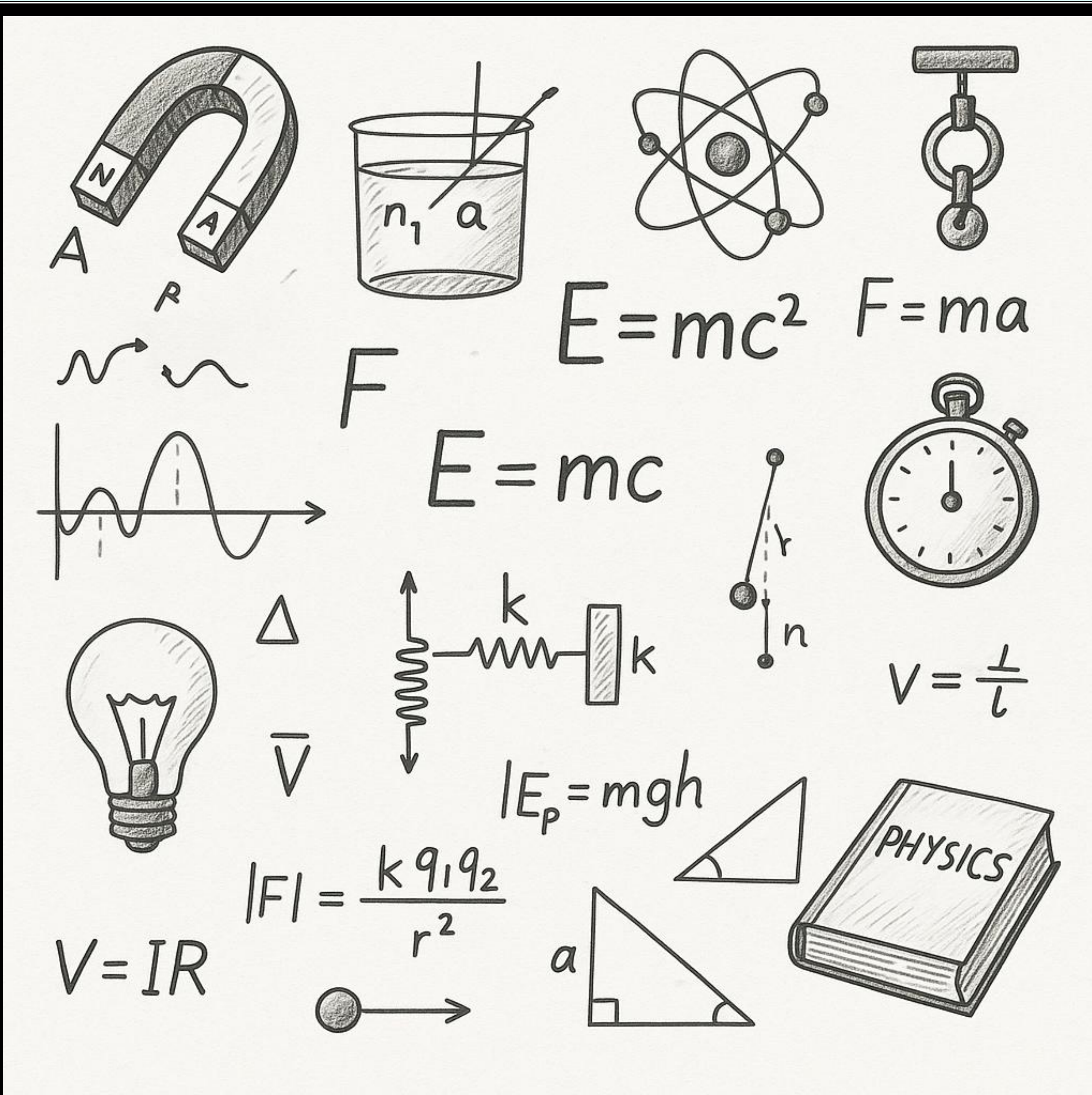


SIMULATORS 2025
PAPER 1

PYQ REPOSITORY WITH HINTS

This page is intentionally left blank.

Physics Syllabus
Paper 1

Subject	Syllabus
Mechanics of Particles	Laws of motion; conservation of energy and momentum; rotating frames; centripetal and Coriolis accelerations; motion under central force; angular momentum conservation; Kepler's laws; gravitational field and potential (spherical bodies); Gauss and Poisson equations; gravitational self-energy; two-body problem; reduced mass; Rutherford scattering; centre of mass and laboratory frame.
Mechanics of Rigid Bodies	System of particles; centre of mass; angular momentum; conservation theorems; elastic and inelastic collisions; rigid body degrees of freedom; Euler's theorem; angular velocity; angular momentum; moments of inertia; parallel and perpendicular axis theorems; rotational motion; molecular rotation; diatomic and triatomic models; gyroscopic motion.
Mechanics of Continuous Media	Elasticity; Hooke's law; elastic constants of isotropic solids and interrelations; laminar flow; viscosity; Poiseuille's law; Bernoulli's equation; Stokes' law and applications.
Special Relativity	Michelson–Morley experiment and implications; Lorentz transformations; time dilation; length contraction; relativistic velocity addition; Doppler and aberration effects; mass-energy relation; four-momentum vector; covariance in physics.
Waves and Optics	Interference (Young's double-slit, Newton's rings, thin films, Michelson interferometer); multiple-beam interference (Fabry–Perot); holography; Fraunhofer and Fresnel diffraction; Cornu's spiral; zone plates; diffraction grating; Airy pattern; polarisation (linear, circular); double refraction; quarter-wave plate; optical activity; fibre optics; lasers (Einstein coefficients, Ruby/He-Ne, coherence, three-level scheme).
Electrostatics and Magnetostatics	Laplace and Poisson equations; energy of charge systems; multipole expansion; method of images; dipole fields; dielectrics and polarization; boundary-value problems; magnetic shells; magnetised spheres; ferromagnetism; hysteresis.
Current Electricity	Kirchhoff's laws; Biot–Savart and Ampère's laws; Faraday and Lenz laws; inductance; AC/DC circuits with RLC components; r.m.s. values; resonance; quality factor; transformer principles.

Subject	Syllabus
Electromagnetic Theory and Radiation	Displacement current; Maxwell's equations; wave equations in vacuum/dielectrics; Poynting theorem; vector/scalar potentials; electromagnetic tensor; Fresnel relations; dispersion (normal/anomalous); total internal reflection; Rayleigh scattering; black body radiation; Planck, Stefan–Boltzmann, Wien, and Rayleigh–Jeans laws.
Thermodynamics	Laws of thermodynamics; reversible/irreversible processes; entropy; thermodynamic processes; Otto and Diesel cycles; Gibbs phase rule; chemical potential; van der Waals gas; critical constants; Maxwell–Boltzmann velocity distribution; transport phenomena; equipartition theorem; virial theorem; specific heat theories (Dulong–Petit, Einstein, Debye); Maxwell relations; Clausius–Clapeyron equation; Joule–Kelvin effect; gas liquefaction; adiabatic demagnetisation.
Statistical Physics	Macro/microstates; statistical distributions (Maxwell–Boltzmann, Bose–Einstein, Fermi–Dirac); applications to heat capacities and radiation; concept of negative temperature.

MECHANICS

Key: C = Conceptual, A = Applied

#	Question	Marks	Year	Type
1	**With an appropriate diagram, show that in the Rutherford scattering, the orbit of the particle is a hyperbola. Obtain an expression for impact parameter.** **Hint:** In Rutherford scattering, an alpha particle moves under the repulsive Coulomb force of the nucleus, resulting in a hyperbolic trajectory. The orbit can be analyzed using the central force problem in polar coordinates. The equation of the trajectory is given by: $$r(\phi) = \frac{L^2/mk}{1 + e\cos\phi},$$ where L is the angular momentum, m is the mass of the particle, $k = Ze^2/4\pi\epsilon_0$, and e is the eccentricity. For a repulsive force, the total energy E is positive, and the eccentricity is given by: $$e = \sqrt{1 + \frac{2EL^2}{k^2 m}}.$$ Since $E > 0$, we have $e > 1$, confirming the hyperbolic nature of the orbit. The impact parameter b is related to the scattering angle θ by: $$b = \frac{Ze^2}{4\pi\epsilon_0 m v^2} \cot\left(\frac{\theta}{2}\right),$$ where v is the initial velocity of the particle. To derive this, use the relationship between the impact parameter, angular momentum, and scattering angle, along with the conservation of energy and angular momentum. Include a diagram showing the hyperbolic trajectory, the nucleus at one focus, and the impact parameter b.	10	2011	A
2	**Define a conservative field. Determine if the field given below is conservative in nature: $\vec{E} = cy^2\hat{i} + (2xy + z^2)\hat{j} + 2yz\hat{k}\, V/m$, where c is a constant.** **Hint:** A field is conservative if the work done is independent of the path. Mathematically, a vector field $\vec{F}$ is conservative if its curl is zero, i.e., $\nabla \times \vec{F} = 0$. Compute $\nabla \times \vec{E}$ for the given field and check whether it is zero to determine if the field is conservative.	12	2012	A

Continued on next page...

#	Question	Marks	Year	Type
3	**Prove that as a result of an elastic collision of two particles under the non-relativistic regime with equal masses, the scattering angle will be 90°. Illustrate your answer with a vector diagram.** **Hint:** Apply conservation of momentum and kinetic energy. For equal masses, the momentum conservation equation is $\vec{u}_1 = \vec{v}_1 + \vec{v}_2$, and the kinetic energy conservation equation is $\|\vec{u}_1\|^2 = \|\vec{v}_1\|^2 + \|\vec{v}_2\|^2$. Squaring the momentum equation and comparing it with the energy equation shows that $\vec{v}_1 \cdot \vec{v}_2 = 0$, which implies that the angle between $\vec{v}_1$ and $\vec{v}_2$ is 90°. Draw a vector diagram to illustrate this result.	5	2013	A
4	**If the forces acting on a particle are conservative, show that the total energy of the particle which is the sum of the kinetic and potential energies is conserved.** **Hint:** Use the work-energy theorem, $W = \Delta K$, and the definition of conservative forces, $W = -\Delta U$. Combining these gives $\Delta K + \Delta U = 0$, which implies that the total energy $E = K + U$ remains constant over time.	20	2013	A
5	**Prove that as a result of an elastic collision of two particles under the non-relativistic regime with equal masses, the scattering angle will be 90°. Illustrate your answer with a vector diagram.** **Hint:** Apply conservation of momentum and kinetic energy. For equal masses, the momentum conservation equation is $\vec{u}_1 = \vec{v}_1 + \vec{v}_2$, and the kinetic energy conservation equation is $\|\vec{u}_1\|^2 = \|\vec{v}_1\|^2 + \|\vec{v}_2\|^2$. Squaring the momentum equation and comparing it with the energy equation shows that $\vec{v}_1 \cdot \vec{v}_2 = 0$, which implies that the angle between $\vec{v}_1$ and $\vec{v}_2$ is 90°. Draw a vector diagram to illustrate this result.	5	2013	A

Continued on next page...

#	Question	Marks	Year	Type
6	**Discuss the problem of scattering of a charged particle by a Coulomb field. Hence, obtain an expression for Rutherford scattering cross-section. What is the importance of the above expression?** **Hint:** Rutherford scattering describes the deflection of charged particles by a nucleus under the influence of the Coulomb force. The differential cross-section is given by $d\sigma/d\Omega = (Ze^2/8\pi\epsilon_0 K)^2(1/\sin^4(\theta/2))$, where Z is the atomic number of the nucleus, e is the elementary charge, ϵ_0 is the permittivity of free space, and K is the kinetic energy of the incident particle. This formula, derived under the assumptions of a point-like nucleus and non-relativistic regime, explains why most particles pass through undeflected (small θ) while some experience large-angle scattering (large θ), confirming the existence of a dense nucleus.	25	2014	A
7	**Write down precisely the conservation theorems for energy, linear momentum, and angular momentum of a particle with their mathematical forms.** **Hint: - Energy:** If the force is conservative, the total mechanical energy $E = K + U$ is conserved: $dE/dt = 0$. **- Linear Momentum:** If the net external force is zero, the total linear momentum $\vec{p} = m\vec{v}$ is conserved: $d\vec{p}/dt = 0$. **- Angular Momentum:** If the net external torque is zero, the total angular momentum $\vec{L} = \vec{r} \times \vec{p}$ is conserved: $d\vec{L}/dt = 0$.	10	2015	C
8	**Draw a neat diagram to explain the scattering of an incident beam of particles by a center of force.** **Hint:** The diagram should include an incident beam of particles approaching a scattering center (e.g., a nucleus). Label the scattering angle θ, impact parameter b, and the trajectory of deflected particles. Indicate the detector position to measure scattered particles.	10	2015	C
9	**Show that the differential scattering cross-section can be expressed as $\sigma(\theta) = \frac{s}{\sin\theta}\left\|\frac{ds}{d\theta}\right\|$, where s is the impact parameter and θ is the scattering angle.** **Hint:** The differential scattering cross-section $\sigma(\theta)$ is derived by equating the number of scattered particles in impact parameter space to the number scattered into a solid angle $d\Omega$. Use $dN = 2\pi s ds = \sigma(\theta)2\pi\sin\theta d\theta$ to obtain the given expression. Since s and θ are inversely related, $ds/d\theta$ is negative, and the absolute value ensures $\sigma(\theta)$ is positive.	15	2015	A

Continued on next page...

#	Question	Marks	Year	Type
10	**i. The distance between the centres of the carbon and oxygen atoms in the carbon monoxide (CO) gas molecule is 1.130×10^{-10} m. Locate the centre of mass of the molecule relative to the carbon atom.** **ii. Find the centre of mass of a homogeneous semicircular plate of radius a.** **Hint:** i. Use the center of mass formula $x = \frac{m_O r}{m_C + m_O}$, where m_C and m_O are the masses of carbon and oxygen atoms, and r is the bond length. ii. The center of mass of a semicircular plate lies at a distance $4a/3\pi$ from the diameter along the symmetry axis. This result is derived by integrating over the semicircular area using polar coordinates.	10	2016	A
11	**A diatomic molecule can be considered to be made up of two masses m_1 and m_2 separated by a fixed distance r. Derive a formula for the distance of centre of mass, C, from mass m_1. Also show that the moment of inertia about an axis through C and perpendicular to r is μr^2 where $\mu = \frac{m_1 m_2}{m_1 + m_2}$.** **Hint:** The center of mass distance from m_1 is given by $x = \frac{m_2 r}{m_1 + m_2}$. To find the moment of inertia about C, use $I = m_1 x^2 + m_2 (r - x)^2$, then substitute x and simplify to get $I = \mu r^2$.	15	2017	A
12	**A ball moving with a speed of 9 m/s strikes an identical stationary ball such that after the collision the direction of each ball makes an angle 30° with the original line of motion. Find the speed of the balls after the collision. Is the kinetic energy conserved in this collision?** **Hint:** Apply conservation of momentum along and perpendicular to the initial direction. Let v_1 be the speed of each ball after the collision. Along the initial direction: $9 = v_1 \cos 30^\circ + v_1 \cos 30^\circ$. Perpendicular to the initial direction: $0 = v_1 \sin 30^\circ - v_1 \sin 30^\circ$. Solve for v_1. Compare initial and final kinetic energies to check for conservation.	15	2017	A

Continued on next page...

#	Question	Marks	Year	Type
13	**i. If a particle of mass m is in a central force field $f(r)\hat{r}$, then show that its path must be a plane curve, where $\hat{r}$ is a unit vector in the direction of position vector $\vec{r}$.** **ii. A block of mass m having negligible dimension is sliding freely in x-direction with velocity $\vec{v} = v\hat{i}$ as shown in the diagram. What is its angular momentum $\vec{L}_O$ about origin O and its angular momentum $\vec{L}_A$ about the point A on y-axis?** **Hint:** i. Since torque due to a central force is zero, angular momentum $\vec{L} = \vec{r} \times \vec{p}$ is conserved, meaning $\vec{r}$ and $\vec{p}$ remain in a plane. ii. Angular momentum is given by $\vec{L} = \vec{r} \times \vec{p}$. For point O, $\vec{L}_O = -mvy\hat{k}$ since $\vec{r}_O = y\hat{j}$. For point A, since the position vector $\vec{r}_A$ is parallel to velocity $\vec{v}$, the cross product is zero, implying $\vec{L}_A = 0$.	10	2018	A
14	**A rod of length l has non-uniform linear mass density (mass per unit length) λ, which varies as $\lambda = \lambda_0(\frac{x}{L})$, where λ_0 is a constant and x is the distance from the end marked '0' (as shown in the figure). Find the centre of mass of the rod.** **Hint:** The center of mass x_{cm} is given by $x_{cm} = \frac{\int x dm}{\int dm}$, where $dm = \lambda dx = \lambda_0 \frac{x}{L} dx$. Integrate from 0 to L to find the total mass and the integral in the numerator.	15	2018	A
15	**i. What is a central force? Give two examples of the central force.** **ii. Show that the angular momentum (L) of the particle in a central force field is a constant of motion.** **Hint:** i. A central force is a force directed along the line joining the centers of two bodies. Examples include gravitational force and Coulomb force. ii. The torque on the particle is $\vec{\tau} = \vec{r} \times \vec{F}$. Since $\vec{F}$ is parallel to $\vec{r}$ in a central force field, $\vec{\tau} = 0$, meaning angular momentum is conserved. This implies both the magnitude and direction of $\vec{L}$ remain constant, ensuring planar motion.	10	2019	C

Continued on next page...

#	Question	Marks	Year	Type
16	**Show that the cross-section for elastic scattering of a point particle from an infinitely massive sphere of radius R is $\frac{R^2}{4}$. What is the inference of this result?** **Hint:** The cross-section σ is defined as the ratio of the number of scattered particles to the incident flux. For an infinitely massive sphere, any particle that hits the sphere is scattered. The total area of the sphere's projection is πR^2. However, due to symmetry and uniform angular distribution, the probability of scattering in any given direction is reduced, leading to an effective cross-sectional area of $\frac{1}{4}\pi R^2$. This shows that the scattering is not uniform over the entire surface but concentrated within certain regions.	10	2019	A
17	**A rocket starts vertically upwards with speed v_0. Then define its speed v at a height h in terms of h, R (radius of Earth) and g (acceleration due to gravity on Earth's surface). Also calculate the maximum height attained by a rocket fired with a speed of 90% of the escape velocity.** **Hint:** Use conservation of energy: initial energy is $\frac{1}{2}mv_0^2 - \frac{GMm}{R}$, and energy at height h is $\frac{1}{2}mv^2 - \frac{GMm}{R+h}$. Solve for v. For maximum height, set $v = 0$ and use escape velocity $v_e = \sqrt{2GM/R}$.	10	2020	A
18	**A particle moving in a central force field describes the path $r = ke^{\alpha\theta}$, where k and α are constants. If the mass of the particle is m, find the law of force.** **Hint:** Use Binet's formula: $F(r) = -\frac{L^2}{mr^2}\left(\frac{d^2u}{d\theta^2} + u\right)$, where $u = 1/r$. Compute the second derivative of u and substitute into the formula to find $F(r)$.	10	2021	A
19	**i. Calculate the mass and momentum of a proton of rest mass 1.67×10^{-27} kg moving with a velocity of $0.8c$, where c is the velocity of light. If it collides and sticks to a stationary nucleus of mass 5.70×10^{-26} kg, find the velocity of the resultant particle.** **ii. Calculate the mass of the particle whose kinetic energy is half of its total energy. Find the velocity with which the particle is travelling.** **Hint:** i. Use relativistic mass and momentum formulas: $m = \frac{m_0}{\sqrt{1-v^2/c^2}}$ and $p = mv$. Apply conservation of momentum in both magnitude and direction, ensuring correct frame transformation. ii. Given $K = \frac{1}{2}E$, use $E = mc^2$ and $K = (m - m_0)c^2$ to solve for m and v.	8+7	2021	A

Continued on next page...

#	Question	Marks	Year	Type
20	**Show that the mean kinetic and potential energies of non-dissipative simple harmonic vibrating systems are equal.** **Hint:** For a simple harmonic oscillator, use $x = A\sin(\omega t)$ and $v = A\omega\cos(\omega t)$. Compute kinetic energy $K = \frac{1}{2}mv^2$ and potential energy $U = \frac{1}{2}kx^2$. Find their time averages over a full cycle and show that $\langle K\rangle = \langle U\rangle$.	10	2022	A
21	**Show that for very small velocity, the equation for kinetic energy, $K = \Delta mc^2$ becomes $K = \frac{1}{2}m_0v^2$, where notations have their usual meanings.** **Hint:** Start with $K = \left(\frac{m_0}{\sqrt{1-v^2/c^2}} - m_0\right)c^2$. For $v \ll c$, use the binomial approximation $(1+x)^n \approx 1+nx$ for small x to simplify the expression and show it reduces to classical kinetic energy.	10	2022	A
22	**A particle P of mass m_1 collides with another particle Q of mass m_2 at rest. The particles P and Q travel at angles θ and ϕ, respectively, with respect to the initial direction of P. Derive the expression for the maximum value of θ.** **Hint:** Apply momentum conservation along both the initial and perpendicular directions: $$m_1v_0 = m_1v_1\cos\theta + m_2v_2\cos\phi$$ $$0 = m_1v_1\sin\theta - m_2v_2\sin\phi$$ where v_0 is the initial velocity of P, and v_1, v_2 are final velocities. The kinetic energy of the system cannot increase, meaning θ is maximized when $\phi = 90^\circ$, ensuring the largest possible perpendicular component of motion. Solve for θ using these conditions.	15	2022	A
23	**A planet revolves around the Sun in an elliptic orbit of eccentricity e. If T is the time period of the planet, find the time spent by the planet between the ends of the minor axis close to the Sun.** **Hint:** Use Kepler's second law, which states that equal areas are swept out in equal times. Compute the area enclosed between the minor axis and perihelion, then relate it to the total orbital area to find the fraction of time spent.	10	2010	A

Continued on next page...

#	Question	Marks	Year	Type
24	**A particle is moving in a central force field on an orbit given by $r = ke^{\alpha\theta}$, where k and α are constants, r is the radial distance and θ is the polar angle.** **(a) Find the force law for the central force field.** **(b) Find $\theta(t)$.** **(c) Find the total energy.** **Hint:** (a) Use Binet's formula: $$F(r) = -\frac{L^2}{mr^2}\left(\frac{d^2u}{d\theta^2} + u\right),$$ where $u = 1/r$. Compute $d^2u/d\theta^2$ and substitute. (b) Use conservation of angular momentum $L = mr^2\frac{d\theta}{dt}$ to relate θ and t. Integrate to find $\theta(t)$. (c) Express kinetic and potential energy in terms of r, use the force expression from (a), and sum them to obtain total energy E.	20	2012	A
25	**A particle describes a circular orbit under the influence of an attractive central force directed towards a point on the circle. Show that the force varies as the inverse fifth power of distance.** **Hint:** Assume a force of the form $F(r) = -kr^n$. The centripetal force for circular motion is given by $$F = \frac{mv^2}{r} = mr\dot{\theta}^2.$$ Express $\dot{\theta}$ using angular momentum conservation $L = mr^2\dot{\theta}$, and substitute to obtain the functional form of $F(r)$. Differentiate and match terms to conclude that $F(r) \propto r^{-5}$.	15	2013	A

Continued on next page...

#	Question	Marks	Year	Type
26	**A charged particle is moving under the influence of a point nucleus. Show that the orbit of the particle is an ellipse. Find out the time period of the motion.** **Hint:** The Coulomb force follows an inverse square law: $$F = -\frac{Ze^2}{4\pi\epsilon_0 r^2}.$$ Using conservation of angular momentum and energy, derive the orbit equation using $$\frac{1}{r} = \frac{Ze^2}{L^2} + A\cos\theta,$$ which represents a conic section. For bound motion ($E < 0$), this is an ellipse. For the time period, use Kepler's third law, which states $$T^2 \propto a^3,$$ where a is the semi-major axis of the ellipse. Solve for T in terms of the given parameters.	15	2014	A
27	**The density inside a solid sphere of radius a is given by $\rho = \rho_0 \frac{a}{r}$, where ρ_0 is the density at the surface and r denotes the distance from the centre. Find the gravitational field due to this sphere at a distance $2a$ from its centre.** **Hint:** Use Gauss's law for gravitation. Consider a spherical Gaussian surface of radius $2a$ and calculate the mass enclosed by integrating ρ over the sphere's volume. Then use $g = GM/r^2$ to find the field.	10	2014	A
28	**A body moving in an inverse square attractive field traverses an elliptical orbit with eccentricity e and period T. Find the time taken by the body to traverse the half of the orbit that is nearer the centre of force. Explain briefly why a comet spends only 18% of its time on the half of its orbit that is nearer the Sun.** **Hint:** Use Kepler's second law, which states that the areal velocity is constant. Since the body moves faster when closer to the center, the time spent in the near-half orbit is less than $T/2$. Comets, with highly elliptical orbits, experience extreme variations in speed, explaining the 18% fraction.	10	2016	A

Continued on next page...

#	Question	Marks	Year	Type
29	**Express angular momentum in terms of kinetic, potential, and total energy of a satellite of mass m in a circular orbit of radius r.** **Hint:** In a circular orbit, the gravitational force provides the centripetal force. Relate the orbital velocity to r using $GMm/r^2 = mv^2/r$. Express kinetic and potential energies in terms of r, then use $L = mvr$ to express angular momentum in terms of energy.	10	2017	A
30	**Use Gauss's theorem to calculate the gravitational potential due to a solid sphere at a point outside the sphere. Calculate the amount of work required to send a body of mass m from the Earth's surface to a height $R/2$, where R is the radius of the Earth.** **Hint:** Apply Gauss's theorem to find the gravitational field outside the sphere. The potential at a distance r from the center is $V = -\frac{GM}{r}$. For work done, compute the potential difference $\Delta V = V(R) - V(3R/2)$ and use $W = m\Delta V$.	15	2018	A
31	**The radius of the Earth is 6.4×10^6 m, its mean density is 5.5×10^3 kg/m^3, and the universal gravitational constant is 6.66×10^{-11} Nm^2/kg^2. Calculate the gravitational potential on the surface of the Earth.** **Hint:** Use the formula for gravitational potential $V = -\frac{GM}{R}$, where G is the gravitational constant, M is the mass of the Earth, and R is the radius of the Earth. Compute M using $M = \rho V = \rho \frac{4}{3}\pi R^3$.	10	2021	A

Continued on next page...

