## PAPER : IIT-JAM 2021
**PHYSICS-PH**

1. **Section-A contains 30 Multiple Choice Questions (MCQ). Each question has 4 choices (a), (b), (c) and (d), for its answer, out of which ONLY ONE is correct. From Q.1 to Q.10 carries 1 Marks and Q.11 to Q.30 carries 2 Marks each.**
2. **Section-B contains 10 Multiple Select Questions(MSQ). Each question has 4 choices (a), (b), (c) and (d) for its answer, out of which ONE or MORE than ONE is/are correct. For each correct answer you will be awarded 2 marks.**
3. **Section-C contains 20 Numerical Answer Type (NAT) questions. From Q.01 to Q.10 carries 1 Mark each and Q.11 to Q.20 carries 2 Marks each. For each NAT type question, the value of answer in between 0 to 9.**
4. **In all sections, questions not attempted will result in zero mark. In Section–A (MCQ), wrong answer will result in negative marks. For all 1 mark questions, 1/3 marks will be deducted for each wrong answer. For all 2 marks questions, 2/3 marks will be deducted for each wrong answer. In Section–B (MSQ),there is no negative and no partial marking provisions. There is no negative marking in Section–C (NAT) as well.**

## SECTION-A

**Multiple Choice Questions (MCQ)**

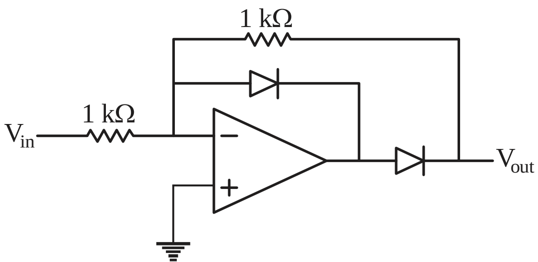
**Q.1 – Q.10 carry one mark each.**

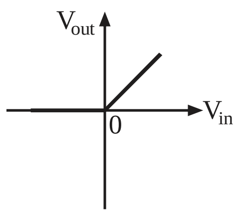
1. A planet is in a highly eccentric orbit about a star. The distance of its closest approach is 300 times smaller than its farthest distance from the star. If the corresponding speeds are $v_c$ and $v_f$, then $v_c/v_f$ is

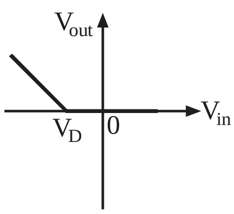
(a) $\frac{1}{300}$ (b) $\frac{1}{\sqrt{300}}$ (c) 300 (d) $\sqrt{300}$



2. For the given circuit, $V_D$ is the threshold voltage of the diode. The graph that best depicts the variation of $V_{out}$ with $V_{in}$ is




(a)



(b)
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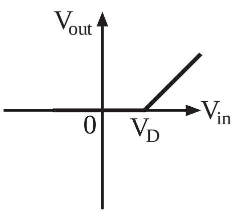
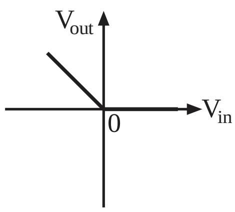



(d)


3. The moment of inertia of a solid sphere (radius $R$ and mass $M$) about the axis which is at a distance of $R/2$ from the center is

(a) $\frac{1}{2}MR^2$ (b) $\frac{13}{20}MR^2$ (c) $\frac{3}{20}MR^2$ (d) $\frac{9}{10}MR^2$

4. Metallic lithium has *bcc* crystal structure. Each unit cell is a cube of side '$a$'. The number of atoms per unit volume is

(a) $\frac{2}{\sqrt{2}a^3}$ (b) $\frac{4}{a^3}$ (c) $\frac{2}{a^3}$ (d) $\frac{1}{a^3}$

5. Let $M$ be a $2 \times 2$ matrix. Its trace is 6 and its determinant has value 8. Its eigenvalues are

(a) 3 and 3 (b) –2 and –3 (c) 2 and 6 (d) 2 and 4

6. Arrange the following telescopes, where $D$ is the telescope diameter and $\lambda$ is the wavelength, in order of decreasing resolving power:

