# PhysicsByAaryan

CSIR NET · GATE · JEST · BARC – Physics

## GATE Physics 2023 — Full Question Paper

Previous Year Questions with Official Answer Key

### Inside this PDF

- Every GATE Physics (PH) 2023 question, in order
- Marking scheme + question type (MCQ/MSQ/NAT) on every question
- Subject & topic classification per question
- Official answer key at the end

**65** Questions with answer key

*Questions taken from official GATE Physics (PH) papers conducted by IITs / IISc.*
*Compiled by PhysicsByAaryan for free use by aspirants. Answer key at the end of this PDF.*

**Q1. [Marks: 1 | MCQ]** General Aptitude · English

| Gate 2023 | MCQ | 1M |
|---|---|---|

"You are delaying the completion of the task. Send ____ contributions at the earliest.“

(A) you are

(B) your

(C) you’re

(D) yore

**Q2. [Marks: 1 | MCQ]** General Aptitude · English

| Gate 2023 | MCQ | 1M |
|---|---|---|

References : ___ : : Guidelines : Implement

(By word meaning)

(A) Sight

(B) Site

(C) Cite

(D) Plagiarise

**Q3. [Marks: 1 | MCQ]** General Aptitude · Geometry

| Gate 2023 | MCQ | 1M |
|---|---|---|

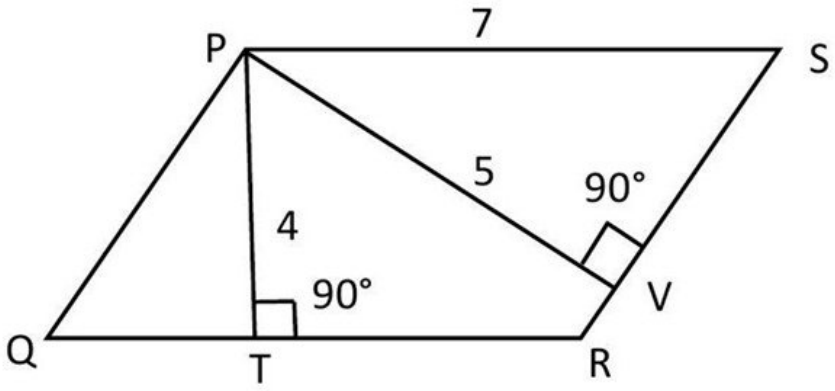
In the given figure, PQRS is a parallelogram with $PS = 7\ cm, PT = 4\ cm$ and $PV = 5\ cm$. What is the length of RS in cm? (The diagram is representative.)

(A) 20/7

(B) 28/5

(C) 9/2

(D) 35/4



**Q4. [Marks: 1 | MCQ]** General Aptitude · Reasoning

| Gate 2023 | MCQ | 1M |
|---|---|---|

In 2022, June Huh was awarded the Fields medal, which is the highest prize in Mathematics. When he was younger, he was also a poet. He did not win any medals in the International Mathematics Olympiads. He dropped out of college. Based only on the above information, which one of the following statements can be logically inferred with certainty?

(A) Every Fields medalist has won a medal in an International Mathematics Olympiad.

(B) Everyone who has dropped out of college has won the Fields medal.

(C) All Fields medalists are part-time poets.

(D) Some Fields medalists have dropped out of college.

**Q5. [Marks: 1 | MCQ]** General Aptitude · Reasoning

| Gate 2023 | MCQ | 1M |
|---|---|---|

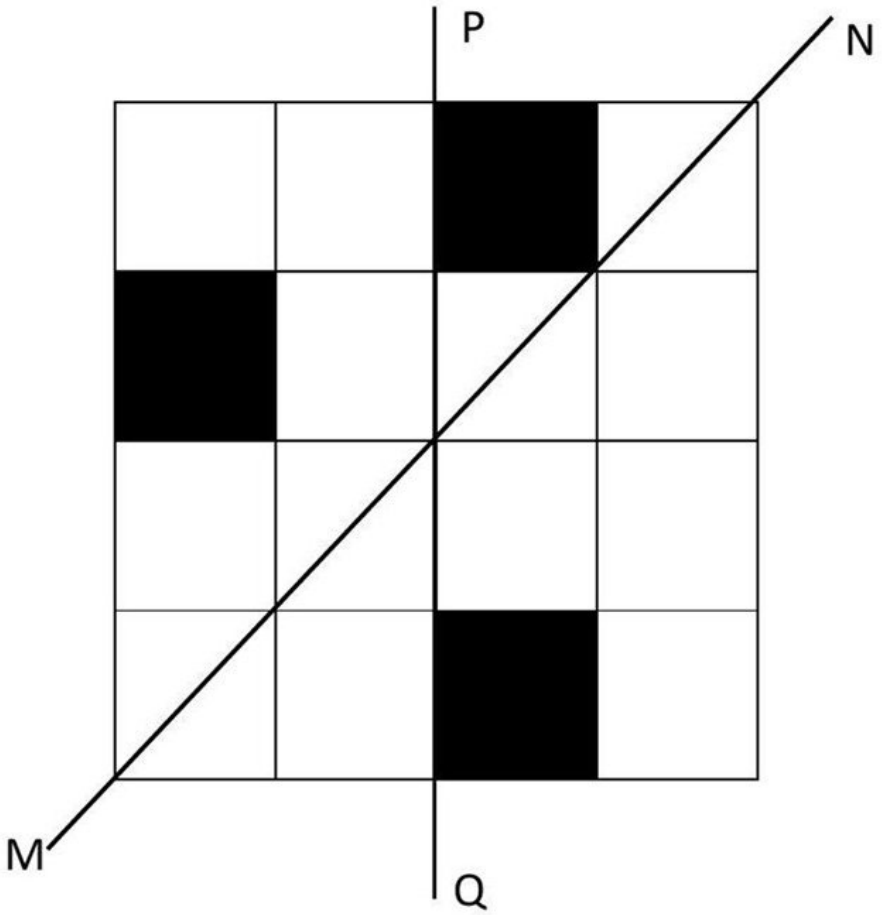
A line of symmetry is defined as a line that divides a figure into two parts in a way such that each part is a mirror image of the other part about that line. The given figure consists of 16 unit squares arranged as shown. In addition to the three black squares, what is the minimum number of squares that must be coloured black, such that both PQ and MN form lines of symmetry? (The figure is representative)

(A) 3

(B) 4

(C) 5

(D) 6



**Q6. [Marks: 2 | MCQ]** General Aptitude · Reasoning

| Gate 2023 | MCQ | 2M |
|---|---|---|

Human beings are one among many creatures that inhabit an imagined world. In this imagined world, some creatures are cruel. If in this imagined world, it is given that the statement "Some human beings are not cruel creatures" is FALSE, then which of the following set of statement(s) can be logically inferred with certainty?

(i) All human beings are cruel creatures.

(ii) Some human beings are cruel creatures.

(iii) Some creatures that are cruel are human beings.

(iv) No human beings are cruel creatures.

(A) only (i)

(B) only (iii) and (iv)

(C) only (i) and (ii)

(D) (i), (ii) and (iii)

**Q7. [Marks: 2 | MCQ]** General Aptitude · Mathematical Analysis

| Gate 2023 | MCQ | 2M |
|---|---|---|

To construct a wall, sand and cement are mixed in the ratio of 3:1. The cost of sand and that of cement are in the ratio of 1:2. If the total cost of sand and cement to construct the wall is 1000 rupees, then what is the cost (in rupees) of cement used?

(A) 400

(B) 600

(C) 800

(D) 200

**Q8. [Marks: 2 | MCQ]** General Aptitude · Reasoning

| Gate 2023 | MCQ | 2M |
|---|---|---|

The World Bank has declared that it does not plan to offer new financing to Sri Lanka, which is battling its worst economic crisis in decades, until the country has an adequate macroeconomic policy framework in place. In a statement, the World Bank said Sri Lanka needed to adopt structural reforms that focus on economic stabilisation and tackle the root causes of its crisis. The latter has starved it of foreign exchange and led to shortages of food, fuel, and medicines. The bank is repurposing resources under existing loans to help alleviate shortages of essential items such as medicine, cooking gas, fertiliser, meals for children, and cash for vulnerable households. Based only on the above passage, which one of the following statements can be inferred with certainty?

(A) According to the World Bank, the root cause of Sri Lanka's economic crisis is that it does not have enough foreign exchange.

(B) The World Bank has stated that it will advise the Sri Lankan government about how to tackle the root causes of its economic crisis.

(C) According to the World Bank, Sri Lanka does not yet have an adequate macroeconomic policy framework.

(D) The World Bank has stated that it will provide Sri Lanka with additional funds for essentials such as food, fuel, and medicines.

**Q9. [Marks: 2 | MCQ]** General Aptitude · Mathematical Analysis

| Gate 2023 | MCQ | 2M |
|---|---|---|

The coefficient of $x^4$ in the polynomial $(x-1)^3(x-2)^3$ is equal to ___

(A) 33

(B) $-3$

(C) 30

(D) 21

**Q10. [Marks: 2 | MCQ]** General Aptitude · Geometry

| Gate 2023 | MCQ | 2M |
|---|---|---|

Which one of the following shapes can be used to tile (completely cover by repeating) a flat plane, extending to infinity in all directions, without leaving any empty spaces in between them? The copies of the shape used to tile are identical and are not allowed to overlap.

