Physics by fiziks

Learn Physics in Right Way

CSIR NET-JRF Physical Sciences

Question Paper December 2023

Be Part of Disciplined Learning

PART A

Q1. All the four entries in column A must be matched with all those in column B. Each correctly matched option gets one mark and no mark is awarded otherwise. Which of the following mark(s) CANNOT be scored?

(1) 3 (2) 1 (3) 2 (4) 4

Ans: (1)

Q2. Four children had 27 apples among them. No child had less than 5 apples. If no two children had the same number of apples, then which of the following could NOT be the number of apples a child had?

(1) 5 (2) 6 (3) 8 (4) 9

Ans: (3)

Q3. In 1979, Ramesh's age was the sum of the digits of his year of birth. In 2017, on his birthday, what was his age?

(1) 49 (2) 57 (3) 60 (4) 64

Ans: (3)

Q4. If $a < x < b$, then for which of the following relations does $0 < y < 1$ always hold?

1. $y = \frac{a-x}{b+a}$ 2. $y = \frac{x-a}{b-a}$ 3. $y = \frac{x-b}{b-a}$ 4. $y = \frac{b-x}{a+b}$

Ans: (2)

Q5. A person's viral load measured in some unit was 15, 25, 50, 200, 300, 150 and 30 on days 1 to 7, respectively. The maximum relative change took place between

1. day 3 to day 4
2. day 4 to day 5
3. day 5 to day 6
4. day 6 to day 7

Ans: (1)

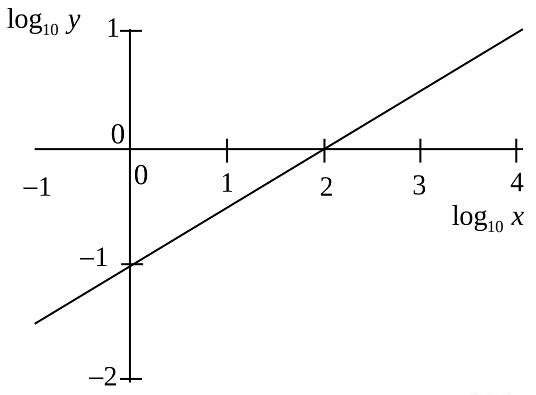
Q6. What is the value of x in the given magic square, (i.e, a square grid in which the sum of the numbers in rows, columns and diagonals is the same)?

x	$x-5$	8
$x+1$	y	$y-2$
2	9	4

(1) 6 (2) 4 (3) 3 (4) 1

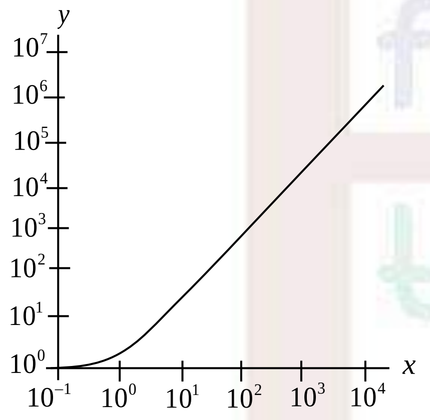
Ans: (1)

Q7. In the figure $\log_{10} y$ is plotted against $\log_{10} x$

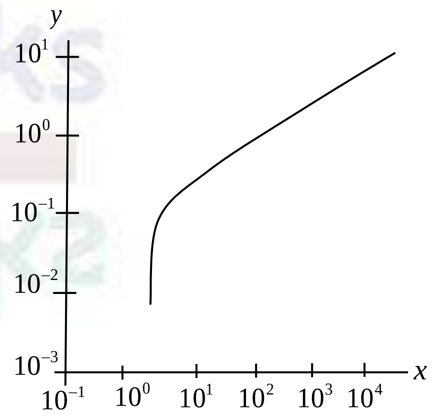


When y is plotted against x, then the plot in the provided range is

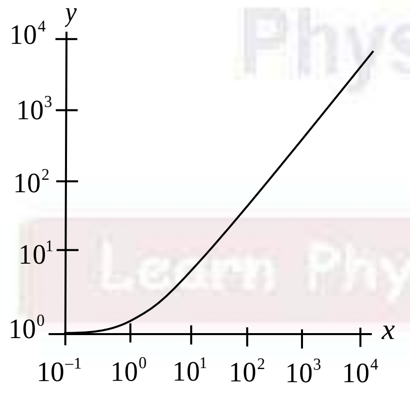
(A)



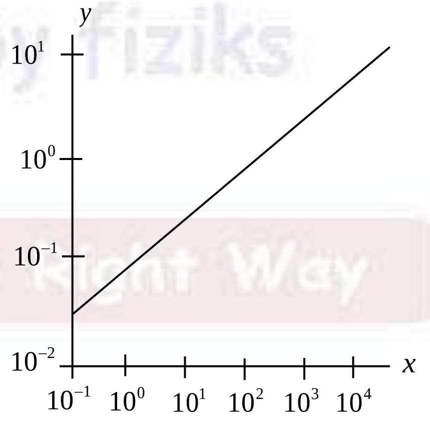
(B)



(C)



(D)



(1) A (2) B (3) C (4) D

Ans: (1)

Q8. Radius of sphere is measured with 5% uncertainty. What is the uncertainty in the volume, determined from this radius?

(1) 5% (2) 6.6% (3) 125% (4) 15%

Ans: (4)

Q9. In a market, you can buy a mango for Rs. 10, a lemon for Re. 1 and 8 chillies for Re.1. How many of these items do you need to buy to get a mix of 100 items for exactly Rs. 100?

(1) 6 mangoes, 22 lemons, 72 chillis (2) 7 mangoes, 21 lemons, 72 chillis

(3) 1 mango, 9 lemons, 80 chillis (4) 8 mangoes, 12 lemons, 80 chillis

Ans: (2)

Q10. A letter is drawn at random from the following string of letters.

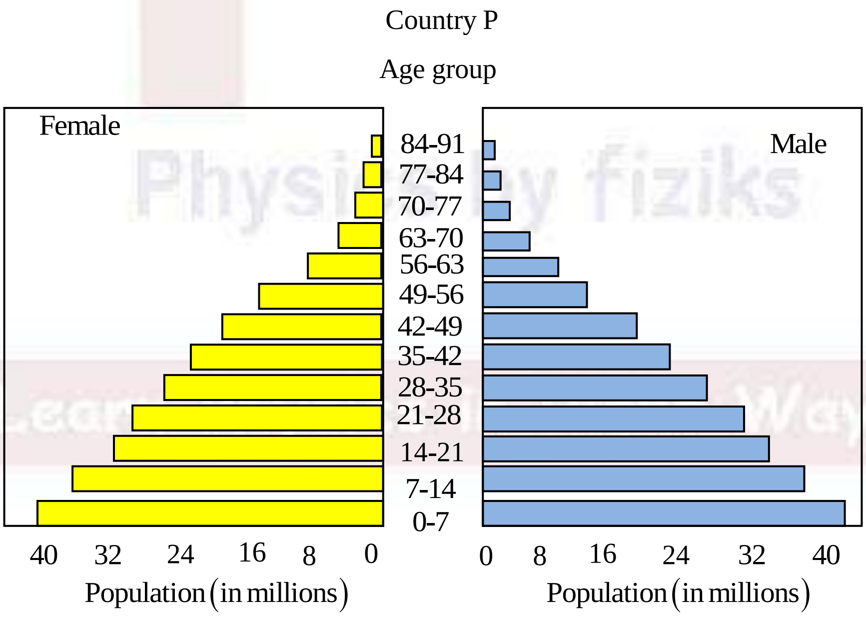
R A M U K Y A J N A S

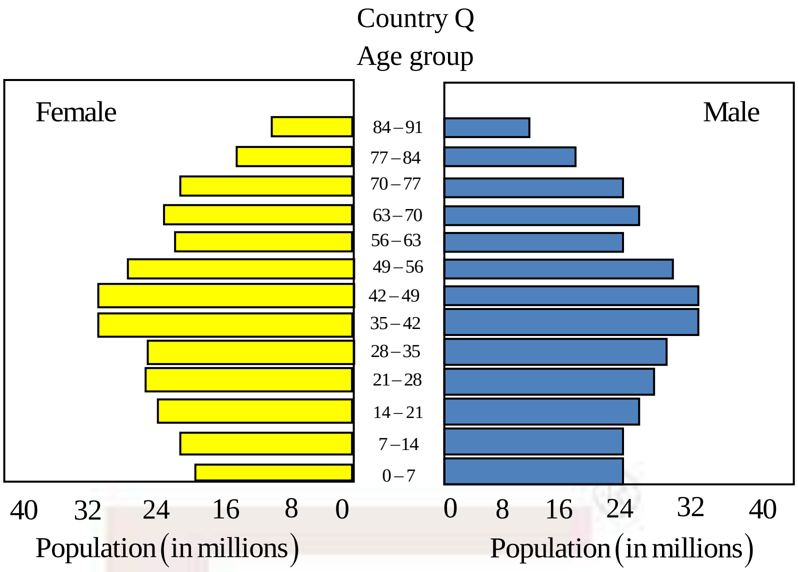
What is the probability that it is NOT a vowel?