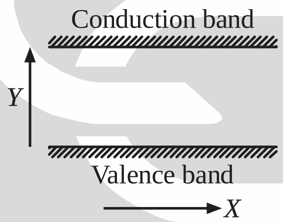
1. $D = 100$ m, $\lambda = 21$ cm
2. $D = 2$ m, $\lambda = 500$ nm
3. $D = 1$ m, $\lambda = 100$ nm
4. $D = 2$ m, $\lambda = 10$ mm

(a) 3, 2, 4, 1 (b) 4, 3, 2, 1 (c) 2, 3, 1, 4 (d) 3, 2, 1, 4

7. The function $e^{\cos x}$ is Taylor expanded about $x = 0$. The co-efficient of $x^2$ is

(a) $e/2$ (b) $-1/2$ (c) Zero (d) $-e/2$

8. For a semiconductor material, the conventional flat band energy diagram is shown in the figure.




The variables $Y, X$, respectively, are

(a) Distance, Energy (b) Momentum, Energy
(c) Energy, Momentum (d) Energy, Distance



9. An experiment with a Michelson interferometer is performed in vacuum using a laser of wavelength 610 nm. One of the beams of the interferometer passes through a small glass cavity 1.3 cm long. After the cavity is completely filled with a medium of refractive index $n$, 472 dark fringes are counted to move past a reference line. Given that the speed of light is $3 \times 10^8$ m/s, the value of $n$ is

(a) 1.01 (b) 1.10 (c) 1.06 (d) 1.04

10. An object of density $\rho$ is floating in a liquid with 75 % of its volume submerged. The density of the liquid is

(a) $\frac{4}{3}\rho$ (b) $\frac{8}{5}\rho$ (c) $\frac{3}{2}\rho$ (d) $2\rho$

**Q.11 – Q.30 carry two marks each.**

11. The solution $y(x)$ of the differential equation $y\frac{dy}{dx} + 3x = 0,\ y(1) = 0$, is described by

(a) a circle (b) a straight line (c) an ellipse (d) a parabola

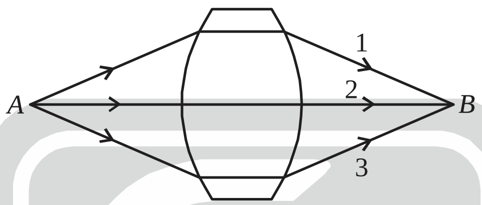
12. A particle, initially at the origin in an inertial frame $S$, has a constant velocity $V\hat{i}$. Frame $S'$ is rotating about the $z$-axis with angular velocity $\omega$ (anticlockwise). The coordinate axes of $S'$ coincide with those of $S$ at $t = 0$. The velocity of the particle $(V_x', V_y')$ in the $S'$ frame, at $t = \frac{\pi}{2\omega}$ is

(a) $\left(\frac{3V\pi}{2}, -V\right)$ (b) $(-V, -V)$ (c) $\left(\frac{V\pi}{2}, -V\right)$ (d) $\left(-\frac{V\pi}{2}, -V\right)$

13. A system undergoes a thermodynamic transformation from state $S_1$ to state $S_2$ via two different paths 1 and 2. The heat absorbed and work done along path 1 are 50 J and 30 J, respectively. If the heat absorbed along path 2 is 30 J, the work done along path 2 is

(a) Zero (b) 10 J (c) 20 J (d) 30 J

14. In the figure below, point $A$ is the object and point $B$ is the image formed by the lens. Let $l_1, l_2$ and $l_3$, denote the optical path lengths of the three rays 1, 2 and 3, respectively. Identify the correct statement.




(a) $l_1 = l_3 < l_2$ (b) $l_1 > l_2 < l_3$ (c) $l_1 = l_2 = l_3$ (d) $l_1 = l_3 > l_2$

15. The condition for maxima in the interference of two waves

$$Ae^{i\left(\frac{k_0}{2}\left(\sqrt{3}x+y\right)-\omega t\right)} \text{ and } Ae^{i\left(\frac{k_0}{\sqrt{2}}(x+y)-\omega t\right)}$$

is given in terms of the wavelength $\lambda$ and $m$, an integer, by

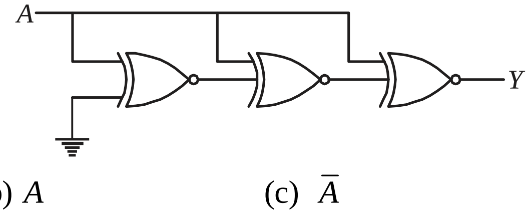
(a) $\left(\sqrt{3}+\sqrt{2}\right)x+\left(1-\sqrt{2}\right)y = 2m\lambda$ (b) $\left(\sqrt{3}-\sqrt{2}\right)x-\left(1-\sqrt{2}\right)y = m\lambda$