(A) circle

(B) regular octagon

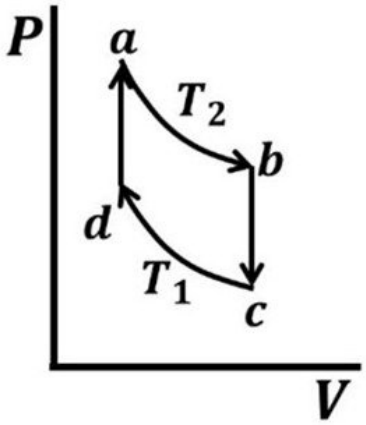
(C) regular pentagon

(D) rhombus

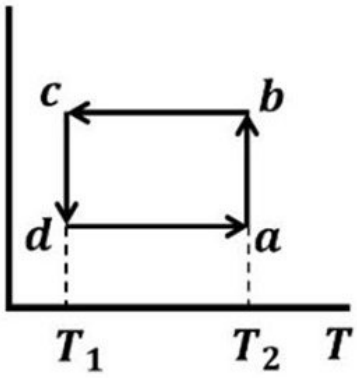
**Q11. [Marks: 1 | MCQ]** Thermodynamics · Carnot Cycle

| Gate 2023 | MCQ | 1M |
|---|---|---|

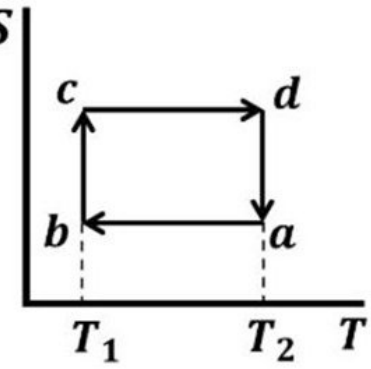
Which one of the following entropy (S) – temperature (T) diagrams CORRECTLY represents the Carnot cycle abcda shown in the P-V diagram?



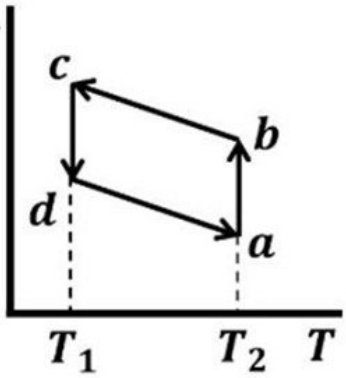

(A)



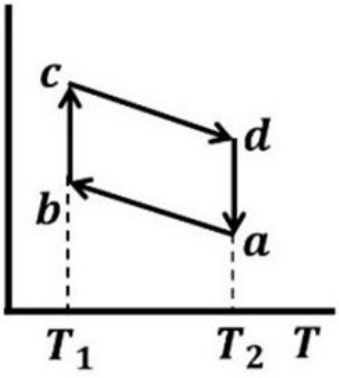

(B)




(C)




(D)



**Q12. [Marks: 1 | MCQ]** Atomic and Molecular Physics · Effects in atomic physics

| Gate 2023 | MCQ | 1M |
|---|---|---|

Which one of the following is a dimensionless constant?

(A) Permittivity of free space

(B) Permeability of free space

(C) Bohr magneton

(D) Fine structure constant

**Q13. [Marks: 1 | MCQ]** Electronics · Diodes

| Gate 2023 | MCQ | 1M |
|---|---|---|

Choose the most appropriate matching of the items in Column 1 with those in Column 2.

| Column 1 | Column 2 |
|---|---|
| (i) PIN diode | P. Voltage regulation |
| (ii) Tunnel diode | Q. Radio frequency and microwave devices |
| (iii) Zener diode | R. Optoelectronic detection |
| (iv) Photo diode | S. Oscillator |

(A) (i) - Q; (ii) - S; (iii) - P; (iv) – R

(B) (i) - R; (ii) - Q; (iii) - P; (iv) – S

(C) (i) - R; (ii) - S; (iii) - P; (iv) – Q

(D) (i) - P; (ii) - Q; (iii) - R; (iv) - S

**Q14. [Marks: 1 | MCQ]** Atomic and Molecular Physics · Effects in atomic physics

| Gate 2023 | MCQ | 1M |
|---|---|---|

The atomic number of an atom is 6. What is the spectroscopic notation of its ground state, according to Hund's rules?

(A) $^3P_0$

(B) $^3P_1$

(C) $^3D_3$

(D) $^3S_1$

**Q15. [Marks: 1 | MCQ]** Quantum Mechanics · Orbital angular momentum and hydrogen atom

| Gate 2023 | MCQ | 1M |
|---|---|---|

$H$ is the Hamiltonian, $\vec{L}$ the orbital angular momentum and $L_Z$ is the z-component of $\vec{L}$. The 1s state of the hydrogen atom in the non-relativistic formalism is an eigen function of which one of the following sets of operators?

(A) $H, L^2$ and $L_Z$

(B) $H, \vec{L}, L^2$ and $L_Z$

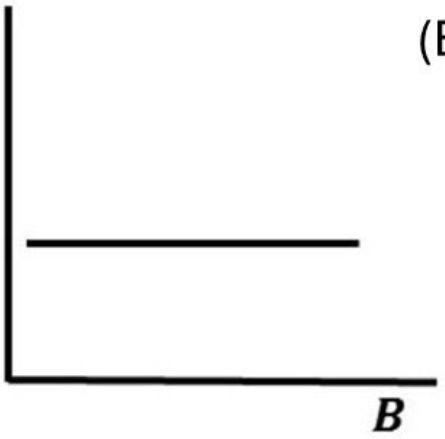
(C) $L^2$ and $L_Z$ only

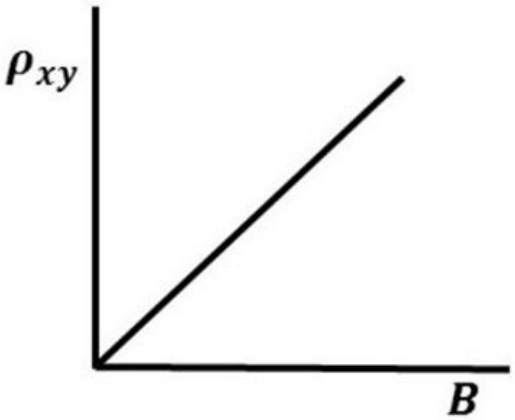
(D) $H$ only and $L_Z$

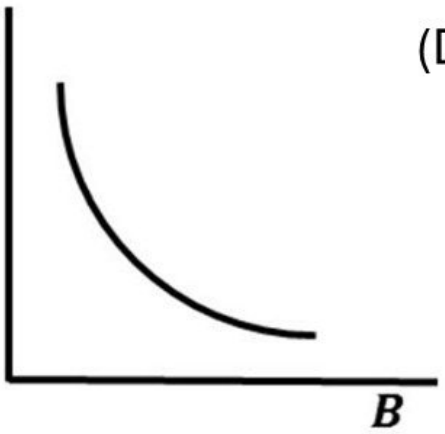
**Q16. [Marks: 1 | MCQ]** Solid State Physics · Hall Effect

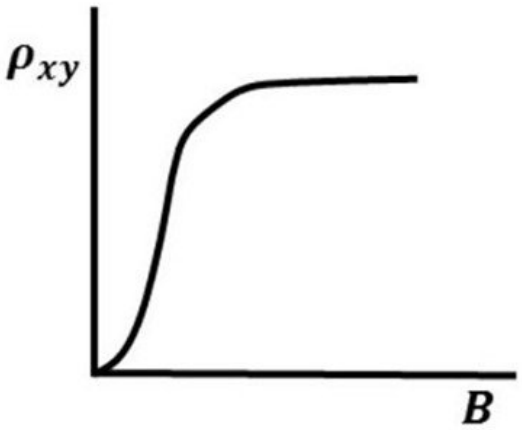
| Gate 2023 | MCQ | 1M |
|---|---|---|

The Hall experiment is carried out with a non-magnetic semiconductor. The current $I$ is along the $X$-axis and the magnetic field $B$ is along the Z-axis. Which one of the following is the CORRECT representation of the variation of the magnitude of the Hall resistivity $\rho_{xy}$ as a function of the magnetic field?

(A) 


(B) 


(C) 


(D) 

**Q17. [Marks: 1 | MCQ]** Mathematical Physics · Tensors

| Gate 2023 | MCQ | 1M |
|---|---|---|

Consider a two dimensional Cartesian coordinate system in which a rank 2 contravariant tensor is represented by the matrix $\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$. The coordinate system is rotated anticlockwise by an acute angle $\theta$ with the origin fixed. Which one of the following matrices represents the tensor in the new coordinate system?

(A) $\begin{pmatrix} 0 & \cos 2\theta \\ -\sin 2\theta & 0 \end{pmatrix}$

(B) $\begin{pmatrix} \sin 2\theta & \cos 2\theta \\ \cos 2\theta & -\sin 2\theta \end{pmatrix}$

(C) $\begin{pmatrix} \sin 2\theta & -\cos 2\theta \\ \cos 2\theta & \sin 2\theta \end{pmatrix}$

(D) $\begin{pmatrix} \sin 2\theta & 0 \\ 0 & -\cos 2\theta \end{pmatrix}$

**Q18. [Marks: 1 | MCQ]** Solid State Physics · Crystallography

| Gate 2023 | MCQ | 1M |
|---|---|---|

A compound consists of three ions $X, Y$ and $Z$ . The Z ions are arranged in an FCC arrangement. The X ions occupy $\frac{1}{6}$ of the tetrahedral voids and the Y ions occupy $\frac{1}{3}$ of the octahedral voids. Which one of the following is the CORRECT chemical formula of the compound?