(1) 1/2 (2) 6/11 (3) 7/11 (4) 8/11

Ans: (3)

Q11. The figure shows age-wise bar graph of male and female population of two countries. Which one of the following is likely to be true?





1. Country Q has higher life expectancy
2. Country P has higher per-capita income
3. The population of country P is decreasing more rapidly than Q
4. Country P has better health facilities

Ans: (1)

Q12. What is the minimum number of pourings needed to get 4 litre of milk from a fully filled 8 litre can, using ungraduated empty 5 and 3 litre cans? No milk should be wasted.

(1) 4 (2) 5 (3) 6 (4) 8

Ans: (3)

Q13. In how many ways can a menu be made from 5 dishes, if the menu contains either 3 or 4 dishes?

(1) 2 (2) 3 (3) 7 (4) 15

Ans: (4)

Q14. SCRIPT : DIRECTOR :: ?? : CHEF

Choose the most appropriate option from the following to fill the blank

(1) MENU (2) RECIPE
(3) RESTAURANT (4) MEAL

Ans: (2)

Q15. The sum of the two positive integers is 14. Then their product CANNOT be divisible by

(1) 12 (2) 13 (3) 14 (4) 49

Ans: (3)

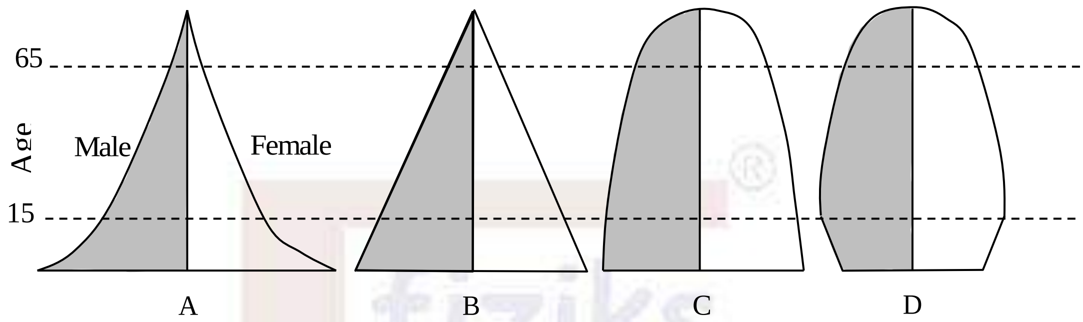
Q16. The time seen in a mirror placed opposite a numberless analog (with hands) wall clock is 4h 55min. What approximately is the correct time?

(1) 4 h 55 min (2) 5 h 05 min

(3) 7 h 05 min (4) 1 h 35 min

Ans: (3)

Q17.



The above figures show population pyramids to four countries A, B, C and D. The country showing the most stable population is

(1) C (2) A (3) B (4) D

Ans: (1)

Q18. For every 5 chocolates that Ramesh gets, Suresh gets 3 chocolates. Geeta gets 3 chocolates for every 2 chocolates that Suresh gets. If Geeta has 18 chocolates, then the sum of chocolates with Ramesh and Suresh is

(1) 16 (2) 30 (3) 32 (4) 38

Ans: (3)

Q19. A truck from a post office is sent to collect post from a plane as per schedule. The plane lands ahead of schedule, therefore its contents are transported by a rickshaw. The rickshaw meets the truck 30 minutes after the arrival of plane, and the post is transferred. The truck returns to the post office 20 minutes early. How early did the plane arrive? (Assume all transactions are instantaneous).

(1) 10 minutes (2) 20 minutes

(3) 30 minutes (4) 40 minutes

Ans: (4)

Q20. A bird keeps flying continuously between two trains, that are following each other on a straight track. The train behind is slower than the one ahead by 1.5 km/h. If the speed of the bird is 20 km/h, what distance would the bird cover in an hour?

(1) 20 km (2) 30 km (3) 50 km (4) 60 km

Ans: (3)

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PART B

Q1. Four distinguishable particle fill up energy levels $0, \in, 2\in$. The number of available microstates for the total energy $4\in$ is

(1) 20 (2) 24 (3) 11 (4) 19

Ans: (4)

Q2. A particle moves in a circular orbit under a force field given by $\vec{F}(\vec{r}) = -\frac{k}{r^2}\hat{r}$, where k is a positive constant. If the force changes suddenly to $\vec{F}(\vec{r}) = -\frac{k}{2r^2}\hat{r}$, the shape of the new orbit would be

(1) parabolic (2) circular (3) elliptical (4) hyperbolic

Ans: (1)

Q3. Let M be a 3×3 real matrix such that $e^{M\theta} = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$

where θ is a real parameter. Then M is given by

(1) $\begin{bmatrix} -1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (2) $\begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (3) $\begin{bmatrix} 0 & 0 & 1 \\ 0 & -1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (4) $\begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

Ans: (2)

Q4. If z is a complex number, which among the following sets is neither open nor closed?

(1) $\{z \mid 0 \le |z-1| \le 2\}$ (2) $\{z \mid |z| \le 1\}$

(3) $\{z \mid z \in (\mathbf{C} - \{3\}) \text{ and } |z| \le 100\}$ (4) $\left\{z \mid z = re^{i\theta}, 0 \le \theta \le \frac{\pi}{4}\right\}$

Ans: (3)

Q5. A classical ideal gas is subjected to a reversible process in which its molar specific heat changes with temperature T as $C(T) = C_V + R\frac{T}{T_0}$. If the initial temperature and volume are T_0 and V_0 respectively, and the final volume is $2V_0$, then the final temperature is

(1) $T_0/\ln 2$ (2) $2T_0$ (3) $T_0/[1-\ln 2]$ (4) $T_0[1+\ln 2]$

Ans: (4)

Q6. A quantum system is described by the Hamiltonian

$$H = JS_z + \lambda S_x$$

where $S_i = \frac{\hbar}{2}\sigma_i$ and $\sigma_i\,(i = x, y, z)$ are the Pauli matrices. If $0 < \lambda << J$, then the leading correction in λ to the partition function of the system at temperature T is

(1) $\frac{\hbar\lambda^2}{2Jk_BT}\coth\left(\frac{J\hbar}{2k_BT}\right)$

(2) $\frac{\hbar\lambda^2}{2Jk_BT}\tanh\left(\frac{J\hbar}{2k_BT}\right)$

(3) $\frac{\hbar\lambda^2}{2Jk_BT}\cosh\left(\frac{J\hbar}{2k_BT}\right)$

(4) $\frac{\hbar\lambda^2}{2Jk_BT}\sinh\left(\frac{J\hbar}{2k_BT}\right)$

Ans: (4)

Q7. In the measurement of a radioactive sample, the measured counts with and without the sample for equal time intervals are $C = 500$ and $B = 100$, respectively. The errors in the measurements of C and B are $|\Delta C| = 20$ and $|\Delta B| = 10$, respectively. The net error $|\Delta Y|$ in the measured counts from the sample $Y = C - B$, is closet to

