \_\_\_\_\_  $C/m^2$ .

Ans. : 2

$$\text{Solution: } \lambda = 8\pi \times 10^{-2} C/m^2, |\vec{E}| = \frac{\lambda}{2\pi\epsilon_0 r} \Rightarrow |\vec{D}| = \epsilon_0 |\vec{E}| = \frac{\lambda}{2\pi r}$$

$$D = \frac{8\pi \times 10^{-2}}{2\pi \times 20 \times 10^{-3}} = \frac{4}{2} C/m^2 = 2 C/m^2$$

- Q49. The 7<sup>th</sup> bright fringe in the Young's double slit experiment using a light of wavelength 550nm shifts to the central maxima after covering the two slits with two sheets of different refractive indices  $n_1$  and  $n_2$  but having same thickness  $6 \mu m$ . The value of  $|n_1 - n_2|$  is \_\_\_\_\_.

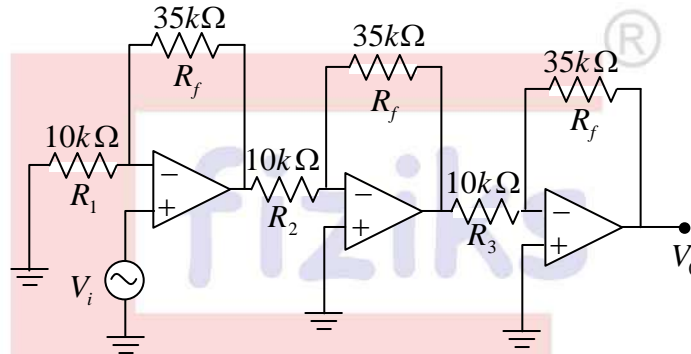
(Round off to 2 decimal places)

Ans. : 0.64

Solution:  $(n_1 - 1)t - (n_2 - 1)t = 7\lambda$

$$(n_1 - n_2) = \frac{7\lambda}{t} = \frac{7 \times 550 \times 10^{-9}}{6 \times 10^{-6}} = 0.64$$

Q50. For the input voltage  $V_i = (200\text{mV})\sin(400t)$ , the amplitude of the output voltage ( $V_o$ ) of the given OPAMP circuit is \_\_\_\_\_ V. (Round off to 2 decimal places)



Ans. : 11.03

$$\text{Solution: } v_{o1} = \left(1 + \frac{35}{10}\right)v_i = (4.5 \times 200\text{mV})\sin(400t)$$

$$v_{o2} = -\frac{35}{10} \times (4.5 \times 200\text{mV})\sin(400t)$$

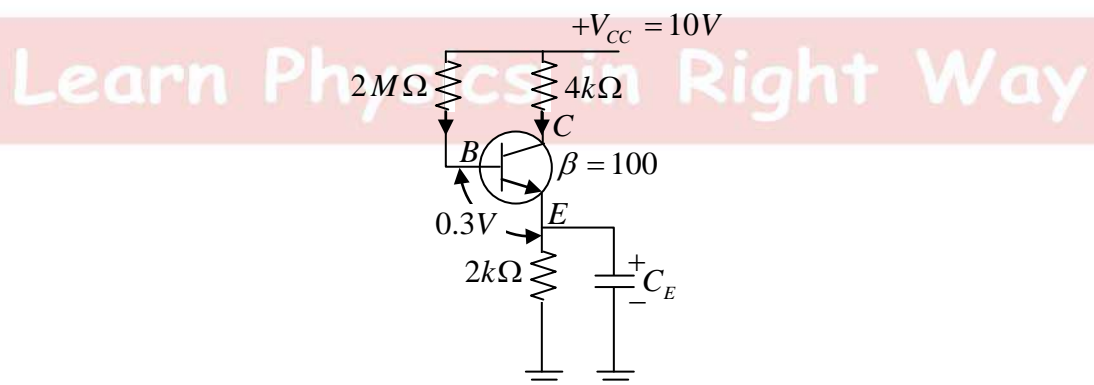
$$v_o = -\frac{35}{10} \times \left(\frac{-35}{10}\right) (4.5 \times 200\text{mV})\sin(400t)$$

$$V_m = (3.5 \times 3.5 \times 4.5 \times 200)\text{mV} = 11.03\text{Volts}$$

Q51. – Q60. carry one mark each.