<table>
<tr><th>#</th><th>Question</th><th>Marks</th><th>Year</th><th>Type</th></tr>
<tr><td>32</td><td>With an appropriate diagram, show that in Rutherford scattering, the orbit of the particle is a hyperbola. Obtain an expression for the impact parameter.
Hint: In Rutherford scattering, an alpha particle is deflected by the Coulomb force of the nucleus, resulting in a hyperbolic trajectory. The impact parameter b is the perpendicular distance between the initial velocity vector of the particle and the nucleus. It determines the scattering angle θ.
The Coulomb force on the particle (charge q, mass m) due to a nucleus of charge Ze is given by $F = \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r^2}$. The initial velocity is v, and its trajectory is along the x-axis with impact parameter b.
Using the conservation of angular momentum, the angular momentum about the nucleus remains constant: $L = mvb$.
By applying energy conservation, the total energy (kinetic + potential) at a large distance is $E = \frac{1}{2}mv^2$. At the point of closest approach, energy conservation gives $E = \frac{1}{2}mv^2_{\text{closest}} - \frac{1}{4\pi\epsilon_0}\frac{Ze^2}{r_{\text{closest}}}$.
The trajectory of the particle follows a hyperbola with eccentricity $e = 1 + \frac{b^2v^4}{\left(\frac{Ze^2}{4\pi\epsilon_0 m}\right)^2}$.
The scattering angle θ satisfies cot $\left(\frac{\theta}{2}\right) = \frac{bv^2}{\frac{Ze^2}{4\pi\epsilon_0 m}}$.
Solving for b, we obtain the expression for the impact parameter:
$$b = \frac{Ze^2}{4\pi\epsilon_0 mv^2}\text{ cot }\left(\frac{\theta}{2}\right).$$
This relation shows how the impact parameter depends on the charge of the nucleus, the velocity of the incoming particle, and the scattering angle.</td><td>10</td><td>2011</td><td>C</td></tr>
<tr><td>33</td><td>Prove that the time taken by the Earth to travel over half of its orbit separated by the minor axis remote from the Sun is two days more than half a year. Given, the period of the Earth is 365 days and the eccentricity of the orbit is $1/60$.
Hint: Use Kepler's second law, which states that the time taken to traverse any part of an orbit is proportional to the area swept out. Compute the areas of the two halves of the ellipse and use the given period to determine the time difference.</td><td>10</td><td>2011</td><td>A</td></tr>
<tr><td colspan="5">Continued on next page...</td></tr>
</table>

#	Question	Marks	Year	Type
34	**A rigid body is spinning with an angular velocity of 4 rad/s about an axis parallel to the direction $(4\hat{j}-3\hat{k})$ passing through the point A with $\overrightarrow{OA} = 12\hat{i}+3\hat{j}-\hat{k}$, where O is the origin. Find the magnitude and direction of the linear velocity of the body at point P with $\overrightarrow{OP} = 4\hat{i} - 2\hat{j} + \hat{k}$.** 💡 **Hint:** Use $\vec{v} = \vec{\omega} \times \vec{r}$, where $\vec{\omega}$ is the angular velocity vector and $\vec{r}$ is the position vector of P relative to A. First, find the unit vector along $\vec{\omega}$, then compute $\vec{\omega}$. Next, determine $\vec{AP} = \vec{OP} - \vec{OA}$, and finally, calculate $\vec{v} = \vec{\omega} \times \vec{AP}$.	12	2012	A
35	**Suppose an S' frame is rotating with respect to a fixed frame having the same origin. Assume that the angular velocity $\vec{\omega}$ of the S'-frame is given by $\vec{\omega} = 2t\hat{i} - t^2\hat{j} + (2t+4)\hat{k}$, where t is time. The position vector $\vec{r}$ of a particle in S' at time t is $\vec{r} = (t^2+1)\hat{i} - 6t\hat{j} + 4t^3\hat{k}$. Calculate the Coriolis acceleration at $t = 1$ second.** 💡 **Hint:** The Coriolis acceleration is given by $\vec{a}_{coriolis} = -2\vec{\omega} \times \vec{v}'$, where $\vec{v}'$ is the velocity in the rotating frame. Compute $\vec{v}' = d\vec{r}/dt$ at $t = 1$, then substitute into the formula to find $\vec{a}_{coriolis}$.	10	2013	A
36	**Calculate the horizontal component of the Coriolis force acting on a body of mass 0.1 kg moving northward with a horizontal velocity of 100 m/s at $30^\circ N$ latitude on Earth.** 💡 **Hint:** The Coriolis force is given by $\vec{F}_{coriolis} = -2m\vec{\omega} \times \vec{v}$, where m is the mass, $\vec{\omega}$ is the angular velocity of the Earth, and $\vec{v}$ is the velocity of the body. The horizontal component is $F_{coriolis} = 2m\omega v \sin\phi$, where ϕ is the latitude.	15	2013	A
37	**Derive the expression for Coriolis force and show that this force is perpendicular to the velocity and to the axis of rotation. What is the nature of this force?** 💡 **Hint:** The Coriolis force in a rotating frame is given by $\vec{F}_{coriolis} = -2m(\vec{\omega} \times \vec{v})$, where m is the mass, $\vec{\omega}$ is the angular velocity, and $\vec{v}$ is the velocity in the rotating frame. Since the force is a cross product, it is always perpendicular to both $\vec{v}$ and $\vec{\omega}$. The Coriolis force is a fictitious force that appears only in a rotating frame and causes deflection of moving objects.	10	2016	A

Continued on next page...

#	Question	Marks	Year	Type
38	**Consider two frames of reference S and S' having a common origin O. The frame S' is rotating with respect to the fixed frame S with uniform $\vec{\omega} = 3\hat{a}_x\, rad/s$. A projectile of unit mass at position $\vec{r} = 7\hat{a}_x + 4\hat{a}_y\, m$ is moving with $\vec{v} = 14\hat{a}_x\, m/s$. Calculate in the rotating frame S' the following forces on the projectile: (i) Euler's force (ii) Coriolis force (iii) Centrifugal force.** **Hint:** (i) Euler's force is $\vec{F}_{Euler} = -m\frac{d\vec{\omega}}{dt} \times \vec{r}$. Since $\frac{d\vec{\omega}}{dt} = 0$, Euler's force is zero. (ii) Coriolis force is $\vec{F}_{Coriolis} = -2m(\vec{\omega} \times \vec{v})$. (iii) Centrifugal force is $\vec{F}_{Centrifugal} = -m\vec{\omega} \times (\vec{\omega} \times \vec{r})$.	15	2022	A
39	**A uniform solid sphere of radius R having moment of inertia I about its diameter is melted to form a uniform disc of thickness t and radius r. The moment of inertia of the disc about an axis passing through its edge and perpendicular to the plane is also equal to I. Show that the radius r of the disc is given by $r = 2R$.** **Hint:** The moment of inertia of a solid sphere about its diameter is $I_{\text{sphere}} = \frac{2}{5}MR^2$. The volume of the sphere is $V_{\text{sphere}} = \frac{4}{3}\pi R^3$. The volume of the disc is $V_{\text{disc}} = \pi r^2 t$. Using volume conservation, equate $V_{\text{sphere}} = V_{\text{disc}}$ to express t in terms of r. The moment of inertia of the disc about an axis at its edge is given by $I_{\text{disc}} = I_{\text{CM}} + Mr^2$, where $I_{\text{CM}} = \frac{1}{2}Mr^2$. Equate this with I_{sphere} and solve for r.	10	2010	A
40	**What are Eulerian angles? A body with rotational symmetry about an axis is rotating under gravity about a point on the axis without friction. What quantities remain constant during the motion? Express them in terms of suitable Eulerian angles. Explain 'precession' and 'nutation' of such a body.** **Hint:** Eulerian angles (ϕ, θ, ψ) describe the orientation of a rotating body in space. For a symmetric body rotating under gravity about a fixed point, the conserved quantities are (1) total energy $E = T + U$, (2) angular momentum component along the vertical axis L_z, and (3) angular momentum component along the symmetry axis L_3. Precession refers to the slow change in the direction of the angular momentum vector, while nutation is the oscillation of the inclination angle θ due to variations in torque.	25	2010	C

Continued on next page...

#	Question	Marks	Year	Type
41	**A rigid body is rotating about a fixed point with angular velocity $\vec{\omega}$. Assuming the coordinate axes coincide with the principal axes, if T is the kinetic energy and $\vec{G}$ is the external torque acting on the body, show that $\frac{dT}{dt} = \vec{G} \cdot \vec{\omega}$.** **Hint:** The kinetic energy of a rotating rigid body is given by $T = \frac{1}{2}\vec{\omega} \cdot \vec{L}$, where $\vec{L}$ is the angular momentum. Differentiate both sides with respect to time: $\frac{dT}{dt} = \frac{1}{2}\left(\frac{d\vec{\omega}}{dt} \cdot \vec{L} + \vec{\omega} \cdot \frac{d\vec{L}}{dt}\right)$. Using $\frac{d\vec{L}}{dt} = \vec{G}$ and assuming no internal torques, simplify to obtain the desired result.	10	2011	A
42	**Determine the number of degrees of freedom for a rigid body: (i) moving freely in 3D space, (ii) having one point fixed, (iii) having two points fixed.** **Hint:** (i) A rigid body in free space has 6 degrees of freedom: 3 translational (x, y, z) and 3 rotational (θ, ϕ, ψ). (ii) A body with one fixed point can rotate about three independent axes, giving 3 rotational degrees of freedom. (iii) If two points are fixed, only one degree of rotational freedom remains (rotation about the line joining the two points).	30	2011	C
43	**Calculate the moment of inertia of a solid cone of mass M, height h, vertical half-angle α, and radius of its base R, about an axis passing through its vertex and parallel to its base.** **Hint:** Consider a thin disc element of radius r and thickness dx at a distance x from the vertex. Express r in terms of x, using the cone's geometry: $r = x\tan\alpha$. The volume element is $dV = \pi r^2 dx$, and the mass element is $dm = (\rho dV) = (\frac{M}{V_{\text{cone}}})\pi x^2 \tan^2\alpha\, dx$. The moment of inertia of the thin disc about its own axis is $dI = \frac{1}{2}dm \cdot r^2$. Integrate over the cone's height from $x = 0$ to $x = h$ to obtain the total moment of inertia.	12	2012	A
44	**Show that the kinetic energy and angular momentum of torque-free motion of a rigid body are constant.** **Hint:** For torque-free motion, the external torque $\vec{\tau} = 0$. The rotational kinetic energy is given by $T = \frac{1}{2}I\omega^2$. Since $\frac{d\vec{L}}{dt} = \vec{\tau} = 0$, we conclude $\vec{L}$ is constant. The time derivative of kinetic energy is $\frac{dT}{dt} = \vec{\omega} \cdot \vec{G}$. Since $\vec{G} = 0$, it follows that $\frac{dT}{dt} = 0$, meaning kinetic energy remains constant.	10	2013	A

Continued on next page...

#	Question	Marks	Year	Type
45	**If I' and I be the moments of inertia of a body about an axis passing through an arbitrary origin and about a parallel axis through the center of mass, respectively, show that $I' = MR^2 + I$, where $\vec{R}$ is the position vector of the center of mass with respect to the arbitrary origin and M is the mass of the body.** **Hint:** This follows from the parallel axis theorem. Consider a mass element dm at a position $\vec{r}'$ from the arbitrary origin. Express $\vec{r}'$ as $\vec{r}' = \vec{R}+\vec{r}$, where $\vec{r}$ is the position relative to the center of mass. Expanding $I' = \int r'^2 dm$, using $\int \vec{r}\, dm = 0$ (since the center of mass is the reference point), leads to $I' = I + MR^2$.	10	2014	A
46	**Consider a rigid body rotating about an axis passing through a fixed point in the body with an angular velocity $\vec{\omega}$. Determine the kinetic energy of such a rotating body in a coordinate system of principal axes. If the Earth suddenly stops rotating, what will happen to the rotational kinetic energy? Comment in detail.** **Hint:** The kinetic energy is given by $T = \frac{1}{2}\vec{\omega} \cdot \vec{L} = \frac{1}{2} I_{ij}\omega_i\omega_j$, where I_{ij} is the inertia tensor. In principal axes, the inertia tensor is diagonal, simplifying the expression. If the Earth stops rotating, the rotational kinetic energy would convert into heat, seismic activity, and atmospheric effects.	25	2014	A
47	**A body turns about a fixed point. Show that the angle between its angular velocity vector and its angular momentum vector about the fixed point is always acute.** **Hint:** The kinetic energy is $T = \frac{1}{2}\vec{\omega}\cdot\vec{L}$. Since T is always positive, and $\vec{\omega} \cdot \vec{L} = \omega L \cos\theta$, it follows that $\cos\theta$ must be positive, meaning θ is always acute.	15	2014	A
48	**How does one obtain the angular velocity of the Earth about the North Pole with respect to a fixed star as $7.292 \times 10^{-5}\ s^{-1}$? Explain your method of calculating the above value.** **Hint:** The Earth completes one rotation (360° or 2π radians) in approximately 24 hours (86400 seconds). The angular velocity is given by $\omega = \frac{2\pi}{T}$, where T is the rotation period.	10	2015	A
49	**Show that the moment of inertia of a circular disc of mass M and radius R about an axis passing through its center and perpendicular to its plane is $\frac{1}{2}MR^2$.** **Hint:** Consider a thin ring of radius r and thickness dr. The moment of inertia of this ring is $dm \cdot r^2$, where dm is the mass of the ring. Integrate this expression from $r = 0$ to $r = R$.	15	2015	A

Continued on next page...

#	Question	Marks	Year	Type
50	**Four solid spheres A, B, C, and D, each of mass m and radius a, are placed with their centers on the four corners of a square of side b as shown in the figure below. Calculate the moment of inertia of the system about one side of the square. Also, calculate the moment of inertia of the system about a diagonal of the square.** **Hint:** Use the parallel axis theorem to find the moment of inertia of each sphere about the given axes. For the axis along one side of the square, determine the perpendicular distance of the spheres from this axis and sum their contributions. For the diagonal axis, express the distances in terms of b and use the parallel axis theorem accordingly.	20	2016	A
51	**Define moment of inertia and explain its physical significance. Calculate the moment of inertia of an annular ring about an axis passing through its center and perpendicular to its plane.** **Hint:** The moment of inertia quantifies rotational inertia and depends on mass distribution. For an annular ring, consider a thin ring of radius r and thickness dr. Integrate from inner radius R_1 to outer radius R_2 to find the total moment of inertia.	20	2017	A
52	**(i) Find the moments of inertia of a rigid diatomic molecule about different symmetry axes through the center of mass. (ii) A proton is 1837 times heavier than an electron. Find the center of mass of a hydrogen atom.** **Hint:** (i) Treat the diatomic molecule as two point masses m_1 and m_2 separated by a distance r. The moments of inertia about axes parallel and perpendicular to the bond can be computed. (ii) The center of mass is found using $mx = 1837m(r - x)$. Solve for x.	15	2019	A
53	**Write down Euler's dynamical equations of motion (no derivation) for a rigid body about a fixed point under the action of a torque. Show that the kinetic energy of the torque-free motion is constant.** **Hint:** Euler's equations describe how the angular velocity evolves in a rotating body. For torque-free motion, the torques are zero, leading to conservation of energy. Show that $\frac{dT}{dt} = 0$, where T is kinetic energy.	10	2019	A

Continued on next page...

#	Question	Marks	Year	Type
54	**Where do you find the applications of gyroscopes? A top of mass 0.200 kg consists of a thin disc of radius 0.12 m. A pin of negligible mass is mounted normal to its plane. The pivot under the disc is 0.03 m long. The top spins with its axis making an angle $\theta = 20^\circ$ with the vertical and a precessional angular speed of 2 rad/s. Calculate its spin angular speed.** 💡 **Hint:** Gyroscopes are used in navigation, stabilization, and physics experiments. The precessional speed is given by $\Omega = \frac{mgr}{I\omega_s}$, where m is mass, g is gravity, r is the pivot length, I is moment of inertia, and ω_s is spin speed. Solve for ω_s.	15	2019	A
55	**Determine the location of the center of mass of a uniform solid hemisphere of radius R and mass M from the center of its base.** 💡 **Hint:** Use integration. Consider a thin disc of radius r and thickness dy at a distance y from the base. The center of mass is given by $\bar{y} = \frac{1}{M}\int y\,dm$, where dm is the mass of the disc.	10	2020	A
56	**Obtain expressions for the moment of inertia of a solid cone about (i) its vertical axis and (ii) an axis passing through its vertex and parallel to its base.** 💡 **Hint:** Use integration. For (i), consider thin discs perpendicular to the vertical axis and sum their contributions. For (ii), use the parallel axis theorem after computing the moment of inertia about the cone's center of mass.	20	2020	A
57	**An electron moves under the influence of a point nucleus of atomic number Z. Show that the orbit of the electron is an ellipse.** 💡 **Hint:** The Coulomb force follows an inverse square law. The potential energy is $V(r) = -\frac{Ze^2}{4\pi\epsilon_0 r}$. Show that energy and angular momentum conservation lead to an equation for $r(\theta)$ representing an ellipse.	10	2021	A
58	**A homogeneous right triangular pyramid with base side a and height h is shown below. Obtain the moment of inertia tensor of the pyramid: (Figure is omitted)** 💡 **Hint:** Use integration to compute the moment of inertia tensor components. Consider thin triangular slices parallel to the base and sum their contributions. The moment of inertia tensor is given by $I_{ij} = \int (r^2\delta_{ij} - x_i x_j)dm$. The symmetry of the pyramid simplifies the off-diagonal terms, making some components zero. Perform the integration carefully to obtain the complete inertia tensor.	20	2021	A

Continued on next page...

#	Question	Marks	Year	Type
59	**When a sphere of radius r falls through a homogeneous viscous fluid of unlimited extent with terminal velocity v, the retarding viscous force acting on the sphere depends on the coefficient of viscosity η, the radius r, and its velocity v. Show how Stokes' law was arrived at by connecting these quantities using dimensional analysis.** **Hint:** Assume the viscous force F follows a power-law relation: $F \propto \eta^a r^b v^c$. The dimensions of force are $[F] = MLT^{-2}$, viscosity is $[\eta] = ML^{-1}T^{-1}$, radius is $[r] = L$, and velocity is $[v] = LT^{-1}$. Express F in terms of η, r, v as $MLT^{-2} = (ML^{-1}T^{-1})^a(L)^b(LT^{-1})^c$. Equate the powers of M, L, and T to solve for a, b, and c, obtaining $F \propto \eta r v$.	10	2010	A
60	**With an appropriate diagram, deduce the velocity profile for streamline flow of a liquid through a capillary of circular cross-section. Also, determine the fraction of liquid flowing through the section up to a distance $a/2$ from the axis, where a is the radius of the capillary.** **Hint:** Use the Navier-Stokes equation for steady, laminar flow in a horizontal pipe. For a cylindrical pipe of radius a, the velocity profile is derived by solving $\frac{d}{dr}\left(r\frac{dv}{dr}\right) = -\frac{\Delta P}{\eta L}r$, where ΔP is the pressure difference, η is the viscosity, and L is the pipe length. The resulting velocity profile is parabolic: $v(r) = v_0\left(1 - \frac{r^2}{a^2}\right)$. To find the fraction of total flow passing through the inner section ($r \leq a/2$), integrate $Q = \int_0^{a/2} v(r) \cdot dA$ and compare with the total flow rate in the full pipe.	20	2011	A
61	**A sphere of radius R moves with velocity $\vec{u}$ in an incompressible, non-viscous ideal fluid. Calculate the pressure distribution over the surface of the sphere. Do you think that a force is necessary to keep the sphere in uniform motion?** **Hint:** Use Bernoulli's equation and the boundary conditions for an ideal fluid. The pressure distribution will be symmetric, leading to no net drag force on the sphere. This is known as D'Alembert's paradox, which states that no external force is required to maintain uniform motion in an ideal fluid.	10	2014	A

Continued on next page...

#	Question	Marks	Year	Type
62	**Using Poiseuille's formula, show that the volume of a liquid with viscosity η passing per second through a series of two capillary tubes of lengths l_1 and l_2 with radii r_1 and r_2 is given by $Q = \frac{\pi p}{8\eta}\left[\frac{l_1}{r_1^4} + \frac{l_2}{r_2^4}\right]^{-1}$, where p is the effective pressure difference across the series.** **Hint:** Use Poiseuille's law, $Q = \frac{\pi p r^4}{8\eta l}$, for each capillary. Since the tubes are connected in series, the total pressure drop is the sum of individual pressure drops. Express p in terms of Q, and solve for Q by combining the two equations.	15	2015	A
63	**Define coefficients of viscosity and kinematic viscosity of a fluid. What are Poise and Stokes?** **Hint:** The coefficient of viscosity (η) is the tangential force per unit area required to maintain a unit velocity gradient in a fluid. Kinematic viscosity (ν) is the ratio of dynamic viscosity to fluid density, given by $\nu = \eta/\rho$. Poise is the CGS unit of viscosity, where 1 Poise = 0.1 Ns/m². Stokes is the CGS unit of kinematic viscosity, where 1 Stokes = 10^{-4} m²/s. For example, water at $20°C$ has $\eta \approx 1$ cP (centipoise) and $\nu \approx 1$ cSt (centistokes).	10	2015	C
64	**Write down Poiseuille's formula and mention its limitations in analyzing the flow of a liquid through a capillary tube.** **Hint:** Poiseuille's law describes laminar flow in a cylindrical tube: $Q = \frac{\pi \Delta p r^4}{8\eta l}$. However, it has limitations: (i) it applies only to steady, incompressible, laminar flow, (ii) it assumes constant viscosity and rigid tube walls, and (iii) it does not account for turbulence, which occurs at high flow velocities (Reynolds number > 2000). This makes it invalid for high-speed or rough-walled pipe flows.	10	2015	C
65	**Show that Young's modulus Y, modulus of rigidity η, and Poisson's ratio σ are related by $Y = 2\eta(1+\sigma)$.** **Hint:** Consider a material under longitudinal stress. Express the longitudinal strain in terms of Y and the lateral strain in terms of η and σ. Relate these strains to derive the given equation.	10	2016	A
66	**A horizontal pipe of non-uniform bore has water flowing through it such that the velocity is 40 cm/s at a point where the pressure is 2 cm of mercury. What is the pressure at a point where the velocity is 60 cm/s? (Take $g = 980\, cm/s^2$ and water density = $1\, g/cc$.)** **Hint:** Apply Bernoulli's equation: $P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$. Convert the pressure from cm of mercury to $dynes/cm^2$ using $P = \rho_{Hg} gh$.	10	2016	A

Continued on next page...

#	Question	Marks	Year	Type
67	**State and explain Stokes' law. A drop of water of radius 0.01 m falls through a medium with density 1.21 kg/m³ and** $\eta = 1.8 \times 10^{-5}\, Ns/m^2$**. Find its terminal velocity.** 💡 **Hint:** Stokes' law states that the viscous drag on a sphere moving in a fluid is $F = 6\pi\eta r v$. At terminal velocity, the forces balance: weight = buoyancy + drag. Solve for v_t.	15	2017	A
68	**Two capillary tubes of lengths** $2l$ **and** l **with internal radii** r **and** $2r$ **are connected in series. Water flows through them in streamline motion. If the pressure difference across the first capillary is** P**, find the pressure difference across the second.** 💡 **Hint:** The total pressure drop is the sum of the pressure drops across both tubes. The flow rate Q is the same in both tubes since they are in series. Using Poiseuille's law, $Q = \frac{\pi \Delta p r^4}{8\eta l}$, write expressions for Δp_1 and Δp_2. Solve for $\frac{\Delta p_2}{\Delta p_1}$ to determine the pressure drop across the second tube in terms of P. Pay attention to the fourth power dependence on radius.	10	2018	A
69	**A water drop of radius 0.04 mm falls through air. If the viscosity of air is** 1.8×10^{-4} **poise, find its terminal velocity. If 100 such drops coalesce, what will be the new terminal velocity?** 💡 **Hint:** Use Stokes' law to find the terminal velocity of a single drop. When drops coalesce, their volume adds up, so the new radius is $R = n^{1/3} r$. Use Stokes' law again for the new drop.	10	2018	A
70	**(i) How does Reynolds number help in the study of fluid motion? (ii) In a horizontal pipeline, the pressure drops by** $5\, Nm^{-2}$ **over 1 km. Calculate the change in kinetic energy per kg of oil. (Density of oil =** $800\, kg/m^3$**.)** 💡 **Hint:** (i) Reynolds number predicts whether flow is laminar or turbulent. (ii) Use Bernoulli's equation: pressure drop is related to change in kinetic energy per unit volume.	10	2019	A
71	**A rubber cord 1 mm in diameter and 1 m long is fixed at one end, and a 1 kg weight is attached to the other. If the Young's modulus of rubber is** $0.05 \times 10^{11}\, dynes/cm^2$**, find the period of vertical oscillations.** 💡 **Hint:** The rubber cord behaves like a spring. The period of oscillation is $T = 2\pi\sqrt{\frac{m}{k}}$, where k is the effective spring constant. The relation between Young's modulus and the force per unit extension is $k = \frac{YA}{L}$, where Y is Young's modulus, A is the cross-sectional area of the cord, and L is its original length. Convert all units to SI before substituting the values.	10	2020	A

Continued on next page...