(1) 22 (2) 10 (3) 30 (4) 43

Ans: (1)

Q8. The normalized wave function of an electron is

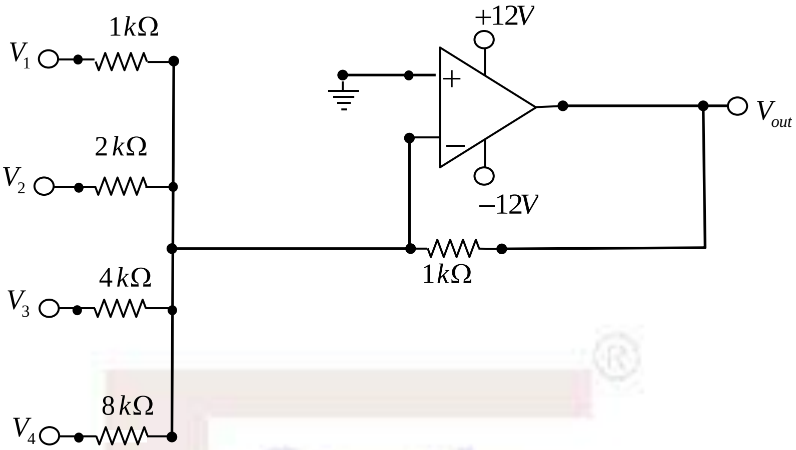
$$\psi(\vec{r}) = R(r)\left[\sqrt{\frac{3}{8}}Y_1^0(\theta,\varphi)\chi_- + \sqrt{\frac{5}{8}}Y_1^1(\theta,\varphi)\chi_+\right],$$

where Y_l^m are the normalized spherical harmonics and $\chi_\pm$ denote the wavefunction for the two spin states with eigenvalues $\pm\frac{1}{2}\hbar$. The expectation value of the z component of the total angular momentum in the above state is

(1) $-\frac{3}{4}\hbar$ (2) $\frac{3}{4}\hbar$ (3) $-\frac{9}{8}\hbar$ (4) $\frac{9}{8}\hbar$

Ans: (2)

Q9. In the circuit shown below using an ideal opamp, inputs $V_j\left(j=1,2,3,4\right)$ may either be open or connected to a $-5V$ battery.



The minimum measurement range of a voltmeter to measure all possible values of V_{out} is

(1) 10 V (2) 30 V (3) 3 V (4) 1 V

Ans: (1)

Q10. A particle of unit mass subjected to the 1-dimensional potential

$$V\left(x\right)=\frac{2\alpha}{x^3}-\frac{3\beta}{x^2}$$

executes small oscillations about its equilibrium position, where α and β are positive constants with appropriate dimensions. The time period of small oscillations is

(1) $\frac{\pi\alpha^2}{\sqrt{6\beta^5}}$ (2) $\frac{\pi\alpha^2}{\sqrt{3\beta^5}}$ (3) $\frac{2\pi\alpha^2}{\sqrt{3\beta^5}}$ (4) $\frac{2\pi\alpha^2}{\sqrt{6\beta^5}}$

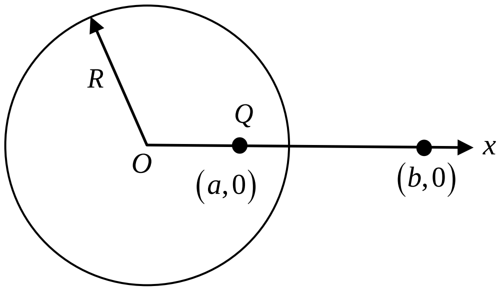
Ans: (4)

Q11. A one dimensional infinite long wire with uniform linear charge density λ is placed along the z-axis. The potential difference $\delta V=V\left(\rho+a\right)-V\left(\rho\right)$, between two points at radial distances $\rho+a$ and ρ from the z-axis, where $a<<\rho$, is closest to

(1) $-\frac{\lambda}{2\pi\varepsilon_0}\frac{a^2}{\rho^2}$ (2) $-\frac{\lambda}{2\pi\varepsilon_0}\frac{a}{\rho}$ (3) $\frac{\lambda}{2\pi\varepsilon_0}\frac{a}{\rho}$ (4) $\frac{\lambda}{2\pi\varepsilon_0}\frac{a^2}{\rho^2}$

Ans: (2)

Q12. A conducting shell of radius R is placed with its centre at the origin as shown below. A point charge Q is placed inside the shell at a distance a along the x-axis from the centre.



The electric field at a distance $b > R$ along the x-axis from the centre is

(1) $\frac{Q}{4\pi\varepsilon_0 b^2}\hat{x}$

(2) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{(b-a)^2}-\frac{aR}{(ab-R^2)^2}\right]\hat{x}$

(3) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{(b-a)^2}+\frac{aR}{(ab-R^2)^2}\right]\hat{x}$

(4) $\frac{Q}{4\pi\varepsilon_0}\left[\frac{1}{b^2}-\frac{R^2}{a^2b^2}\right]\hat{x}$

Ans: (1)

Q13. A small bar magnet is placed in a magnetic field $B(\vec{r}) = B(x)\hat{z}$. The magnet is initially at rest with its magnetic moment along $\hat{y}$. At later times, it will undergo

(1) angular motion in the yz plane and translational motion along $\hat{y}$

(2) angular motion in the yz plane and translational motion along $\hat{x}$

(3) angular motion in the zx plane and translational motion along $\hat{z}$

(4) angular motion in the xy plane and translational motion along $\hat{z}$

Ans: (2)

Q14. For three inputs A, B and C, the minimum number of 2-input NAND gates required to generate the output $Y = \overline{A+B}+\overline{C}$ is

(1) 3 (2) 4 (3) 7 (4) 6

Ans: (2)

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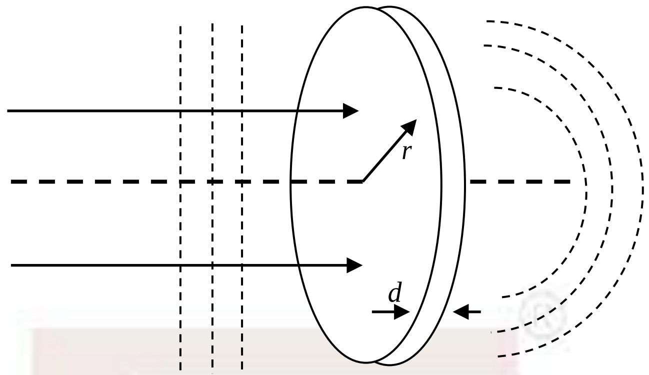
Q15. For a flat circular glass plate of thickness d, the refractive index $n(r)$ varies radially, where r is the radial distance from the centre of the plate. A coherent plane wavefront is normally incident on this plate as shown in the figure below.



If the emergent wavefront is spherical and centered on the axis of the plate, then $n(r)-n(0)$ should be proportional to

(1) $r^{1/2}$ (2) r (3) r^2 (4) $r^{3/2}$

Ans: (3)

Q16. Each allowed energy level of a system of non-interacting fermions has a degeneracy M. If there are N fermions and R is the remainder upon dividing N by M, then the degeneracy of the ground state is

(1) R^M (2) 1 (3) M (4) ${}^M C_R$

Ans: (4)

Q17. The Beta function is defined as $B(x,y)=\int_0^1 t^{x-1}(1-t)^{y-1}\,dt$.