(c) $\left(\sqrt{3}-\sqrt{2}\right)x+\left(1-\sqrt{2}\right)y = (2m+1)\lambda$ (d) $\left(\sqrt{3}-\sqrt{2}\right)x+\left(1-\sqrt{2}\right)y = 2m\lambda$

16. The radial component of acceleration in plane polar coordinates is given by

(a) $\frac{d^2r}{dt^2}+r\left(\frac{d\theta}{dt}\right)^2$ (b) $\frac{d^2r}{dt^2}$ (c) $\frac{d^2r}{dt^2}-r\left(\frac{d\theta}{dt}\right)^2$ (d) $2\frac{dr}{dt}\frac{d\theta}{dt}+r\frac{d^2\theta}{dt^2}$

17. For the given circuit, the output $Y$ is




(a) 0 (b) $A$ (c) $\overline{A}$ (d) 1

18. The electric field of an electromagnetic wave has the form $\vec{E} = E_0 \cos(\omega t - kz)\hat{i}$. At $t$ = 0, a test particle of charge $q$ is at $z$ = 0, and has velocity $\vec{v} = 0.5c\hat{k}$, where $c$ is the speed of light. The total instantaneous force on the particle is

(a) $\frac{qE_0}{2}\hat{i}$ (b) Zero (c) $\frac{qE_0}{2}\left(\hat{i} - \hat{k}\right)$ (d) $\frac{qE_0}{\sqrt{2}}\left(\hat{i} + \hat{j}\right)$

19. A linearly polarized light falls on a quarter wave plate and the emerging light is found to be elliptically polarized. The angle between the fast axis of the quarter wave plate and the plane of polarization of the incident light, can be

(a) 180º (b) 90º (c) 45º (d) 30º

20. A thin circular disc lying in the $xy$-plane has a surface mass density $\sigma$, given by

$$\sigma(r) = \begin{cases} \sigma_0\left(1 - \frac{r^2}{R^2}\right) & \text{if} \quad r \le R \\ 0 & \text{if} \quad r > R \end{cases}$$

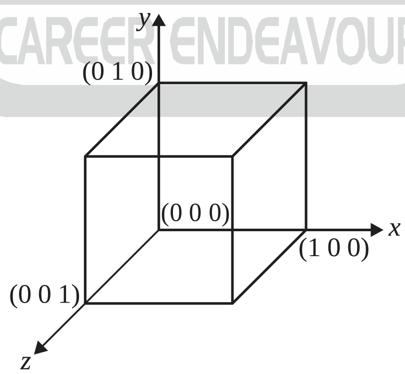
where $r$ is the distance from its center. Its moment of inertia about the $z$-axis, passing through its center is

(a) $\sigma_0 R^4$ (b) $2\pi\sigma_0 R^4$ (c) $\frac{\sigma_0 R^4}{4}$ (d) $\frac{\pi\sigma_0 R^4}{6}$

21. At $t = 0$, $N_0$ number of a radioactive nuclei $A$ start decaying into $B$ with a decay constant $\lambda_a$. The daughter nuclei $B$ decay into nuclei $C$ with a decay constant $\lambda_b$. Then, the number of nuclei $B$ at small time $t$ (to the leading order) is

(a) $\lambda_b N_0 t$ (b) $(\lambda_a - \lambda_b)N_0 t$ (c) $\lambda_a N_0 t$ (d) $(\lambda_a + \lambda_b)N_0 t$

22. The total charge contained within the cube (see figure), in which the electric field is given by $\vec{E} = k\left(4x^2\,\hat{i} + 3y\,\hat{j}\right)$ where $\varepsilon_0$ is the permittivity of free space, is