(A) $XY_2Z_4$

(B) $XYZ_3$

(C) $XYZ_2$

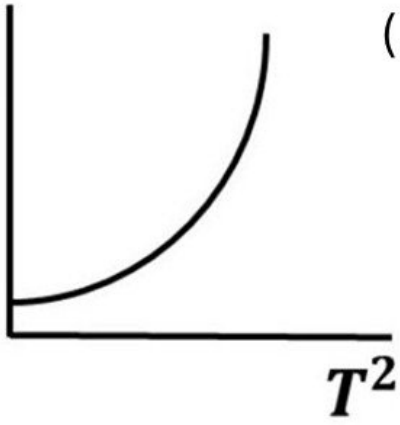
(D) $XYZ_4$

**Q19. [Marks: 1 | MCQ]** Solid State Physics · Lattice vibration

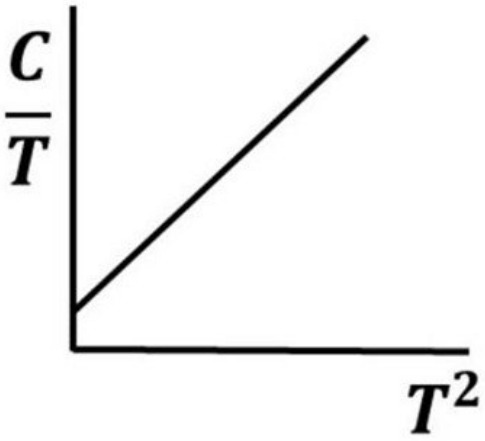
| Gate 2023 | MCQ | 1M |
|---|---|---|

For a non-magnetic metal, which one of the following graphs best represents the behaviour of $\frac{C}{T}$ vs. $T^2$, where $C$ is the heat capacity and $T$ is the temperature?

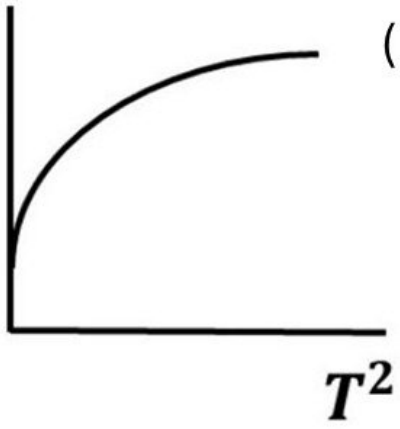
(A)



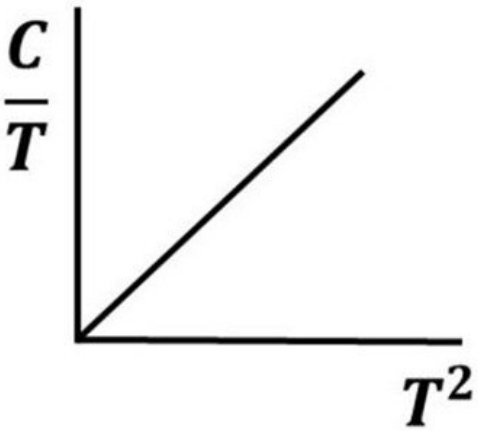

(B)




(C)




(D)



**Q20. [Marks: 1 | MCQ]** Solid State Physics · Tight binding model

| Gate 2023 | MCQ | 1M |
|---|---|---|

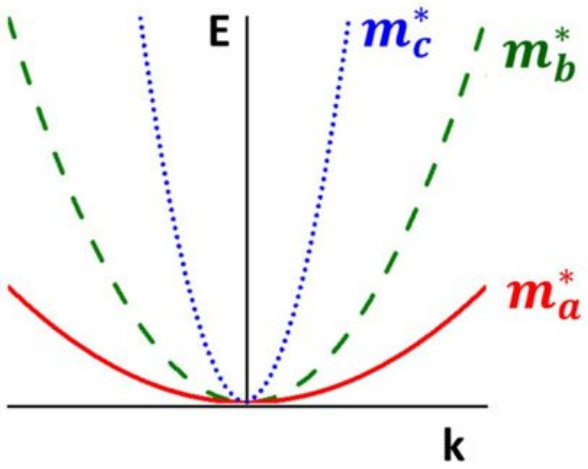
For nonrelativistic electrons in a solid, different energy dispersion relations (with effective masses $m_a^*, m_b^*$, and $m_c^*$) are schematically shown in the plots. Which one of the following options is CORRECT?

(A) $m_a^* = m_b^* = m_c^*$

(B) $m_b^* > m_c^* > m_a^*$

(C) $m_c^* > m_b^* > m_a^*$

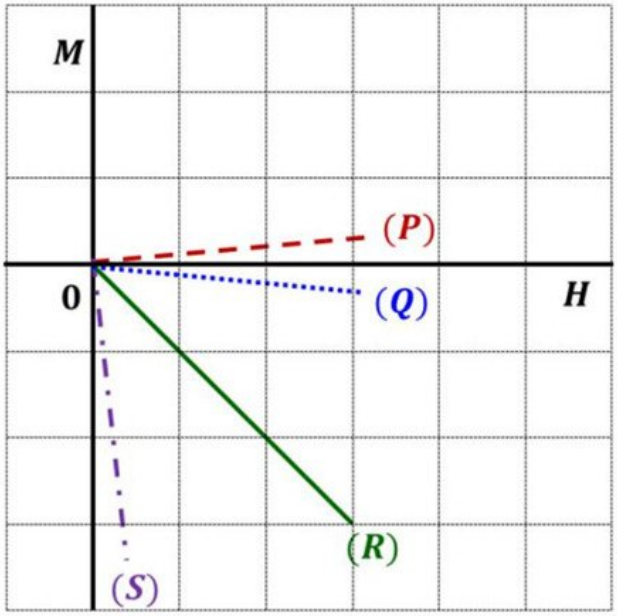
(D) $m_a^* > m_b^* > m_c^*$



**Q21. [Marks: 1 | MCQ]** Solid State Physics · Magnetic properties of solids

| Gate 2023 | MCQ | 1M |
|---|---|---|

The figure schematically shows the M (magnetization) – H (magnetic field) plots for certain types of materials. Here M and H are plotted in the same scale and units. Which one of the following is the most appropriate combination?




(A) (Q) - Paramagnet; (R) - Type-I Superconductor; (S) – Antiferromagnet

(B) (P) - Paramagnet; (Q) - Diamagnet; (R) - Type-I Superconductor

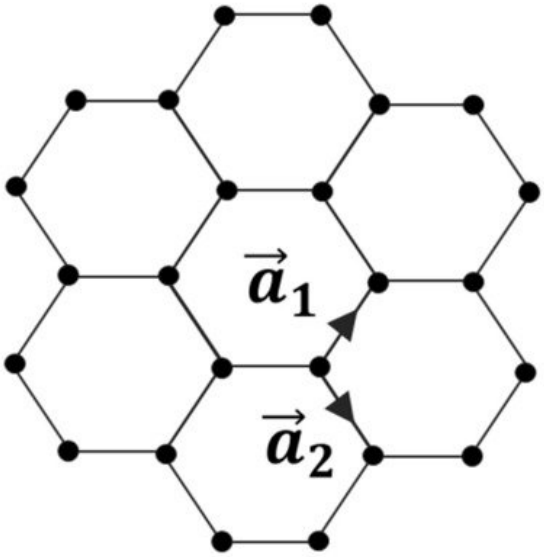
(C) (P) - Paramagnet; (Q) - Antiferromagnet; (R) - Type-I Superconductor

(D) (P) - Diamagnet; (R) - Paramagnet; (S) - Type-I Superconductor

**Q22. [Marks: 1 | MCQ]** Solid State Physics · Crystallography

| Gate 2023 | MCQ | 1M |
|---|---|---|

Graphene is a two dimensional material, in which carbon atoms are arranged in a honeycomb lattice with lattice constant a. As shown in the figure, $\vec{a}_1$ and $\vec{a}_2$ are two lattice vectors. Which one of the following is the area of the first Brillouin zone for this lattice?




(A) $\frac{8\pi^2}{3\sqrt{3}a^2}$

(B) $\frac{4\pi^2}{3\sqrt{3}a^2}$

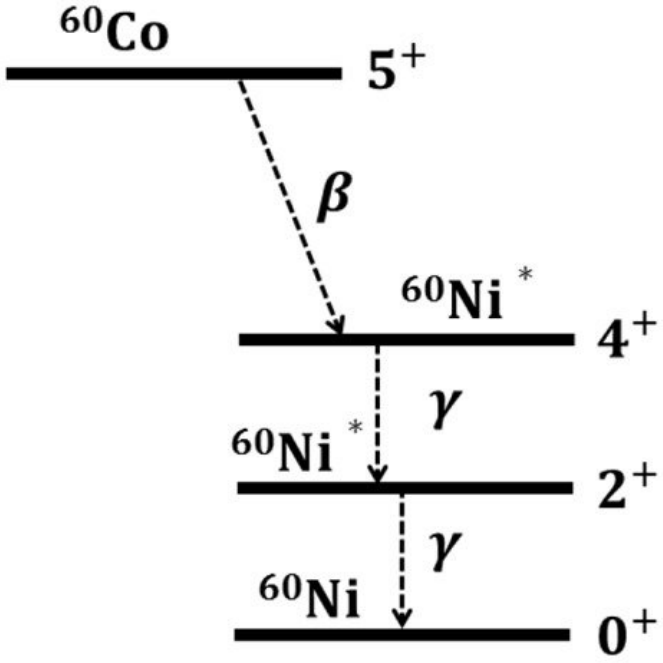
(C) $\frac{8\pi^2}{\sqrt{3}a^2}$

(D) $\frac{4\pi^2}{\sqrt{3}a^2}$

**Q23. [Marks: 1 | MCQ]** Nuclear and Particle Physics · Radioactivity

| Gate 2023 | MCQ | 1M |
|---|---|---|

A $^{60}$Co nucleus emits a β-particle and is converted to $^{60}\mathrm{Ni}^{*}$ with $\mathrm{J^P} = 4^+$, which in turn decays to the $^{60}$Ni ground state with $\mathrm{J^P} = 0^+$ by emitting two photons in succession, as shown in the figure. Which one of the following statements is CORRECT?