Then $B(x,y+1)+B(x+1,y)$ can be expressed as

(1) $B(x,y-1)$ (2) $B(x+y,1)$

(3) $B(x+y,x-y)$ (4) $B(x,y)$

Ans: (4)

Q18. The 1-dimensional Hamiltonian of a classical particle of mass m is

$$H=\frac{P^2}{2m}e^{-x/a}+V(x),$$

where a is a constant with appropriate dimensions. The corresponding Lagrangian is,

(1) $\frac{m}{2}\left(\frac{dx}{dt}\right)^2 e^{x/a}-V(x)$ (2) $\frac{m}{2}\left(\frac{dx}{dt}\right)^2 e^{-x/a}-V(x)$

(3) $\frac{3m}{2}\left(\frac{dx}{dt}\right)^2 e^{x/a} - V(x)$ (4) $\frac{3m}{2}\left(\frac{dx}{dt}\right)^2 e^{-x/a} - V(x)$

Ans: (1)

Q19. The coordinates of the following events in an observer's inertial frame of reference are as follows:

Event 1: $t_1 = 0, x_1 = 0$: A rocket with uniform velocity $0.5c$ crosses the observer at origin along x axis

Event 2: $t_2 = T, x_2 = 0$: The observer sends a light pulse towards the rocket

Event 3: t_3, x_3: The rocket receives the light pulse

The values of t_3, x_3 respectively are

(1) $2T, cT$ (2) $2T, \frac{c}{2}T$ (3) $\frac{\sqrt{3}}{2}T, \frac{2}{\sqrt{3}}cT$ (4) $\frac{2}{\sqrt{3}}T, \frac{\sqrt{3}}{2}cT$

Ans: (1)

Q20. The light incident on a solar cell has a uniform photon flux in the energy range of 1 eV to 2 eV and is zero elsewhere. The active layer of the cell has a bandgap of 1.5 eV and absorbs 80% of the photons with energies above the bandgap. Ignoring non-radiative losses, the power conversion efficiency (ratio of the output power to the input power) is closest to

(1) 47% (2) 70% (3) 23% (4) 35%

Ans: (1)

Q21. The Schrodinger wave function for a stationary state of an atom in spherical polar coordinates (r, θ, ϕ) is

$$\psi = Af(r)\sin\theta\cos\theta e^{i\phi}$$

where A is the normalization constant. The eigenvalue of $\hat{L}_z$ for this state is

(1) $2\hbar$ (2) $\hbar$ (3) $-2\hbar$ (4) $-\hbar$

Ans: (2)

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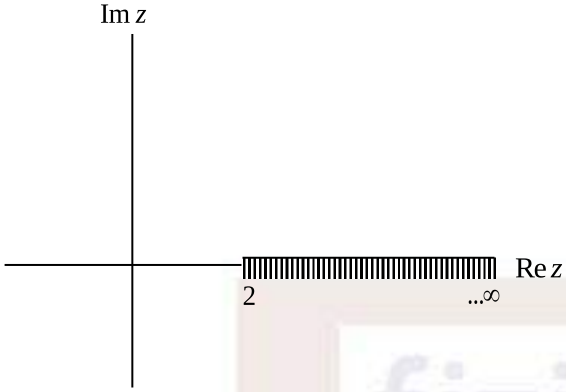
Q22. The branch line for the function $f(z)=\sqrt{\dfrac{z^2-5z+6}{z^2+2z+1}}$ is

(1)



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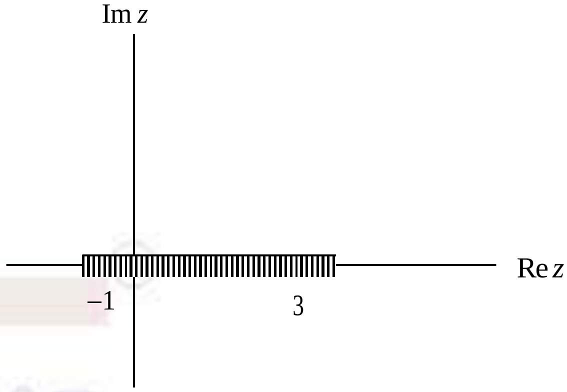

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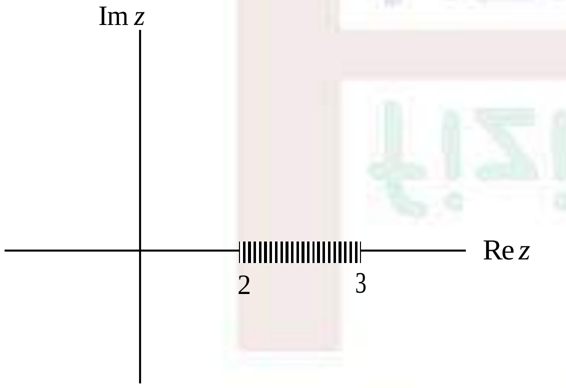

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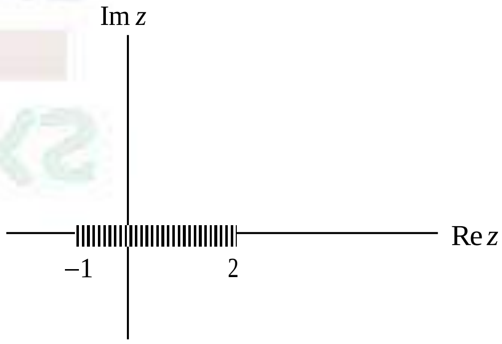

Ans: (3)

Q23. A system of N non-interacting classical spins, where each spin can take values $\sigma=-1,0,1$, is placed in a magnetic field h. The single spin Hamiltonian is given by

$$H=-\mu_B h\sigma+\Delta\left(1-\sigma^2\right),$$

where μ_B,Δ are positive constants with appropriate dimensions. If M is the magnetization, the zero-field magnetic susceptibility per spin $\left.\dfrac{1}{N}\dfrac{\partial M}{\partial h}\right|_{h\to 0}$, at a temperature $T=1/\beta k_B$ is given by

(1) $\beta\mu_B^2$ (2) $\dfrac{2\beta\mu_B^2}{2+e^{-\beta\Delta}}$ (3) $\beta\mu_B^2 e-\beta\Delta$ (4) $\dfrac{\beta\mu_B^2}{1+e^{-\beta\Delta}}$

Ans: (2)

Q24. A particle of mass m is moving in a stable circular orbit or radius r_0 with angular momentum L. For a potential energy $V(r)=\beta r^k$ ($\beta>0$ and $k>0$), which of the following options is correct?

(1) $k=3, r_0=\left(\frac{3L^2}{5m\beta}\right)^{1/5}$ (2) $k=2, r_0=\left(\frac{L^2}{2m\beta}\right)^{1/4}$

(3) $k=2, r_0=\left(\frac{L^2}{4m\beta}\right)^{1/4}$ (4) $k=3, r_0=\left(\frac{5L^2}{3m\beta}\right)^{1/5}$

Ans: (2)

Q25. The Hamiltonian for two particles with angular momentum quantum numbers $l_1=l_2=1$, is

$$\hat{H}=\frac{\in}{\hbar^2}\left[\left(\hat{L}_1+\hat{L}_2\right)\cdot\hat{L}_2-\left(\hat{L}_{1z}+\hat{L}_{2z}\right)^2\right]$$

If the operator for the total angular momentum is given by $\hat{L}=\hat{L}_1+\hat{L}_2$, then the possible energy eigenvalues for states with $l=2$, (where the eigenvalues of $\hat{L}^2$ are $l(l+1)\hbar^2$) are

(1) $3\in, 2\in, -\in$ (2) $6\in, 5\in, 2\in$

(3) $3\in, 2\in, \in$ (4) $-3\in, -2\in, \in$

Ans: (1)

PART C

Q1. In the rotational-vibrational spectrum of an idealized carbon monoxide (CO) molecule, ignoring rotational-vibrational coupling, two transitions between adjacent vibrational levels with wavelength λ_1 and λ_2, correspond to the rotational transition from $J'=0$ to $J''=1$ and $J'=1$ to $J''=0$, respectively. Given that the reduced mass of CO is $1.2\times^{-26}\ kg$, equilibrium bond length of CO is 0.12 nm and vibrational frequency is 5×10^{13} Hz, the ratio of $\frac{\lambda_1}{\lambda_2}$ is closest to

(1) 0.9963 (2) 0.0963 (3) 1.002 (4) 1.203

Ans: (1)