(a) Zero (b) $7k\varepsilon_0$ (c) $5k\varepsilon_0$ (d) $3k\varepsilon_0$

23. Three events, $E_1(ct = 0, x = 0)$, $E_2(ct = 0, x = L)$ and $E_3(ct = 0, x = -L)$ occur, as observed in an initial frame $S$. Frame $S'$ is moving with a speed $v$ along the positive $x$-direction with respect to $S$. In $S'$, let $t_1', t_2', t_3'$ be the respective times at which $E_1, E_2$ and $E_3$ occured. Then,

(a) $t_3' < t_1' < t_2'$ (b) $t_3' < t_2' < t_1'$ (c) $t_1' = t_2' = t_3'$ (d) $t_2' < t_1' < t_3'$

24. In the Fourier series expansion of two functions $f_1(t) = 4t^2 + 3$ and $f_2(t) = 6t^3 + 7t$ in the interval $-T/2$ to $+T/2$, the Fourier co-efficients $a_n$ and $b_n$ ($a_n$ and $b_n$ are coefficients of $\cos(n\omega t)$ and $\sin(n\omega t)$, respectively) satisfy

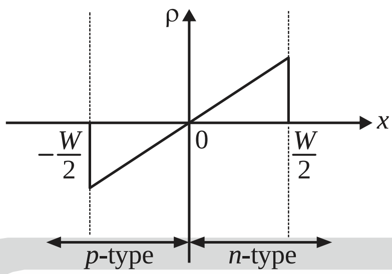
(a) $a_n \neq 0$ and $b_n \neq 0$ for $f_1(t)$; $a_n = 0$ and $b_n \neq 0$ for $f_2(t)$

(b) $a_n \neq 0$ and $b_n = 0$ for $f_1(t)$; $a_n = 0$ and $b_n \neq 0$ for $f_2(t)$

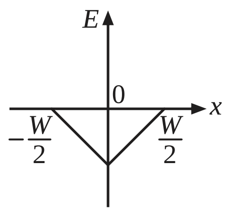
(c) $a_n = 0$ and $b_n \neq 0$ for $f_1(t)$; $a_n \neq 0$ and $b_n \neq 0$ for $f_2(t)$

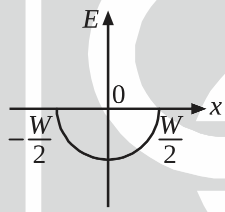
(d) $a_n = 0$ and $b_n \neq 0$ for $f_1(t)$; $a_n \neq 0$ and $b_n = 0$ for $f_2(t)$

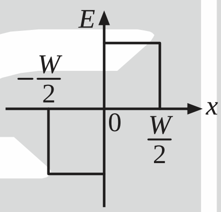
25. A semiconductor *pn* junction at thermal equilibrium has the space charge density $\rho(x)$ profile as shown in the figure.

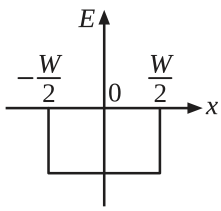



The figure that best depicts the variation of the electric field *E* with *x* is (*W* denotes the width of the depletion layer)

(a) 

(b) 

(c) 

(d) 

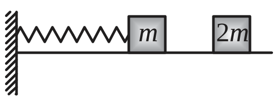

26. Let $(x, y)$ denote the coordinates in a rectangular Cartesian coordinate system $C$. Let $(x', y')$ denote the coordinates in another coordinate system $C'$, defined by $x' = 2x + 3y$, $y' = -3x + 4y$. The area element in $C'$, is

(a) $x'\,dx'\,dy'$ (b) $12\,dx'\,dy'$ (c) $\frac{1}{17}dx'\,dy'$ (d) $dx'\,dy'$

27. The r.m.s. velocity of molecules of oxygen gas is given by *v* at some temperature *T*. The molecules of another gas have the same r.m.s. velocity at temperature *T*/16. The second gas is

(a) Neon (b) Nitrogen (c) Helium (d) Hydrogen

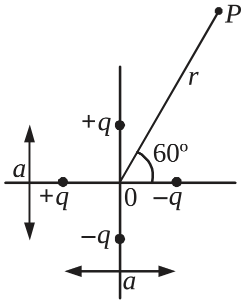
28. A mass *m* is connected to a massless spring of spring constant *k*, which is fixed to a wall. Another mass 2*m*, having kinetic energy *E*, collides collinearly with the mass *m* completely inelastically (see figure).