(A) $4^+ \rightarrow 2^+$ is an electric octupole transition

(B) $4^+ \rightarrow 2^+$ is a magnetic quadrupole transition

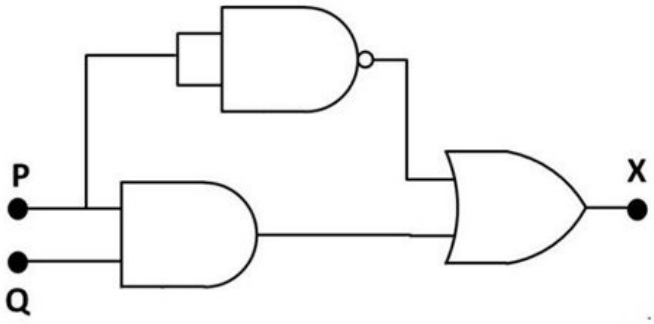
(C) $2^+ \rightarrow 0^+$ is an electric quadrupole transition

(D) $2^+ \rightarrow 0^+$ is a magnetic quadrupole transition

**Q24. [Marks: 1 | MCQ]** Electronics · Logic Gates

| Gate 2023 | MCQ | 1M |
|---|---|---|

Which one of the following options is CORRECT for the given logic circuit?




(A) $P = 1, Q = 1; X = 0$

(B) $P = 1, Q = 0; X = 1$

(C) $P = 0, Q = 1; X = 0$

(D) $P = 0, Q = 0; X = 1$

**Q25. [Marks: 1 | MCQ]** Quantum Mechanics · Spin and Total Angular momentum

| Gate 2023 | MCQ | 1M |
|---|---|---|

An atom with non-zero magnetic moment has an angular momentum of magnitude $\sqrt{12}\hbar$. When a beam of such atoms is passed through a Stern-Gerlach apparatus, how many beams does it split into?

(A) 3

(B) 7

(C) 9

(D) 25

**Q26. [Marks: 1 | MCQ]** Mathematical Physics · Matrices

| Gate 2023 | MCQ | 1M |
|---|---|---|

A $4 \times 4$ matrix $M$ has the property $M^{\dagger} = -M$ and $M^4 = 1$, where $1$ is the $4 \times 4$ identity matrix. Which one of the following is the CORRECT set of eigenvalues of the matrix $M$?

(A) $(1,1,-1,-1)$

(B) $(i, i, -i, -i)$

(C) $(i, i, i, -i)$

(D) $(1,1, -i, -i)$

**Q27. [Marks: 1 | MCQ]** Nuclear and Particle Physics · Particle Physics

| Gate 2023 | MCQ | 1M |
|---|---|---|

The $\Xi^{0*}$ particle is a member of the Baryon decuplet with isospin state $|I, I_3\rangle = \left|\frac{1}{2}, \frac{1}{2}\right\rangle$ and strangeness quantum number -2. In the quark model, which one of the following is the flavour part of the $\Xi^{0*}$ wavefunction?

(A) $\frac{1}{\sqrt{2}}(uss - ssu)$

(B) $\frac{1}{\sqrt{3}}(uss + sus + ssu)$

(C) $\frac{1}{\sqrt{2}}(uss + ssu)$

(D) $\frac{1}{\sqrt{3}}(uss - sus + ssu)$

**Q28. [Marks: 1 | MSQ]** Thermodynamics · Laws of thermodynamics

| Gate 2023 | MSQ | 1M |
|---|---|---|

Which of the following is(are) the CORRECT option(s) for the Joule-Thomson effect?

(A) It is an isentropic process

(B) It is an isenthalpic process

(C) It can result in cooling as well as heating

(D) For an ideal gas it always results in cooling

**Q29. [Marks: 1 | MSQ]** Nuclear and Particle Physics · Nuclear Force, deuteron problem and scatteri

| Gate 2023 | MSQ | 1M |
|---|---|---|

The deuteron is a bound state of a neutron and a proton. Which of the following statements is(are) CORRECT?

(A) The deuteron has a finite value of electric quadrupole moment due to nonspherical electronic charge distribution

(B) The magnetic moment of the deuteron is equal to the sum of the magnetic moments of the neutron and the proton

(C) The deuteron state is an admixture of $^3S_1$ and $^3D_1$ states

(D) The deuteron state is an admixture of $^3S_1$ and $^3P_1$ states

**Q30. [Marks: 1 | MSQ]** Nuclear and Particle Physics · Particle detector and accelerator

| Gate 2023 | MSQ | 1M |
|---|---|---|

The Geiger-Muller counter is a device to detect $\alpha$, $\beta$ and $\gamma$ radiations. It is a cylindrical tube filled with monatomic gases like argon, and polyatomic gases such as ethyl alcohol. The inner electrode is along the axis of the cylindrical tube and the outer electrode is the tube. Which of the following statements is(are) CORRECT?

(A) Argon is used so that ambient light coming from the surroundings do not produce any signal in the detector

(B) Ethyl alcohol is used as a quenching gas

(C) The electric field strength decreases from the axis to the edge of the tube and the direction of the field is radially outward

(D) The electric field increases from the axis to the edge of the tube and the field direction is radially inward

**Q31. [Marks: 1 | MSQ]** Electromagnetism · Magnetism in matter

| Gate 2023 | MSQ | 1M |
|---|---|---|

Consider an isolated magnetized sphere of radius R with a uniform magnetization $\vec{M}$ along the positive z direction, with the north and south poles of the sphere lying on the Z axis. It is given that the magnetic field inside the sphere is $\vec{B} = \frac{2\mu_0}{3}\vec{M}$, where $\mu_0$ is the permeability of vacuum. Which of the following statements is(are) CORRECT?

(A) The bound volume current density is zero

(B) The bound surface current density has maximum magnitude at the equator, where this magnitude equals $|\vec{M}|$

(C) The auxiliary field $\vec{H} = -\frac{2}{3}\vec{M}$

(D) Far from the sphere, the magnetic field is due to a dipole of moment $\vec{m}$, where $\frac{\vec{m}}{4\pi R^3} = \frac{B}{2\mu_0}\hat{z}$

**Q32. [Marks: 1 | MSQ]** Quantum Mechanics · Basics Quantum Mechanics

| Gate 2023 | MSQ | 1M |
|---|---|---|

Which of the following options represent(s) linearly independent pair(s) of functions of a real variable $x$ ?

(A) $e^{ix}$ and $e^{-ix}$

(B) $x$ and $e^{x}$

(C) $2^{x}$ and $2^{-3+x}$

(D) $e^{ix}$ and $\sin x$

**Q33. [Marks: 1 | NAT]** Atomic and Molecular Physics · Vector Model

| Gate 2023 | NAT | 1M |
|---|---|---|

In the vector model of angular momentum applied to atoms, what is the minimum angle in degrees (in integer) made by the orbital angular momentum vector and the positive $Z$ axis for a $2p$ electron?

**Q34. [Marks: 1 | NAT]** Electronics · Transistors

| Gate 2023 | NAT | 1M |
|---|---|---|

For a transistor amplifier, the frequency response is such that the mid band voltage gain is 200 . The cutoff frequencies are 20 Hz and 20 kHz . What is the ratio (rounded off to two decimal places) of the voltage gain at 10 Hz to that at 100 kHz?

**Q35. [Marks: 1 | NAT]** Electromagnetism · Electrostatics

| Gate 2023 | NAT | 1M |
|---|---|---|

An electric field as a function of radial coordinate r has the form $\vec{E} = \alpha \frac{e^{-r^2}}{r} \hat{r}$, where $\alpha$ is a constant. Assume that dimensions are appropriately taken care of. The electric flux through a sphere of radius $\sqrt{2}$, centered at the origin, is $\Phi$. What is the value of $\frac{\Phi}{2\pi\alpha}$ (rounded off to two decimal places)?

**Q36. [Marks: 2 | MCQ]** Atomic and Molecular Physics · Molecular Physics

| Gate 2023 | MCQ | 2M |
|---|---|---|

It is given that the electronic ground state of a diatomic molecule $X_2$ has even parity and the nuclear spin of X is 0. Which one of the following is the CORRECT statement with regard to the rotational Raman spectrum (J is the rotational quantum number) of this molecule?

(A) Lines of all J values are present

(B) Lines have alternating intensity in the ratio of 3: 1

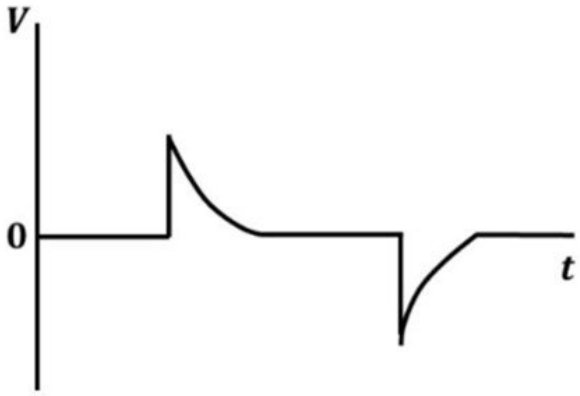
(C) Lines of only even J values are present

(D) Lines of only odd J values are present

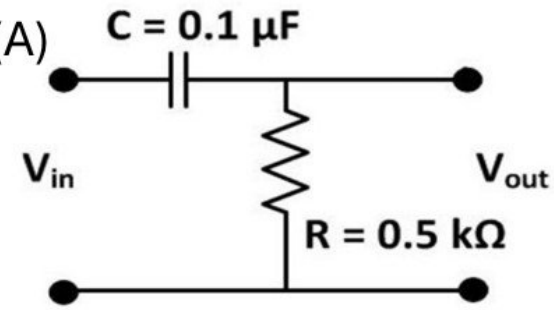
**Q37. [Marks: 2 | MCQ]** Electronics · Filters

| Gate 2023 | MCQ | 2M |
|---|---|---|

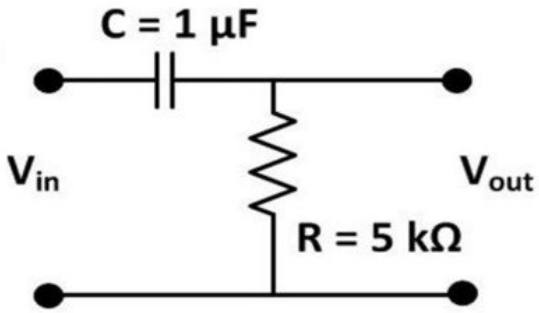
An input voltage in the form of a square wave of frequency 1 kHz is given to a circuit, which results in the output shown schematically below. Which one of the following options is the CORRECT representation of the circuit?