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Q2. A quantum particle of mass m is moving in a one dimensional potential

$$V(x) = V_0\theta(x) - \lambda\delta(x),$$

where V_0 and λ are positive constants, $\theta(x)$ is the Heaviside step function and $\delta(x)$ is the Dirac delta function. The leading contribution to the reflection coefficient for the particle incident from the left with energy $E >> V_0 > \lambda$ and $\sqrt{2mE} >> \frac{V_0\hbar}{\lambda}$ is

(1) $\frac{V_0^2}{4E^2}$ (2) $\frac{V_0^2}{8E^2}$ (3) $\frac{m\lambda^2}{2E\hbar^2}$ (4) $\frac{m\lambda^2}{4E\hbar^2}$

Ans: (3)

Q3. Atmospheric neutrinos are produced from the cascading decays of cosmic pions $(\pi^{\pm})$ to stable particles. Ignoring all other neutrino sources, the ratio of muon neutrino $(v_\mu + \bar{v}_\mu)$ flux to electron neutrino $(v_e + \bar{v}_e)$ flux in atmosphere is expected to be closest to

(1) 2:3 (2) 1:1 (3) 1:2 (4) 2:1

Ans: (4)

Q4. A Lagrangian is given by $L = \frac{1}{2}m\left(\dot{x}^2 + \dot{y}\dot{z} + \dot{z}^2\right) - \alpha(2x + 3y + z)$

The conserved momentum is

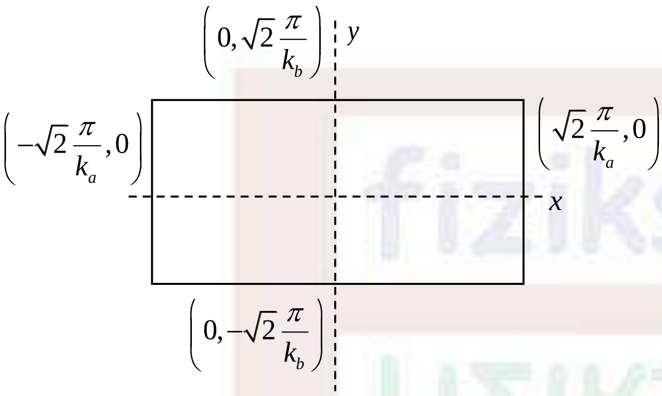
(1) $m[2\dot{x} + \dot{z}]$ (2) $m[2\dot{x} + \dot{y} + \dot{z}]$

(3) $m\left[\dot{x} + \frac{3}{2}\dot{y} + \frac{1}{2}\dot{z}\right]$ (4) $m[2\dot{x} + 3\dot{z}]$

Ans: (2)

Q5. A 2-dimensioanl resonant cavity supports a TM mode built from a function $\psi(x,y,t)=\sin(\vec{k}_a\cdot\vec{r}-\omega t)+\sin(\vec{k}_b\cdot\vec{r}-\omega t)+\sin(\vec{k}_a\cdot\vec{r}+\omega t)+\sin(\vec{k}_b\cdot\vec{r}+\omega t)$ where $\vec{k}_a$ and $\vec{k}_b$ lie in the xy-plane and make angles $\frac{\pi}{4}$ and $\frac{3\pi}{4}$ with the x-axis, respectively. If $0<|\vec{k}_a|<|\vec{k}_b|$, then which of the following closely describes the outline of the cavity?

(1)



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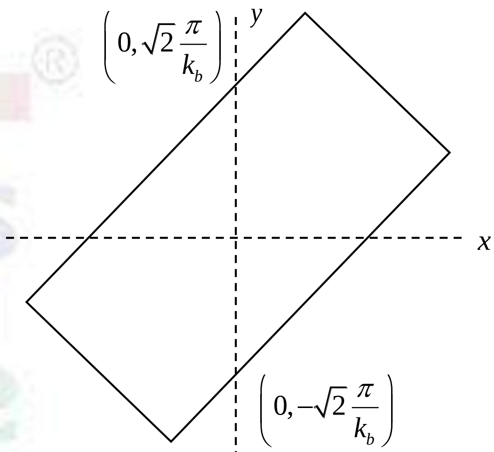

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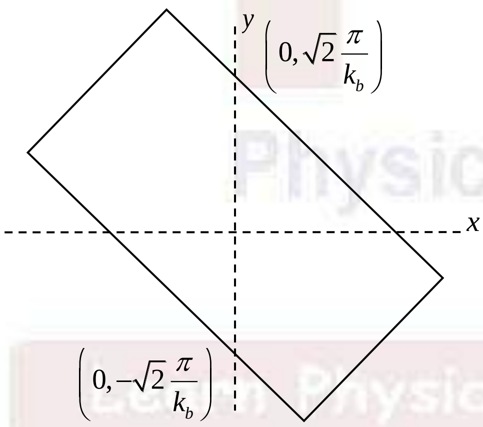

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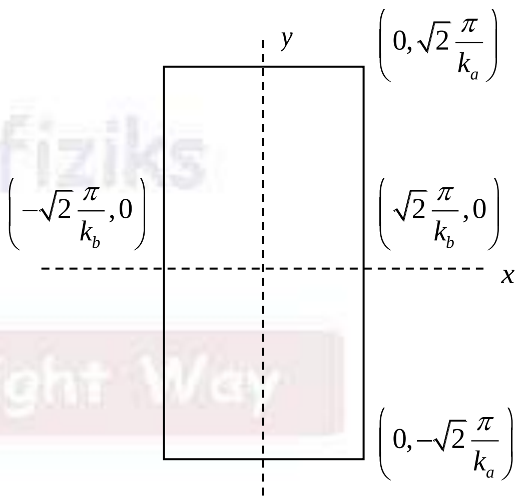


Ans: (2)

Q6. An incident plane wave with wavenumber k is scattered by a spherically symmetric soft potential. The scattering occurs only in S- and P-waves. The approximate scattering amplitude an angles $\theta = \frac{\pi}{3}$ and $\theta = \frac{\pi}{2}$ are

$$f\left(\theta = \frac{\pi}{3}\right) \approx \frac{1}{2k}\left(\frac{5}{2} + 3i\right) \text{ and } f\left(\theta = \frac{\pi}{2}\right) \approx \frac{1}{2k}\left(1 + \frac{3i}{2}\right)$$

Then the total scattering cross-section is closest to

(1) $\frac{37\pi}{4k^2}$ (2) $\frac{10\pi}{k^2}$ (3) $\frac{35\pi}{4k^2}$ (4) $\frac{9\pi}{k^2}$

Ans: (1)

Q7. The permittivity of a medium $\varepsilon(\vec{k}, \omega)$, where ω and $\vec{k}$ are the frequency and wavevector, respectively, has no imaginary part. For a longitudinal wave, $\vec{k}$ is parallel to the electric field such that $\vec{k} \times \vec{E} = 0$, while for a transverse wave $\vec{k} \cdot \vec{E} = 0$. In the absence of free charges and free currents, the medium can sustain

(1) longitudinal waves with $\vec{k}$ and ω when $\varepsilon(\vec{k}, \omega) > 0$

(2) transverse waves with $\vec{k}$ and ω when $\varepsilon(\vec{k}, \omega) < 0$

(3) longitudinal waves with $\vec{k}$ and ω when $\varepsilon(\vec{k}, \omega) = 0$

(4) both longitudinal and transverse waves with $\vec{k}$ and ω when $\varepsilon(\vec{k}, \omega) > 0$

Ans: (3)

Q8. The ionization potential of hydrogen atom is 13.6 eV and λ_H and λ_D denote longest wavelengths in Balmer spectrum of hydrogen and deuterium atoms, respectively. Ignoring the fine and hyperfine structures, the percentage difference $y = \frac{\lambda_H - \lambda_D}{\lambda_H} \times 100$, is closest to

(1) 1.0003% (2) -0.03%

(3) 0.03% (4) -1.0003%

Ans: (3)