The entire set up is placed on a frictionless floor. The maximum compression of the spring is

(a) $\sqrt{\frac{E}{5k}}$ (b) $\sqrt{\frac{4}{3}\frac{E}{k}}$ (c) $\sqrt{\frac{E}{3k}}$ (d) $\sqrt{\frac{E}{7k}}$

29. Four charges are placed very close to each other, as shown. The separation between the two charges on the y-axis is '$a$'. The separation between the two charges on the $x$-axis is also '$a$'. The leading order (non-vanishing) form of the electrostatic potential, at point $P$, at a distance '$r$' from the origin $(r \gg a)$, is




(a) $\frac{1}{4\pi\varepsilon_0}\frac{qa}{2r^2}\left(\sqrt{3}-1\right)$ (b) $\frac{1}{4\pi\varepsilon_0}\frac{qa}{r^2}\left(1-\sqrt{3}\right)$

(c) $\frac{1}{4\pi\varepsilon_0}\frac{2qa}{r^2}$ (d) $\frac{1}{4\pi\varepsilon_0}\frac{qa}{r^2}\left(\sqrt{5}-1\right)$

30. The expression for the magnetic field that induces the electric field $\vec{E} = k\left(yz\,\hat{i} + 3z\,\hat{j} + 4y\,\hat{k}\right)\cos(\omega t)$ is

(a) $-\frac{k}{\omega}\left(\hat{i} + y\hat{j} + z\hat{k}\right)\sin(\omega t)$ (b) $-\frac{k}{\omega}\left(-\hat{i} - y\hat{j} + z\hat{k}\right)\sin(\omega t)$

(c) $-\frac{k}{\omega}\left(\hat{i} - y\hat{j} + z\hat{k}\right)\sin(\omega t)$ (d) $-\frac{k}{\omega}\left(\hat{i} + y\hat{j} - z\hat{k}\right)\sin(\omega t)$

## SECTION-B

**Multiple Select Questions (MSQ)**

**Q.1 – Q.10 carry TWO marks each.**

1. A Carnot engine operates between two temperatures, $T_L = 100$ K and $T_H = 150$ K. Each cycle of the engine lasts for 0.5 seconds during which the power delivered is 500 J/second. Let $Q_H$ be the corresponding heat absorbed by the engine and $Q_L$ be the heat lost. Identify the correct statement(s).

(a) $\frac{Q_H}{Q_L} \le \frac{2}{3}$

(b) The change in entropy of the engine and the hot bath in a cycle is 5 J/K.

(c) $Q_H = 750$ J

(d) The change in entropy of the engine in 0.5 seconds is zero.

2. Consider the following differential equation that describes the oscillations of a physical system:

$$\alpha\frac{d^2y}{dt^2} + \beta\frac{dy}{dt} + \gamma y = 0$$

If $\alpha$ and $\beta$ are held fixed, and $\gamma$ is increased, then,

(a) the frequency of oscillations increases. (b) the frequency of oscillations decreases.

(c) the oscillations decay slower. (d) the oscillations decay faster.

3. An isolated ideal gas is kept at a pressure $P_1$ and volume $V_1$. The gas undergoes free expansion and attains a pressure $P_2$ and volume $V_2$. Identify the correct statement(s). $\left(\gamma = \dfrac{C_P}{C_V}\right)$

(a) $P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$ (b) This is an adiabatic process

(c) $P_1 V_1 = P_2 V_2$ (d) This is an isobaric process

4. A time dependent conservative force $\vec{F}$ has the form, $\vec{F} = 3y\,\hat{i} + f(x, y)\,\hat{j}$. Its magnitude at $x = y = 0$ is 8. The allowed form(s) of $f(x, y)$ is/are:

(a) $3x + 8$ (b) $3x + 8e^{-y^2}$ (c) $2x + 8\cos y$ (d) $2x + 8(y-1)^2$

5. A particle of mass *m* is in an infinite square well potential of length *L*. It is in a superposed state of the first two energy eigenstates, as given by $\psi(x) = \dfrac{1}{\sqrt{3}}\psi_{n=1}(x) + \sqrt{\dfrac{2}{3}}\psi_{n=2}(x)$. Identify the correct statement(s).
(*h* is Plancks's constant)