#	Question	Marks	Year	Type
72	**A shaft of diameter 8 cm and length 5 m transmits power of 8 kW at 300 revolutions per minute. If the coefficient of rigidity of the shaft material is $8 \times 10^{11}\ dynes/cm^2$, calculate the relative shift between the shaft ends.** 💡 **Hint:** Power is given by $P = \tau\omega$, where τ is torque and ω is angular velocity. Compute $\omega = \frac{2\pi N}{60}$, where N is the rotational speed in rpm. Solve for τ. The torque relates to the angle of twist θ as $\tau = \frac{\pi G r^4 \theta}{2l}$, where G is the shear modulus, r is the shaft radius, and l is its length. Solve for θ.	15	2020	A
73	**A capillary tube of 1.0 mm diameter and 20 cm length is fitted horizontally to a vessel containing alcohol up to the neck. The density of alcohol is $8 \times 10^2\ kg/m^3$. The tube's center is 40 cm below the liquid surface. Find the amount of alcohol flowing out in 10 minutes. The viscosity of alcohol is $0.0012\ Ns/m^2$.** 💡 **Hint:** Use Poiseuille's formula $Q = \frac{\pi \Delta p r^4}{8\eta l}$. The pressure difference $\Delta p = \rho g h$, where h is depth. The volume of outflow is $V = Qt$.	10	2021	A
74	**A horizontal 100 cm light rod is suspended from the ceiling by two vertical wires of equal length tied to its ends. One wire is steel ($0.05\ cm^2$ cross-section), and the other is brass ($0.1\ cm^2$ cross-section). Find where a weight should be hung to produce: (i) Equal stress, (ii) Equal strain in both wires. Young's modulus: brass $1.0 \times 10^{11}\ N/m^2$, steel $2.0 \times 10^{11}\ N/m^2$.** 💡 **Hint:** Let the weight be placed at a distance x from the steel wire. For equal stress, $\frac{F_1}{A_1} = \frac{F_2}{A_2}$, where F_1 and F_2 are the tensions in the wires and A_1, A_2 are their cross-sections. For equal strain, $\frac{F_1}{A_1 Y_1} = \frac{F_2}{A_2 Y_2}$. Additionally, the total force on the rod balances the weight: $F_1 + F_2 = mg$. Solve for x.	15	2021	A
75	**Consider the diagram below with water flow rate Q. Derive an expression for Q in terms of the difference in manometer heights h and the cross-section areas A_1 and A_2: (Diagram omitted)** 💡 **Hint:** Apply Bernoulli's equation between two points in the pipe: $\frac{P_1}{\rho} + \frac{v_1^2}{2} = \frac{P_2}{\rho} + \frac{v_2^2}{2}$. Use the continuity equation $A_1 v_1 = A_2 v_2$ to express velocities in terms of A_1, A_2, and h. The pressure difference relates to the manometer height by $\Delta p = \rho g h$. Solve for Q.	15	2022	A

Continued on next page...

#	Question	Marks	Year	Type
76	**Define moment of inertia and radius of gyration of a rotating mass M. State and prove the Parallel Axis Theorem.** **Hint:** Moment of inertia measures resistance to rotational acceleration. The radius of gyration is the distance from the axis where the entire mass can be concentrated to give the same moment of inertia. The Parallel Axis Theorem states $I = I_{cm} + Mh^2$, where I_{cm} is the moment of inertia about the center of mass, and h is the distance between axes.	15	2022	C
77	**What is the significance of the null result of the Michelson-Morley experiment? Does it disprove the existence of ether? Justify.** **Hint:** The Michelson-Morley experiment attempted to detect the Earth's motion through the luminiferous ether by measuring changes in light interference patterns. The null result, meaning no observable fringe shift, indicated that the speed of light is constant in all inertial frames. This result contradicted the ether hypothesis and provided strong evidence for Einstein's special relativity, eliminating the need for an ether medium. However, it does not explicitly disprove ether; it only shows that if ether exists, it does not affect light propagation as originally thought.	10	2010	C
78	**A spaceship measures 50 m in length on the ground but appears 49.7 m in space as observed from the ground. Find the speed of the spaceship.** **Hint:** Use the length contraction formula $L' = L\sqrt{1 - \frac{v^2}{c^2}}$, where L is the proper length, L' is the contracted length, v is velocity, and c is the speed of light. Solve for v.	10	2011	A
79	**Two identical relativistic particles of rest mass m and kinetic energy T collide head-on. What is the relative kinetic energy T^r of one in the rest frame of the other?** **Hint:** Use the relativistic velocity addition formula to find the relative velocity between the two particles: $v' = \frac{v+v}{1+v^2/c^2}$. Then, apply the relativistic kinetic energy formula $T = (\gamma - 1)mc^2$ using this new velocity to compute T^r.	12	2012	A

Continued on next page...

#	Question	Marks	Year	Type
80	**A projectile of mass M explodes in flight into three fragments. One fragment of mass $M/2$ continues in the original direction, a second fragment of mass $M/6$ moves in the opposite direction, and the third fragment of mass $M/3$ comes to rest. The explosion releases energy $E_r = 5K$, where K is the initial kinetic energy. Find the velocities of the fragments.** **Hint:** Use conservation of momentum: $Mv = m_1v_1 + m_2v_2$. Also, apply the energy relation: $E_r + K = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$. Since $E_r = 5K$, substitute and solve for v_1 and v_2. Additionally, since the third fragment is at rest, ensure its energy contribution is properly considered.	15	2012	A
81	**A particle of rest mass $M = 4\times10^{-27}$ kg disintegrates into two particles of rest masses $M_1 = 3\times10^{-27}$ kg and $M_2 = 1\times10^{-27}$ kg. Show that the energies E_1 and E_2 satisfy $E_1 = 3E_2$ while moving in opposite directions with equal momenta.** **Hint:** Use conservation of energy: $E = E_1 + E_2$, and conservation of momentum: $p_1 = p_2$. Also, use the relativistic energy relation $E_i^2 = p_i^2c^2 + M_i^2c^4$ to derive the result.	15	2013	A
82	**Show that the operator $(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2})$ is invariant under Lorentz transformations.** **Hint:** The d'Alembertian operator is $\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2} = \partial^\mu\partial_\mu$. Under Lorentz transformations, space-time derivatives transform as $\partial'^\mu = \Lambda^\mu{}_\nu\partial^\nu$. Since the Minkowski metric remains unchanged under Lorentz transformations, the operator $\partial^\mu\partial_\mu$ retains its form, proving its invariance.	20	2013	A
83	**Show that a particle of rest mass m_0, total energy E, and momentum $\vec{p}$ satisfies $E^2 = c^2p^2 + m_0^2c^4$.** **Hint:** Start with the energy-momentum relations: $E = \gamma m_0c^2$ and $p = \gamma m_0v$. Express $\gamma = (1 - v^2/c^2)^{-1/2}$. Square both energy and momentum expressions, subtract them, and simplify to derive $E^2 = c^2p^2 + m_0^2c^4$.	10	2013	A
84	**Derive the relativistic length contraction using Lorentz transformations.** **Hint:** Consider two events marking the ends of an object in its proper frame. Use Lorentz transformations to relate the spatial coordinates in another frame while ensuring that the two positions are measured at the same time in the moving frame. This derivation leads to the contracted length formula.	10	2013	A

Continued on next page...

#	Question	Marks	Year	Type
85	**A mirror moves at relativistic speed v in the x-direction. A light beam with frequency ω_i is normally incident from $x = \infty$. Find the frequency of the reflected beam. Additionally, find: (i) What is the frequency of the reflected light expressed in terms of ω_{i}, c, and v?** **(ii) What is the energy of each reflected photon?** **Hint:** (i) Use the relativistic Doppler effect formula: $\omega' = \omega_i\sqrt{\frac{1+v/c}{1-v/c}}$ to transform the incident frequency into the mirror's frame. Then, apply the same transformation to get the reflected frequency back in the lab frame. (ii) The energy of a photon is given by $E = \hbar\omega$. Use the reflected frequency to determine the energy of each reflected photon.	25	2014	A
86	**Prove mathematically that the addition of any velocity of a particle to the velocity of light in free space merely reproduces the velocity of light in free space only.** **Hint:** Use the relativistic velocity addition formula: $v_{\text{rel}} = \frac{v_1+c}{1+\frac{v_1 c}{c^2}}$. Show that regardless of v_1, the result simplifies to $v_{\text{rel}} = c$, confirming that the speed of light remains unchanged.	10	2015	A
87	**Show that the rest mass energy of an electron is 0.51 MeV. (Use the standard values of physical parameters).** **Hint:** Use Einstein's equation $E_0 = m_0c^2$, where m_0 is the rest mass of the electron. Substitute $m_0 = 9.11 \times 10^{-31}$ kg and $c = 3 \times 10^8$ m/s to compute E_0. Convert the result from joules to MeV using $1\text{J} = 6.24 \times 10^{12}$ MeV.	10	2015	A
88	**Calculate the percentage contraction in the length of a rod in a frame moving with velocity $0.8c$ in a direction (i) parallel to its length and (ii) at an angle of 30° with its length. What is the orientation of the rod in the moving frame in case (ii)?** **Hint:** (i) Use the length contraction formula $L = L_0\sqrt{1-v^2/c^2}$. Compute the percentage contraction as $\frac{L_0-L}{L_0} \times 100$. (ii) The length contraction applies only to the component parallel to the motion, while the perpendicular component remains unchanged. The new angle in the moving frame is given by $\tan\theta' = \frac{\sin\theta_0}{\gamma\cos\theta_0}$, where $\gamma = (1-v^2/c^2)^{-1/2}$.	20	2016	A

Continued on next page...

#	Question	Marks	Year	Type
89	**Given a proton for which $\beta = 0.995$ measured in the laboratory. What are the corresponding relativistic energy and momentum? Take, $m_p = 1.67 \times 10^{-24}$ g.** **Hint:** The relativistic energy is given by $E = \gamma m_p c^2$, where $\gamma = (1-\beta^2)^{-1/2}$. The relativistic momentum is $p = \gamma m_p \beta c$. Convert the mass from grams to kilograms before substituting values. To express energy in MeV, use 1J $= 6.242 \times 10^{12}$ MeV.	10	2016	A
90	**Describe the Michelson-Morley experiment and show how the negative results obtained from this experiment were interpreted.** **Hint:** The Michelson-Morley experiment aimed to detect the Earth's motion through the hypothetical luminiferous ether, which was believed to be the medium for light waves. Using an interferometer, the experiment expected a fringe shift due to different light speeds in different directions. However, the null result (no fringe shift) contradicted the ether theory and provided strong support for Einstein's postulate that the speed of light is constant in all inertial frames, forming the basis of special relativity.	10	2017	C
91	**Prove that $x^2+y^2+z^2-c^2t^2$ is invariant under Lorentz transformation.** **Hint:** Write down the Lorentz transformation equations for x', y', z', and t'. Substitute these into the expression $x'^2+y'^2+z'^2-c^2t'^2$ and show that it simplifies to $x^2+y^2+z^2-c^2t^2$, proving its invariance.	10	2017	A
92	**A rod of length l_0 is kept at rest in the $x'y'$ plane of its rest frame, making an angle θ_0 with the x' axis. What is the length and orientation of the rod in a laboratory frame (x, y) in which the rod moves to the right with velocity v?** **Hint:** The length in the lab frame is given by $l = l_0\sqrt{1-v^2/c^2}\cos\theta_0$. Only the component of the rod's length parallel to motion contracts, while the perpendicular component remains unchanged. The new orientation is given by $\tan\theta = \gamma\tan\theta_0$, where $\gamma = (1-v^2/c^2)^{-1/2}$.	15	2018	A

Continued on next page...

#	Question	Marks	Year	Type
93	**i. A reference frame S' moves with respect to rest frame S with a uniform velocity v parallel to the x-direction. Show from Lorentz transformation that two events simultaneous $(t_1 = t_2)$ at different positions $(x_1 \neq x_2)$ in S frame are not, in general, simultaneous in S' frame.** **ii. The mean life of a π-meson is 2×10^{-8} s. Calculate the mean life of a meson moving with a velocity of $0.8c$, where c is the velocity of light.** **Hint:** (i) Use the Lorentz transformation for time: $t' = \gamma(t - \frac{vx}{c^2})$. If $t_1 = t_2$ but $x_1 \neq x_2$, then $t'_1 \neq t'_2$, proving that simultaneity is not absolute.	15	2019	A
94	**Two β-particles A and B emitted by a radioactive source R travel in opposite directions, each with a velocity of $0.9c$ with respect to the source. Find the velocity of B with respect to A (Here c is the velocity of light).** **Hint:** Use the relativistic velocity addition formula: $v = \frac{v_B - v_A}{1 - \frac{v_A v_B}{c^2}}$. Since A and B travel in opposite directions with respect to the source, assign $v_A = -0.9c$ and $v_B = 0.9c$ before substituting into the formula.	15	2019	A
95	**What do you understand by length contraction? Calculate the percentage length contraction of a rod moving with a velocity $0.8c$ in a direction at 60° with respect to its own length.** **Hint:** Length contraction is the shortening of an object's length along the direction of motion, as observed from a stationary frame. The contracted length is given by $L = L_0\sqrt{1 - \frac{v^2}{c^2}}\cos\theta$, where θ is the angle with the velocity. Since only the parallel component of the length undergoes contraction, the percentage contraction is given by $\frac{L_0 - L}{L_0} \times 100$.	15	2020	A
96	**Derive the relativistic expression for kinetic energy by considering mass variation with velocity. Hence, establish the relation between momentum (p) and energy (E) for a relativistic particle; $\frac{dE}{dp} = v$.** **Hint:** The relativistic mass is $m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}$. The kinetic energy is $K = (\gamma - 1)m_0c^2$. Differentiate E with respect to p and use $E^2 = p^2c^2 + m_0^2c^4$ to obtain the given relation.	20	2020	A

Continued on next page...

#	Question	Marks	Year	Type
97	**An observer detects two explosions, one that occurs near him at a certain time and another that occurs 2 ms later 100 km away. Another observer finds that the two explosions occur at the same place. What time interval separates the explosions for the second observer?** **Hint:** Use the Lorentz transformation for time: $\Delta t' = \gamma\left(\Delta t - \frac{v\Delta x}{c^2}\right)$. Since the second observer sees both explosions at the same location, $\Delta x' = 0$. Solve for $\Delta t'$.	10	2021	A
98	**A body of mass m at rest splits into two masses m_1 and m_2 by an explosion. After the split, the bodies move with a total kinetic energy T in opposite directions. Show that their relative speed is $\sqrt{\frac{2Tm}{m_1 m_2}}$.** **Hint:** Apply conservation of momentum: $m_1 v_1 = -m_2 v_2$. Use the total kinetic energy: $T = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2 v_2^2$. Solve for $v_1 - v_2$.	15	2021	A
99	**Two spaceships approach each other, both moving with the same speed as measured by a stationary observer on Earth. Their relative speed is $0.7c$. Determine the velocity of each spaceship as measured by the stationary observer on Earth.** **Hint:** Let v be the velocity of each spaceship relative to Earth. Since they approach each other with the same speed, apply the relativistic velocity addition formula: $v_{\text{rel}} = \frac{2v}{1+\frac{v^2}{c^2}}$. Solve for v under the condition that both spaceships move symmetrically with respect to the Earth.	15	2022	A
100	**A force $\vec{F}$ is given by $\vec{F} = x^2 y\hat{x} + zy^2\hat{y} + xz^2\hat{z}$. Determine whether or not the force is conservative.** **Hint:** A force is conservative if its curl is zero, i.e., $\nabla \times \vec{F} = 0$. Calculate the curl of the given force and check if it is zero.	10	2023	A
101	**Calculate the gravitational self-energy of the Earth. Given: Mass of Earth $M_e = 6 \times 10^{24}$ kg and the Radius of Earth $R_e = 6.4 \times 10^6$ m.** **Hint:** The gravitational self-energy of a uniform sphere is given by $U = -\frac{3}{5}\frac{GM^2}{R}$, where G is the gravitational constant, M is the mass, and R is the radius. Substitute the given values to calculate U.	10	2023	A

Continued on next page...

#	Question	Marks	Year	Type
102	**What are the consequences of Lorentz transformations on length and time when observed from a frame moving at relativistic velocities?** **Hint:** Lorentz transformations describe how space and time change in a moving frame. They result in length contraction, where objects moving at relativistic speeds appear shorter along the direction of motion, and time dilation, where moving clocks run slower. These effects become significant when the velocity approaches the speed of light.	10	2023	C
103	**(i) Prove that the separation of two colliding particles is same, when observed in centre of mass and laboratory system.** (TC) **Hint:** Use the relation between laboratory frame and centre of mass frame velocities. Show that relative separation between two particles depends only on their relative velocities, which are invariant under Galilean transformations. Hence the separation before and after collision remains the same in both frames.	10	2023	C
	(ii) Determine the kinetic energy of a thin disc of mass 0.5 kg and radius 0.2 m rotating with 100 rotations per second around the axis passing through its centre and perpendicular to its plane. (AN) **Hint:** Kinetic energy $K = \frac{1}{2}I\omega^2$ for rotational motion. Moment of inertia of disc about its centre $I = \frac{1}{2}MR^2$. Convert rotations per second into angular velocity ω in rad/s.	5	2023	A
104	**Prove that the separation of two colliding particles is the same when observed in the center of mass and laboratory frames.** **Hint:** In the center of mass frame, the total momentum is zero, meaning both particles move symmetrically about the center of mass. The relative distance between them is independent of the observer's frame. Use the Lorentz transformation equations to show that their separation remains the same in both the center of mass and laboratory frames.	10	2023	A
105	**Determine the kinetic energy of a thin disc of mass 0.5 kg and radius 0.2 m rotating with 100 rotations per second around the axis passing through its center and perpendicular to its plane.** **Hint:** The kinetic energy of a rotating object is given by $K = \frac{1}{2}I\omega^2$, where I is the moment of inertia and ω is the angular velocity in radians per second. For a thin disc rotating about its central axis, $I = \frac{1}{2}MR^2$. Convert the given 100 rotations per second into angular velocity as $\omega = 100 \times 2\pi$ rad/s before substituting into the formula.	5	2023	A

Continued on next page...

#	Question	Marks	Year	Type
106	**A particle of mass m kg having an initial velocity V_0 is subjected to a retarding force proportional to its instantaneous velocity. Obtain the expression for the velocity and position of the particle as a function of time.** (AN) 💡 **Hint:** Apply $m\frac{dv}{dt} = -kv$. Solve using separation of variables. Integrate to find $v(t)$ and $x(t)$.	10	2024	A
107	**Show that the kinetic energy of a system of n particles is given by $T = \frac{1}{2}MV_{\text{cm}}^2 + \frac{1}{2}\sum_{i=1}^{n} m_i V_i'^2$, where M is the total mass, V_{cm} is the velocity of the centre of mass, V_i' is the velocity of the particles about the centre of mass and m_i is the mass of the ith particle.** (TC) 💡 **Hint:** Decompose total velocity into centre of mass motion and motion relative to COM. Expand total kinetic energy accordingly.	10	2024	C
108	**A charged π-meson with rest mass of $273m_e$ at rest decays into a neutrino and a μ-meson of rest mass $207m_e$. Find the kinetic energy of the μ-meson and the energy of the neutrino. (m_e is the rest mass of the electron.)** (AN) 💡 **Hint:** Apply conservation of both energy and momentum simultaneously. Assume neutrino is massless. Use $E = mc^2$ and momentum balance to solve for kinetic energy and neutrino energy.	10	2024	A
109	**Briefly discuss the Kepler's laws of planetary motion.** (TC) 💡 **Hint:** Kepler's laws describe planetary motion: (1) Orbits are ellipses with the Sun at one focus; (2) A line joining planet to Sun sweeps equal areas in equal times, implying speed variations; (3) $T^2 \propto r^3$ shows the relationship between period and orbit size.	5	2024	C
110	**Show that the escape velocity V_e on the surface of the Earth is given by $V_e = \sqrt{2gR}$, where $g = 9.8$ m/s^2 and R is the radius of the Earth.** (TC) 💡 **Hint:** Use conservation of energy: initial kinetic energy equals gravitational potential energy change. Derive escape velocity formula.	5	2024	C
111	**Two satellites A and B of same mass are orbiting the Earth at altitudes R and $5R$, respectively, where R is the radius of the Earth. Assuming their orbits to be circular, calculate the ratios of their kinetic and potential energies.** (AN) 💡 **Hint:** Use formulas $K = \frac{GMm}{2r}$ and $U = -\frac{GMm}{r}$, with $r = R +$ altitude. Compare for $r = 2R$ and $r = 6R$.	5	2024	A

Continued on next page...

#	Question	Marks	Year	Type
112	**Show that the angular momentum of a rigid body consisting of n particles of masses m_i, $i = 1, 2, 3, ..., n$ rotating with an instantaneous angular velocity ω about an axis passing through the origin O of the coordinate system $OXYZ$ is given by $L = I\omega$, where I is known as the inertia tensor.** (TC) **Hint:** Derive angular momentum of each particle about origin. Express vectorially and sum over all particles to form inertia tensor.	20	2024	C
113	**Explain the Poiseuille's equation for the rate of flow of a liquid through a capillary tube. From this, show that if two capillary tubes of radii r_1 and r_2 having lengths l_1 and l_2 respectively, are connected in series, the rate of flow of the liquid is given by $Q = \frac{\pi P}{8\eta}\left(\frac{l_1}{r_1^4} + \frac{l_2}{r_2^4}\right)^{-1}$, where P is the pressure across the arrangement and η is the coefficient of viscosity of the liquid.** (TC) **Hint:** First derive Poiseuille's law for a single tube from Navier-Stokes. Then treat two tubes connected in series analogously to resistances in series for flow rate.	10	2024	C
114	**Consider three inertial frames of reference O, O' and O''. Let O' move with a velocity V with respect to O and O'' move with a velocity V' with respect to O'. Both velocities are in the same direction. Write down the transformation equations relating x, y, z, t with x', y', z', t' and also those relating x', y', z', t' with x'', y'', z'', t''. Hence obtain the relations between x, y, z, t and x'', y'', z'', t''. (The direction of velocity is chosen along the x-axis as per convention.)** (TC) **Hint:** Write two Galilean transformations along the x-axis for frames O', O'' moving with velocities V and V' respectively. Combine them to relate O and O''.	15	2024	C
115	**A galaxy in the constellation Ursa Major is receding from the Earth at 15000 km/s. If one of the characteristic wavelengths of light emitted by the galaxy is 550 nm, what is the corresponding wavelength measured by astronomers on the Earth?** (AN) **Hint:** Use redshift formula $\lambda' = \lambda\left(1 + \frac{v}{c}\right)$.	5	2024	A

Continued on next page...

#	Question	Marks	Year	Type
116	**State and explain the Hooke's law of elasticity. Briefly discuss the features of stress-strain diagram for the behaviour of a wire undergoing increasing stress.** (TC) **Hint:** Hooke's law states that, within the elastic limit, the stress σ is directly proportional to the strain ϵ, i.e., $\sigma = E\epsilon$, where E is Young's modulus. The stress-strain diagram exhibits distinct regions: the elastic region (linear behavior), the yield point (onset of plastic deformation), the plastic region (permanent deformation), the ultimate tensile strength (maximum stress), and the fracture or breaking point.	10	2024	C

WAVES & OPTICS

Key: C = Conceptual, A = Applied

#	Question	Marks	Year	Type
117	**In the propagation of longitudinal waves in a fluid contained in an infinitely long tube of cross-section A, show that $\rho = \rho_0\left(1 - \frac{\partial\xi}{\partial x}\right)$, where ρ_0 = equilibrium density, ρ = density of the fluid in the disturbed state, $\frac{\partial\xi}{\partial x}$ = volume strain $\left(\left\vert\frac{\partial\xi}{\partial x}\right\vert \ll 1\right)$.** **Hint:** Consider the continuity equation for mass conservation in the fluid. Small strain approximation ($\left\vert\frac{\partial\xi}{\partial x}\right\vert \ll 1$) simplifies the relation between the density in the disturbed state and the equilibrium density. Carefully expand using a Taylor series if needed.	15	2010	C
118	**Write down the one-dimensional harmonic oscillator differential equation under damping and its solution for the lightly damped condition, with the meanings of symbols. Determine the dependent energy in the lightly damped condition.** **Hint:** Start with $m\ddot{x} + b\dot{x} + kx = 0$, where m is mass, b is damping coefficient, k is spring constant. For light damping ($b^2 \ll 4mk$), the solution is a decaying sinusoidal motion. The energy depends on the square of the amplitude, which decays exponentially with time.	10	2011	C
119	**Explain the physical significance of group velocity from the concept of phase velocity with relevant expressions.** **Hint:** Group velocity v_g is the velocity with which the envelope of a wave packet propagates. It is given by $v_g = \frac{d\omega}{dk}$, where ω is angular frequency and k is wave number. Phase velocity is $v_p = \frac{\omega}{k}$. In dispersive media, $v_g \neq v_p$, and group velocity determines the energy or information transmission speed.	15	2011	C
120	**Prove that the group velocity V_g of electromagnetic waves in a dispersive medium with refractive index $n(\lambda_0)$ at wavelength λ_0 is given by $V_g = \frac{c}{n(\lambda_0) - \lambda_0 \frac{dn(\lambda_0)}{d\lambda_0}}$. Find the time taken for the electromagnetic pulse to travel a distance D.** **Hint:** Start from the dispersion relation for EM waves in a medium. Use $v_p = \frac{c}{n(\lambda)}$, then differentiate carefully with respect to λ to find v_g. To find time, use $t = \frac{D}{V_g}$.	20	2011	C

Continued on next page...