Q9. A canonical transformation from the phase space coordinates (q, p) to (Q, P) is generated by the function $\psi(p,Q) = \frac{p^2}{2\omega}\tan 2\pi Q$,

where ω is a positive constant. The function $\psi(p,Q)$ is related to $F(q,Q)$ by the Legendre transform $\psi = pq - F$, where F is defined by $dF = pdq - PdQ$. If the solution for (P,Q) is $P(t) = \frac{\omega}{4\pi}t^2, Q(t) = Q_0 =$ constant

where t is time, then the solution for (p,q) variables can be written as

(1) $p = \frac{\omega t}{2\pi}\cos 2\pi Q_0$, $q = \frac{t}{2\pi}\sin 2\pi Q_0$

(2) $p = -\frac{\omega t}{2\pi}\cos 2\pi Q_0$, $q = \frac{t}{2\pi}\sin 2\pi Q_0$

(3) $p = \frac{\omega t}{2\pi}\sin 2\pi Q_0$, $q = \frac{t}{2\pi}\cos 2\pi Q_0$

(4) $p = -\frac{\omega t}{2\pi}\sin 2\pi Q_0$, $q = \frac{t}{2\pi}\cos 2\pi Q_0$

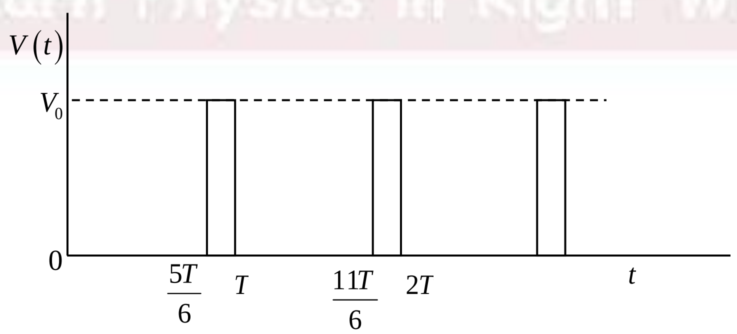
Ans: (1)

Q10. The function $f(z) = \frac{1}{(z+1)(z+3)}$ is defined on the complex plane. The coefficient of the $(z-z_0)^2$ term of the Laurent series of $f(z)$ about $z_0 = 1$ is

(1) $\frac{7}{64}$ (2) $\frac{7}{128}$ (3) $\frac{9}{64}$ (4) $\frac{9}{128}$

Ans: (2)

Q11. An infinite waveform $V(t)$ varies as shown in the figure below



The lowest harmonic that vanishes in the Fourier series of $V(t)$ is

(1) 2 (2) 3 (3) 6 (4) None

Ans: (3)

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Q12. In a shell model description, neglecting Coulomb effects, which of the following statements for the energy and spin-parity is correct for the first excited state of $A = 12$ isobars ${}^{12}_{5}B, {}^{12}_{6}C, {}^{12}_{7}N$?

(1) same for ${}^{12}_{5}B, {}^{12}_{6}C$ and ${}^{12}_{7}N$

(2) different for each ${}^{12}_{5}B, {}^{12}_{6}C$ and ${}^{12}_{7}N$

(3) same for ${}^{12}_{6}C$ and ${}^{12}_{7}N$, but different for ${}^{12}_{5}B$

(4) same for ${}^{12}_{5}B$ and ${}^{12}_{7}N$ but different for ${}^{12}_{6}C$

Ans: (4)

Q13. Gauge factor of a strain gauge is defined as the ratio of the fractional change in resistance $\left(\frac{\Delta R}{R}\right)$ to the fractional change in length $\left(\frac{\Delta L}{L}\right)$. A metallic strain gauge with a gauge factor 2 has a resistance of 100Ω under unstrained condition. An aluminum foil with Young's modulus $Y = 70\,GN/m^2$ is installed on the metallic gauge. Keeping the foil within its elastic limit, a stress of $0.2\,GN/m^2$ is applied on the foil. The change in the resistance of the gauge will be closest to

(1) 0.14Ω (2) 1.23Ω

(3) 0.28Ω (4) 0.56Ω

Ans: (4)

Q14. The work done on a material to change its magnetization M in an external field H is $dW = HdM$. Its Gibbs free energy is

$$G(T,H) = -\left(\gamma T + \frac{aH^2}{2T}\right)$$

where $\gamma, a > 0$ are constants. The material is in equilibrium at a temperature $T = T_0$ and in an external field $H = H_0$. If the field is decreased to $\frac{H_0}{2}$ adiabatically and reversibly, the temperature changes to

(1) $2T_0$ (2) $\frac{T_0}{2}$

(3) $\left(\frac{a}{2\gamma}\right)^{\frac{1}{4}}\sqrt{H_0T_0}$ (4) $\left(\frac{a}{\gamma}\right)^{\frac{1}{4}}\sqrt{H_0T_0}$

Ans: (2)

Q15. Given the data points

x	1	3	5
y	4	28	92

Using Lagrange's method of interpolation, the value of y at $x=4$ is closest to

(1) 54 (2) 55 (3) 53 (4) 56

Ans: (2)

Q16. The lattice constant of the bcc structure of sodium metal is 4.22Å. Assuming the mass of the electron inside the metal to be the same as free electron mass, the free electron Fermi energy is closest to

(1) 3.2 eV (2) 2.9 eV (3) 3.5 eV (4) 2.5 eV

Ans: (1)

Q17. A quantum system is described by the Hamiltonian $H=-J\sigma_z+\lambda(t)\sigma_x$, where $\sigma_i\,(i=x,y,z)$ are Pauli matrices, J and λ are positive constants $(J>>\lambda)$ and

$$\lambda(t)=\begin{cases} 0 \text{ for } t<0 \\ \lambda \text{ for } 0<t<T \\ 0 \text{ for } t>T \end{cases}$$

At $t<0$, the system is in the ground state. The probability of finding the system in the excited state at $t>>T$, in the leading order in λ is

(1) $\frac{\lambda^2}{8J^2}\sin^2\frac{JT}{\hbar}$ (2) $\frac{\lambda^2}{J^2}\sin^2\frac{JT}{\hbar}$

(3) $\frac{\lambda^2}{4J^2}\sin^2\frac{JT}{\hbar}$ (4) $\frac{\lambda^2}{16J^2}\sin^2\frac{JT}{\hbar}$

Ans: (2)

Q18. A transmission line has the characteristic impedance of $(50+1j)\Omega$ and is terminated in a load resistance of $(70-7j)\Omega$ (where $j^2=-1$). The magnitude of the reflection coefficient will be closest to

(1) $\frac{5}{7}$ (2) $\frac{1}{2}$ (3) $\frac{1}{6}$ (4) $\frac{1}{7}$

Ans: (3)

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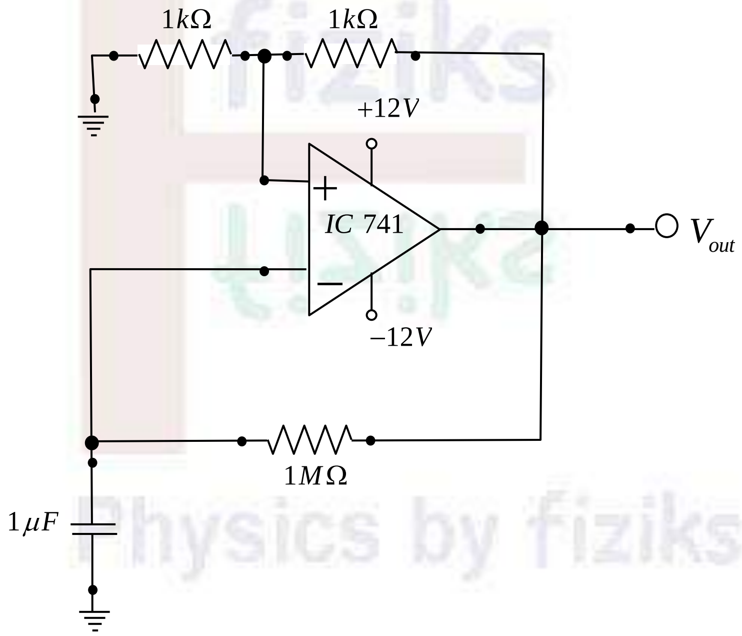
Q19. The radius of a sphere oscillates as a function of time as $R + a\cos\omega t$, with $a < R$. It carries a charge Q uniformly distributed on its surface at all times. If P is the time averaged radiated power through a sphere of radius r, such that $r >> R + a$ and $r >> \frac{c}{\omega}$, then