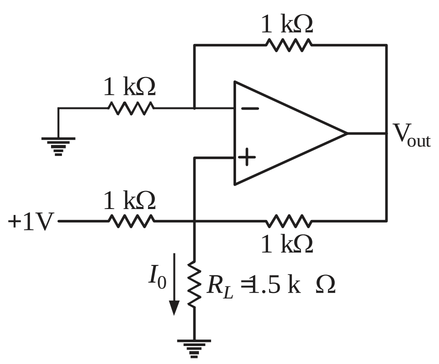
(a) $\langle E \rangle = \dfrac{3h^2}{8mL^2}$ (b) $\Delta p = \dfrac{\sqrt{3}h}{2L}$ (c) $\Delta x = 0$ (d) $\langle p \rangle = 0$

6. A gaseous system, enclosed in an adiabatic container, is in equilibrium at pressure $P_1$ and volume $V_1$. Work is done on the system in a quasi-static manner due to which the pressure and volume change to $P_2$ and $V_2$, respectively, in the final equilibrium state. At every instant, the pressure and volume obey the condition $PV^{\gamma} = C$, where $\gamma = \dfrac{C_P}{C_V}$ and *C* is a constant. If the work done is zero, then identify the correct statement(s).

(a) $P_2 V_2 = (\gamma + 1) P_1 V_1$ (b) $P_2 V_2 = \gamma P_1 V_1$

(c) $P_2 V_2 = (\gamma - 1) P_1 V_1$ (d) $P_2 V_2 = P_1 V_1$

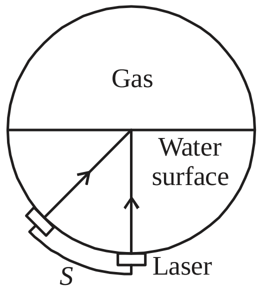
7. For the given circuit, identify the correct statement(s):




(a) $I_0 = 1\,\text{mA}$ (b) $V_0 = 3\,\text{V}$

(c) If $R_L$ is doubled, $V_0$ will change to 6 V (d) If $R_L$ is doubled, $I_0$ will change to 0.5 mA

8. The figure shows the cross-section of a hollow cylindrical tank, 2.2 m in diameter, which is half filled with water (refractive index of 1.33). The space above the water is filled with a gas of unknown refractive index. A small laser moves along the bottom surface and aims a light beam towards the center (see figure).




When the laser moves a distance of $S = 1.09$ m or beyond from the lowest point in the water, no light enters the gas. Identify the correct statement(s) (speed of light is $3 \times 10^8$ m/s).

(a) The refractive index of the gas is 1.05.

(b) The time taken for the light beam to travel from the laser to the rim of the tank when $S < 1.09$ m is 8.9 ns.

(c) The critical angle for the water-gas interface is 56.77°.

(d) The time taken for the light beam to travel from the laser to the rim of the tank when $S > 1.09$ m is 9.7 ns.

9. Identify the CORRECT statement(s) regarding nuclei.

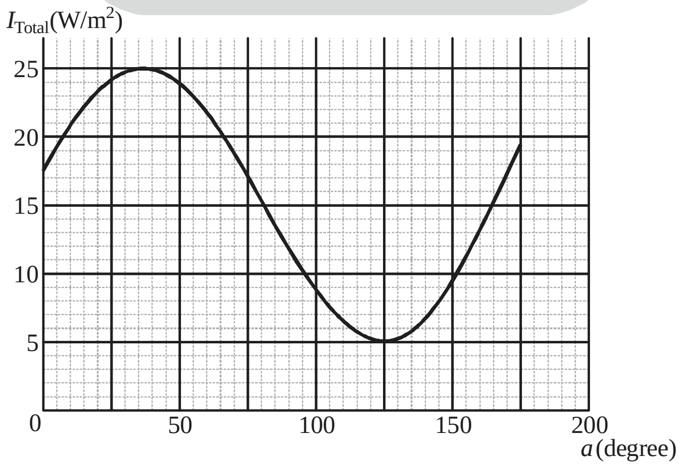
(a) The energy of $\gamma$ rays due to de-excitation of a nucleus can be of the order of MeV.

(b) The uncertainty in the momentum of a proton in a nucleus is roughly $10^5$ times the uncertainty in the momentum of the electron in the ground state of Hydrogen atom.