Q51. The value of emitter current in the given circuit is \_\_\_\_\_  $\mu\text{A}$ .

(Round off to 1 decimal places)



Ans. : 444.9

$$\text{Solution: } I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$$

$$I_B = \frac{10 - 0.3}{2 \times 10^6 + 101 \times 2 \times 10^3} = \frac{9.7}{2.202 \times 10^6} \text{ A}$$

$$I_E = (\beta + 1)I_B = 101 \times \frac{9.7}{2.202} \mu\text{A} = 444.9 \mu\text{A}$$

Q52. The value of  $\left| \int_0^{3+i} (\bar{z})^2 dz \right|^2$ , along the line  $3y = x$ , where  $z = x + iy$  is \_\_\_\_\_

(Round off to 1 decimal places)

Ans. : 111.1

Solution:

$$z = x + iy \Rightarrow z = 3y + iy \quad \because 3y = x$$

$$\bar{z} = x - iy = 3y - iy = (3 - i)y$$

$$dz = 3dy + idy = (3 + i)dy$$

$$\left| \int_0^{3+i} (\bar{z})^2 dz \right|^2 = \left| \int_0^1 (3-i)^2 (3+i)y^2 dy \right|^2 = 1000 \left| \int_0^1 y^2 dy \right|^2 = \frac{1000}{9} \times 1 = 111.11$$

Q53. If the wavelength of  $K\alpha$  X-ray line of an element is  $1.544 \text{ \AA}$ . Then the atomic number ( $Z$ ) of the element is \_\_\_\_\_

(Rydberg constant  $R = 1.097 \times 10^7 \text{ m}^{-1}$  and velocity of light  $c = 3 \times 10^8 \text{ m/s}$ )

Ans. : 29

Solution: According to Mosely's formula, the frequency of  $K\alpha$  X-ray line is related to atomic number by the formula

$$f(K\alpha) = (3.29 \times 10^{15}) \times \frac{3}{4} \times (Z-1)^2 \text{ Hz}$$

$$\text{or } \frac{c}{\lambda} = (3.29 \times 10^{15}) \times \frac{3}{4} \times (Z-1)^2$$

$$\text{or } \frac{3 \times 10^8}{1.544 \times 10^{-10}} = (3.29 \times 10^5) \times \frac{3}{4} \times (Z-1)^2$$

$$\text{Therefore, } Z-1 = 28.06 \text{ or } Z = 29.06$$

Since atomic number must be an integer  $Z = 29$ .

Q54. A proton is confined within a nucleus of size  $10^{-13}$  cm . The uncertainty in its velocity is \_\_\_\_\_  $\times 10^8$  m/s.

(Round off to 2 decimal places)

(Planck's constant  $h = 6.626 \times 10^{-34}$  J and proton mass  $m_p = 1.672 \times 10^{-27}$  kg)

Ans. : 0.31

$$\text{Solution: } \Delta p \Delta x \approx \frac{h}{4\pi}$$

$$\Delta v \approx \frac{h}{4\pi m \Delta x} \approx \frac{6.6 \times 10^{-34}}{4 \times 3.14 \times 1.672 \times 10^{-27} \times (10^{-15})} \approx 0.31 \times 10^8 \text{ m/s}$$

Q55. Given the wave function of a particle  $\psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{\pi}{L}x\right)$   $0 < x < L$  and 0 elsewhere

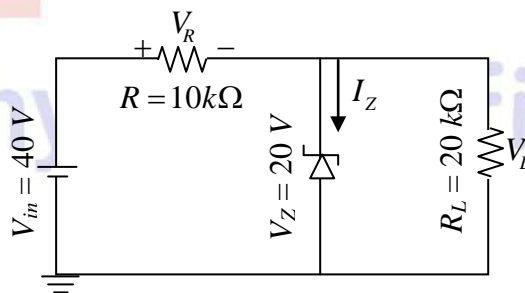
the probability of finding the particle between  $x = 0$  and  $x = \frac{L}{2}$  is \_\_\_\_\_.