(1) $P \propto \frac{Q^2\omega^4 a^2}{c^3}$ (2) $P \propto \frac{Q^2\omega^4}{c}$

(3) $P = 0$ (4) $P \propto \frac{Q^2\omega^6 a^4}{c^5}$

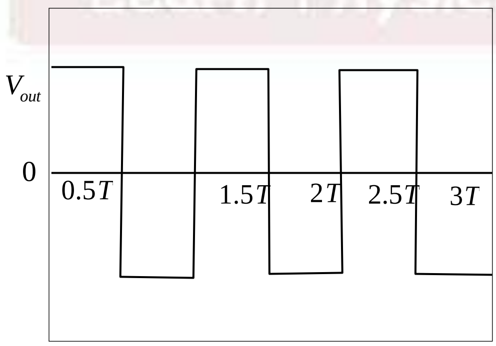
Ans: (3)

Q20. A circuit with operational amplifier is shown in the figure below.



The output voltage waveform V_{out} will be closest to

(1)



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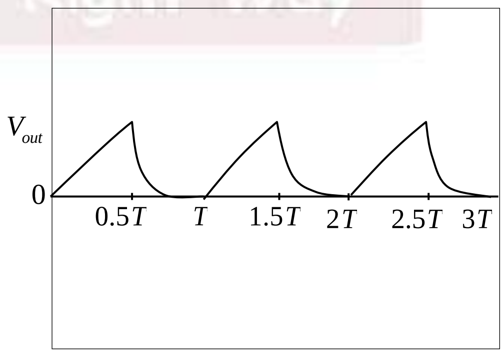

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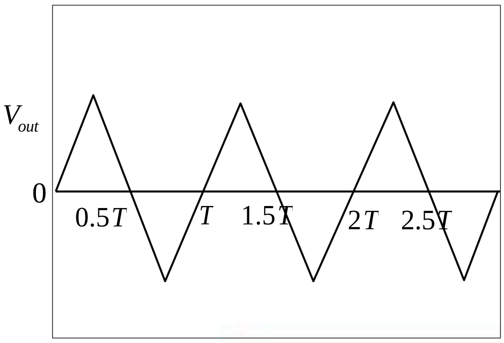

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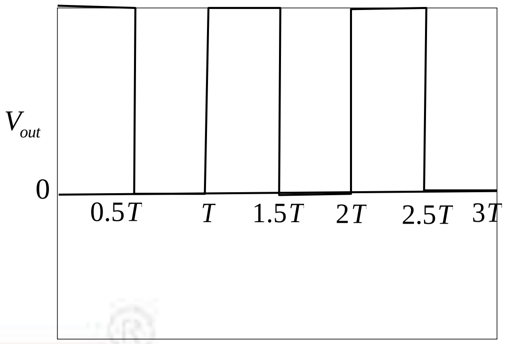

Ans: (1)

Q21. The collision time of the electrons in a metal in the Drude model is τ and their plasma frequency is ω_p. If this metal is placed between the plates of a capacitor, the time constant associated with the decay of the electric field inside the metal is

(1) $\tau + \frac{1}{\omega_p}$ (2) $\omega_p \tau^2$

(3) $\frac{1}{\omega_p^2 \tau}$ (4) $\frac{\tau}{1+\omega_p \tau}$

Ans: (3)

Q22. A photon inside the sun executes a random walk process. Given the radius of the sun $\approx 7\times10^8 km$ and mean free path of a photon $\approx 10^{-3} m$, the time taken by the photon to travel from the centre to the surface of the sun is closest to

(1) 10^6 sec (2) 10^{24} sec

(3) 10^{12} sec (4) 10^{18} sec

Ans: (3)

Q23. In a quantum harmonic oscillator problem, $\hat{a}$ and $\hat{N}$ are the annihilation operator and the number operator, respectively. The operator $e^{\hat{N}}\hat{a}e^{-\hat{N}}$ is

(1) $\hat{a}$ (2) $e^{-1}\hat{a}$

(3) $e^{-(\hat{I}+\hat{a})}$ (4) $e^{\hat{a}}$

(where $\hat{I}$ is the identity operator)

Ans: (2)

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Q24. The regular representation of two nonidentity elements of the group of order 3 are given by

(1) $\begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix}$ (2) $\begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$

(3) $\begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{pmatrix}$ (4) $\begin{pmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{pmatrix}, \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$

Ans: (3)

Q25. A solar probe mission detects a fractional wavelength shift $(\Delta\lambda/\lambda)$ of the spectral line $\lambda = 630\,nm$ within a sunspot to be of the order of 10^{-5}. Assuming this shift is caused by the normal Zeeman effect (i.e., neglecting other physical effects), the estimated magnetic field (in tesla) within the observed sunspot is closest to

(1) 3×10^{-5} (2) 300

(3) 0.3 (4) 3×10^{5}

Ans: (3)

Q26. A particle of mass m is moving in a 3-dimensional potential

$$\phi(r) = -\frac{k}{r} - \frac{k'}{3r^3},\ k, k' > 0$$

For the particle with angular momentum l, the necessary condition to have a stable circular orbit is

(1) $kk' < \frac{l^4}{4m^2}$ (2) $kk' > \frac{l^4}{4m^2}$

(3) $kk' < \frac{l^4}{m^2}$ (4) $kk' > \frac{l^4}{m^2}$

Ans: (1)

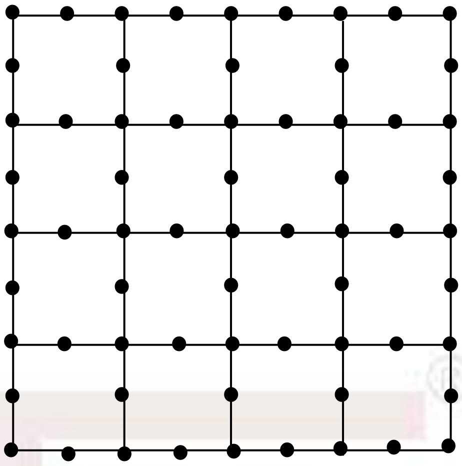
Q27. A system of non-relativistic and non-interacting bosons of mass m in two dimensions has a density n. The Bose-Einstein condensation temperature T_c is

(1) $\frac{12n\hbar^2}{\pi m k_B}$ (2) $\frac{3n\hbar^2}{\pi m k_B}$

(3) $\frac{6n\hbar^2}{\pi m k_B}$ (4) 0

Ans: (4)

Q28. In the section of an infinite lattice shown in the figure below, all sites are occupied by identical hard circular discs so that the resulting structure is tightly packed.