#	Question	Marks	Year	Type
121	**The motion of a damped mechanical oscillator is represented by $m\ddot{x} + a\dot{x} + \beta x = 0$, where m, a and β are constants. The oscillator is critically damped. The system is given an impulse at $x = 0$ and $t = 0$, resulting in an initial velocity v. After how much time the system experiences maximum displacement?** 💡 **Hint:** For critical damping, the solution is of the form $x(t) = (A + Bt)e^{-\gamma t}$. Use initial conditions to determine constants. Differentiate to find maximum displacement condition by setting $\dot{x}(t) = 0$. Solve for t.	12	2012	A
122	**Show that a travelling wave on the string, clamped on both the ends, undergoes a phase change of π. Hence obtain the time-independent form of the wave equation representing a standing wave on the string.** 💡 **Hint:** At a clamped boundary, the wave undergoes a reflection with a phase change of π. Superposition of incident and reflected waves gives a standing wave. Write $y(x,t) = A\sin(kx)\cos(\omega t)$ for the standing wave mode, satisfying boundary conditions at both ends.	12	2012	C
123	**During an earthquake, a horizontal shelf moves vertically. If its motion can be regarded simple harmonic, calculate the maximum value of amplitude of oscillation so that the books resting on it stay in contact with it always. Take $g = 9.8\ \text{ms}^{-2}$ and $T = 0.5$ s.** 💡 **Hint:** For the books to remain in contact, the maximum acceleration of the shelf should be less than or equal to g. Maximum acceleration in SHM is $a_{max} = \omega^2 A$, where $\omega = \frac{2\pi}{T}$. Solve for A using $a_{max} \leq g$.	10	2013	A
124	**The dispersion relation for deep water waves is given by $\omega^2 = gk + ak^3$, where g and a are constants. Obtain expressions for phase velocity and group velocity in terms of the wavelength λ. ω and k represent the angular frequency and wave number, respectively.** 💡 **Hint:** Use $v_p = \frac{\omega}{k}$ and $v_g = \frac{d\omega}{dk}$. Substitute the dispersion relation, compute derivatives carefully, then express k in terms of λ using $k = \frac{2\pi}{\lambda}$.	10	2013	C
125	**The displacement associated with a three-dimensional plane wave is given by $\Psi(x,y,z,t) = a\cos\left[\frac{\sqrt{3}}{2}kx + \frac{1}{2}ky - \omega t\right]$. Calculate the angles made by the propagating wave with the x, y and z-axes.** 💡 **Hint:** The direction cosines of the wave vector determine the angles with coordinate axes. Use the components of the wave vector $\vec{k} = \left(\frac{\sqrt{3}}{2}k, \frac{1}{2}k, 0\right)$ to find angles via $\cos\theta = \frac{k_i}{\lvert\vec{k}\rvert}$.	10	2013	C

Continued on next page...

#	Question	Marks	Year	Type
126	**In a certain engine, a piston undergoes vertical SHM with an amplitude of 10 cm. A washer rests on the top of the piston. As the motor is slowly speeded up, at what frequency will the washer no longer stay in contact with the piston?** **Hint:** The washer loses contact when the maximum acceleration of the piston exceeds g. Use $a_{max} = \omega^2 A$ and solve for ω such that $a_{max} = g$, then convert to frequency.	10	2014	A
127	**Show that the group velocity is equal to particle velocity. Also prove that the group velocity of the photons is equal to c, the velocity of light.** **Hint:** Use $\omega = ck$ for photons to find $v_g = \frac{d\omega}{dk} = c$. In wave mechanics, particle velocity is defined as $v = v_g$ for massless particles like photons, showing the equivalence.	15	2014	C
128	**Find out the phase and group velocities of a radio wave of frequency $\omega = \sqrt{2}\omega_p$ in the ionosphere (as a dielectric medium) of refractive index $n = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$. Here, ω_p is the ionospheric plasma frequency.** **Hint:** Use $v_p = \frac{c}{n}$, where $n = \sqrt{1 - \frac{\omega_p^2}{\omega^2}}$. Differentiate $\omega(k)$ relation to find v_g. Express both velocities in terms of ω and ω_p, and substitute $\omega = \sqrt{2}\,\omega_p$ to compute numerical values.	15	2015	A
129	**The equation of a progressive wave moving on a string is $y = 5\sin\pi(0.01x - 2t)$. In this equation, y and x are in centimetres and t is in seconds. Calculate amplitude, frequency and velocity of the wave. If two particles at any instant are situated 200 cm apart, what will be the phase difference between these particles?** **Hint:** Compare the given wave equation to standard form $y = A\sin(kx - \omega t)$. Identify amplitude, frequency, and wave speed. Use $\Delta\phi = k\Delta x$ to calculate phase difference between two points.	10	2016	A
130	**Find the velocity of sound in a gas in which two waves of wavelengths 1.00 m and 1.01 m produce 10 beats in 3 seconds.** **Hint:** Beat frequency is 10/3 Hz. Use $v = f\lambda$ for both waves and solve for v by setting up equations for f_1 and f_2, then using beat frequency = $\lvert f_1 - f_2\rvert$.	10	2017	A

Continued on next page...

#	Question	Marks	Year	Type
131	**When the two waves of nearly equal frequencies interfere, then show that the number of beats produced per second is equal to the difference of their frequencies.** **Hint:** Consider superposition: $y = \sin(\omega_1 t) + \sin(\omega_2 t)$. Use trigonometric identity to get $2\cos(\Delta\omega t/2)\sin(\bar{\omega}t)$, showing modulation at beat frequency $\Delta f = \|f_1 - f_2\|$.	10	2018	C
132	**The equation for displacement (X) of a point on a damped oscillator is given by $x = 5e^{-0.25t}\sin\left(\frac{\pi}{2}t\right)$ metres. Find the velocity of oscillating point at $t = \frac{T}{4}$ and T, where T is the time period of the oscillator. What is the direction of velocity in each case?** **Hint:** Differentiate $x(t)$ using the product rule: $v(t) = \frac{d}{dt}[5e^{-0.25t}\sin\left(\frac{\pi}{2}t\right)]$. Then substitute $t = \frac{T}{4}$ and $t = T$ to find velocities and their directions based on the sign.	10	2020	A
133	**A mass m is suspended by two springs having force constants k_1 and k_2 as shown in the figure. The mass m is displaced vertically downward and then released. If at any instant t, the displacement of the mass m is x, then show that the motion of the mass is simple harmonic motion having frequency $f = \frac{1}{2\pi}\sqrt{\frac{1}{m}\left(\frac{k_1 k_2}{k_1+k_2}\right)}$.** **Hint:** When springs are in series, the effective spring constant is given by $k_{\text{eff}} = \frac{k_1 k_2}{k_1+k_2}$. Use $f = \frac{1}{2\pi}\sqrt{\frac{k_{\text{eff}}}{m}}$ to derive the result. The SHM condition is valid as the restoring force is proportional to displacement.	10	2021	C
134	**What is damped harmonic oscillation? Write the equation of motion and obtain the general solution for this oscillation. Discuss the cases of dead beat, critical damping and oscillatory motion based on the general solution.** **What would be the logarithmic decrement of the damped vibrating system, if it has an initial amplitude 30 cm, which reduces to 3 cm after 20 complete oscillations?** **Hint:** The general equation is $m\ddot{x} + b\dot{x} + kx = 0$. Solve for the underdamped case to get $x(t) = Ae^{-\gamma t}\cos(\omega' t + \phi)$. Logarithmic decrement is $\delta = \frac{1}{n}\ln\left(\frac{x_0}{x_n}\right)$. Plug in $x_0 = 30$, $x_n = 3$, $n = 20$ to compute δ.	20	2021	C

Continued on next page...

#	Question	Marks	Year	Type
135	**Two thin symmetrical lenses of two different natures (convex and concave) and of different materials have equal radii of curvature $R = 15$ cm. The lenses are put close together and immersed in water $\mu_w = 4/3$. The focal length of the system in water is 30 cm. Show that the difference between the refractive indices of two lenses is 1/3.** **Hint:** Use the lens maker's formula in water: $\frac{1}{f} = (\mu_{\text{lens}} - \mu_w)\left(\frac{2}{R}\right)$ for both lenses. Since they are thin and symmetric, combine their powers and equate to the total power. Solve for $\mu_1 - \mu_2$.	10	2010	C
136	**Show that two convex lenses of the same material kept separated by a distance a, which is equal to the average of two focal lengths, may be used as an achromat, that is, $a = \frac{1}{2}(f_1 + f_2)$.** **Hint:** For an achromatic combination, the chromatic aberrations must cancel. This requires careful choice of separation a. Using lens combination and dispersion relations, derive the condition $a = \frac{1}{2}(f_1 + f_2)$ under given constraints.	10	2010	C
137	**Use matrix method to obtain an expression for the focal length of a coaxial combination of two thin lenses having focal lengths f_1 and f_2 separated by distance d.** **Hint:** Use the ray transfer matrix method. Matrix for thin lens is $\begin{bmatrix} 1 & 0 \\ -1/f & 1 \end{bmatrix}$ and for free space of length d is $\begin{bmatrix} 1 & d \\ 0 & 1 \end{bmatrix}$. Multiply matrices for lens1, gap d, and lens2. Use the final matrix to get the equivalent focal length.	20	2012	C
138	**A convex lens of focal length 20 cm is placed after a slit of width 0.5 mm. If a plane wave of wavelength 5000 Å falls normally on the slit, calculate the separation between the second minima on either side of the central maximum.** **Hint:** Use the single slit diffraction formula for angular position of minima: $\theta_n = \frac{n\lambda}{a}$. For small angles, $y_n = f\theta_n$. Total separation between second minima on both sides is $2y_2$. Use $\lambda = 5000$ Å, $a = 0.5$ mm, $f = 20$ cm.	10	2015	A
139	**Using matrix method, find out the equivalent focal length for a combination of two thin lenses of focal lengths f_1 and f_2 separated by a distance a.** **Hint:** Use ray transfer matrices: lens matrix and translation matrix. Combine them as $M = M_{\text{lens}_2} M_{\text{translation}} M_{\text{lens}_1}$ and relate to system matrix. From the system matrix, extract the equivalent focal length.	10	2015	C

Continued on next page...

#	Question	Marks	Year	Type
140	**Obtain the system matrix for a thin lens placed in air and made of material of refractive index 1.5 having radius of curvature 50 cm each. Also find its focal length.** 💡 **Hint:** For a thin lens, system matrix is $M = \begin{bmatrix} 1 & 0 \\ -\frac{1}{f} & 1 \end{bmatrix}$. Use lens maker's formula $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$. Given $R_1 = +50$ cm, $R_2 = -50$ cm. Compute f.	10	2017	A
141	**What do you mean by spherical aberration of a lens? Show that if two plano-convex lenses are kept at a distance equal to the difference of their focal lengths, the spherical aberration would be minimum.** 💡 **Hint:** Spherical aberration arises because marginal rays and paraxial rays focus at different points. In two plano-convex lenses, setting the separation $d = f_1 - f_2$ minimizes spherical aberration by compensating the deviations.	15	2018	C
142	**What is axial chromatic aberration?** **A convex lens has a focal length of 15.5×10^{-2} m for red colour and 14.45×10^{-2} m for violet colour. If an object is kept at a distance of 40 cm from the lens, calculate the longitudinal chromatic aberration of the lens.** 💡 **Hint:** Axial chromatic aberration refers to change in focal length with wavelength. Calculate image distances for red and violet using lens formula $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$. Find difference between red and violet image positions to get longitudinal chromatic aberration.	10	2019	A
143	**Prove that when light goes from one point to another via a plane mirror, the path followed by light is the one for which the time of flight is the least.** 💡 **Hint:** Apply Fermat's principle of least time. Reflect the point across the mirror and show that the straight line joining real and image points satisfies minimum time condition.	20	2019	C
144	**State and explain Fermat's principle of extremum path. Discuss the cases of rectilinear propagation of light and reversibility of light rays in context of Fermat's principle. Using Fermat's principle, deduce the thin lens formula.** 💡 **Hint:** Fermat's principle states that light travels along the path that renders the time stationary. Apply it to derive reflection and refraction laws, and then derive the thin lens formula by minimizing optical path length for a lens.	15	2020	C

Continued on next page...

#	Question	Marks	Year	Type
145	**A thin film of petrol of thickness 9×10^{-6} cm is viewed at an angle 30° to the normal. Find the wavelength(s) of light in visible spectrum which can be viewed in the reflected light. The refractive index of the film $\mu = 1.35$.** **Hint:** For constructive interference in thin film, use $2\mu t \cos\theta = m\lambda$. Solve for λ and check within 4000–7000 Å range by selecting appropriate integers m.	10	2021	A
146	**What is chromatic aberration? Obtain the condition for achromatism using combination of two thin lenses placed in contact to each other. Can this system work as achromatic doublet if both are of same material? Justify your answer.** **Hint:** Chromatic aberration arises from wavelength-dependent focal length. Achromatism condition: $\frac{\phi_1}{v_1} + \frac{\phi_2}{v_2} = 0$, where ϕ are powers and v are dispersive powers. Same material lenses cannot satisfy this.	15	2021	C
147	**Obtain the system matrix for a thick lens and derive the thin lens formula.** **Hint:** Thick lens matrix is a product of two surface matrices and one translation matrix. For a thin lens, thickness approaches zero, simplifying the matrix to standard thin lens form $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$.	20	2022	C
148	**An optical beam of spectral width 7.5 GHz at wavelength $\lambda = 600$ nm is incident normally on Fabry-Perot etalon of thickness 100 mm. Taking refractive index unity, find the number of axial modes which can be supported by the etalon.** **Hint:** Free Spectral Range (FSR) is the frequency separation between successive transmission peaks and is given by $\Delta\nu = \frac{c}{2nL}$. Number of axial modes $= \frac{\text{spectral width}}{\text{FSR}}$. Use $n = 1$, $L = 100$ mm.	10	2010	A
149	**Describe Michelson interferometer for evaluation of coherence length of an optical beam. Calculate coherence length of a light beam of wavelength 600 nm with spectral width of 0.01 nm.** **Hint:** Michelson interferometer splits a beam into two paths and recombines to produce interference based on path difference. Coherence length $L_c = \frac{\lambda^2}{\Delta\lambda}$. Use $\lambda = 600$ nm and $\Delta\lambda = 0.01$ nm to find L_c.	20	2010	A

Continued on next page...

#	Question	Marks	Year	Type
150	**Show that two light beams polarized in perpendicular directions will not interfere.** **Hint:** Interference requires a non-zero dot product of electric fields. Perpendicularly polarized beams have orthogonal electric fields, so their superposition yields zero net intensity modulation.	15	2010	C
151	**When a thin film of a transparent material is put behind one of the slits in Young's double-slit interference experiment, the zero-order fringe moves to the position previously occupied by the fourth-order bright fringe. The index of refraction of the film is $n = 1.2$ and the wavelength of light, $\lambda = 5000$ Å. Determine the thickness of the film.** **Hint:** Optical path difference introduced by film is $(n-1)t = m\lambda$. Given $m = 4$, solve for t using $\lambda = 5000$ Å.	10	2011	A
152	**The separation between the slits is 0.5 mm in Young's double-slit experiment. The interference pattern observed on a screen placed 5 m away reveals the location of the first maximum which is 6 mm from the centre of the pattern. Calculate the wavelength of light and separation between second and third bright fringes.** **Hint:** Use $\beta = \frac{\lambda D}{d}$. First maximum gives $\lambda = \frac{yd}{D}$. Then β gives separation between adjacent fringes (e.g., second and third).	12	2012	A
153	**In a Young double slit experiment, the first bright maximum is displaced by $y = 2$ cm from the central maximum. If the spacing between slits and distance from the screen are 0.1 mm and 1 m respectively, find the wavelength of light.** **Hint:** Use $y_n = n\frac{\lambda D}{d}$ with $n = 1$, $y_1 = 2$ cm, $D = 1$ m, $d = 0.1$ mm. Rearranging gives $\lambda = \frac{y_1 d}{D}$.	10	2014	A
154	**In Michelson interferometer, 100 fringes cross the field of view when the movable mirror is displaced through 0.029 mm. Calculate the wavelength of the light source used.** **Hint:** Each fringe shift corresponds to a path change of one wavelength. Total mirror displacement d results in optical path change $2d = N\lambda$. Solve for $\lambda = \frac{2d}{N}$.	5	2016	A
155	**Obtain the conditions for constructive interference and destructive interference in a thin film due to reflected light.** **Hint:** Account for both path difference $2nt\cos\theta$ and phase change upon reflection. Constructive: $2nt\cos\theta = m\lambda$, Destructive: $2nt\cos\theta = (2m+1)\frac{\lambda}{2}$, adjusting for phase reversals.	15	2016	C

Continued on next page...

#	Question	Marks	Year	Type
156	**Explain with proper example the interferences due to 'division of wavefront' and 'division of amplitude'.** **Hint:** Division of wavefront splits the wavefront itself (e.g., Young's experiment), while division of amplitude splits the beam's intensity (e.g., Michelson interferometer). Explain splitting and recombination mechanism in both.	10	2017	C
157	**What is multiple-beam interference? Discuss the advantages of multiple-beam interferometry over two-beam interferometry. Explain the fringes formed by Fabry-Perot interferometer.** **Hint:** Multiple-beam interference involves repeated reflections producing sharp fringes. Fabry-Perot uses high reflectivity mirrors, leading to high finesse (ratio of FSR to fringe width) and sharper, more resolved fringes compared to two-beam systems.	15	2017	C
158	**What are the fringes of equal thickness and fringes of equal inclination?** **In a Newton's ring arrangement with a source emitting two wavelengths $\lambda_1 = 6 \times 10^{-7}$ m and $\lambda_2 = 5.9 \times 10^{-7}$ m, it is found that the m^{th} dark ring due to one wavelength coincides with the $(m+1)^{\text{th}}$ dark ring due to the other. Find the diameter of the m^{th} dark ring, if the radius of curvature of the lens is 90 cm.** **Hint:** Use Newton's ring formula: $D_m^2 = 4mR\lambda$. Equate $(m+1)\lambda_2 = m\lambda_1$ to find m, then calculate D_m. Define both types of fringes with diagram if possible.	10	2019	A
159	**What are Newton's rings? How are they formed by two curved surfaces?** **Hint:** Newton's rings are concentric interference fringes formed due to air film between plano-convex lens and flat glass surface. Interference occurs due to varying thickness and reflection.	10	2020	C
160	**Discuss the conditions for interference. Describe Young's double-slit experiment and derive an expression for the estimation of fringe width. Discuss its dependency on various parameters.** **Green light of wavelength 5100 Å from a narrow slit is incident on a double-slit. If the overall separation of 10 fringes on a screen 200 cm away is 2 cm, find the slit separation.** **Hint:** Condition: constant phase difference, same polarization, coherent sources. Use $\beta = \frac{\lambda D}{d}$ and solve for $d = \frac{\lambda D}{\beta}$. Given total fringe distance and number of fringes.	20	2020	A

Continued on next page...

#	Question	Marks	Year	Type
161	**Newton's rings are observed between a spherical surface of radius of curvature 100 cm and a plane glass plate. The diameters of 4th and 15th bright rings are 0.314 cm and 0.574 cm, respectively. Calculate the diameters of 24th and 36th bright rings and also the wavelength of light used.** **Hint:** Use Newton's rings formula $D_m^2 = 4mR\lambda$. Set up equations for known m and D_m, solve for λ, and then calculate D_{24} and D_{36}.	10	2022	C
162	**Obtain the expression for the primary focal length of Fresnel zone plate.** **Hint:** Start from the condition that the optical path difference between adjacent Fresnel zones is $\lambda/2$. Use $r_n^2 = n\lambda f$ to derive the expression for the primary focal length: $f = \frac{r_n^2}{n\lambda}$.	20	2010	C
163	**The Fraunhofer single-slit diffraction intensity is given by $I = I_0 \frac{\sin^2 x}{x^2}$, where $x = \frac{\pi d y}{\lambda l}$ with l as distance from slit to source, d the slit width, y the detector distance, and λ the wavelength. What is the value of cumulative intensity $\int_{-\infty}^{\infty} I(y)dy$?** **Hint:** Recognize that the integral of $I(y)$ over all y gives the total transmitted intensity, proportional to I_0 times slit width, by Fourier transform of a rectangle function.	10	2011	C
164	**In relation to a plane diffraction grating having 5000 lines per cm and irradiated by light of wavelength 6000 Å, answer the following: (i) What is the highest order spectrum which may be observed? (ii) If the width of opaque space is exactly twice that of transparent space, which order of spectra will be absent?** **Hint:** (i) Use $n\lambda = d\sin\theta$ with $\sin\theta \leq 1$ to find maximum order. (ii) If opaque to transparent width ratio is 2:1, every third-order spectrum will be missing (missing orders depend on grating structure periodicity).	15	2011	A
165	**Distinguish between Fresnel and Fraunhofer classes of diffraction. Show that the area of each Fresnel half-period zone is same.** **Hint:** Fresnel diffraction occurs at finite distances; Fraunhofer at infinity or with lens arrangement. Derive equal area property using geometry of half-period zones.	20	2012	C

Continued on next page...

#	Question	Marks	Year	Type
166	**A diffraction grating of width 5 cm with slits of width 10^{-4} cm separated by a distance of 2×10^{-4} cm is illuminated by light of wavelength 550 nm. What will be the width of the principal maximum in the diffraction pattern? Would there be any missing orders?** 💡 **Hint:** Use grating equation $d \sin\theta = n\lambda$ to find maxima positions. Width of principal maximum relates to the angular range over which constructive interference persists. Check for missing orders using ratio of slit and spacing.	20	2012	A
167	**A parallel beam of light from a He-Ne laser ($\lambda = 630$ nm) is made to fall on a narrow slit of width 0.2×10^{-3} m. The Fraunhofer diffraction pattern is observed on a screen placed in the focal plane of a convex lens of focal length 0.3 m. Calculate the distance between (i) first two minima and (ii) first two maxima on the screen.** 💡 **Hint:** Positions of minima are given by $y = m\lambda f/a$. Find y for $m = 1$ and $m = 2$, then calculate the separation. For maxima, use approximate locations between minima.	15	2013	A
168	**Explain the physical significance of resolving power of a grating with relevant mathematical expression.** 💡 **Hint:** Resolving power $R = \frac{\lambda}{\Delta\lambda} = nN$, where n is the order and N is total number of slits illuminated. Derive and explain physical meaning.	10	2013	C
169	**Considering a plane transmission diffraction grating, where d is the distance between two consecutive ruled lines, m as the order number and 0 as the angle of diffraction for normal incidence, calculate the angular dispersion $\frac{d\theta}{d\lambda}$ for an incident light of wavelength λ.** 💡 **Hint:** Differentiate grating equation $d \sin\theta = m\lambda$ with respect to λ to find $\frac{d\theta}{d\lambda}$.	10	2014	C
170	**Can D_1 and D_2 lines of sodium light ($\lambda_{D_1} = 5890$ Å and $\lambda_{D_2} = 5896$ Å) be resolved in second-order spectrum if the number of lines in the given grating is 450? Explain.** 💡 **Hint:** Use resolving power $R = nN$. Check if $R \geq \frac{\lambda}{\Delta\lambda}$. Here, $n = 2$, $N = 450$, $\Delta\lambda = 6$ Å.	10	2016	A
171	**Obtain an expression for the resolving power of a grating explaining the Rayleigh's criterion of resolution.** 💡 **Hint:** Apply Rayleigh criterion that two wavelengths are resolved if the principal maximum of one coincides with the first minimum of the other. Derive $R = nN$.	15	2016	C

Continued on next page...

#	Question	Marks	Year	Type
172	**Show that the areas of all the half-period zones are nearly the same. Find the radius of 1st half-period zone in a zone plate whose focal length is 50 cm and the wavelength of the incident light is 500 nm.** **Hint:** Use $r_n^2 = n\lambda f$ to show that difference between r_n and r_{n-1} is small, implying equal areas. Calculate r_1 using $n = 1$.	15	2017	A
173	**A plane transmission grating has 3000 lines in all, having width of 3 mm. What would be the angular separation in the first order spectrum of the two sodium lines of wavelengths 5890 Å and 5896 Å? Can they be seen distinctly?** **Hint:** Compute angular dispersion using $\frac{d\theta}{d\lambda} = \frac{m}{d\cos\theta}$. Find angular separation $\Delta\theta$ and check if it is larger than the angular width of principal maxima to determine resolvability.	10	2018	A
174	**Discuss the intensity distribution in Fraunhofer diffraction pattern due to a single slit. Obtain conditions for maxima and minima of the intensity distribution. Show that the intensity of the first maxima is about 4.95% of that of the principal maxima.** **Hint:** Intensity is $I = I_0 \left(\frac{\sin\beta}{\beta}\right)^2$ where $\beta = \frac{\pi a \sin\theta}{\lambda}$. Minima occur when $\beta = n\pi$, maxima occur in between. Calculate intensity at first secondary maximum and show $I/I_0 \approx 0.0495$.	20	2018	C
175	**Show that the phenomenon of Fraunhofer diffraction at two vertical slits is modulation of two terms viz. double slit interference and single slit diffraction. Obtain the condition for positions of maxima and minima.** **Hint:** Total intensity is the product of single slit diffraction envelope and double slit interference pattern: $I = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \cos^2\gamma$. Derive conditions for maxima and minima.	20	2021	C
176	**Discuss the phenomenon of Fraunhofer diffraction at a single slit and show that the intensities of successive maxima are nearly in the ratio $1 : \frac{4}{9\pi^2} : \frac{4}{25\pi^2} : \frac{4}{49\pi^2}$.** **Hint:** Secondary maxima occur approximately midway between minima. Use β values around these points, evaluate intensities, and derive ratios step-by-step for successive maxima.	20	2022	C

Continued on next page...

#	Question	Marks	Year	Type
177	**An unpolarized light beam of intensity $1000\ \mathrm{W/m^2}$ is incident on an ideal linear polarizer with its transmission axis parallel to vertical direction. Describe an experiment to reduce the intensity of light beam to $500\ \mathrm{W/m^2}$.** **Hint:** Unpolarized light intensity reduces by half after passing through polarizer ($I = I_0/2$). Rotate analyzer polarizer at an angle θ to further adjust intensity by $I = (I_0/2)\cos^2\theta$. Find θ to achieve $500\ \mathrm{W/m^2}$.	10	2010	A
178	**What should be the refractive index of cladding of an optical fibre with numerical aperture 0.5 with refractive index of core as 1.5?** **Hint:** Numerical Aperture (NA) is given by $\sqrt{n_{\text{core}}^2 - n_{\text{clad}}^2}$. Rearrange and solve for n_{clad}.	10	2010	A
179	**A laser beam of 1 micrometer wavelength with 3 megawatts power of beam diameter 10 mm is focussed by a lens of focal length 50 mm. Evaluate the electric field associated with the light beam at the focal point. (Dielectric permittivity of free space, $\epsilon_0 = 8.8542 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$)** **Hint:** First calculate intensity at the focal point using beam power and focused spot area. Then use $I = \frac{1}{2}\epsilon_0 c E^2$ to solve for the electric field E at the focal point.	25	2010	A
180	**A plane wave has the following expression for its electric field: $\vec{E} = \hat{x}E_{0x}\cos(\omega t - kz + \alpha) + \hat{y}E_{0y}\cos(\omega t - kz + \beta)$. If the phase difference is defined as $\delta = \beta - \alpha$, under what conditions do we achieve elliptic polarization? What are the conditions for circular polarization?** **Hint:** Elliptic polarization occurs when $E_{0x} \neq E_{0y}$ and δ is arbitrary. Circular polarization occurs when $E_{0x} = E_{0y}$ and $\delta = \pm\frac{\pi}{2}$.	10	2011	C
181	**For calcite, the refractive indices of ordinary and extraordinary rays are 1.65836 and 1.48641 at $\lambda_0 = 5893$ Å respectively. A left circularly polarized beam of this wavelength is incident normally on such crystal of thickness 0.005141 mm having its optic axis cut parallel to the surface. What will be the state of polarization of the emergent beam?** **Hint:** Calculate phase retardation $\Delta\phi = \frac{2\pi}{\lambda}(n_e - n_o)d$. If $\Delta\phi$ equals an odd multiple of π, the output polarization becomes linear. Identify the exact retardation type.	15	2011	A

Continued on next page...