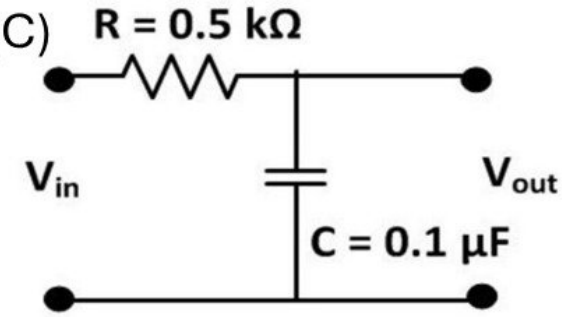

(A)



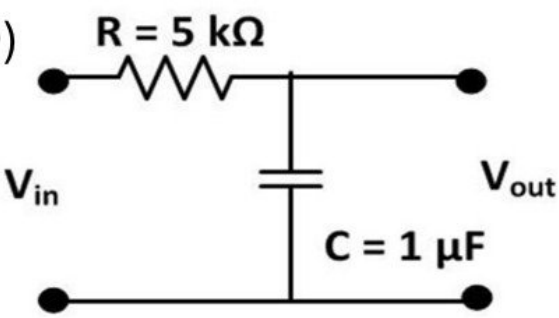

(B)




(C)




(D)



**Q38. [Marks: 2 | MCQ]** Statistical Mechanics · Canonical ensemble

| Gate 2023 | MCQ | 2M |
|---|---|---|

A simple harmonic oscillator with an angular frequency $\omega$ is in thermal equilibrium with a reservoir at absolute temperature T, with $\omega = \frac{2k_B T}{\hbar}$. Which one of the following is the partition function of the system?

(A) $\frac{e}{e^2-1}$

(B) $\frac{e}{e^2+1}$

(C) $\frac{e}{e-1}$

(D) $\frac{e}{e+1}$

**Q39. [Marks: 2 | MCQ]** Quantum Mechanics · Basics Quantum Mechanics

| Gate 2023 | MCQ | 2M |
|---|---|---|

Which one of the following options is the most appropriate match between the items given in Column 1 and Column 2?

| Column 1 | Column 2 |
|---|---|
| (i) Visible light | P. Transition between core energy levels of atom |
| (ii) X-rays | Q. Transition between nuclear energy levels |
| (iii) Gamma rays | R. Pair production |
| (iv) Thermal neutrons | S. Crystal structure determination |
| | T. Photoelectric effect |

(A) (i) - T; (ii) - P,S,T; (iii) - Q,R; (iv) – S

(B) (i) - P,T; (ii) - S; (iii) - R,S; (iv) - S,T

(C) (i) - T; (ii) - R,S; (iii) - Q,R; (iv) – S

(D) (i) - S,T; (ii) - P,S; (iii) - R,T; (iv) - S

**Q40. [Marks: 2 | MCQ]** Classical Mechanics · Special theory of relativity

| Gate 2023 | MCQ | 2M |
|---|---|---|

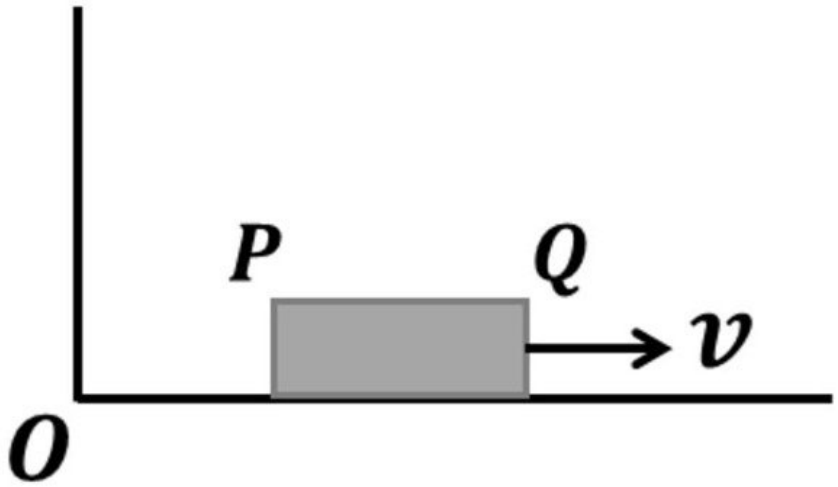
A rod PQ of proper length L lies along the $\mathcal{X}$-axis and moves towards the positive x direction with speed $v = \frac{3c}{5}$ with respect to the ground (see figure), where c is the speed of light in vacuum. An observer on the ground measures the positions of P and Q at different times $t_P$ and $t_Q$ respectively in the ground frame, and finds the difference betwen them to be $\frac{9L}{10}$. What is the value of $t_Q - t_P$ ?

(A) $\frac{L}{3c}$

(B) $\frac{L}{5c}$

(C) $\frac{L}{6c}$

(D) $\frac{2L}{3c}$



**Q41. [Marks: 2 | MCQ]** Classical Mechanics · Rotation Motion

| Gate 2023 | MCQ | 2M |
|---|---|---|

A symmetric top has principal moments of inertia $I_1 = I_2 = \frac{2\alpha}{3}, I_3 = 2\alpha$ about a set of principal axes 1, 2, 3 respectively, passing through its center of mass, where $\alpha$ is a positive constant. There is no force acting on the body and the angular speed of the body about the 3 -axis is $\omega_3 = \frac{1}{8}\text{rad/s}$. With what angular frequency in rad/s does the angular velocity vector $\vec{\omega}_1$ precess about the 3 -axis?

(A) 2

(B) 3

(C) 5

(D) 7

**Q42. [Marks: 2 | MCQ]** Classical Mechanics · Lagrangian and Hamiltonian

| Gate 2023 | MCQ | 2M |
|---|---|---|

A particle of mass $m$ is free to move on a frictionless horizontal two dimensional $(r, \theta)$ plane, and is acted upon by a force $\vec{F} = -\frac{k}{2r^3}\hat{r}$ with $k$ being a positive constant. If $p_r$ and $p_\theta$ are the generalised momenta corresponding to $r$ and $\theta$ respectively, then what is the value of $\frac{dp_r}{dt}$?

(A) $\frac{p_\theta^2 - 2mk}{2mr^3}$

(B) $\frac{2p_\theta^2 - mk}{mr^3}$

(C) $\frac{p_\theta^2 - 2mk}{mr^3}$

(D) $\frac{2p_\theta^2 - mk}{2mr^3}$

**Q43. [Marks: 2 | MCQ]** Mathematical Physics · Complex Analysis

| Gate 2023 | MCQ | 2M |
|---|---|---|

Consider two real function

$$U(x,y) = xy(x^2 - y^2),$$
$$V(x,y) = ax^4 + by^4 + cx^2y^2 + k,$$

where $k$ is a real constant and $a, b, c$ are real coefficients. If $U(x,y) + iV(x,y)$ is analytic, then what is the value of $a \times b \times c$ ?

(A) 1/8
(B) 3/28
(C) 5/36
(D) 3/32

**Q44. [Marks: 2 | MCQ]** Optics · Interference and Diffraction

| Gate 2023 | MCQ | 2M |
|---|---|---|

Young's double slit experiment is performed using a beam of $C_{60}$ (fullerene) molecules, each molecule being made up of 60 carbon atoms. When the slit separation is 50 nm , fringes are formed on a screen kept at a distance of 1 m from the slits. Now, the experiment is repeated with $C_{70}$ molecules with a slit separation of 92.5 nm. The kinetic energies of both the beams are the same. The position of the $4^{th}$ bright fringe for $C_{60}$ will correspond to the $n^{th}$ bright fringe for $C_{70}$. What is the value of $n$ (rounded off to the nearest integer)?

(A) 5

(B) 6

(C) 7

(D) 8

**Q45. [Marks: 2 | MCQ]** Solid State Physics · Xray diffraction

| Gate 2023 | MCQ | 2M |
|---|---|---|

A neutron beam with a wave vector $\vec{k}$ and an energy 20.4 meV diffracts from a crystal with an outgoing wave vector $\vec{k}'$. One of the diffraction peaks is observed for the reciprocal lattice vector $\vec{G}$ of magnitude $3.14\text{Å}^{-1}$. What is the diffraction angle in degrees (rounded off to the nearest integer) that $\vec{k}$ makes with the plane? (Use mass of neutron $= 1.67 \times 10^{-27}\text{Kg}$ )

(A) 15

(B) 30

(C) 45

(D) 60

**Q46. [Marks: 2 | MCQ]** Solid State Physics · Lattice vibration

| Gate 2023 | MCQ | 2M |
|---|---|---|

In the first Brillouin zone of a rectangular lattice (lattice constants a = 6Å and b = 4Å ), three incoming phonons with the same wave vector $\langle 1.2\text{Å}^{-1}, 0.6\text{Å}^{-1}\rangle$ interact to give one phonon. Which one of the following is the CORRECT wave vector of the resulting phonon?