(Round off to 1 decimal places)

Ans. : 0.5

$$\text{Solution: } \psi(x) = \sqrt{\frac{2}{L}} \sin\left(\frac{\pi}{L}x\right) \quad 0 < x < L, \quad p\left(0 \leq x \leq \frac{L}{2}\right) = \int_0^{L/2} |\psi|^2 dx = \frac{1}{2}$$

Q56. The Zener current  $I_z$  for the given circuit is \_\_\_\_\_ mA.



Ans. : 1

$$\text{Solution: Open circuit voltage } V_i = \frac{20k}{20k + 10k} \times 40V = \frac{2}{3} \times 40 = 26.7 \text{ Volts}$$

$V_i > V_Z$ , Zener "ON"

$$I_L = \frac{V_Z}{R_L} = \frac{20}{20} = 1 \text{ mA} \quad \text{and} \quad I_R = \frac{40 - 20}{10} = 2 \text{ mA}$$

$$I_Z = I_R - I_L = 1 \text{ mA}$$

Q57. If the diameter of the Earth is increased by 4% without changing the mass, then the length of the day is \_\_\_\_\_ hours.

(Take the length of the day before the increment as 24 hours. Assume the Earth to be a sphere with uniform density)

(Round off to 2 decimal places)

Ans. : 25.95

$$\text{Solution: } I_1\omega_1 = I_2\omega_2 \Rightarrow MR^2 \times \frac{2\pi}{T_1} = M(R + .04R)^2 \times \frac{2\pi}{T_2}$$

$$T_2 = T_1 \times (1.04)^2 = 24 \times (1.04)^2 = 25.95$$

Q58. A di-atomic gas undergoes adiabatic expansion against the piston of a cylinder. As a result, the temperature of the gas drops from 1150 K to 400 K. The number of moles of the gas required to obtain 2300 J of work from the expansion is \_\_\_\_\_. (The gas constant  $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ .)

(Round off to 2 decimal places)

Ans. : 0.1475

Solution:

$$W = \frac{nR(T_2 - T_1)}{1 - \gamma} \quad \text{where } \gamma = \frac{7}{5}$$

$$\Rightarrow 2300 = n \times 8.314 \times \frac{(400 - 1150)}{1 - 1.4} \Rightarrow n = 0.1475$$

Q59. The decimal equivalent of the binary number 110.101 is \_\_\_\_\_.

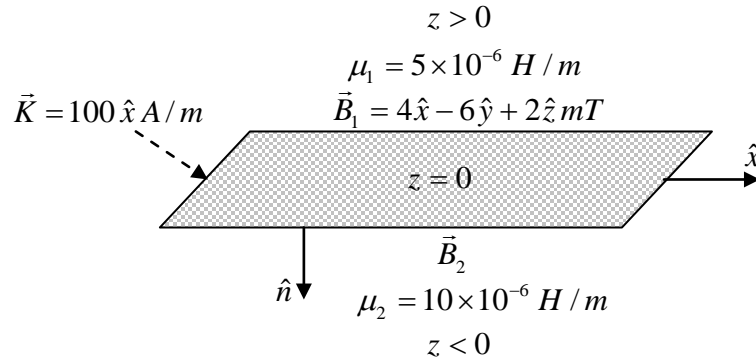
Ans. : 6.625

$$\text{Solution: } 110.101 = 1^2 + 1 \times 2^1 + 0 \times 2^0 + 1 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3}$$

$$= (4 + 2 + 0) \cdot \left( \frac{1}{2} + 0 + \frac{1}{8} \right)$$

$$= 6 \cdot (0.5 + 0 + 0.125) = 6.625$$

Q60. A surface current  $\vec{K} = 100\hat{x} \text{ A/m}$  flows on the surface  $z = 0$ , which separates two media with magnetic permeabilities  $\mu_1$  and  $\mu_2$  as shown in the figure. If the magnetic field in the region 1 is  $\vec{B}_1 = 4\hat{x} - 6\hat{y} + 2\hat{z} \text{ mT}$ , then the magnitude of the normal component of  $\vec{B}_2$  will be \_\_\_\_\_ mT



Ans. : 2

Solution:  $B_2^\perp = B_1^\perp = 2\hat{z}mT$  (Since  $B_1^\perp = 2\hat{z}mT$ )

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