#	Question	Marks	Year	Type
182	**Bring out the essential differences between the physical principles of spontaneous and stimulated emission of radiation. Why is it difficult to get efficient lasing action in case of an ideal two-level material system? Can you propose a scheme to enhance efficiency? Discuss.** **Hint:** Discuss probability differences of spontaneous and stimulated emission. In two-level systems, population inversion is difficult. Suggest three- or four-level laser systems to improve efficiency.	15	2011	C
183	**Show with proper mathematical analysis that the ratio of Einstein's A and B coefficients depends upon the energy separation between the two energy levels participating in the optical transitions. What is the physical significance of A coefficient? Justify the statement: "It is very difficult to develop an X-ray laser".** **Hint:** Use detailed balance conditions: $\frac{A}{B} \propto \nu^3$. Higher energy transitions (higher ν) result in larger A, making population inversion more difficult for X-rays.	20	2011	C
184	**Derive an expression for intermodal dispersion for a multimodal step-index fibre.** **Hint:** Derive pulse broadening by considering that different modes travel with slightly different group velocities in a multimodal fibre. Relate delay differences to intermodal dispersion.	20	2012	C
185	**A pulse of $\lambda_0 = 600$ nm and $\Delta\lambda = 10$ nm propagates through a fibre which has a material dispersion coefficient of 50 ps per km per nm at 600 nm. Calculate the pulse broadening in traversing a 10 km length of the fibre. If the pulse width at the input of the fibre is 12 ns, what will be the pulse width at the output of the fibre?** **Hint:** Pulse broadening $\Delta t = D\Delta\lambda L$, where D is material dispersion coefficient. Use resultant pulse width formula: $\sqrt{\Delta t_{\text{initial}}^2 + \Delta t^2}$.	10	2012	A
186	**Calculate the minimum thickness of a quartz plate which would behave as a quarter-wave plate for wavelength of light, $\lambda = 6000$ Å. The refractive indices for ordinary and extraordinary rays are $\mu_o = 1.544$ and $\mu_e = 1.553$.** **Hint:** Phase difference $\Delta\phi = 2\pi(\mu_e - \mu_o)d/\lambda = \pi/2$ for quarter-wave plate. Solve for d.	15	2012	A

Continued on next page...

#	Question	Marks	Year	Type
187	**Explain why information carrying capacity of an optical fibre can be enhanced by reducing the pulse dispersion. How does one minimize pulse dispersion using a graded index optical fibre?** **Hint:** Pulse broadening limits bit rate. Graded index fibre minimizes intermodal dispersion by equalizing mode velocities through refractive index grading.	10	2013	C
188	**What is the physical significance of Einstein's A-coefficient? Explain why it is more difficult to achieve lasing action at X-ray wavelength than at infrared wavelength.** **Hint:** A represents spontaneous emission probability. Since $A \propto \nu^3$, spontaneous emission dominates at X-ray frequencies, making population inversion and lasing harder.	10	2014	C
189	**For a multimode step index optical fibre, the core refractive index is 1.5 and fractional index difference is 0.001. Calculate the pulse broadening for 1 km length of the fibre. Over a length of 2 km of the fibre, calculate the minimum pulse separation that can be transmitted without overlap.** **Hint:** Use intermodal dispersion formula $\Delta t = \frac{n_1 \Delta}{c} L$. For minimum pulse separation, ensure adjacent pulses do not overlap after dispersion over 2 km.	10	2014	A
190	**Explain the working principle of a 3-level laser with a specific example. Comment on why the third level is needed.** **Hint:** In a three-level laser, electrons are excited to a higher energy level, quickly decay to a metastable state, and lasing occurs from metastable to ground state. Third level enables population inversion. Example: Ruby laser.	10	2014	C
191	**How does holography differ from conventional photography? What are the requirements for the formation and reading of a hologram?** **Hint:** Photography records intensity; holography records both amplitude and phase using coherent light and reference beams. Requirements include coherent source, reference and object beams, and interference recording medium.	10	2014	C
192	**What is the role of an optical resonator in a laser? Why does one prefer curved mirrors instead of plane mirrors in designing an optical resonator?** **Hint:** Optical resonators provide feedback and spatial mode selection. Curved mirrors form stable resonators by confining rays via focusing, preventing beam divergence and enhancing laser efficiency.	10	2015	C

Continued on next page...

#	Question	Marks	Year	Type
193	**Find out the angle between the reflected and refracted rays when a parallel beam of light is incident on a dielectric surface at an angle equal to the Brewster's angle. Explain how do you use this concept to produce linearly polarized light.** **Hint:** At Brewster's angle, reflected and refracted rays are perpendicular (90° apart). Brewster's angle = $\tan^{-1}(n_2/n_1)$. Light reflected is completely polarized perpendicular to the plane of incidence.	10	2015	C
194	**Using the concept of Einstein's A and B coefficients for a two-level atomic system under thermal equilibrium, determine the ratio of the number of atoms per unit volume in the two levels experiencing spontaneous and stimulated emission. How does the principle of population inversion lead to the gain mechanism in the active medium of the laser?** **Hint:** Apply Boltzmann distribution under thermal equilibrium and Einstein's relations. Population inversion (more atoms in excited state) leads to gain via enhanced stimulated emission.	10	2015	C
195	**The refractive indices of core and cladding in a step index optical fiber are 1.52 and 1.48 respectively. The diameter of the core is $30\mu m$. If the operating wavelength is $1.3\mu m$, calculate the V parameter and the maximum number of modes supported by the fiber.** **Hint:** $V = \frac{2\pi a}{\lambda}\sqrt{n_1^2 - n_2^2}$. For multimode fiber, modes $\approx V^2/2$. Compute V, then find number of modes.	10	2016	A
196	**Explain the principle of (i) induced absorption, (ii) spontaneous emission and (iii) stimulated emission. Show that the ratio of Einstein's coefficients is given by $\frac{A}{B} = \frac{8\pi h\nu^3}{c^3}$.** **Hint:** Describe each process individually. Derive Einstein relations from blackbody radiation law, showing dependence on ν^3.	20	2016	C
197	**Explain the principle of producing polarized light by the method of reflection, refraction and double refraction with the help of neat diagrams.** **Hint:** Explain polarization by (i) reflection at Brewster's angle, (ii) refraction in birefringent materials, (iii) double refraction using crystals like calcite. Use neat ray diagrams.	15	2016	C
198	**Sunlight is reflected from a calm lake. The reflected light is 100% polarized at a certain instant. What is the angle between the sun and horizon?** **Hint:** At Brewster's angle, $\theta_B = \tan^{-1}(n_2/n_1)$. For air-water interface, $n_2 \approx 1.33$. Angle between sun and horizon is $90^\circ - \theta_B$.	10	2017	A

Continued on next page...

#	Question	Marks	Year	Type
199	**A plane-polarized light passes through a double-refracting crystal of thickness $40\mu m$ and emerges out as circularly polarized. If the birefringence of the crystal is 0.00004, then find the wavelength of the incident light.** 💡 **Hint:** Phase retardation for quarter-wave plate: $\Delta\phi = \frac{2\pi d\Delta n}{\lambda} = \pi/2$. Solve for λ.	10	2017	A
200	**How is laser light different from ordinary light? Discuss the working principle of ruby laser. What role do chromium ions play in this process?** 💡 **Hint:** Laser light is coherent, monochromatic, highly directional. In ruby laser, chromium ions are active medium providing metastable states for population inversion.	15	2017	C
201	**Explain the principle and working of He-Ne laser. What is the role of He gas? Why is it necessary to use narrow tube? How many longitudinal modes can be excited for an He-Ne laser in a cavity of length 30 cm and having half width of gain profile of laser material 2×10^{-3} nm? The emission wavelength is 6328 Å.** 💡 **Hint:** He atoms transfer energy non-radiatively to excited Ne atoms through collisions, populating Ne's upper laser level. Narrow tube ensures sufficient excitation length. Find longitudinal mode spacing $\Delta\nu = c/2L$ and fit within gain bandwidth.	15	2018	A
202	**Distinguish between positive and negative crystals in terms of double refraction. How are these crystals used to make quarter wave plates? Explain how the quarter wave plate is used in producing elliptically and circularly polarized light.** 💡 **Hint:** Positive crystals have $n_e > n_o$; negative crystals have $n_e < n_o$. In quarter-wave plates, phase retardation of $\pi/2$ is introduced between orthogonal components, converting linear to elliptical or circular polarization.	15	2018	C
203	**How can one convert a left-handed circularly polarised light into a right-handed one (and vice versa)?** **Calculate the thickness of a quarter-wave plate when the wavelength of light is 589 nm. Given: $\mu_o = 1.544$, $\mu_e = 1.553$.** 💡 **Hint:** A quarter-wave plate flips the handedness of circular polarization. Thickness d is found using $\Delta\phi = \frac{2\pi}{\lambda}(\mu_e - \mu_o)d = \pi/2$. Solve for d.	10	2019	A

Continued on next page...

#	Question	Marks	Year	Type
204	**Discuss how population inversion is achieved in Ruby laser. What is 'laser spiking'? Why does it occur?** **Hint:** Population inversion in ruby laser is achieved by optical pumping of chromium ions. Laser spiking refers to intensity fluctuations due to transient build-up and relaxation oscillations during early laser operation.	20	2019	C
205	**In what way is holography different from conventional photography? Discuss the salient features of a hologram. What are the requirements for the formation and reading of a hologram?** **Hint:** Holography records both amplitude and phase; conventional photography only records intensity. Requires coherent source, object beam, reference beam, and photographic plate.	20	2019	C
206	**What is a zone plate? Give its theoretical description. Show that a zone plate has multiple foci. Differentiate a zone plate from a convex lens. Calculate the radius of the first half period zone in a zone plate behaving like a convex lens of focal length 60 cm for light of wavelength 6000 Å.** **Hint:** Zone plate focuses light via diffraction, not refraction. For zone plate, $r_n = \sqrt{n\lambda f}$. Derive formula and calculate r_1.	15	2020	A
207	**Briefly discuss the postulates of Einstein to explain stimulated emission. Derive an expression for Einstein's A and B coefficients and show that the ratio of coefficients of spontaneous versus stimulated emission is proportional to the third power of frequency of radiation. Why is it difficult to achieve laser action in higher frequency ranges such as X-rays?** **Can there be a temperature at which the rates of spontaneous and stimulated emission are equal? Illustrate with wavelength $\lambda = 5000$ Å.** **Hint:** Use Planck's law and Einstein coefficients relations: $\frac{A}{B} \propto \nu^3$. High ν (e.g., X-rays) means spontaneous dominates. Find temperature where $n(\nu) \approx 1$.	15	2020	C

Continued on next page...

#	Question	Marks	Year	Type
208	**Explain the phenomenon of double refraction in calcite crystal. Considering birefringent crystal as non-conducting material, explain double refraction using electromagnetic theory. Calculate the thickness of a double refracting plate which produces a path difference of $\frac{\lambda}{4}$ between extraordinary and ordinary waves. Given: $\lambda = 5890$ Å, $\mu_o = 1.53$, $\mu_e = 1.54$.** **Hint:** Ordinary and extraordinary rays arise due to different refractive indices for E-fields parallel and perpendicular to optic axis. Use phase retardation $\Delta\phi = \frac{2\pi d(\mu_e - \mu_o)}{\lambda} = \pi/2$ to calculate d for quarter-wave plate.	15	2020	A
209	**In a step-index optical fiber system, explain the terms pulse dispersion and material dispersion. An optical fiber having refractive indices of core and cladding $n_1 = 1.463$ and $n_2 = 1.444$ respectively, uses a Laser diode with $\lambda_0 = 1.50\ \mu m$ with a spectral width of 2 nm. At this wavelength, if the material dispersion coefficient, D_m is 18.23 ps/km.nm, then calculate the pulse dispersion and material dispersion for 1 km length of the fiber.** **Hint:** Pulse dispersion refers to the temporal broadening of optical pulses due to different velocities of light components within a fiber. Material dispersion arises because refractive index depends on wavelength. Use $\Delta t = D_m \Delta\lambda L$, where D_m is the material dispersion coefficient, $\Delta\lambda$ is spectral width, and L is the fiber length.	20	2021	A
210	**A phase retardation plate of quartz has thickness 0.1436 mm. For what wavelength in the visible region will it act as quarter-wave plate? Given that $\mu_o = 1.5443$ and $\mu_e = 1.5533$.** **Hint:** Use phase retardation condition: $\Delta\phi = \frac{2\pi}{\lambda}(\mu_e - \mu_o)d = \pi/2$ for a quarter-wave plate. Solve for λ.	10	2022	A
211	**In He-Ne laser, what is the function of He gas? Explain the answer with the help of energy level diagram for He-Ne laser.** **Hint:** He atoms are excited first and transfer energy to Ne atoms by resonant energy transfer. He enables population inversion in Ne levels crucial for laser action. Draw neat energy level diagram showing transitions.	15	2022	C

Continued on next page...

#	Question	Marks	Year	Type
212	**Using Huygens' principle for a plane wave travelling from rarer medium 1 to a denser medium 2, show that $\frac{\sin i}{\sin r} = \frac{v_1}{v_2} = \frac{\mu_2}{\mu_1}$, where i and r are the angles of incidence and refraction, respectively. v_1, μ_1 and v_2, μ_2 are the velocities and refractive indices in media 1 and 2, respectively.** (TC) **Hint:** Apply Huygens' construction at the interface. Use wavefront normals and geometry to derive Snell's law linking angles and velocities. Connect velocities with refractive indices.	10	2023	C
213	**What are three and four level pumping schemes? Explain the lasing action in these with schematic diagrams.** (TC) **Hint:** Three-level lasers require pumping to a higher level with relaxation to a metastable lasing level; four-level lasers have an additional lower energy level to facilitate easier population inversion. Draw diagrams showing levels and transitions.	10	2023	C
214	**Obtain condition for achromatism of two thin lenses separated by a finite distance. If the dispersive powers of the materials of the two lenses are 0.020 and 0.028, their focal lengths are 10 cm and 5 cm, respectively. Calculate the separation between them in order to form achromatic combination.** (AN) **Hint:** For achromatism, dispersive powers and focal lengths must satisfy: $\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0$. When lenses are separated by distance d, use system focal length formula: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$. Apply both conditions to solve for d.	15	2023	A
215	**(i) What are the requisite conditions for observation of interference pattern on a screen?** (TC) **Hint:** For observable interference, sources must be coherent (constant phase difference), have nearly equal amplitudes, and the screen must be at an appropriate distance to resolve the fringe separation clearly.	5	2023	C
	(ii) Derive the expression for fringe width and intensity at a point on the screen in a double slit experiment. (TC) **Hint:** Use path difference $\Delta = \frac{dx}{D}$, phase difference $\phi = \frac{2\pi}{\lambda}\Delta$, and derive $I = 4I_0 \cos^2\left(\frac{\pi dx}{\lambda D}\right)$. Fringe width $\beta = \frac{\lambda D}{d}$.	10	2023	C

Continued on next page...

#	Question	Marks	Year	Type
216	**Write equation for damped harmonic oscillations and obtain expression for logarithmic decrement.** **In a damped harmonic motion, the first amplitude is 10 cm, which reduces to 2 cm after 50 oscillations, each of period 4 seconds. Determine the logarithmic decrement. Also, calculate the number of oscillations in which the amplitude decreases to 25%.** (TC) **Hint:** Equation: $x(t) = A_0 e^{-\beta t}\cos(\omega t + \phi)$ for damped oscillations. Logarithmic decrement δ measures the rate of exponential decay: $\delta = \frac{1}{n}\ln\left(\frac{A_0}{A_n}\right)$. Calculate δ and find number of oscillations for 25% amplitude.	20	2023	C
217	**Write conditions for working of a step-index optical fiber. In a step-index fiber, the core and cladding materials have refractive indices 1.50 and 1.43, respectively.** **Find the following:** **(i) Critical propagation angle** **(ii) Acceptance angle** **(iii) Total time delay in 1 km length of the fiber** **(iv) Total dispersion in 50 km length of the fiber** (AN) **Hint:** Use total internal reflection conditions: $\sin\theta_c = \frac{n_2}{n_1}$. Acceptance angle using numerical aperture. Time delay using group velocity. Total dispersion via pulse broadening calculations.	20	2023	A
218	**(i) What is the difference between Fresnel diffraction and Fraunhofer diffraction?** (TC) **Hint:** Fresnel diffraction occurs when the source and screen are at finite distances; wavefront curvature is significant. Fraunhofer diffraction occurs for plane waves with source and screen at effectively infinite distances, often using lenses to achieve parallel rays.	5	2023	C
	(ii) What is resolving power of a telescope? Why is the resolving power of microscope more with UV light than with visible light? (TC) **Hint:** Resolving power is ability to distinguish two close objects. Telescope: $\theta = 1.22\frac{\lambda}{D}$. Smaller wavelength (UV) leads to better resolution in microscope according to Rayleigh criterion.	10	2023	C
219	**The intensity at the central maximum observed on a screen in a double-slit experiment is 2×10^{-3} W/m^2. If the path difference between interfering waves reaching a point on the screen is $\frac{\lambda}{6}$, where λ is the wavelength of the light used in the experiment, determine the intensity at that point.** (AN) **Hint:** Use the relation $I = I_0\cos^2\left(\frac{\delta}{2}\right)$ where $\delta = \frac{2\pi}{\lambda}\times$ path difference.	10	2024	A

Continued on next page...

#	Question	Marks	Year	Type
220	**A weakly damped harmonic oscillator consisting of spring-mass system has mass $m = 0.25$ kg, spring constant $k = 100$ N m^{-1}, damping coefficient $\gamma = 1$ N s m^{-1}. A periodic force $F = 5\cos\omega t$ (newton) is applied to the system. Determine (i) the amplitude of the oscillator at resonance and (ii) the Q-value of the oscillator.** (AN) **Hint:** At resonance, amplitude $A = \frac{F_0}{\gamma\omega_0}$ where $\omega_0 = \sqrt{k/m}$. Q-factor is given by $Q = \frac{m\omega_0}{\gamma}$.	15	2024	A
221	**Explain the phenomenon of double refraction. What are positive and negative crystals? Give their examples.** (TC) **Hint:** Double refraction refers to the splitting of an unpolarized light beam into two polarized rays (ordinary and extraordinary) due to anisotropy. Positive crystals: $n_e > n_o$ (e.g., Quartz); negative crystals: $n_o > n_e$ (e.g., Calcite).	5	2024	C
222	**What do you understand by optical activity? A linearly polarized light is propagating along the optic axis of a quartz crystal of thickness 0.2 cm. If the difference in the refractive indices corresponding to right circularly polarized and left circularly polarized beams is 7×10^{-5} and the wavelength of the light is 0.5 μm, calculate the angle of polarization.** (AN) **Hint:** Use formula for rotation $\theta = \pi d(n_r - n_l)/\lambda$.	10	2024	A
223	**What do you understand by attenuation in optical fibers? What are the factors responsible for the attenuation?** (TC) **Hint:** Attenuation refers to reduction of signal power during propagation. Major factors include absorption, scattering, and bending losses.	5	2024	C
224	**Consider a 10 mW laser beam passing through a 50 km fiber link of attenuation 0.5 dB/km. Calculate the power of the laser at the end of the link.** (AN) **Hint:** Use the formula $P = P_0 \times 10^{-\frac{\alpha L}{10}}$ where α is attenuation in dB/km and L is length in km.	10	2024	A
225	**Write down the system matrix for a combination of two thin lenses in paraxial approximation. Hence obtain the focal length of the combination and the positions of unit planes.** (TC) **Hint:** In paraxial approximation, multiply the lens and translation matrices. Extract focal length and unit planes from the combined matrix.	10	2024	C

Continued on next page...

#	Question	Marks	Year	Type
226	**Consider a thin lens combination of two convex lenses of focal lengths $f_1 = +10$ cm and $f_2 = +20$ cm, separated by 25 cm. Determine the focal length of the combination and the positions of unit planes.** (AN) **Hint:** Use lens combination formula $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$, with distances in cm. Calculate effective focal length and positions of unit planes.	10	2024	A
227	**The diameter of central zone of a zone plate is 2.4 mm. If a point source of light of wavelength 600 nm is placed at a distance of 5.0 m from the zone plate, calculate the position of the first image.** (AN) **Hint:** Use the relation for first focus: $f = \frac{r_1^2}{\lambda}$ where r_1 is radius of first zone.	10	2024	A

ELECTRODYNAMICS

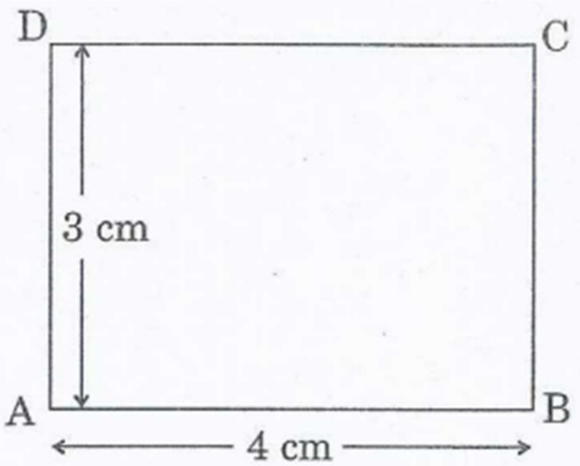
Key: C = Conceptual, A = Applied

#	Question	Marks	Year	Type
228	**Obtain Poisson's equation in electrostatics from Gauss' law. What form does it take when the charge density is zero?** **Hint:** Start with Gauss's law in differential form $\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$. Use the relation $\vec{E} = -\nabla V$ to express the electric field in terms of potential V. This leads to Poisson's equation $\nabla^2 V = -\frac{\rho}{\varepsilon_0}$. When the charge density $\rho = 0$, the equation reduces to Laplace's equation $\nabla^2 V = 0$.	10	2010	C
229	**What is meant by a dielectric? Define polarization vector P and relate it with the average molecular dipole moment. Obtain expression for the potential due to a polarized dielectric in terms of the polarization vector.** **Hint:** A dielectric is an insulating material that becomes polarized in an electric field. The polarization vector $\vec{P}$ represents the dipole moment per unit volume. It relates to bound charge densities as $\rho_b = -\nabla \cdot \vec{P}$ (volume) and $\sigma_b = \vec{P} \cdot \hat{n}$ (surface). Derive the potential using the analogy with potentials of continuous charge distributions.	20	2010	C
230	**Find out the total electric potential energy of a single spherical object of uniform charge density ρ, total charge Q and radius R.** **Hint:** Use the energy expression $U = \frac{1}{2}\int \rho V \, d\tau$, where V is the potential due to the charge distribution. First, find V inside the sphere using Gauss's law and continuity at $r = R$, then integrate over the sphere's volume, treating the sphere as a continuous charge distribution.	10	2011	C

Continued on next page...

#	Question	Marks	Year	Type
231	**Determine the torque experienced by an electric dipole of moment $\vec{p}$ if placed in an electric field $\vec{E}$ in nonaligned state. Also show that the interaction energy of two dipoles of moments $\vec{p_1}$ and $\vec{p_2}$ separated by a displacement $\vec{r}$ is $U = \frac{1}{4\pi\varepsilon_0}\frac{1}{r^3}[\vec{p_1}\cdot\vec{p_2} - 3(\vec{p_1}\cdot\hat{r})(\vec{p_2}\cdot\hat{r})]$, assuming the expression for field due to a dipole.** **Hint:** Recall that torque on a dipole is given by $\vec{\tau} = \vec{p}\times\vec{E}$. For the interaction energy, use $U = -\vec{p}\cdot\vec{E}$, where $\vec{E}$ is the field due to the first dipole at the position of the second. Carefully expand the dipole field and evaluate the scalar product systematically.	20	2011	A
232	**The electric potential of a grounded conducting sphere of radius a in a uniform electric field is given as $\phi(r,\theta) = -E_0 r\left[1 - \left(\frac{a}{r}\right)^3\cos\theta\right]$. Find the surface charge distribution.** **Hint:** Use the relation $\sigma = -\varepsilon_0\left(\frac{\partial\phi}{\partial r}\right)_{r=a}$ to find the surface charge density. Carefully differentiate the given potential with respect to r and substitute $r = a$ to get the required expression for σ.	10	2011	A
233	**The volume between two concentric conducting spherical surfaces of radii a and $b(a < b)$ is filled with an inhomogeneous dielectric with $\varepsilon = \varepsilon_0/(1 + cr)$, where c is a constant and r is the radial coordinate. A charge $+Q$ is placed on the inner surface, while the outer surface is grounded. Determine: (a) $\vec{D}$ in the region $a < r < b$; (b) capacitance of the device; (c) polarization charge density in the region $a < r < b$; (d) surface polarization charge densities at $r = a$ and $r = b$.** **Hint:** Apply Gauss's law $\nabla\cdot\vec{D} = \rho_f = 0$ to find $\vec{D}$ first, recognizing spherical symmetry. Then use $\vec{D} = \varepsilon(r)\vec{E}$ to determine $\vec{E}$. Find the potential difference ΔV by integrating $\vec{E}$, leading to capacitance. Use $\vec{P} = \vec{D} - \varepsilon_0\vec{E}$ to find bound volume and surface charges, carefully handling the r-dependence of ε.	15	2012	A
234	**Assume $\vec{E} = 0$ inside a perfect conductor. Elaborate on any other four electrostatic properties that arise from this property.** **Hint:** Since $\vec{E} = 0$ inside a conductor, (i) the conductor's surface is an equipotential, (ii) any excess charge resides on the surface, (iii) the electric field just outside is normal to the surface, and (iv) charges rearrange to maintain electrostatic equilibrium, minimizing potential energy. Each property ensures stability under electrostatic conditions.	15	2012	C

Continued on next page...