(A) $\langle 2.56\text{Å}^{-1}, 0.23\text{Å}^{-1}\rangle$

(B) $\langle 3.60\text{Å}^{-1}, 1.80\text{Å}^{-1}\rangle$

(C) $\langle 0.48\text{Å}^{-1}, 0.23\text{Å}^{-1}\rangle$

(D) $\langle 3.60\text{Å}^{-1}, -0.80\text{Å}^{-1}\rangle$

**Q47. [Marks: 2 | MCQ]** Solid State Physics · Lattice vibration

| Gate 2023 | MCQ | 2M |
|---|---|---|

For a covalently bonded solid consisting of ions of mass $m$, the binding potential can be assumed to be given by

$$U(r) = -\epsilon\left(\frac{r}{r_0}\right)e^{-\frac{r}{r_0}},$$

where $\epsilon$ and $r_0$ are positive constants. What is the Einstein frequency of the solid in Hz ?

(A) $\frac{1}{2\pi}\sqrt{\frac{\epsilon e}{mr_0^2}}$

(B) $\frac{1}{2\pi}\sqrt{\frac{\epsilon}{mer_0^2}}$

(C) $\frac{1}{2\pi}\sqrt{\frac{2\epsilon}{mer_0^2}}$

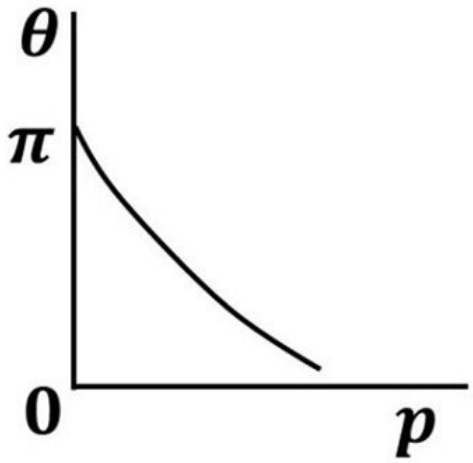
(D) $\frac{1}{2\pi}\sqrt{\frac{\epsilon e}{2mr_0^2}}$

**Q48. [Marks: 2 | MCQ]** Nuclear and Particle Physics · Nuclear Force, deuteron problem and scatteri

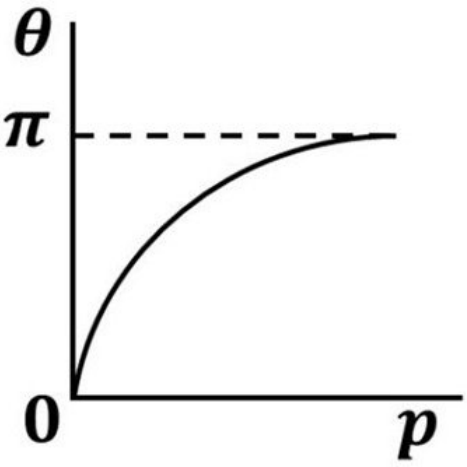
| Gate 2023 | MCQ | 2M |
|---|---|---|

In a hadronic interaction, $\pi^0$, s are produced with different momenta, and they immediately decay into two photons with an opening angle $\theta$ between them. Assuming that all these decays occur in one plane, which one of the following figures depicts the behaviour of $\theta$ as a function of the $\pi^0$ momentum p?

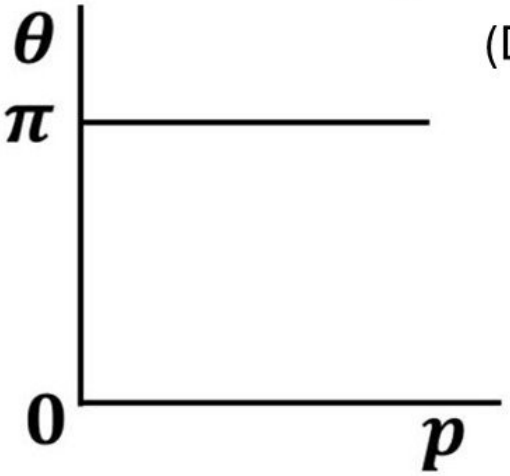
(A)



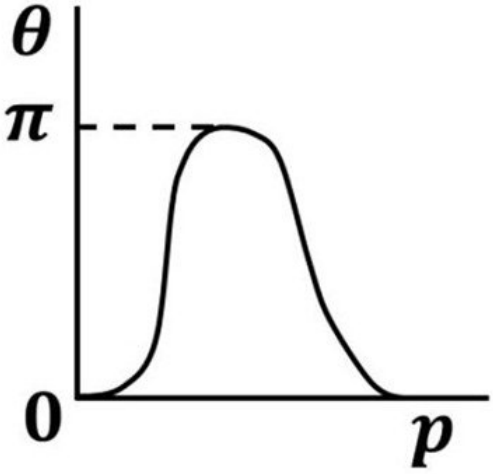

(B)




(C)




(D)



**Q49. [Marks: 2 | MCQ]** Quantum Mechanics · Orbital angular momentum and hydrogen atom

| Gate 2023 | MCQ | 2M |
|---|---|---|

A particle has wavefunction

$$\psi(x, y, z) = Nze^{-\alpha(x^2+y^2+z^2)},$$

where $N$ is a normalization constant and $\alpha$ is a positive constant. In this state, which one of the following options represents the eigenvalues of $L^2$ and $L_Z$ respectively?

Some values of $Y_\ell^m$ are :

$$Y_0^0 = \sqrt{\frac{1}{4\pi}}, Y_1^0 = \sqrt{\frac{3}{4\pi}}\cos\theta, Y_1^{\pm 1} = \mp\sqrt{\frac{3}{8\pi}}\sin\theta e^{\pm i\phi}$$

(A) 0 and 0

(B) $\hbar^2$ and $-\hbar$

(C) $2\hbar^2$ and 0

(D) $\hbar^2$ and $\hbar$

**Q50. [Marks: 2 | MCQ]** Quantum Mechanics · Basics Quantum Mechanics

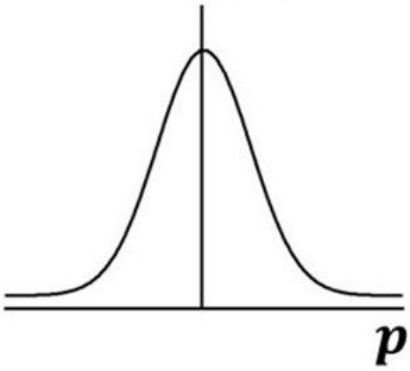
| Gate 2023 | MCQ | 2M |
|---|---|---|

The wavefunction of a particle in one dimension is given by

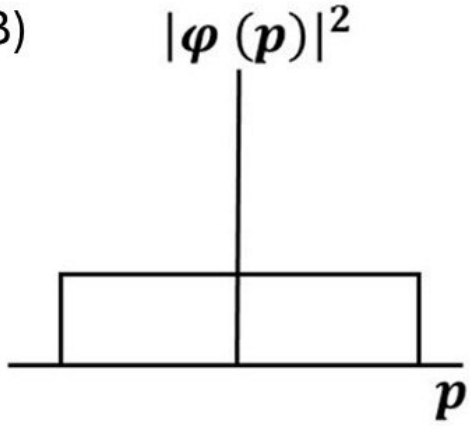
$$\psi(x) = \begin{cases} M, & -a < x < a \\ 0, & \text{otherwise}. \end{cases}$$

Here M and a are positive constants. If $\varphi(p)$ is the corresponding momentum space wavefunction, which one of the following plots best represents $|\varphi(p)|^2$ ?

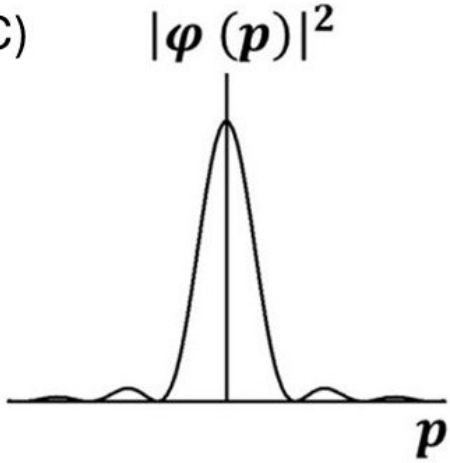
(A)



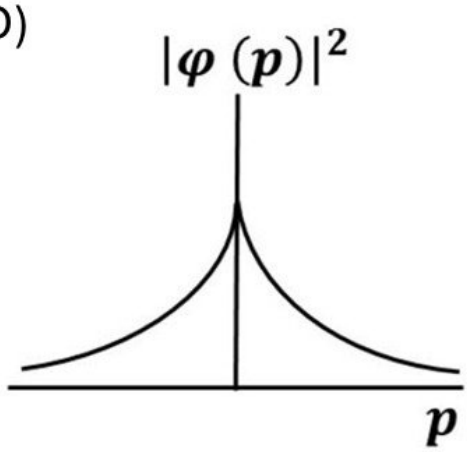

(B)




(C)




(D)



**Q51. [Marks: 2 | MCQ]** Quantum Mechanics · Potential Well

| Gate 2023 | MCQ | 2M |
|---|---|---|

Consider a particle in a two dimensional infinite square well potential of side $L$, with $0 \leq x \leq L$ and $0 \leq y \leq L$. The wavefunction of the particle is zero only along the line $y = \frac{L}{2}$, apart from the boundaries of the well. If the energy of the particle in this state is $E$, what is the energy of the ground state?