The packing fraction is

(1) $\frac{3\pi}{4}$ (2) $\frac{\pi}{4}$

(3) $\frac{3\pi}{16}$ (4) $\frac{9\pi}{16}$

Ans: (3)

Q29. The ground state of ${}^{207}_{82}Pb$ nucleus has spin-parity $J^{\pi}=\left(\frac{1}{2}\right)^{-}$, while first excited state has $J^{\pi}=\left(\frac{5}{2}\right)^{-}$. For the transition from the first excited state to the ground state, possible multipolarities of emitted electromagnetic radiation are

(1) E2, E3 (2) M2, M3

(3) M2, E3 (4) E2, M3

Ans: (4)

Q30. The solution $y(x)$ of the differential equation $y''+\frac{y}{4}=\frac{x}{2}$, where $0\le x\le \pi$, together with the boundary conditions $y(0)=y(\pi)=0$ is

(1) $\frac{2}{\pi}\sum_{n=1}^{\infty}(-1)^{n}\frac{\pi}{n}\frac{\sin nx}{\frac{1}{4}-n^{2}}$ (2) $\frac{2}{\pi}\sum_{n=1}^{\infty}(-1)^{n}\frac{\pi}{2n}\frac{\sin nx}{\frac{1}{4}-n^{2}}$

(3) $\frac{2}{\pi}\sum_{n=1}^{\infty}(-1)^{n+1}\frac{\pi}{n}\frac{\sin nx}{\frac{1}{4}-n^{2}}$ (4) $\frac{2}{\pi}\sum_{n=1}^{\infty}(-1)^{n+1}\frac{\pi}{2n}\frac{\sin nx}{\frac{1}{4}-n^{2}}$

Ans: (4)

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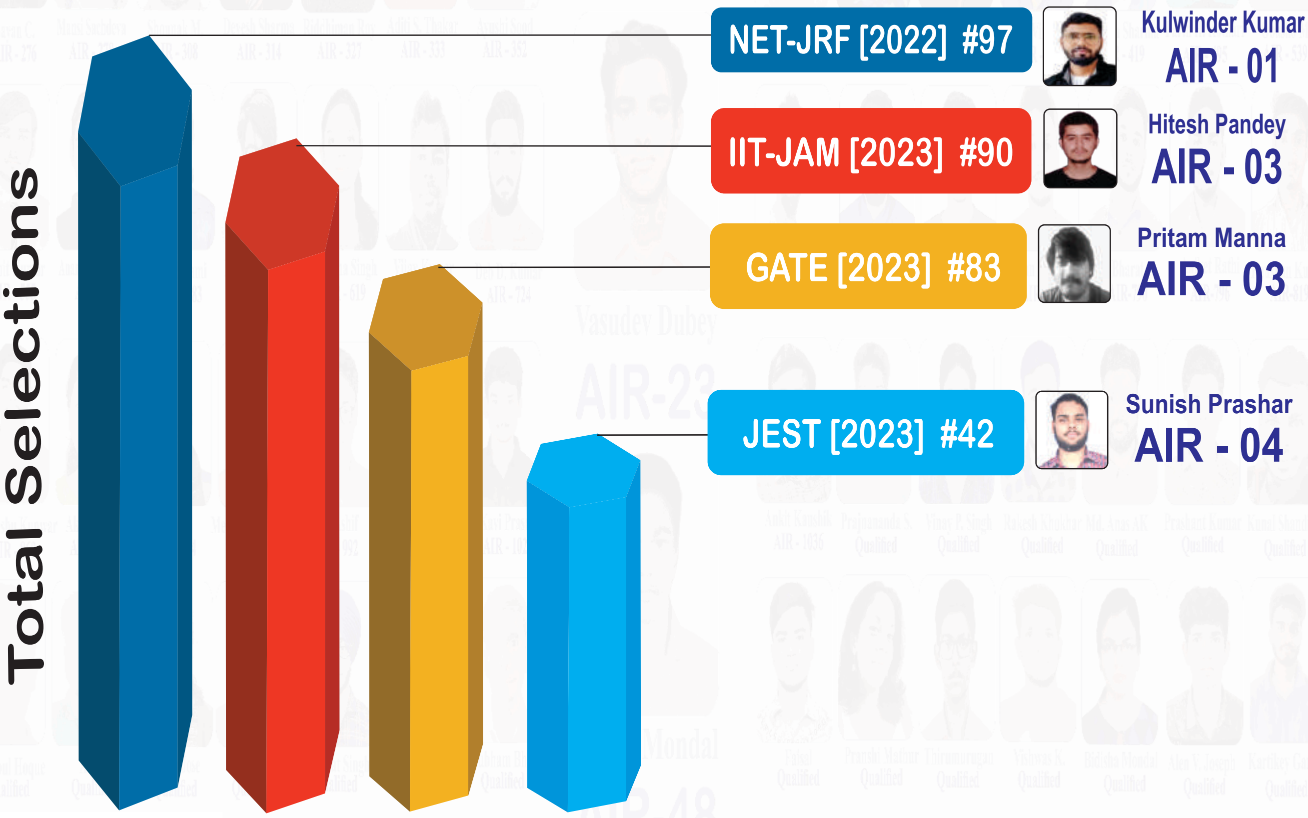

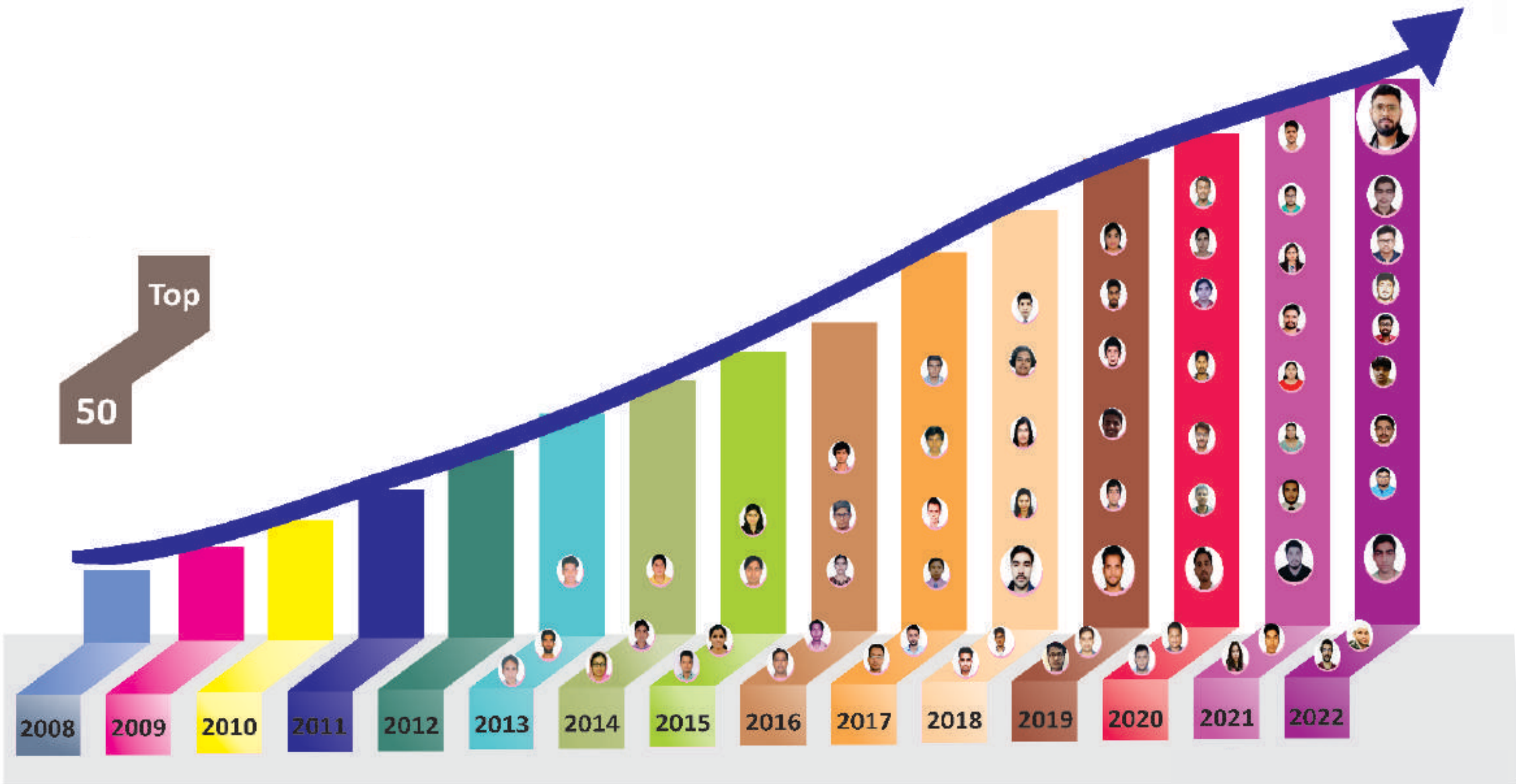

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