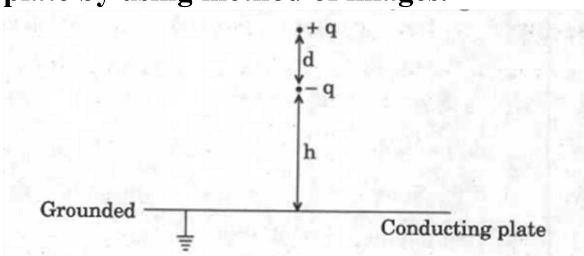
#	Question	Marks	Year	Type
235	**Using the fundamental concepts of electromagnetism, determine the electric field of an electric dipole $\vec{p}$ at a distance $\vec{r}$ and its energy in an electric field $\vec{E}$.** **Hint:** For the dipole field, start with the known formula: $\vec{E} = \frac{1}{4\pi\varepsilon_0}\left(\frac{3(\vec{p}\cdot\hat{r})\hat{r}-\vec{p}}{r^3}\right)$. For energy, use $U = -\vec{p}\cdot\vec{E}$. Be cautious in vector calculations and in defining $\hat{r} = \vec{r}/r$.	15	2013	C
236	**$ABCD$ is a rectangle in which charges of $+10^{-11}$C, -2×10^{-11}C and 10^{-11}C are placed at corners B, C and D, respectively. Calculate the potential at the corner A and the work done in carrying a charge of 2 coulombs to A.**  **Hint:** Find the potential at A due to each charge using $V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$ and sum the contributions algebraically. The work done W in bringing a charge q_0 from infinity to A is given by $W = q_0 V_A$, considering the correct signs and distances carefully.	10	2013	A
237	**Under one-dimensional configuration, the charge density is given by $\rho(x) = \frac{\rho_0 x}{5}$, where ρ_0 is a constant charge density. If the electric field $\vec{E} = 0$ at $x = 0$ and potential $V = 0$ at $x = 5$, determine V and $\lvert\vec{E}\rvert$.** **Hint:** Use Gauss's law in one dimension $\frac{dE}{dx} = \frac{\rho(x)}{\varepsilon_0}$. Integrate to find $E(x)$ and then use $E = -\frac{dV}{dx}$ to find $V(x)$. Apply boundary conditions to find constants of integration.	10	2015	A
238	**A conducting sphere of radius 5 cm has a total charge of 12 nC uniformly distributed on its surface in free space. Determine the displacement vector $\vec{D}$ on its surface and outside at a distance r from the centre of the sphere.** **Hint:** For $r \geq 5$ cm, use Gauss's law $\oint \vec{D}\cdot d\vec{A} = Q_{free}$ to find $\lvert\vec{D}\rvert$, noting that $\vec{D}$ is radial and inversely proportional to r^2. For $r < 5$ cm, $\vec{D} = 0$ inside the conductor.	10	2015	A

Continued on next page...

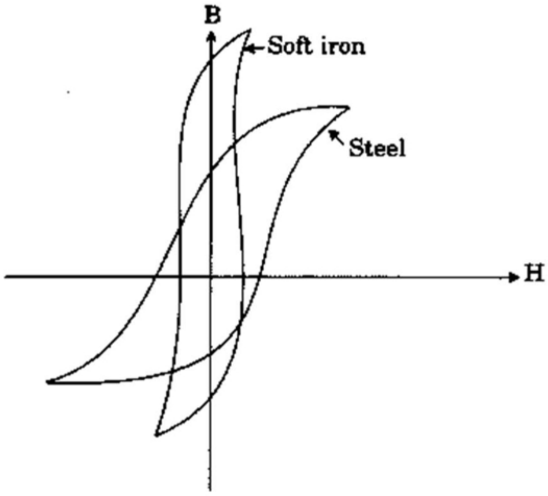
#	Question	Marks	Year	Type
239	**With the help of a neat diagram, show that the potential due to a dipole at a point is given by $V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$, where p is the dipole moment, θ is the angle between the dipole axis and the point of interest.** 💡 **Hint:** Start with the potential due to two charges $+q$ and $-q$ separated by a small distance d. Approximate using $r \gg d$ and express the result in terms of dipole moment $p = qd$. Carefully expand using binomial approximation if necessary.	10	2016	C
240	**Discuss the principle of 'artificial dielectric'. Where do you find its use?** 💡 **Hint:** Artificial dielectrics are engineered materials consisting of embedded conducting structures within an insulating matrix, designed to mimic dielectric properties. They are used in radar systems, antennas, and microwave devices. The effective permittivity depends critically on the geometry and distribution of the embedded conductors.	10	2017	C
241	**A charge $q = 2\mu$C is placed at $a = 10$ cm from an infinite grounded conducting plane sheet. Find the (i) total charge induced on the sheet, (ii) force on the charge q and (iii) total work required to remove the charge slowly to an infinite distance from the plane.** 💡 **Hint:** Use the method of image charges: replace the conducting plane by an image charge $-q$ at a distance $-a$. (i) Induced charge equals $-q$. (ii) Force between real and image charges: $F = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{(2a)^2}$. (iii) Work is the integral of force from a to infinity.	10	2017	A
242	**A current $i(t) = (2e^{-t} - e^{-2t})\mu$A charges up a 120 nF capacitor for a period of 2 seconds. If the final voltage across the capacitor is 15 V, what was the initial voltage across it?** 💡 **Hint:** Use $q(t) = \int i(t)dt$ to find the charge at any time. Then use $V(t) = \frac{q(t)}{C}$ where C is capacitance. Knowing $V(2) = 15$ V, solve for constants and backtrack to find initial voltage.	10	2017	A
	Continued on next page...			

#	Question	Marks	Year	Type
243	**Why does a soap bubble expand upon electrification? A sphere of radius R contains a charge $+Q$ and a charge $-Q$ distributed uniformly in the upper and lower hemispheres respectively. Show that the dipole moment of charge distribution is $\frac{3}{4}QR\hat{k}$, where $\hat{k}$ is directed along the polar axis of the spherical coordinate system.** **Hint:** (i) Electrification of the bubble results in repulsive electrostatic forces between like charges on its surface, causing expansion. (ii) For the dipole moment, evaluate $\vec{p} = \int \vec{r}\rho(\vec{r})d\tau$, utilizing spherical symmetry and separation of charges in the hemispheres to simplify the integral and show $\vec{p} = \frac{3}{4}QR\hat{k}$.	15	2017	C
244	**Discuss briefly the features of 'guard rings'. The plates of a capacitor are square-shaped, each of side l. The plates are inclined at an angle α to each other. The smallest distance between the plates is a. Calculate the capacitance when α is small.** **Hint:** Guard rings reduce edge effects by surrounding the main capacitor plates, ensuring a uniform electric field. For capacitance, approximate the inclined plates as parallel with separation $d(x) = a + x\tan\alpha$, where x is the coordinate along one side (0 to l). Use $C = \varepsilon_0 \int_0^l \int_0^l \frac{dxdy}{d(x)}$ and assume small α so $\tan\alpha \approx \alpha$.	15	2017	C
245	**A 0.5 m long cylindrical medium between two conducting plates has uniform charge density of 100 nC/m^3. The axis of the cylindrical medium is along z-axis. The left plate is at $z = 0$ and has a potential of 10 kV and the right plate is grounded. Determine the electric field at axial distance $z = 0.2$ m.** **Hint:** Use Gauss's law in one dimension $\frac{dE}{dz} = \frac{\rho}{\varepsilon_0}$. Integrate E with appropriate boundary conditions given by the potentials at $z = 0$ and $z = 0.5$ m. Relate electric field and potential gradient: $E = -\frac{dV}{dz}$.	15	2018	A
246	**A uniformly magnetized sphere of radius R has magnetization $\vec{M} = M_0\hat{z}$. If the scalar magnetic potentials inside and outside the sphere are given as $\phi_m = \frac{M_0}{3}z,\ r < R$ and $\phi_m = \frac{M_0R^3}{3r^2}\cos\theta,\ r > R$, find the magnetic field inside and outside the sphere.** **Hint:** Use $\vec{B} = -\mu_0\nabla\phi_m$ to find the magnetic field. Inside the sphere, compute the gradient in Cartesian coordinates since $\phi_m \propto z$. Outside, use spherical coordinates for $\phi_m \propto \cos\theta/r^2$, ensuring proper handling of radial and angular components. Verify that $\vec{B}$ is uniform inside and resembles a dipole field outside.	15	2018	A

Continued on next page...

#	Question	Marks	Year	Type
247	**Starting from the expression for the electrostatic potential $\phi(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\int_V \frac{\rho(\vec{r}_0)}{\lvert\vec{r}-\vec{r}_0\rvert}dV_0$, obtain Poisson's equation $\nabla^2\phi = -\frac{\rho}{\varepsilon_0}$.** **Hint:** Apply Laplacian operator ∇^2 to $\phi(\vec{r})$. Use the known identity $\nabla^2\left(\frac{1}{\lvert\vec{r}-\vec{r}_0\rvert}\right) = -4\pi\delta(\vec{r}-\vec{r}_0)$ and simplify. Remember that δ-function property will localize the integral.	10	2019	C
248	**Find the capacitance of two concentric spherical metal shells having radii a and b.** **Hint:** Assume a charge Q on the inner shell (radius a) and $-Q$ on the outer shell (radius b, where $b > a$). Use Gauss's law to find the electric field $E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ in the region $a < r < b$. Integrate E from $r = a$ to $r = b$ to find the potential difference V, then compute $C = \frac{Q}{V}$.	10	2019	C
249	**Two conducting planes, intersecting at right-angles to each other, are kept at a potential ϕ_0. Calculate the potential at a point in space if the total charge on a plane of area α be Q.** **Hint:** Solve Laplace's equation $\nabla^2\phi = 0$ in the region outside the planes, using cylindrical coordinates with the intersection along the z-axis. Apply boundary conditions: $\phi = \phi_0$ on both planes (at $\theta = 0$ and $\theta = \pi/2$). Use the method of images to account for the right-angle geometry, placing image charges to enforce ϕ_0. The charge Q relates to the surface charge density via the electric field near the planes.	15	2019	C
250	**A vertically oriented electric dipole having dipole moment $\vec{p}$ is kept at height h above an infinitely large horizontal conducting plate, which is grounded as shown in the diagram. Calculate the force between the electric dipole and the conducting plate by using method of images.**  **Hint:** Model the grounded plate by placing an image dipole with moment $-\vec{p}$ at height $-h$ below the plate. Compute the interaction energy between the real and image dipoles, considering their separation $2h$ and opposite orientations. The force is the negative gradient of the energy with respect to h. Ensure the dipole orientation is correctly accounted for in the energy expression.	10	2020	C

Continued on next page...

#	Question	Marks	Year	Type
251	**Based on the hysteresis loops for soft iron and steel as shown in the diagram, which material would you prefer to utilise for making transformer cores and why?**  **Hint:** Prefer the material with a smaller hysteresis loop area (soft iron) for transformer cores to minimize energy loss. During AC magnetization cycles, hysteresis loss per cycle is proportional to the loop area—explain how soft iron's smaller loop reduces heat dissipation and improves efficiency.	10	2020	C
252	**Write expressions for divergence and curl of an electrostatic field. From these, obtain Poisson and Laplace equations. Two concentric conducting spherical shells having radii r_1 and r_2 ($r_1 < r_2$) are charged to potentials V_1 and V_2, respectively. What are the electric potential and hence electric field in the space between the shells? Also find the charge on the inner shell.** **Hint:** (i) In electrostatics, $\nabla \times \vec{E} = 0$ and $\nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$, leading to Poisson's and Laplace's equations. (ii) Solve Laplace's equation under spherical symmetry for $\phi(r)$ and obtain $\vec{E}(r)$ between the shells. (iii) Apply Gauss's law to find the charge on the inner shell.	15	2020	C
253	**Given that the electric potential of a system of charges is $V = \frac{12}{r^2} + \frac{1}{r^3}$ volt. Calculate the electric field vector at the Cartesian point $(4, 2, 3)$ m.** **Hint:** Find $\vec{E} = -\nabla V$. Express V as a function of $r = \sqrt{x^2 + y^2 + z^2}$. Compute partial derivatives with respect to x, y, and z to find components of $\vec{E}$ at the given point.	10	2021	A

Continued on next page...

#	Question	Marks	Year	Type
254	**Given an infinite line charge of charge density 2 nC/m parallel to the y-axis and passing through the point $(3, 0, 4)$ m and an infinite sheet of charge of charge density 4 nC/m^2 parallel to the x-y plane and passing through the point $(0, 0, 6)$ m. Calculate the electric field intensity at the point $(10, 10, 10)$ m. Assume free space.** **Hint:** (i) Electric field due to the infinite line charge at $(3, 0, 4)$ with $\lambda = 2\,\text{nC/m}$: $E = \frac{\lambda}{2\pi\varepsilon_0 r}$, where r is the perpendicular distance from the line to the point $(10, 10, 10)$. (ii) Field due to the sheet at $z = 6$ with $\sigma = 4\,\text{nC/m}^2$: $E = \frac{\sigma}{2\varepsilon_0}$, directed along the z-axis (upward or downward based on the point's position). (iii) Determine vector directions using geometry, then apply the superposition principle to sum the fields at $(10, 10, 10)$.	15	2021	A
255	**Consider two point particles of charge q each, separated by a distance d, and travelling at non-relativistic velocity $\vec{v}$. If the line joining the two charges is perpendicular to $\vec{v}$, then write an expression for the magnetic force between the two particles, and illustrate the direction of the force on each particle.** **Hint:** Each charge moving at velocity $\vec{v}$ creates a magnetic field at the other's position: $B = \frac{\mu_0 q v \sin\theta}{4\pi d^2}$, where $\theta = 90^\circ$ since the line joining the charges is perpendicular to $\vec{v}$. Use the Lorentz force $\vec{F} = q\vec{v} \times \vec{B}$ to find the magnetic force on each charge. Determine the direction of $\vec{B}$ and the force using the right-hand rule, noting the field and force directions for each particle.	10	2022	C
256	**Starting from the Laplace's equation in a cylindrical polar coordinate system and using the method of separation of variables, obtain the differential equations for the solutions of r, ϕ and z components of the potential.** **Hint:** Start with Laplace's equation in cylindrical coordinates. Assume $\phi(r, \phi, z) = R(r)\Phi(\phi)Z(z)$ and substitute. Separate variables by dividing through by $R\Phi Z$ and setting each separated term equal to a constant. Derive three ordinary differential equations (ODEs) corresponding to $R(r)$, $\Phi(\phi)$, and $Z(z)$.	15	2022	C
257	**What happens if the primary winding of a transformer is connected to a battery?** **Hint:** A steady DC current produces no changing magnetic flux, so no EMF is induced in the secondary coil. The steady primary current can saturate the magnetic core, causing overheating due to large current and lack of counteracting back EMF. Transformer operation relies on changing flux; hence, DC renders it ineffective and hazardous.	10	2010	C

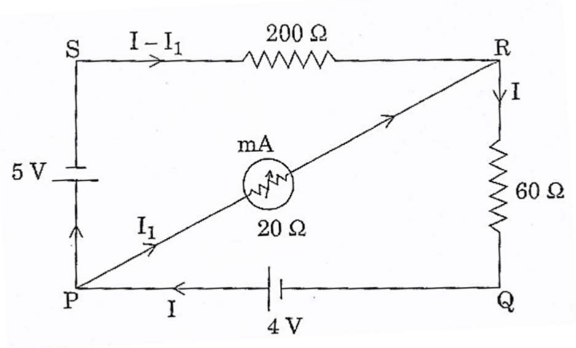
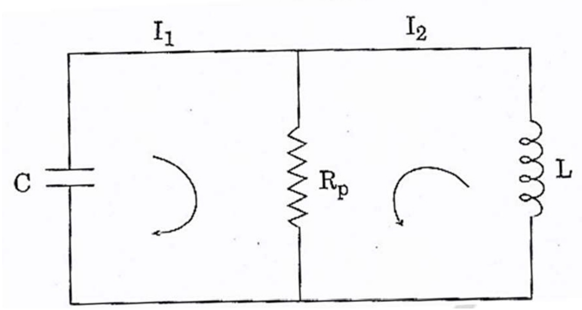
Continued on next page...

#	Question	Marks	Year	Type
258	**Discuss the growth of current when an e.m.f. is suddenly applied to a circuit containing resistance, inductance and capacitance in series. What is the time constant of the circuit?** **Hint:** Apply Kirchhoff's loop rule: $V = L\frac{dI}{dt} + RI + \frac{q}{C}$, where $I = \frac{dq}{dt}$. This yields a second-order differential equation. Solve for $I(t)$ using the characteristic equation, noting the time constant depends on R, L, and C. Consider special cases: underdamped (LC oscillations) or overdamped (RL growth) based on R^2 vs. $4L/C$.	20	2010	C
259	**A series circuit has an inductance of 200 microhenries, a capacitance of 0.0005 microfarad and a resistance of 10 ohms. Find the resonant frequency and quality factor of the circuit.** **Hint:** Resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$. Quality factor $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$. Be careful with unit conversions for microhenry and microfarad.	20	2010	A
260	**Find whether the discharge of a condenser through the inductive circuit is oscillatory when $C = 0.1\mu$F, $L = 10$ mH and $R = 200\Omega$. If it is oscillatory, calculate its frequency.** **Hint:** Compare $\frac{R^2}{4L^2}$ with $\frac{1}{LC}$. If $\frac{R^2}{4L^2} < \frac{1}{LC}$, the system is underdamped and oscillatory. Find angular frequency $\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$ and then frequency $f = \frac{\omega}{2\pi}$.	10	2011	A
261	**The four arms of a Wheatstone bridge have the following resistances: $AB = 100\Omega$, $BC = 10\Omega$, $CD = 5\Omega$, $DA = 60\Omega$. A galvanometer of 15Ω resistance is connected across BD. Calculate the current through the galvanometer when a potential difference of 10 volts is maintained across AC.** **Hint:** Use Kirchhoff's laws to write equations for the Wheatstone bridge branches. Assign branch currents and set up voltage drops. Calculate potentials at points B and D, then use Ohm's law to find the galvanometer current $I_g = \frac{V_B - V_D}{15\Omega}$, considering the 10 V across AC.	10	2011	A
262	**A long solenoid has 220 turns/cm; its diameter is 3.2 cm. Inside the solenoid at its centre, we place a 130-turn closed packed coil of diameter 2.1 cm along its axis. The current in the solenoid is increased from zero to 1.5 amperes at a steady rate over a period of 0.16 second. What is the magnitude of the induced e.m.f. that appears in the central coil when the current in the solenoid is being changed?** **Hint:** Induced emf $\mathcal{E} = -N\frac{d\Phi_B}{dt}$. Use $\Phi_B = BA$, where $B = \mu_0 nI$. Differentiate with respect to time considering dI/dt is constant.	10	2011	A

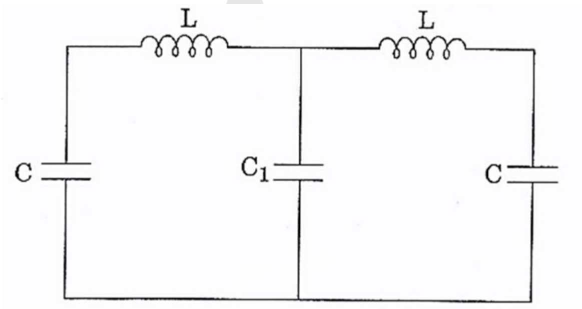
Continued on next page...

#	Question	Marks	Year	Type
263	**An electrical circuit consists of a resistance R, inductance L and capacitance C in series. If a charge is put on the capacitor at some instant, determine the condition that V_C, the voltage across the capacitor, is subsequently oscillatory. Derive an expression for the quality factor Q of the circuit by considering the decay of the oscillation, using the result that the amplitude falls by a factor of e in $\left(\frac{Q}{\pi}\right)$ period.** **Hint:** For oscillations, the circuit must be underdamped: $R^2 < 4L/C$. Derive $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ by analyzing the damped oscillation's energy loss rate. Use the given relation (amplitude decays by e in $\frac{Q}{\pi}$ periods) to connect Q to the decay constant, integrating the energy dissipation over one cycle.	20	2011	C
264	**A resistor $R(= 6.2M\Omega)$ and a capacitor $C(= 2.4\mu$F) are connected in series and a 12 V battery of negligible internal resistance is connected across their combination. (i) What is the capacitive time constant of this circuit? (ii) At what time, after the battery is connected, does the potential difference across the capacitor become 5.6 V?** **Hint:** (i) Time constant $\tau = RC$. (ii) Use charging equation $V(t) = V_0(1 - e^{-t/\tau})$ and solve for t when $V(t) = 5.6$ V.	5+5	2011	A
265	**A resistance R and a lossless capacitor C are connected through a switch. The capacitor is charged to potential V_0, and the switch is closed at $t = 0$. Prove that the energy stored in the capacitor is equal to the energy dissipated in the resistor.** **Hint:** Write the initial energy stored in the capacitor as $\frac{1}{2}CV_0^2$. When the switch closes, the capacitor discharges with current $i(t) = \frac{V_0}{R}e^{-t/RC}$. Show that the energy dissipated in the resistor, found by integrating $i^2(t)R$ from $t = 0$ to ∞, equals $\frac{1}{2}CV_0^2$.	12	2012	C

Continued on next page...

#	Question	Marks	Year	Type
266	**In the circuit diagram shown below, calculate the current passing through the milliammeter.**  💡 **Hint:** Apply Kirchhoff's Voltage Law (KVL) to define mesh currents: I (through the 200Ω and 60Ω branches) and I_1 (through the 20Ω branch including the milliammeter). Write KVL equations for each loop considering the 5 V source, solve for I and I_1, and find the milliammeter current as the difference $I - I_1$.	10	2013	A
267	**Consider the equation for a series RLC circuit and compare this to the parallel resonant circuit shown below: (Diagram: Parallel RLC with capacitor C, resistor R_p, and inductor L in parallel). Calculate the value of R_p if a series RLC circuit and the parallel RLC circuit are to have same equations for the potential of capacitance while they both have the same L, C and Q with Q being the total charge.**  💡 **Hint:** For equivalence, equate the quality factors $Q_p = Q_s$, where $Q_p = R_p\sqrt{\frac{C}{L}}$ for the parallel RLC and $Q_s = \frac{1}{R}\sqrt{\frac{L}{C}}$ for the series RLC, assuming same L, C, and Q (total charge). Set $R_p\sqrt{\frac{C}{L}} = \frac{1}{R}\sqrt{\frac{L}{C}}$ and solve for R_p in terms of R, L, and C.	10	2013	C

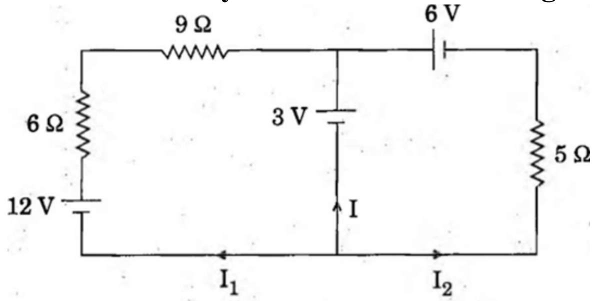
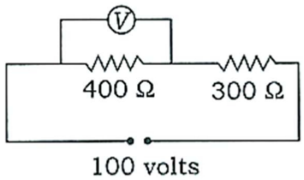
Continued on next page...

#	Question	Marks	Year	Type
268	**A series LCR circuit has resonant frequency ω_0 and a large quality factor Q. Write down in terms of R, ω, ω_0 and Q: (i) its impedance at resonance, (ii) impedance at half-power points, and (iii) approximate forms of its impedance at low and high frequencies.** **Hint:** (i) At resonance, $Z = R$. (ii) At half-power points, $Z = \sqrt{R^2 + (\omega L - 1/\omega C)^2}$ evaluated at $\omega = \omega_0 \pm \Delta\omega$, where $\Delta\omega = \omega_0/(2Q)$. (iii) For low frequencies ($\omega \ll \omega_0$), capacitive reactance dominates ($Z \sim 1/(\omega C)$); for high frequencies ($\omega \gg \omega_0$), inductive reactance dominates ($Z \sim \omega L$).	15	2013	C
269	**Consider the following coupled inductor-capacitor circuit: (Diagram: Two inductors L coupled with capacitors C, C_1.) Calculate the ratio of the frequencies of the anti-symmetric and symmetric modes ω_a/ω_s.** $$\left(\text{Given } k = \frac{1}{LC}, k' = \frac{1}{LC_1}\right)$$  **Hint:** Set up normal mode equations using Kirchhoff's laws for the coupled LC circuit. For symmetric mode, assume voltages across inductors add; for antisymmetric mode, assume they subtract. Derive the coupled differential equations, solve for eigenfrequencies ω_s and ω_a considering the effective capacitance C and C_1, and compute the ratio ω_a/ω_s.	10	2013	C
270	**For initial current conditions $I = I_0$ and $\frac{dI}{dt} = 0$ at $t = 0$, show that the time dependent current in the critical damping case for an LCR circuit is given by $I = I_0\left(1 + \frac{\gamma t}{2}\right)e^{-\gamma t/2}$, where $\gamma = \frac{R}{L}, \omega_0^2 = \frac{1}{LC}, \omega = \sqrt{\omega_0^2 - \frac{\gamma^2}{4}}$ and $\tan\delta = \frac{-\gamma}{2\omega}$.** **Hint:** Start from the differential equation for critical damping: $\frac{d^2I}{dt^2} + \gamma\frac{dI}{dt} + \omega_0^2 I = 0$, where critical damping occurs when $\gamma^2 = 4\omega_0^2$. Solve the equation with roots $\lambda = -\gamma/2$, leading to $I(t) = (A + Bt)e^{-\gamma t/2}$. Apply boundary conditions $I(0) = I_0$ and $\frac{dI}{dt}(0) = 0$ to find A and B, yielding the given $I(t)$.	20	2014	A

Continued on next page...