(c) The volume of a nucleus grows linearly with the number of nucleons in it

(d) $^{56}Fe$ is the most stable nucleus.

10. A beam of light traveling horizontally consists of an unpolarized component with intensity $I_0$ and a polarized component with intensity $I_p$. The plane of polarization is oriented at an angle $\theta$ with respect to the vertical. The figure shows the total intensity $I_{\text{Total}}$ after the light passes through a polarizer as a function of the angle $a$, that the axis of the polarizer makes with respect to the vertical. Identify the correct statement(s).




(a) $I_0 = 10\ \text{W/m}^2$; $I_p = 20\ \text{W/m}^2$

(b) $I_0 = 17.5\ \text{W/m}^2$

(c) $\theta = 125°$

(d) $I_p = 5\ \text{W/m}^2$

## SECTION-C

**Numerical Answer Type (NAT)**

**Q.1 – Q.10 carry ONE mark each.**

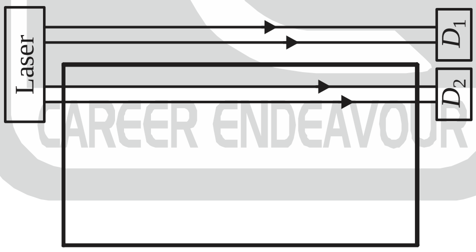
1. A particle with positive charge $10^{-3}$ C and mass 0.2 kg is thrown upwards from the ground at an angle 45° with the horizontal with a speed of 5 m/s. The projectile moves through a horizontal electric field of 10 V/m, which is in the same direction as the horizontal component of the initial velocity of the particle. The acceleration due to gravity is 10 m/s$^2$. The range is _______ m. (Round off to three decimal places).

2. A small conducting square loop of side $l$ is placed inside a concentric large conducting square loop of side $L(L \gg \ell)$. The value of mutual inductance of the system is expressed as $\frac{n\mu_0 l^2}{\pi L}$. The value of $n$ is _______. (Round off to two decimal places)

3. A particle is moving with a velocity $0.8c\hat{j}$ ($c$ is the speed of light) in an inertial frame $S_1$. Frame $S_2$ is moving with a velocity $0.8c\hat{i}$ with respect to $S_1$. Let $E_1$ and $E_2$ be the respective energies of the particle in the two frames. Then, $E_2/E_1$ is ________. (Round off to two decimal places)

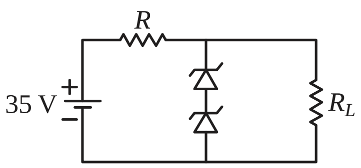
4. A crystal has monoclinic structure, with lattice parameters, $a$ = 5.14 Å, $b$ = 5.20 Å, $c$ = 5.30 Å and angle $\beta = 99^\circ$. It undergoes a phase transition to tetragonal structure with lattice parameters, $a$ =$b$= 5.09 Å and $c$ = 5.27 Å The fractional change in the volume $|\Delta V/V|$ of the crystal due to this transition is ________. (Round off to two decimal places)

5. A laser beam shines along a block of transparent material of length 2.5 m. Part of the beam goes to the detector $D_1$ while the other part travels through the block and then hits the detector $D_2$. The time delay between the arrivals of the two light beams is inferred to be 6.25 ns. The speed of light $c = 3 \times 10^8$ m/s. The refractive index of the block is _______. (Round off to two decimal places).




6. One of the roots of the equation, $z^6 - 3z^4 - 16 = 0$ is given by $z_1 = 2$. The value of the product of the other five roots is _______.

7. The following Zener diode voltage regulator circuit is used to obtain 20 V regulated output at load resistance $R_L$ from a 35 V dc power supply. Zener diodes are rated at 5 W and 10 V. The value of the resistance $R$ is _______ Ω.



8. Consider $N_1$ number of ideal gas particles enclosed in a volume $V_1$. If the volume is changed to $V_2$ and the number of particles is reduced by half, the mean free path becomes four times of its initial value. The ratio $V_1/V_2$ is ________. (Round off to one decimal place).