(A) $\frac{1}{4}E$

(B) $\frac{2}{5}E$

(C) $\frac{3}{8}E$

(D) $\frac{1}{2}E$

**Q52. [Marks: 2 | MCQ]** Quantum Mechanics · Spin and Total Angular momentum

| Gate 2023 | MCQ | 2M |
|---|---|---|

Consider two non-identical spin $\frac{1}{2}$ particles labelled 1 and 2 in the spin product state $\left|\frac{1}{2},\frac{1}{2}\right\rangle\left|\frac{1}{2},-\frac{1}{2}\right\rangle$. The Hamiltonian of the system is

$$H=\frac{4\lambda}{\hbar^2}\vec{S}_1\cdot\vec{S}_2,$$

where $\vec{S}_1$ and $\vec{S}_2$ are the spin operators of particles 1 and 2, respectively, and $\lambda$ is a constant with appropriate dimensions. What is the expectation value of $H$ in the above state?

(A) $-\lambda$

(B) $-2\lambda$

(C) $\lambda$

(D) $2\lambda$

**Q53. [Marks: 2 | MCQ]** Quantum Mechanics · Spin and Total Angular momentum

| Gate 2023 | MCQ | 2M |
|---|---|---|

A spin $\frac{1}{2}$ particle is in a spin up state along the x-axis (with unit vector $\hat{x}$) and is denoted as $\left|\frac{1}{2},\frac{1}{2}\right\rangle_x$. What is the probability of finding the particle to be in a spin up state along the direction $\hat{x}'$, which lies in the xy-plane and makes an angle $\theta$ with respect to the positive x-axis, if such a measurement is made?

(A) $\frac{1}{2}\cos^2\frac{\theta}{4}$

(B) $\cos^2\frac{\theta}{4}$

(C) $\frac{1}{2}\cos^2\frac{\theta}{2}$

(D) $\cos^2\frac{\theta}{2}$

**Q54. [Marks: 2 | MCQ]** Atomic and Molecular Physics · Model of atom

| Gate 2023 | MCQ | 2M |
|---|---|---|

Different spectral lines of the Balmer series (transitions $n \to 2$, with $n$ being the principal quantum number) fall one at a time on a Young's double slit apparatus. The separation between the slits is $d$ and the screen is placed at a constant distance from the slits. What factor should $d$ be multiplied by to maintain a constant fringe width for various lines, as $n$ takes different allowed values?

(A) $\frac{n^2-4}{4n^2}$

(B) $\frac{n^2+4}{4n^2}$

(C) $\frac{4n^2}{n^2-4}$

(D) $\frac{4n^2}{n^2+4}$

**Q55. [Marks: 2 | MSQ]** Nuclear and Particle Physics · Particle Physics

| Gate 2023 | MSQ | 2M |
|---|---|---|

Under parity and time reversal transformations, which of the following statements is(are) TRUE about the electric dipole moment p and the magnetic dipole moment μ?

(A) p is odd under parity and μ is odd under time reversal

(B) p is odd under parity and μ is even under time reversal

(C) p is even under parity and μ is odd under time reversal

(D) p is even under parity and μ is even under time reversal

**Q56. [Marks: 2 | MSQ]** Mathematical Physics · Complex Analysis

| Gate 2023 | MSQ | 2M |
|---|---|---|

Consider the complex function

$$f(z) = \frac{z^2 \sin z}{(z-\pi)^4}$$

At $Z = \pi$, which of the following options is(are) CORRECT?

(A) The order of the pole is 4

(B) The order of the pole is 3

(C) The residue at the pole is $\frac{\pi}{6}$

(D) The residue at the pole is $\frac{2\pi}{3}$

**Q57. [Marks: 2 | MSQ]** Mathematical Physics · Vector Analysis

| Gate 2023 | MSQ | 2M |
|---|---|---|

Consider the vector field $\vec{V}$ consisting of the velocities of points on a thin horizontal disc of radius $R = 2\text{m}$, moving anticlockwise with uniform angular speed $\omega = 2rad/sec$ about an axis passing through its center. If $V = |\vec{V}|$, then which of the following options is(are) CORRECT ? (In the options, $\hat{r}$ and $\hat{\theta}$ are unit vectors corresponding to the plane polar coordinates $r$ and $\theta$ ). You may use the fact that in cylindrical coordinates $(s, \phi, z)$ ($S$ is the distance from the $Z$-axis), the gradient, divergence, curl and Laplacian operators are:

$$\vec{\nabla} f = \frac{\partial f}{\partial s}\hat{s} + \frac{1}{s}\frac{\partial f}{\partial \phi}\hat{\phi} + \frac{\partial f}{\partial z}\hat{z};$$

$$\vec{\nabla} \cdot \vec{A} = \frac{1}{s}\frac{\partial}{\partial s}(sA_S) + \frac{1}{s}\frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z};$$

$$\vec{\nabla} \times \vec{A} = \left(\frac{1}{s}\frac{\partial A_z}{\partial \phi} - \frac{\partial A_\phi}{\partial z}\right)\hat{s} + \left(\frac{\partial A_s}{\partial z} - \frac{\partial A_z}{\partial s}\right)\hat{\phi} + \frac{1}{s}\left(\frac{\partial}{\partial s}(sA_\phi) - \frac{\partial A_s}{\partial \phi}\right)\hat{z}$$

$$\vec{\nabla}^2 f = \frac{1}{s}\frac{\partial}{\partial s}\left(s\frac{\partial f}{\partial s}\right) + \frac{1}{s^2}\frac{\partial^2 f}{\partial \phi^2} + \frac{\partial^2 f}{\partial z^2}.$$

(A) $\vec{\nabla} V = 2\hat{r}$

(B) $\vec{\nabla} \cdot \vec{V} = 2$

(C) $\vec{\nabla} \times \vec{V} = 4\hat{Z}$, where $\hat{Z}$ is a unit vector perpendicular to the $(r, \theta)$ plane

(D) $\vec{\nabla}^2 V = \frac{4}{3}$ at $r = 1.5$ m

**Q58. [Marks: 2 | MSQ]** Nuclear and Particle Physics · Particle Physics

| Gate 2023 | MSQ | 2M |
|---|---|---|

A slow moving $\pi^-$particle is captured by a deuteron ( d ) and this reaction produces two neutrons (n) in the final state, i.e., $\pi^- + d \rightarrow n + n$. Neutron and deuteron have even intrinsic parities, whereas $\pi^-$has odd intrinsic parity. L and S are the orbital and spin angular momenta, respectively of the system of two neutrons. Which of the following statements regarding the final two-neutron state is(are) CORRECT?

(A) It has odd parity

(B) $L + S$ is odd

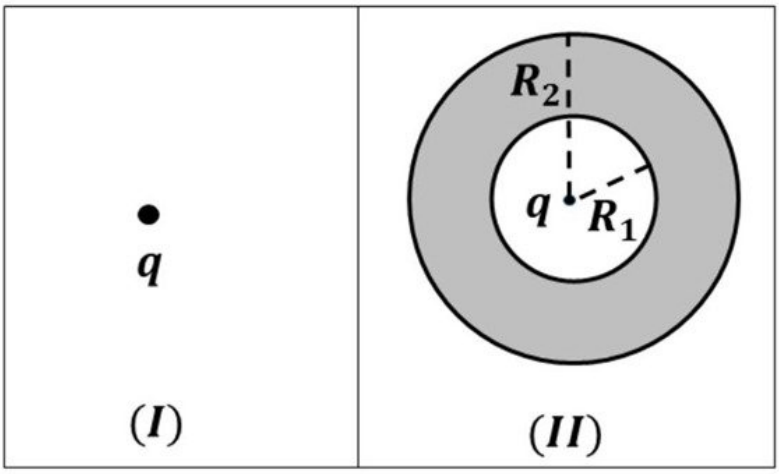
(C) $L = 1, S = 1$

(D) $L = 2, S = 0$

**Q59. [Marks: 2 | NAT]** Electromagnetism · Electrostatics

| Gate 2023 | NAT | 2M |
|---|---|---|

Two independent electrostatic configurations are shown in the figure. Configuration (I) consists of an isolated point charge $q = 1C$, and configuration (II) consists of another identical charge surrounded by a thick conducting shell of inner radius $R_1 = 1\,m$ and outer radius $R_2 = 2\,m$, with the charge being at the center of the shell. $W_I = \frac{\epsilon_0}{2}\int E_I^2 dV$ and $W_{II} = \frac{\epsilon_0}{2}\int E_{II}^2 dV$, where $E_I$ and $E_{II}$ are the magnitudes of the electric fields for configurations (I) and (II) respectively, $\epsilon_0$ is the permittivity of vacuum, and the volume integrations are carried out over all space. If $\frac{8\pi}{\epsilon_0}|W_I - W_{II}| = \frac{1}{n}$, what is the value of the integer $n$ ?



**Q60. [Marks: 2 | NAT]** Nuclear and Particle Physics · Radioactivity

| Gate 2023 | NAT | 2M |
|---|---|---|

In pion nucleon scattering, the pion and nucleon can combine to form a short lived bound state called the $\Delta$ particle ( $\pi + N \rightarrow \Delta$ ). The masses of the pion, nucleon and the $\Delta$ particle are $140\,\mathrm{MeV/c^2}, 938\,\mathrm{MeV/c^2}$ and $1230\,\mathrm{MeV/c^2}$, respectively. In the lab frame, where the nucleon is at rest, what is the minimum energy (in $\mathrm{MeV/c^2}$, rounded off to one decimal place) of the pion to produce the $\Delta$ particle?