#	Question	Marks	Year	Type
271	**Using Ampere's Law and continuity equation, show that the divergence of the total current density is zero.** **Hint:** Start from Ampere's Law with Maxwell's correction: $\nabla \times \vec{B} = \mu_0 \left(\vec{J} + \varepsilon_0 \frac{\partial \vec{E}}{\partial t}\right)$. Take divergence of both sides and use $\nabla \cdot (\nabla \times \vec{B}) = 0$. Apply continuity equation $\nabla \cdot \vec{J} + \frac{\partial \rho}{\partial t} = 0$.	15	2014	C
272	**When connected in series, L_1, C_1 have the same resonant frequency as L_2, C_2 also connected in series. Prove that if all these circuit elements are connected in series, the new circuit will have the same resonant frequency as either of the circuits first mentioned.** **Hint:** Resonant frequency $\omega_0 = \frac{1}{\sqrt{LC}}$. Given $\frac{1}{L_1 C_1} = \frac{1}{L_2 C_2}$, the individual circuits have the same ω_0. For the combined series circuit, compute equivalent inductance $L_{eq} = L_1 + L_2$ and capacitance $C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$, then show that $\omega_0 = \frac{1}{\sqrt{L_{eq} C_{eq}}}$ remains the same.	15	2014	C
273	**A series RLC circuit has a resistance of 100Ω and an impedance of 210Ω. If this circuit is connected to an a.c. source with an r.m.s. voltage of 220 V, how much is the average power dissipated in the circuit?** **Hint:** Average power dissipated $P = V_{rms} I_{rms} \cos\phi$, where $\cos\phi = R/Z$. Find $I_{rms} = V_{rms}/Z$ and substitute to get P.	10	2015	A
274	**A series RLC circuit has $R = 2\Omega$. The energy stored in the circuit decreases by 1% per period of oscillation. Its natural undamped frequency is 2 kHz. Determine the values of inductor L and the quality factor.** **Hint:** Energy decay per cycle $\Delta E/E = 2\pi/Q$. Given a 1% decay ($\Delta E/E = 0.01$), solve for Q. Use natural frequency $\omega_0 = 2\pi \times 2 \times 10^3$ rad/s and $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$. From $\omega_0 = \frac{1}{\sqrt{LC}}$, express C in terms of L, then substitute into the Q equation to solve for L.	15	2015	A

Continued on next page...

#	Question	Marks	Year	Type
275	**In the circuit given below, find the values of currents I_1, I_2 and I. (Diagram: Parallel resistors 6Ω and 5Ω with a 9Ω resistor, and 12 V battery with 3 V branch voltage across 6Ω.)**  **Hint:** For the parallel resistors (6Ω and 5Ω), use the given 3 V across the 6Ω resistor to find $I_1 = V/R$. Find I_2 across the 5Ω resistor using the same potential difference. Apply KVL around the outer loop with the 12 V battery, 9Ω resistor, and parallel combination to find total current I. Then, confirm $I = I_1 + I_2$.	15	2015	A
276	**In the circuit diagram shown below, the voltmeter reads 50 volts when it is connected across the 400Ω resistance. Calculate what the same voltmeter will read when connected across the 300Ω resistance. (Diagram: 400Ω and 300Ω resistors connected across 100 V supply.)**  **Hint:** Find current in the series combination first. Knowing total voltage and resistor values, compute voltage drop across 300Ω using Ohm's Law.	10	2016	A
277	**An alternating current varying sinusoidally with a frequency of 50 Hz has an r.m.s. value of 40 A. Find the instantaneous value of the current at 0.00125 second after passing through maximum positive value.** **Hint:** Use $i(t) = I_{max} \sin(\omega t)$ where $I_{max} = \sqrt{2} I_{rms}$. Calculate $\omega = 2\pi f$. Substitute $t = 0.00125$ s into the expression.	10	2016	A
278	**How large an inductance needs to be connected in series with a 120 V, 60 W lightbulb if it is to operate normally when the combination is connected across a 240 V, 60 Hz supply?** **Hint:** Find resistance of bulb $R = \frac{V^2}{P}$. The total voltage (240 V) drops across R and inductive reactance $V_L = \omega L I$, where $\omega = 2\pi f$. Find I from $V_R = 120$ V, then solve for L.	10	2017	A

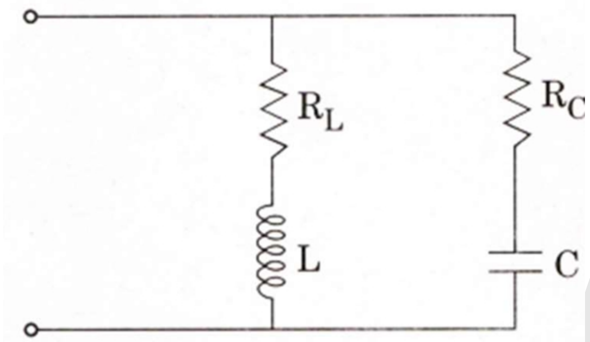
Continued on next page...

#	Question	Marks	Year	Type
279	**When a person carrying something metallic walks through the doorway of a metal detector, it emits a sound. Explain the reason behind it.** **Hint:** A metallic object passing through the detector alters the magnetic flux in the coils, changing the inductance or resonant frequency due to eddy currents or mutual inductance. This shift disrupts the circuit's balance, triggering an alarm via induced EMF—explain how this relates to the detector's operation.	15	2017	C
280	**A 200Ω resistor and a 15μF capacitor are connected in series to 220 V, 50 Hz a.c. supply. Calculate the current in the circuit and the r.m.s. voltage across the resistor and the capacitor. Is the algebraic sum of these voltages more than the supply voltage? If yes, resolve the paradox.** **Hint:** Find reactance $X_C = \frac{1}{\omega C}$. Impedance $Z = \sqrt{R^2 + X_C^2}$. Calculate current $I = V/Z$. Then find voltages $V_R = IR$, $V_C = IX_C$. The algebraic sum $V_R + V_C$ exceeds V because voltages are not added arithmetically but vectorially (phasor sum).	10	2018	A
281	**A current carrying circular wire loop of radius 1.0 cm has a magnetic moment 2.0 mJ/T. Determine the magnetic field at an axial distance of 3.0 cm from the centre of the loop.** **Hint:** Use magnetic field on axis of loop: $B = \frac{\mu_0}{4\pi}\frac{2m}{(r^2+x^2)^{3/2}}$, where m is magnetic moment and x is distance along axis.	10	2018	A
282	**A 12.0 V battery is connected at $t = 0$ to a series combination of a resistor $R = 10.0\Omega$ and inductor $L = 5.0$H. At what rate is energy being stored in the inductor when the current in the circuit is 0.4 A?** **Hint:** Power stored in the inductor is $P = Li\frac{di}{dt}$. Find $\frac{di}{dt}$ from growth equation $i(t) = \frac{V}{R}\left(1 - e^{-Rt/L}\right)$. Alternatively, use $P = V_L i$ where $V_L = V - iR$.	10	2018	A
283	**Two solenoids have 500 and 800 turns of wire and are placed co-axially close to each other. A current of 5.0 A in the first solenoid produces an average flux of 200μWb through its each turn and a flux of 100μWb through each turn of the second solenoid. Find the self-inductance of the first solenoid and the mutual inductance of the solenoids.** **Hint:** Self-inductance $L = \frac{N\Phi}{I}$. Mutual inductance $M = \frac{N_2\Phi_{21}}{I_1}$. Apply directly using given turns and flux linkage per turn.	10	2018	A

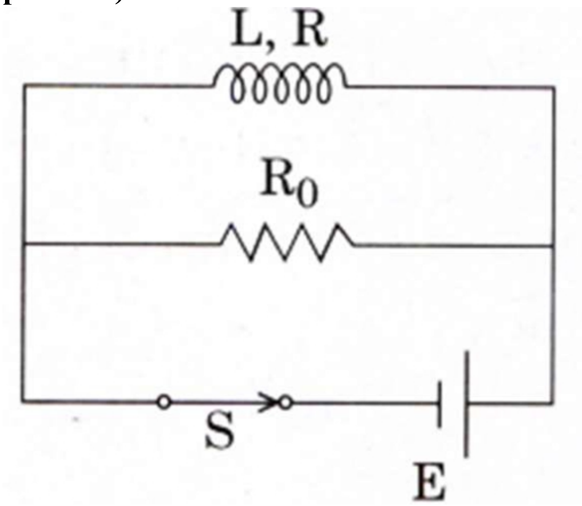
Continued on next page...

#	Question	Marks	Year	Type
284	**Why do we prefer to work with a critically damped ballistic galvanometer in a laboratory? What is external critical damping resistance?** **Hint:** Critically damped galvanometers return to equilibrium fastest without oscillations, ensuring quick and accurate readings by avoiding overshoot. External damping resistance is adjusted to set the damping coefficient $\gamma = \frac{R}{L}$ such that $\gamma^2 = 4\omega_0^2$, balancing response time and stability.	10	2019	C
285	**Three cells are connected in parallel with similar poles connected together with wires having negligible resistance. The emfs of the cells are 2, 1 and 4 volts respectively and the corresponding internal resistances are 4, 3 and 2 ohms. Calculate the current flowing through the 4 V cell.** **Hint:** Apply Kirchhoff's current law for parallel cells. Use $I = \frac{E-V}{r}$ for each cell, where V is the common terminal voltage. Set the net current to zero (no external load) and solve $\sum \frac{E-V}{r} = 0$ to find V, then compute I for the 4V cell.	15	2019	A
286	**Describe the oscillations of electric and magnetic fields in an ideal LC circuit. The applied voltage phasor in a circuit is $(4 + 3i)$ volt and resulting current phasor is $(3 + 4i)$ ampere. Draw the phasor diagram. Determine the impedance of the circuit and indicate whether it is inductive or capacitive in nature. Also find the power dissipation in the circuit.** **Hint:** Describe LC oscillations as energy exchange between inductor's magnetic field and capacitor's electric field. Find impedance $Z = V/I$ by dividing complex numbers $(4+3i)/(3+4i)$. Analyze phase difference to determine inductive or capacitive nature. Power $P = V_{rms} I_{rms} \cos\phi$.	15	2020	C
287	**A 10Ω resistor is connected in series with a capacitor of 1.0μF and a battery with emf 12.0 V. Before the switch is closed at time $t = 0$, the capacitor is uncharged. Calculate the following: (i) The time constant. (ii) What fraction of the final charge is on the plates at the time $t = 46$ seconds? (iii) What fraction of the initial current remains at the time $t = 46$ seconds? Consider that the internal resistance of the battery is zero and neglect the resistance of all the connecting wires.** **Hint:** (i) Time constant $\tau = RC$. (ii) Charge $q(t) = Q_f(1 - e^{-t/\tau})$. (iii) Current $i(t) = i_0 e^{-t/\tau}$. Substitute $t = 46$ seconds to find fractions.	15	2020	A

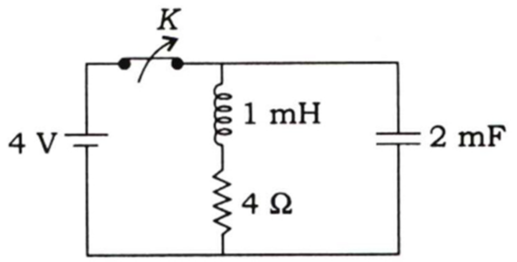
Continued on next page...

#	Question	Marks	Year	Type
288	**A rod of length l is perpendicular to a uniform magnetic field B. The rod revolves at an angular speed ω about an axis passing through one end of the rod and parallel to the magnetic field B. Find the voltage induced across the rod's ends.** **Hint:** Use motional EMF: $V = \int_0^l B\omega r\, dr$. Integrate considering the linear velocity $v = \omega r$ at distance r from the axis to find the induced voltage.	10	2021	C
289	**Consider the two branch parallel circuit shown in the diagram. Determine the resonant frequency of the circuit. (Diagram: Parallel branches with RL and RC components.)**  **Hint:** At resonance in a parallel RL-RC circuit, the total susceptance is zero ($B_{total} = B_L + B_C = 0$). Compute admittances for each branch: $Y_L = \frac{1}{R_L + j\omega L}$, $Y_C = \frac{1}{R_C + \frac{1}{j\omega C}}$. Equate the imaginary parts (susceptances) to zero and solve for the resonant frequency ω, considering L, C, R_L, and R_C.	10	2021	C

Continued on next page...

#	Question	Marks	Year	Type
290	**In the given circuit, $L = 2.0\mu$H, $R = 1.0\Omega$, $R_0 = 2.0\Omega$ and $E = 3.0$V. Find the amount of heat generated in the coil after the switch S is disconnected. (Diagram: Coil and resistor in parallel.)**  **Hint:** Find the initial magnetic energy stored in the inductor $U = \frac{1}{2}LI^2$, where I is found using the equivalent resistance $R_{eq} = \frac{RR_0}{R+R_0}$ and $E = 3.0$ V. After disconnection, the total magnetic energy is fully dissipated as heat in R, assuming coil resistance is negligible.	10	2021	A
291	**A cell of internal resistance 1Ω, 1.5 V e.m.f., and another cell of internal resistance 2Ω, 2 V e.m.f., are connected in parallel across the ends of an external resistance of 5Ω. Find the current in each branch of the circuit.** **Hint:** Apply Kirchhoff's laws for the parallel cells. For each cell, $I = \frac{E-V}{r}$, where V is the common voltage across the 5Ω resistor. Set the total current through the resistor as $I_{total} = I_1 + I_2$, and use $V = I_{total} \times 5$. Solve the system of equations to find V, then compute the current through each cell.	10	2022	A

Continued on next page...

#	Question	Marks	Year	Type
292	**Consider the R-L-C circuit shown here. Calculate the Q-factor of the circuit. Does the circuit have a resonant frequency? Justify your answer.**  **Hint:** For a series RLC circuit, $Q = \frac{1}{R}\sqrt{\frac{L}{C}}$. Resonance occurs when reactances cancel: $\omega L = \frac{1}{\omega C}$, giving $\omega_0 = \frac{1}{\sqrt{LC}}$. Verify that R, L, and C allow for a real ω_0, confirming resonance exists, and justify with the physical behavior of energy oscillation between L and C.	10	2022	A
293	**A wire of length 2 m is perpendicular to $X - Y$ plane. It is moved with a velocity $\vec{V} = (2\hat{i} + 3\hat{j} + \hat{k})$ ms^{-1} through a region of uniform induction $\vec{B} = (\hat{i} + 2\hat{j})$ Wm^{-2}. Compute the potential difference between the ends of the wire.** **Hint:** Use the formula for motional EMF: $V = \vec{v} \times \vec{B} \cdot \vec{l}$. Calculate the cross product of $\vec{v}$ and $\vec{B}$ first, then find the dot product with the length vector of the wire. Direction of wire and fields must be carefully considered.	10	2010	A
294	**Using Maxwell's field equations for a homogeneous non-conducting medium, derive the wave equation for the electric field. Calculate the velocity of EM wave in free space.** **Hint:** Start with Maxwell's curl equations. Take the curl of $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ and use vector identities and other Maxwell equations. Remember that in free space, $\vec{D} = \epsilon_0 \vec{E}$ and $\vec{B} = \mu_0 \vec{H}$. This leads to the wave equation and the velocity $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$.	20	2010	C
295	**Explain the term 'Poynting vector' and state the significance of Poynting theorem.** **Hint:** The Poynting vector $\vec{S} = \vec{E} \times \vec{H}$ represents the power per unit area carried by an electromagnetic wave, indicating the direction of energy flow. The Poynting theorem, $\nabla \cdot \vec{S} + \vec{J} \cdot \vec{E} + \frac{\partial}{\partial t}\left(\frac{1}{2}\epsilon E^2 + \frac{1}{2}\mu H^2\right) = 0$, relates the energy flux to the work done on charges and the rate of energy stored in EM fields—explain its analogy to energy conservation and applications like energy transfer in circuits.	20	2010	C

Continued on next page...

#	Question	Marks	Year	Type
296	**Calculate the skin depth for radio waves in free space of wavelength 3 m in copper, given that electrical conductivity for copper is $6 \times 10^7 \Omega^{-1}$ m^{-1}.** **Hint:** Skin depth δ is given by $\delta = \sqrt{\frac{2}{\mu\sigma\omega}}$, where μ is the permeability, σ is the conductivity, and $\omega = 2\pi f$ with $f = \frac{c}{\lambda}$.	20	2010	A
297	**Consider Maxwell's equation in differential form in media. For $j = \rho = 0$, assume $\epsilon = \epsilon_0 e^{\alpha t}$ and $\mu = \mu_0 e^{\alpha t}$ and show that the relevant wave equation for a plane wave propagating along x-direction is $\frac{\partial^2 E}{\partial x^2} = \mu \frac{\partial^2 D}{\partial t^2} + \mu\alpha \frac{\partial D}{\partial t}$, where $\vec{E} = E\hat{y}$ and $\vec{H} = H\hat{z}$.** **Hint:** Start with Maxwell's curl equations: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ and $\nabla \times \vec{H} = \frac{\partial \vec{D}}{\partial t}$, with $\vec{D} = \epsilon\vec{E}$, $\vec{B} = \mu\vec{H}$, $\epsilon = \epsilon_0 e^{\alpha t}$, and $\mu = \mu_0 e^{\alpha t}$. For a plane wave ($\vec{E} = E\hat{y}$, $\vec{H} = H\hat{z}$), take the curl of the first equation, substitute $\nabla \times \vec{H}$, and account for the time derivatives of ϵ and μ to derive the given wave equation.	10	2011	C
298	**Consider a plane wave travelling along the positive y-direction incident upon a glass of refractive index $n = 1.6$. Find the transmission coefficient.** **Hint:** Use the Fresnel transmission coefficient formula for normal incidence: $T = \frac{2n_1}{n_1+n_2}$, where n_1 and n_2 are refractive indices of initial and final media. Substitute appropriate values for air and glass to compute T.	25	2011	A
299	**Justify which of the four Maxwell's equations imply that there are no magnetic monopoles. How these equations would have been written if they were?** **Hint:** Gauss's law for magnetism ($\nabla \cdot \vec{B} = 0$) implies no magnetic monopoles, as there are no isolated magnetic charges. If magnetic monopoles existed with density ρ_m, this would modify to $\nabla \cdot \vec{B} = \rho_m$, and Faraday's law would include a magnetic current term: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} - \vec{J}_m$, where $\vec{J}_m$ is the magnetic current density—discuss the impact on all Maxwell equations.	15	2011	C
300	**What is a displacement current? Prove that lines of conduction current plus displacement current are continuous.** **Hint:** Displacement current is defined as $\vec{J}_d = \epsilon_0 \frac{\partial \vec{E}}{\partial t}$. Use Ampère-Maxwell law: $\nabla \times \vec{B} = \mu_0 \left(\vec{J} + \epsilon_0 \frac{\partial \vec{E}}{\partial t}\right)$. Apply divergence to both sides and use continuity equation $\nabla \cdot \vec{J} + \frac{\partial \rho}{\partial t} = 0$ to show continuity.	15	2012	C

Continued on next page...

#	Question	Marks	Year	Type
301	**The electric field of a plane e.m. wave travelling along the z-axis is $\vec{E} = (E_{0x}\hat{x} + E_{0y}\hat{y})\sin(\omega t - kz + \phi)$. Determine the magnetic field.** **Hint:** In free space, for a plane EM wave, $\vec{B} = \frac{1}{c}(\hat{k} \times \vec{E})$. Find the cross product of the direction of propagation $\hat{z}$ with the electric field vector and divide by speed of light c.	10	2013	A
302	**(i) Considering an isotropic, linear, non-conducting, non-magnetic and inhomogeneous dielectric medium with $\vec{D} = \epsilon\vec{E} = \epsilon_0 n^2(x, y, z)\vec{E}$, show that the electromagnetic wave equation for the field $\vec{E}$ is given by $\nabla^2\vec{E} + \nabla\left(\frac{1}{n^2}\nabla n^2 \cdot \vec{E}\right) - \mu_0\epsilon_0 n^2\frac{\partial^2\vec{E}}{\partial t^2} = 0$.** **(ii) Write down the scalar equation for E_x from the above equation.** **(iii) Interpret physically the situation if we move from homogeneous to an inhomogeneous medium.** **(iv) Obtain the similar vector equation for the magnetic field $\vec{H}$ in inhomogeneous medium.** **Hint:** (i) Start with Maxwell's equations in an inhomogeneous dielectric ($\vec{D} = \epsilon_0 n^2(x, y, z)\vec{E}$, $\vec{B} = \mu_0\vec{H}$). Take $\nabla \times (\nabla \times \vec{E}) = -\frac{\partial}{\partial t}(\nabla \times \vec{B})$, use $\nabla \times \vec{H} = \frac{\partial\vec{D}}{\partial t}$, and account for $\nabla \cdot \vec{D} = 0$ with varying n. (ii) For E_x, isolate the x-component considering ∇n^2. (iii) In an inhomogeneous medium, ∇n^2 causes wave bending (e.g., refraction). (iv) For $\vec{H}$, apply similar steps starting with $\nabla \times (\nabla \times \vec{H})$, using $\vec{B} = \mu_0\vec{H}$.	15	2013	C
303	**For a uniform wire of length L and radius a having a potential difference V between the ends and a current I along it, calculate the energy per unit time delivered to the wire by Poynting vector.** **Hint:** The Poynting vector $\vec{S} = \vec{E} \times \vec{H}$. Find the electric field inside the wire using $E = \frac{V}{L}$ and magnetic field from Ampère's law $B = \mu_0\frac{I}{2\pi r}$ at radius r. Integrate $\vec{S}$ over the cylindrical surface area to get total power delivered.	10	2013	C

Continued on next page...

#	Question	Marks	Year	Type
304	**Starting from Maxwell's equation, obtain the wave equation for the electric field $\vec{E}$ in free space and appropriate wave equation for the electric field $E_z(x, y, z)\hat{z}$.** **Hint:** Start with Maxwell's equation $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$. Take the curl: $\nabla\times(\nabla\times\vec{E}) = -\frac{\partial}{\partial t}(\nabla\times\vec{B})$, and use $\nabla\times\vec{B} = \mu_0\epsilon_0\frac{\partial \vec{E}}{\partial t}$. Apply the identity $\nabla\times(\nabla\times\vec{E}) = \nabla(\nabla\cdot\vec{E})-\nabla^2\vec{E}$, noting $\nabla\cdot\vec{E} = 0$ in free space, to derive $\nabla^2\vec{E} = \mu_0\epsilon_0\frac{\partial^2\vec{E}}{\partial t^2}$. For $E_z(x, y, z)$, the equation reduces to $\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + \frac{\partial^2 E_z}{\partial z^2} = \mu_0\epsilon_0\frac{\partial^2 E_z}{\partial t^2}$.	10	2014	C
305	**Show that the energy flow due to a plane electromagnetic wave propagating along z-direction in a dielectric medium is given by $\hat{z}\frac{k}{\omega\mu}E_0^2\cos^2(kz - \omega t)$, where $\vec{k}$ and ω are the propagation vector and angular frequency, E_0 is electric field amplitude, μ is the relative permeability of the medium.** **Hint:** Use the Poynting vector $\vec{S} = \vec{E} \times \vec{H}$. For a plane wave along z-direction, $\vec{E} = E_0\cos(kz-\omega t)\hat{x}$, and $\vec{H} = \frac{1}{\mu}(\vec{k}/\omega)\times\vec{E}$, so $\vec{H} = \frac{k}{\omega\mu}E_0\cos(kz - \omega t)\hat{y}$. Compute $\vec{S} = \vec{E} \times \vec{H}$, noting $\hat{x} \times \hat{y} = \hat{z}$, and simplify to match the given expression with $\cos^2(kz-\omega t)$.	10	2014	C
306	**Derive the equation that represents Poynting's theorem. What is its physical significance?** **Hint:** Start with the scalar product of electric field with Ampère-Maxwell equation and magnetic field with Faraday's law. Add the two results to derive the energy conservation relation. Physical significance: it relates the rate of energy loss inside a volume to the energy flux through the surface and work done on charges.	20	2015	C
307	**A radio station transmits electromagnetic waves isotropically with an average power of 200 kW. Determine the average magnitude of the maximum electric field at a distance of 5 km from it.** **Hint:** Power per unit area $S = \frac{P}{4\pi r^2}$. The relation between intensity S and electric field E is $S = \frac{1}{2}\epsilon_0 cE^2$. Solve for E after calculating S at the given distance $r = 5$ km.	15	2015	A

Continued on next page...