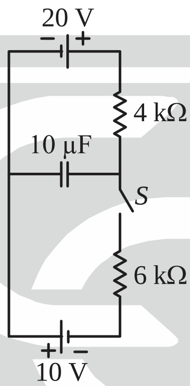
9. At some temperature $T$, two metals $A$ and $B$, have Fermi energies $\varepsilon_A$ and $\varepsilon_B$, respectively. The free electron density of $A$ is 64 times that of $B$. The ratio $\varepsilon_A/\varepsilon_B$ is ________.

10. An ideal black-body at temperature $T$, emits radiation of energy density $u$. The corresponding value for a material at temperature $\frac{T}{2}$ is $\frac{u}{256}$. Its emissivity is ________. (Round off to three decimal places).

**Q.11 – Q.20 carry TWO marks each.**

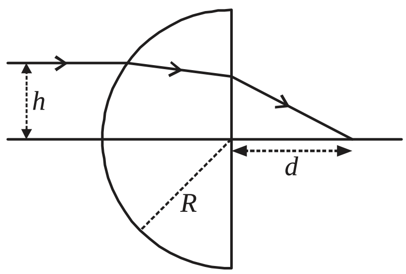
11. A current $I$ is uniformly distributed across a long straight non-magnetic wire $(\mu_r = 1)$ of circular cross-section with radius '$a$'. Two points $P$ and $Q$ are at distances $a/3$ and $9a$, respectively, from the axis of the wire. The ratio of the magnetic fields at points $P$ and $Q$ is _________.

12. An $RC$ circuit is connected to two dc power supplies, as shown in the figure.



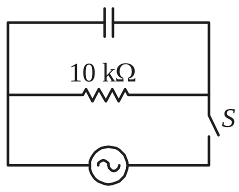

With switch $S$ open, the capacitor is fully charged, $S$ is then closed at time $t$ = 0. The voltage across the capacitor at $t$ = 2.4 milliseconds is ________ V. (Round off to one decimal place).

13. Consider a hemispherical glass lens (refractive index is 1.5) having radius of curvature $R$ =12 cm for the curved surface. An incoming ray, parallel to the optical axis, is incident on the curved surface at a height $h$ = 1 cm above the optical axis, as shown in the figure.




The distance $d$ (from the flat surface of the lens) at which the ray crosses the optical axis is _________ cm. (Round off to two decimal places)

14. A parallel plate capacitor having plate area of 50 cm$^2$ and separation of 0.1 mm is completely filled with a dielectric (dielectric constant $K = 10$). The capacitor is connected to a 10 k$\Omega$ resistance and an alternating voltage $v = 10\sin(100\pi t)$, as shown in the figure.




The switch $S$ is initially open and then closed at $t = 0$. The ratio of the displacement current in the capacitor, to the current in the resistance, at time $t = \frac{2}{\pi}$ seconds is ________. (Round off to three decimal places)

15. Twenty non-interacting spin 1/2 particles are trapped in a three-dimensional simple harmonic oscillator potential of frequency $\omega$. The ground state energy of the system, in units of $\hbar\omega$, is ________.

16. In an X-ray diffraction experiment with Cu crystals having lattice parameter 3.61 Å, X-rays of wavelength of 0.090 nm are incident on the family of planes {1 1 0}. The highest order present in the diffraction pattern is _________.

17. A thin film of alcohol is spread over a surface. When light from a tunable source is incident normally, the intensity of reflected light at the detector is maximum for $\lambda$ = 640 nm and minimum for $\lambda$ = 512 nm. Taking the refractive index of alcohol to be 1.36 for both the given wavelengths, the minimum thickness of the film would be ________ nm. (Round off to two decimal places).

18. A particle $A$ of mass $m$ is moving with a velocity $v\hat{i}$, and collides elastically with a particle $B$, of mass $2m$. $B$ is initially at rest. After collision, $A$ moves with a velocity $v_A\hat{j}$. If $v_B$ is the final speed of $B$, then $v_A^2 = kv_B^2$. The value of $k$ is ________.

19. For the Boolean expression $Y = ABC + \bar{A}\bar{B}C + \bar{A}B\bar{C} + A\bar{B}\bar{C}$, the number of combinations for which the output $Y = 1$ is ________.

20. The wavelength of characteristic $K_\alpha$ X-ray photons from Mo (atomic number 42) is ________ Å. (Speed of light is $3 \times 10^8$ m/s; Rydberg constant $R = 1.09 \times 10^7$/m) (Round off to one decimal place).