**Q61. [Marks: 2 | NAT]** Electromagnetism · EM Waves

| Gate 2023 | NAT | 2M |
|---|---|---|

Consider an electromagnetic wave propagating in the z-direction in vacuum, with the magnetic field given by $\vec{B} = \vec{B}_0 e^{i(kz-\omega t)}$. If $B_0 = 10^{-8}\,\mathrm{T}$, the average power passing through a circle of radius 1.0 m placed in the xy plane is P (in Watts). Using $\epsilon_0 = 10^{-11}\,\frac{C^2}{Nm^2}$, what is the value of $\frac{10^3 P}{\pi}$ (rounded off to one decimal place)?

**Q62. [Marks: 2 | NAT]** Nuclear and Particle Physics · Radioactivity

| Gate 2023 | NAT | 2M |
|---|---|---|

An α-particle is emitted from the decay of Americium (Am) at rest, i.e., ${}^{241}_{94}\mathrm{Am} \rightarrow {}^{237}_{92}\mathrm{U} + \alpha$. The rest masses of ${}^{241}_{94}\mathrm{Am}$, ${}^{237}_{92}\mathrm{U}$ and α are $224.544\ \mathrm{GeV/c^2}$, $220.811\ \mathrm{GeV/c^2}$ and $3.728\ \mathrm{GeV/c^2}$ respectively. What is the kinetic energy (in $\mathrm{MeV/c^2}$, rounded off to two decimal places) of the α-particle?

**Q63. [Marks: 2 | NAT]** Statistical Mechanics · Microstates

| Gate 2023 | NAT | 2M |
|---|---|---|

Consider 6 identical, non-interacting, spin $\frac{1}{2}$ atoms arranged on a crystal lattice at absolute temperature T. The Z-component of the magnetic moment of each of these atoms can be $\pm\mu_B$. If P and Q are the probabilities of the net magnetic moment of the solid being $2\mu_B$ and $6\mu_B$ respectively, what is the value of $\frac{P}{Q}$ (in integer)?

**Q64. [Marks: 2 | NAT]** Statistical Mechanics · Microstates

| Gate 2023 | NAT | 2M |
|---|---|---|

Two identical, non-interacting $^4He_2$ atoms are distributed among 4 different nondegenerate energy levels. The probability that they occupy different energy levels is $p$. Similarly, two $^3He_2$ atoms are distributed among 4 different non-degenerate energy levels, and the probability that they occupy different levels is $q$. What is the value of $\frac{p}{q}$ (rounded off to one decimal place)?

**Q65. [Marks: 2 | NAT]** Thermodynamics · Carnot Cycle

| Gate 2023 | NAT | 2M |
|---|---|---|

Two identical bodies kept at temperatures 800 K and 200 K act as the hot and the cold reservoirs of an ideal heat engine, respectively. Assume that their heat capacity ($C$) in Joules/K is independent of temperature and that they do not undergo any phase change. Then, the maximum work that can be obtained from the heat engine is $n \times C$ Joules. What is the value of $n$ (in integer)?

# Answer Key

65 questions · Subject & topic for quick revision · Official keys (IIT/IISc)

| Q.No | Subject | Topic | Type | Marks | Answer |
|---|---|---|---|---|---|
| Q1 | General Aptitude | English | MCQ | 1 | **B** |
| Q2 | General Aptitude | English | MCQ | 1 | **C** |
| Q3 | General Aptitude | Geometry | MCQ | 1 | **B** |
| Q4 | General Aptitude | Reasoning | MCQ | 1 | **D** |
| Q5 | General Aptitude | Reasoning | MCQ | 1 | **C** |
| Q6 | General Aptitude | Reasoning | MCQ | 2 | **D** |
| Q7 | General Aptitude | Mathematical Analysis | MCQ | 2 | **A** |
| Q8 | General Aptitude | Reasoning | MCQ | 2 | **C** |
| Q9 | General Aptitude | Mathematical Analysis | MCQ | 2 | **A** |
| Q10 | General Aptitude | Geometry | MCQ | 2 | **D** |
| Q11 | Thermodynamics | Carnot Cycle | MCQ | 1 | ** |
| Q12 | Atomic and Molecular Ph… | Effects in atomic physics | MCQ | 1 | **D** |
| Q13 | Electronics | Diodes | MCQ | 1 | **A** |
| Q14 | Atomic and Molecular Ph… | Effects in atomic physics | MCQ | 1 | **A** |
| Q15 | Quantum Mechanics | Orbital angular momentum and hydr… | MCQ | 1 | ** |
| Q16 | Solid State Physics | Hall Effect | MCQ | 1 | **B** |
| Q17 | Mathematical Physics | Tensors | MCQ | 1 | **B** |
| Q18 | Solid State Physics | Crystallography | MCQ | 1 | **B** |
| Q19 | Solid State Physics | Lattice vibration | MCQ | 1 | **B** |
| Q20 | Solid State Physics | Tight binding model | MCQ | 1 | **D** |
| Q21 | Solid State Physics | Magnetic properties of solids | MCQ | 1 | **B** |
| Q22 | Solid State Physics | Crystallography | MCQ | 1 | **A** |
| Q23 | Nuclear and Particle Phy… | Radioactivity | MCQ | 1 | **C** |
| Q24 | Electronics | Logic Gates | MCQ | 1 | **D** |
| Q25 | Quantum Mechanics | Spin and Total Angular momentum | MCQ | 1 | **B** |
| Q26 | Mathematical Physics | Matrices | MCQ | 1 | **B** |
| Q27 | Nuclear and Particle Phy… | Particle Physics | MCQ | 1 | **B** |
| Q28 | Thermodynamics | Laws of thermodynamics | MSQ | 1 | **B,C** |
| Q29 | Nuclear and Particle Phy… | Nuclear Force, deuteron problem an… | MSQ | 1 | **A,C** |
| Q30 | Nuclear and Particle Phy… | Particle detector and accelerator | MSQ | 1 | **A,B,C** |
| Q31 | Electromagnetism | Magnetism in matter | MSQ | 1 | **A,B,D** |
| Q32 | Quantum Mechanics | Basics Quantum Mechanics | MSQ | 1 | **A,B,D** |
| Q33 | Atomic and Molecular Ph… | Vector Model | NAT | 1 | **45 to 45** |
| Q34 | Electronics | Transistors | NAT | 1 | **2.20 to 2.36** |
| Q35 | Electromagnetism | Electrostatics | NAT | 1 | **0.36 to 0.40** |
| Q36 | Atomic and Molecular Ph… | Molecular Physics | MCQ | 2 | **C** |

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| Q.No | Subject | Topic | Type | Marks | Answer |
|---|---|---|---|---|---|
| Q37 | Electronics | Filters | MCQ | 2 | **A** |
| Q38 | Statistical Mechanics | Canonical ensemble | MCQ | 2 | **A** |
| Q39 | Quantum Mechanics | Basics Quantum Mechanics | MCQ | 2 | **A** |
| Q40 | Classical Mechanics | Special theory of relativity | MCQ | 2 | **C** |
| Q41 | Classical Mechanics | Rotation Motion | MCQ | 2 | ** |
| Q42 | Classical Mechanics | Lagrangian and Hamiltonian | MCQ | 2 | **D** |
| Q43 | Mathematical Physics | Complex Analysis | MCQ | 2 | **D** |
| Q44 | Optics | Interference and Diffraction | MCQ | 2 | **D** |
| Q45 | Solid State Physics | Xray diffraction | MCQ | 2 | **B** |
| Q46 | Solid State Physics | Lattice vibration | MCQ | 2 | **C** |
| Q47 | Solid State Physics | Lattice vibration | MCQ | 2 | **B** |
| Q48 | Nuclear and Particle Phy… | Nuclear Force, deuteron problem an… | MCQ | 2 | **A** |
| Q49 | Quantum Mechanics | Orbital angular momentum and hydr… | MCQ | 2 | **C** |
| Q50 | Quantum Mechanics | Basics Quantum Mechanics | MCQ | 2 | **C** |
| Q51 | Quantum Mechanics | Potential Well | MCQ | 2 | **B** |
| Q52 | Quantum Mechanics | Spin and Total Angular momentum | MCQ | 2 | **A** |
| Q53 | Quantum Mechanics | Spin and Total Angular momentum | MCQ | 2 | **D** |
| Q54 | Atomic and Molecular Ph… | Model of atom | MCQ | 2 | **C** |
| Q55 | Nuclear and Particle Phy… | Particle Physics | MSQ | 2 | **A** |
| Q56 | Mathematical Physics | Complex Analysis | MSQ | 2 | **B** |
| Q57 | Mathematical Physics | Vector Analysis | MSQ | 2 | **A,C,D** |
| Q58 | Nuclear and Particle Phy… | Particle Physics | MSQ | 2 | **A,C** |
| Q59 | Electromagnetism | Electrostatics | NAT | 2 | ** |
| Q60 | Nuclear and Particle Phy… | Radioactivity | NAT | 2 | **326.9 to 327.1** |
| Q61 | Electromagnetism | EM Waves | NAT | 2 | **11.0 to 13.7** |
| Q62 | Nuclear and Particle Phy… | Radioactivity | NAT | 2 | **4.90 to 4.94** |
| Q63 | Statistical Mechanics | Microstates | NAT | 2 | **15 to 15** |
| Q64 | Statistical Mechanics | Microstates | NAT | 2 | **0.6 to 0.6** |
| Q65 | Thermodynamics | Carnot Cycle | NAT | 2 | **200 to 200** |