#	Question	Marks	Year	Type
308	**A plane electromagnetic wave propagating along $+z$ direction is incident normally on the boundary at $z = 0$ between medium $A(z < 0)$ and medium $B(z > 0)$. Determine the reflection coefficient and transmission coefficient for the wave.** **Hint:** Apply boundary conditions at $z = 0$: tangential components of $\vec{E}$ and $\vec{H}$ are continuous. For normal incidence, use the relations from these conditions to derive the Fresnel formulas: reflection coefficient $r = \frac{n_1 - n_2}{n_1 + n_2}$ and transmission coefficient $t = \frac{2n_1}{n_1 + n_2}$, where n_1 and n_2 are the refractive indices of media A and B (amplitude coefficients). Substitute the appropriate n_1 and n_2 to compute r and t.	20	2015	C
309	**In free space, the electric field of electromagnetic wave is given as $\vec{E}(x, t) = 120\cos(\omega t - kx)\hat{y}$ V/m. Find the average power crossing a circular area of radius one metre in the yz-plane.** **Hint:** Power per unit area is given by the magnitude of the time-averaged Poynting vector: $\langle S \rangle = \frac{1}{2}\epsilon_0 c E_0^2$. Multiply by the area of the circle πr^2 to find total average power crossing the area.	10	2016	A
310	**Write down Maxwell's equations for linear dielectrics and deduce the equation of continuity.** **Hint:** Maxwell's equations in linear media are $\nabla \cdot \vec{D} = \rho_f$, $\nabla \cdot \vec{B} = 0$, $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$, $\nabla \times \vec{H} = \vec{J}_f + \frac{\partial \vec{D}}{\partial t}$. Take divergence of Ampère-Maxwell law and use Gauss's law to derive continuity equation $\nabla \cdot \vec{J}_f + \frac{\partial \rho_f}{\partial t} = 0$.	10	2016	C
311	**State and prove Poynting's theorem.** **Hint:** Start with taking the dot product of $\vec{E}$ with Ampère-Maxwell law and $\vec{H}$ with Faraday's law. Combine and simplify to get $\nabla \cdot \vec{S} + \frac{\partial u}{\partial t} + \vec{J} \cdot \vec{E} = 0$, where $\vec{S}$ is the Poynting vector and u is the electromagnetic energy density. It represents conservation of electromagnetic energy.	20	2016	C
312	**Show that the displacement current between the plates of a parallel-plate capacitor is equal to the conduction current across the conductor.** **Hint:** Use the definition of displacement current $I_d = \epsilon_0 \frac{d\Phi_E}{dt}$, where $\Phi_E = \int \vec{E} \cdot d\vec{A}$ is the electric flux between the plates. Apply the Ampère-Maxwell law $\oint \vec{B} \cdot d\vec{l} = \mu_0(I_c + I_d)$ over a loop enclosing the capacitor. In steady-state alternating conditions, equate the conduction current I_c in the wires to I_d between the plates to maintain continuity of magnetic field lines.	10	2016	C

Continued on next page...

#	Question	Marks	Year	Type
313	**Write down the electromagnetic wave equations in non-conducting dielectric medium. Hence show that the velocity of wave propagation is given by $v = \sqrt{\frac{1}{\epsilon\mu}}$ where the symbols have their usual meanings.** **Hint:** Start with Maxwell's curl equations: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ and $\nabla \times \vec{B} = \mu\epsilon\frac{\partial \vec{E}}{\partial t}$ (with $\vec{J} = 0$). Take the curl of the first equation, use the second, and apply $\nabla \times (\nabla \times \vec{E}) = \nabla(\nabla \cdot \vec{E}) - \nabla^2\vec{E}$ (with $\nabla \cdot \vec{E} = 0$) to derive $\nabla^2\vec{E} = \mu\epsilon\frac{\partial^2 \vec{E}}{\partial t^2}$. Similarly for $\vec{B}$, and identify the wave speed as $v = \frac{1}{\sqrt{\epsilon\mu}}$.	10	2017	C
314	**Write down the physical significance of Maxwell's equations and explain the concept of displacement current by using a proper example.** **Hint:** Discuss how Maxwell's equations (Gauss's laws, Faraday's law, Ampère-Maxwell law) unify electric and magnetic fields, enable electromagnetic wave propagation, and account for time-varying fields. For displacement current, use the example of a charging parallel-plate capacitor: conduction current I_c in the wires is continuous with displacement current $I_d = \epsilon\frac{dE}{dt}A$ between plates, ensuring magnetic field consistency via Ampère-Maxwell law.	10	2017	C
315	**Define a plane electromagnetic wave. A plane polarized wave is incident on the interface between two dielectric media. Obtain expressions for the amplitudes of the reflected and transmitted waves when the incident wave is polarized with its electric field $\vec{B}$ vector perpendicular to the plane of incidence. Discuss the phase relationships of the reflected and transmitted waves with respect to the incident wave.** **Hint:** Define a plane EM wave as a transverse wave with $\vec{E}$ and $\vec{B}$ perpendicular to each other and the propagation direction. For s-polarization (electric field perpendicular to the plane of incidence), use boundary conditions: continuity of tangential $\vec{E}$ and $\vec{H}$ at the interface. Derive reflection coefficient $r = \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t}$ and transmission coefficient $t = \frac{2n_1 \cos\theta_i}{n_1 \cos\theta_i + n_2 \cos\theta_t}$. Discuss phase: reflected wave has a π phase shift if $n_1 > n_2$, while transmitted wave is in phase unless total internal reflection occurs.	20	2018	C

Continued on next page...

#	Question	Marks	Year	Type
316	**Write down Maxwell's equations in integral form. Explain the significance of each of these equations.** 💡 **Hint:** List Maxwell's equations using integral forms: Gauss's laws for $\vec{E}$ and $\vec{B}$, Faraday's law, and Ampère-Maxwell law. Explain how each relates to physical quantities: electric flux, magnetic flux, induced emf, and displacement currents respectively.	5	2018	C
317	**A parallel plate capacitor has plate area** $= 4.0$ **cm^2 and plate separation** $= 2.0$ **mm. An a.c. voltage** $V = 20\sin(5\times 10^3 t)$ **volts is applied across the plates. If the dielectric constant of the medium between the plates is** $\epsilon_r = 2.0$**, calculate the displacement current.** 💡 **Hint:** Displacement current $I_d = \epsilon_0 \epsilon_r A \frac{dE}{dt}$, where $E = \frac{V}{d}$. Differentiate V with respect to t, substitute values, and calculate I_d. Be cautious with units conversion (cm^2 to m^2).	5	2018	A
318	**Find the values of** $\vec{E}$ **and** $\vec{H}$ **on the surface of a wire carrying a current. By computing the Poynting vector, show that it represents a flow of energy into the wire.** 💡 **Hint:** Find $\vec{E}$ using Ohm's law $\vec{E} = \frac{V}{L}\hat{z}$ along the wire (with $V = IR$). Use Ampère's law $\oint \vec{B}\cdot d\vec{l} = \mu_0 I_{\text{enc}}$ to get $\vec{H} = \frac{I}{2\pi r}\hat{\phi}$ on the surface ($r = a$). Calculate the Poynting vector $\vec{S} = \vec{E}\times\vec{H}$, noting $\hat{z}\times\hat{\phi} = -\hat{r}$, and integrate over the cylindrical surface to show inward energy flow ($\vec{S}$ directed radially inward).	20	2019	C
319	**For the electric field given by** $\vec{E} = E_0 e^{i\omega t}$**, show that the conduction current is in phase with the electric field, while the displacement current leads the electric field by** $\frac{\pi}{2}$ **radians. Also, show that the displacement current in a good conductor is negligible compared to the conduction current at any frequency lower than the optical frequencies** ($f < 10^{15}$ **Hz).** 💡 **Hint:** Conduction current density $\vec{J}_c = \sigma\vec{E}$ is in phase with $\vec{E}$. Displacement current $\vec{J}_d = \epsilon\frac{\partial \vec{E}}{\partial t}$ introduces a phase shift of $\frac{\pi}{2}$. At low frequencies, $\sigma \gg \omega\epsilon$, so conduction dominates.	10	2020	C
320	**For free space show that electromagnetic (EM) wave is transverse in nature. Show that for free space, the total outward flux of EM energy through surface** S **bounding volume** V **is equal to the rate of loss of EM energy from the volume** V**.** 💡 **Hint:** Use Maxwell's equations in free space: $\nabla\cdot\vec{E} = 0$ and $\nabla\cdot\vec{B} = 0$ imply $\vec{E}$ and $\vec{B}$ are perpendicular to $\vec{k}$ (propagation direction) for a plane wave. Apply the Poynting theorem $\oint \vec{S}\cdot d\vec{A} = -\frac{d}{dt}\int u\,dV$, where $\vec{S} = \frac{1}{\mu_0}\vec{E}\times\vec{B}$ and $u = \frac{1}{2}(\epsilon_0 E^2 + \frac{1}{\mu_0}B^2)$, to show the outward flux equals the rate of energy loss from volume V.	20	2020	A

Continued on next page...

#	Question	Marks	Year	Type
321	**Write Maxwell's equations in free space in both differential and integral forms. Obtain wave equations and show that electromagnetic waves can travel in free space with a speed of light. Can one get the wave equations from the integral form of the Maxwell's equations?** **Hint:** Write Maxwell's equations in free space in differential form ($\nabla \cdot \vec{E} = 0$, $\nabla \cdot \vec{B} = 0$, $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$, $\nabla \times \vec{B} = \mu_0 \epsilon_0 \frac{\partial \vec{E}}{\partial t}$) and integral form using Gauss's and Stokes' theorems. Derive the wave equations by taking the curl of $\nabla \times \vec{E}$, substituting $\nabla \times \vec{B}$, and applying $\nabla \times (\nabla \times \vec{E}) = -\nabla^2 \vec{E}$. This yields $\nabla^2 \vec{E} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{E}}{\partial t^2}$ and similarly for $\vec{B}$. Identify the wave speed $v = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = c$. Using Stokes' theorem, the differential forms can be obtained from the integral forms, thus wave equations can also be indirectly inferred.	15	2020	C
322	**A region 1, $z < 0$, has a dielectric material with $\epsilon_r = 3.2$ and a region 2, $z > 0$, has a dielectric material with $\epsilon_r = 2.0$. Let the displacement vector in the region 1 be, $\vec{D}_1 = -30\hat{x} + 50\hat{y} + 70\hat{z}$ nCm^{-2}. Assume the interface charge density is zero. Find in the region 2, the $\vec{D}_2$ and $\vec{P}_2$, where $\vec{P}_2$ is the electric polarization vector in the region 2.** **Hint:** Apply boundary conditions: normal component of $\vec{D}$ is continuous (since surface charge density is zero), so $D_{1z} = D_{2z}$, and tangential $E_{1x} = E_{2x}$, $E_{1y} = E_{2y}$. Given $\vec{D}_1 = -30\hat{x} + 50\hat{y} + 70\hat{z}$ nC/m^2, convert units, and use $\vec{D} = \epsilon_0 \epsilon_r \vec{E}$ to find $\vec{E}_2$ in region 2 ($\epsilon_{r2} = 2.0$). Then compute $\vec{P}_2 = (\epsilon_{r2} - 1)\epsilon_0 \vec{E}_2$.	20	2021	A
323	**Calculate the skin depth of electromagnetic waves of 1 MHz incident on a good conductor having $\sigma = 5.8 \times 10^7$ Sm^{-1}. Assume that inside the conductor $\mu = \mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}.** **Hint:** Skin depth $\delta = \sqrt{\frac{2}{\mu \sigma \omega}}$, where $\omega = 2\pi f$. Substitute $f = 1$ MHz, σ and μ values properly and compute δ.	10	2021	A

Continued on next page...

#	Question	Marks	Year	Type
324	**Write down Maxwell's equations in a non-conducting medium with constant permeability and susceptibility ($\rho = j = 0$). Show that $\vec{E}$ and $\vec{B}$ each satisfies the wave equation, and find an expression for the wave velocity. Write down the plane wave solutions for $\vec{E}$ and $\vec{B}$, and show how $\vec{E}$ and $\vec{B}$ are related.** **Hint:** Derive the wave equations for $\vec{E}$ and $\vec{B}$ fields in a non-conducting medium ($\vec{J} = 0$, $\rho = 0$) using Maxwell's equations. Show that $\nabla^2\vec{E} = \mu\epsilon\frac{\partial^2\vec{E}}{\partial t^2}$ and similarly for $\vec{B}$, identifying wave speed $v = \frac{1}{\sqrt{\mu\epsilon}}$. Write plane wave solutions (e.g., $\vec{E} = E_0\cos(kz - \omega t)\hat{x}$, $\vec{B} = B_0\cos(kz - \omega t)\hat{y}$) and explain that $\vec{E}$ and $\vec{B}$ are perpendicular and related by $B_0 = \frac{E_0}{v}$.	15	2022	C
325	**A metal guitar string with a length of 70 cm vibrates at its fundamental frequency of 246.94 Hz in a uniform magnetic field of 10 T oriented perpendicular to the plane of vibration of the string. Assume a sinusoidal form for the amplitude of the vibrational mode, and a maximum displacement of 3 mm at the centre of the string. What is the maximum e.m.f. generated across the length of the guitar string, and at what point in time in the string's motion does that occur? What would be the e.m.f. for the same guitar string vibrating at its second harmonic frequency? Briefly explain.** **Hint:** Induced e.m.f. is $e = Blv_{\text{max}}$. Construct the displacement function $y(x,t) = A\sin(kx)\sin(\omega t)$ with $A = 3$ mm, $l = 70$ cm, and $\omega = 2\pi \times 246.94$ Hz. Differentiate to find $v_{\text{max}} = A\omega\cos(kx)$ (maximum at $x = l/2$). For the second harmonic, use $f_2 = 2 \times 246.94$ Hz, adjust k (nodes at $l/4, 3l/4$), and recompute v_{max}.	20	2022	A
326	**A current sheet having $\vec{K} = 9.0\hat{a}_y$ A m^{-1} is located at $z = 0$. The interface is between the region 1, $z < 0$, $\mu_r = 4$, and region 2, $z > 0$, $\mu_r = 3$. Given that $\vec{H}_2 = 14.5\hat{a}_x + 8.0\hat{a}_z$ A m^{-1}. Find $\vec{H}_1$ and $\vec{B}_1$.** **Hint:** Apply boundary conditions at $z = 0$: tangential $H_{2x} - H_{1x} = K_y$ (discontinuity due to $\vec{K} = 9.0\hat{a}_y$), and normal $B_{1z} = B_{2z}$ (continuous). Given $\vec{H}_2 = 14.5\hat{a}_x + 8.0\hat{a}_z$, use $\mu_{r1} = 4$, $\mu_{r2} = 3$, and $\vec{B} = \mu_0\mu_r\vec{H}$ to solve for $\vec{H}_1$ and $\vec{B}_1$.	15	2022	A

Continued on next page...

#	Question	Marks	Year	Type
327	**In deriving the Rayleigh-Jeans law, we count the number of modes dn corresponding to a wave number k for a photon gas in a cubical box. Consider a cubical container of volume V containing such gas in equilibrium. Calculate the differential number of allowable normal modes of frequency ω.** **Hint:** The number of modes between k and $k + dk$ corresponds to the volume of a spherical shell in k-space: $dn = \frac{V}{(2\pi)^3} 4\pi k^2 dk$. For photons, account for two independent polarization states (multiply by 2). Use the dispersion relation $k = \frac{\omega}{c}$ to express dk in terms of $d\omega$. Thus, derive $dn \propto \omega^2 d\omega$ for the photon gas.	20	2011	C
328	**State and explain Stefan-Boltzmann Law. Show that** $\log P = \log K + 4 \log R$**, where** P **is the power emitted by black body and** R **is the resistance of the black body,** K **is a constant.** **Hint:** Stefan-Boltzmann law states $P = \sigma AT^4$, where P is the radiated power, A is the surface area, and T is the absolute temperature. Express the area A in terms of the resistance R by relating $R = \rho\frac{l}{a}$ (with a as cross-sectional area) and the filament's surface area $A \sim 2\pi rl$. Using $a = \pi r^2$, eliminate r and find $A \propto \sqrt{R}$. Substitute into the Stefan-Boltzmann law, define K appropriately, and take logarithms to obtain $\log P = \log K + 4 \log R$.	10	2014	C
329	**Two spheres A and B having same temperature** T **are kept in the surroundings of temperature** T_0**. Consider** $T > T_0$**. The spheres are made of same material but have different radii** r_A **and** r_B**. Using Stefan-Boltzmann distribution, determine which of these will lose heat by radiation faster.** **Hint:** Power radiated by a sphere is $P = \sigma A(T^4 - T_0^4)$, where $A = 4\pi r^2$. Since the material and temperatures are identical, compare powers based on surface areas alone: the sphere with the larger radius (and hence larger surface area) will lose heat faster by radiation.	10	2015	C
330	**Using Planck's radiation law, deduce Wien's displacement law. How does this law enable one to estimate the surface temperature of the Sun or a star?** **Hint:** Start with Planck's spectral radiance $u(\lambda, T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT}-1}$. Differentiate with respect to λ, set the derivative to zero to find λ_{max}, and use substitution $x = \frac{hc}{\lambda kT}$ to solve $5(1 - e^{-x}) = x$, yielding $\lambda_{\text{max}} T = \frac{hc}{kx} \approx 2.897 \times 10^{-3}$ m·K (Wien's law). Use this to estimate a star's surface temperature from its observed peak emission wavelength.	15	2015	C

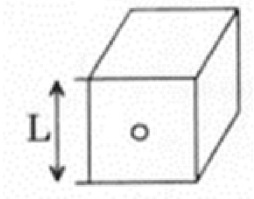
Continued on next page...

#	Question	Marks	Year	Type
331	**What are the characteristic features of Rayleigh scattering? A very thin monochromatic beam of light is incident on a particle. Suggest a simple experimental method to ascertain whether the scattering by the particle is of Rayleigh type.** **Hint:** Rayleigh scattering occurs when the particle size is much smaller than the wavelength, with scattering intensity proportional to $\frac{1}{\lambda^4}$, favoring shorter wavelengths (e.g., blue light scatters more). Experimentally, use a monochromatic laser beam and observe angular distribution or use a polarizer to confirm polarization properties of scattered light, validating Rayleigh's λ^{-4} dependence.	20	2015	C
332	**The spectral energy curve of the moon shows maxima at 470 nm and 14 μm. What inference can you draw from this data? Also calculate the energy density and radiation pressure in both cases. Given, Wien's constant $b = 2.892 \times 10^{-3}$ m K, Stefan's constant $\sigma = 5.67 \times 10^{-8}$ J m^{-2} s^{-1} K^{-4} and speed of light $c = 3 \times 10^8$ m s^{-1}.** **Hint:** Use Wien's law $\lambda_{\text{max}} T = b$ to infer surface temperatures corresponding to the two peaks. Then calculate energy density $u = \frac{4\sigma}{c} T^4$ and radiation pressure $P = \frac{u}{3}$ separately for each temperature.	10	2016	A
333	**Briefly explain Planck's law of blackbody radiation. Show that Planck's law reduces to Wien's law and Rayleigh-Jeans law at lower and higher wavelength limits respectively.** **Hint:** Planck's law for spectral radiance is $u(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$. For $\lambda \to 0$ (short wavelengths), $e^{hc/\lambda kT} \gg 1$ leads to Wien's exponential law. For $\lambda \to \infty$ (long wavelengths), expand $e^{hc/\lambda kT}$ and obtain Rayleigh-Jeans classical result $u(\lambda, T) \propto \frac{1}{\lambda^4}$.	20	2016	C
334	**Write down Stefan-Boltzmann law of radiation and derive it from Planck's law of radiation. An aluminium foil of relative emittance 0.1 is placed between two concentric spheres (assumed perfectly black) at temperatures 300 K and 200 K respectively. Find the temperature of the foil once the steady state is reached.** **Hint:** Stefan-Boltzmann law states $P = \sigma A T^4$. Derive it by integrating Planck's law over all wavelengths and using the relation for energy flux density. For the foil at steady state, balance radiation power absorbed and emitted: $\epsilon\sigma(T_1^4 - T_f^4) = \epsilon\sigma(T_f^4 - T_2^4)$, where $\epsilon = 0.1$, and solve for T_f.	15	2017	A

Continued on next page...

#	Question	Marks	Year	Type
335	**What are the limitations of Rayleigh-Jeans law in explaining the spectrum of radiations from a blackbody? Explain how these limitations were overcome in Planck's radiation law. Deduce Wien's displacement law from Planck's radiation law.** **Hint:** Rayleigh-Jeans law predicts infinite energy at high frequencies, leading to the ultraviolet catastrophe. Planck resolved this by proposing quantized energy exchanges $E = nh\nu$. To deduce Wien's displacement law, differentiate Planck's distribution with respect to λ, set to zero, and solve the transcendental equation to obtain $\lambda_{\text{max}}T =$ constant.	20	2018	C
336	**Discuss in brief the ultraviolet catastrophe. How did Planck solve this problem?** **Hint:** The ultraviolet catastrophe refers to the failure of classical physics (Rayleigh-Jeans law) to predict finite energy density at short wavelengths, leading to infinite predicted radiation. Planck solved this by proposing that electromagnetic energy is quantized, emitted and absorbed in discrete packets $E = nh\nu$, resulting in Planck's radiation formula which accurately matches experimental blackbody spectra.	10	2019	C
337	**Briefly outline the theory of scattering of electromagnetic radiation by a bound electron and hence derive the conditions for Rayleigh scattering. How can you explain the blue of the sky?** **Hint:** Model the bound electron as a driven damped harmonic oscillator under the influence of the incident EM wave's electric field. The induced dipole radiates, and the scattering intensity becomes proportional to $\frac{1}{\lambda^4}$ when the particle size is much smaller than the wavelength (Rayleigh scattering condition). Blue light ($\lambda \approx$ 400–500 nm) scatters more strongly than red light, explaining the blue color of the sky.	20	2019	C

Continued on next page...

#	Question	Marks	Year	Type
338	**A historic failure of Classical Physics is its inability to describe the electromagnetic radiation emitted from a black body. Consider a simple model for an ideal black body consisting of a cubic cavity of side L with a small hole on one side. Assuming the classical equipartition of energy, derive an expression for the average energy per unit volume and unit frequency range. In what way does this result deviate from actual observation? What is this law called? Repeat the calculations now using quantum idea to obtain an expression that properly accounts for the observed spectral distribution. Find the temperature dependence of the total power emitted from the hole.**  **Hint:** Apply classical equipartition of energy to a cubic cavity: the number of modes between k and $k + dk$ is proportional to $\frac{Vk^2dk}{2\pi^2}$. Using $k = \frac{2\pi\nu}{c}$, and assigning energy kT per mode, derive $u(\nu) = \frac{8\pi\nu^2kT}{c^3}$ (Rayleigh-Jeans law), predicting infinite energy at high frequencies (ultraviolet catastrophe). Using Planck's hypothesis that energy is quantized as $E = h\nu$, derive $u(\nu) = \frac{8\pi h\nu^3}{c^3}\frac{1}{e^{h\nu/kT}-1}$, yielding finite energy density and leading to total emitted power proportional to T^4 (Stefan-Boltzmann law).	20	2020	C
339	**The spectral composition of solar radiation is similar to that of a black body radiator whose maximum emission corresponds to the wavelength 0.48 μm. Find the mass lost by the Sun every second due to radiation. Evaluate the time interval during which the mass of the Sun reduces by 1 per cent. Given: Stefan-Boltzmann constant = 5.669×10^{-8} W m^{-2} K^{-4}, radius of the Sun = 6.957×10^8 m, surface temperature of the Sun = 5772 K and mass of the Sun = 1.9885×10^{30} kg.** **Hint:** Total power radiated by the Sun is $P = \sigma AT^4$, where $A = 4\pi R^2$ is the surface area. The corresponding energy loss per second equals mass loss rate using Einstein's relation $P = \frac{dm}{dt}c^2$. Calculate $\frac{dm}{dt}$ and then estimate the time needed for 1% reduction of the Sun's mass.	20	2021	A

Continued on next page...

#	Question	Marks	Year	Type
340	**Find the energy stored in a system of four charges $Q_1 = 1$ nC, $Q_2 = 2$ nC, $Q_3 = 3$ nC and $Q_4 = 4$ nC placed at the cartesian coordinates $R_1(1,1)$, $R_2(2,1)$, $R_3(1,4)$ and $R_4(2,2)$ respectively. Assume free space.** **Hint:** The total electrostatic energy is given by $U = \frac{1}{4\pi\epsilon_0}\sum_{i<j}\frac{Q_iQ_j}{r_{ij}}$. Calculate all pairwise distances r_{ij} using the distance formula between two points, then sum the interaction energies over all distinct pairs.	10	2023	A
341	**Derive the expression for the inductance per unit length of two long parallel wires each of radius a, separated by distance d from their axes and carrying equal and opposite current I.** **Hint:** Use Ampère's law to find the magnetic field between the wires: $B(r) = \frac{\mu_0 I}{2\pi r}$, valid for $a \leq r \leq d-a$. Compute the magnetic energy density $\frac{B^2}{2\mu_0}$, integrate over the cylindrical region outside each wire, and find total energy per unit length. The inductance per unit length is $L' = \frac{2U}{I^2 l}$, yielding $L' \approx \frac{\mu_0}{\pi}\ln\left(\frac{d}{a}\right)$ assuming $d \gg a$.	10	2023	A
342	**Show that Continuity equation is embedded in Maxwell's equations.** **Hint:** Take divergence of Ampère-Maxwell equation: $\nabla\times\vec{B} = \mu_0\left(\vec{J}+\epsilon_0\frac{\partial\vec{E}}{\partial t}\right)$. Using the identity $\nabla\cdot(\nabla\times\vec{B}) = 0$, derive $\nabla\cdot\vec{J}+\frac{\partial\rho}{\partial t} = 0$, representing the local conservation of electric charge.	10	2023	C
343	**Two inductors having inductances L_1 and L_2 are connected in parallel. The inductors have a mutual inductance M. Derive the expression for the effective inductance. Assume the inductors have negligible resistances.** **Hint:** For two parallel inductors with mutual coupling M, write voltage equations: $V = L_1\frac{di_1}{dt}+M\frac{di_2}{dt}$ and $V = L_2\frac{di_2}{dt}+M\frac{di_1}{dt}$. Express total current $I = i_1+i_2$, solve for $\frac{dI}{dt}$, and define $V = L_{\text{eff}}\frac{dI}{dt}$. The effective inductance becomes $L_{\text{eff}} = \frac{L_1L_2-M^2}{L_1+L_2\mp 2M}$, with sign depending on current directions.	15	2023	C

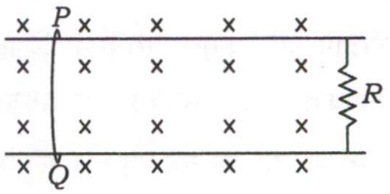
Continued on next page...

#	Question	Marks	Year	Type
344	**Consider the interaction of an electromagnetic wave at the interface of two dielectric media. If electric field $\vec{E}$ is parallel to the plane of incidence, obtain Fresnel's equations and Brewster's law of polarization.** **Hint:** For p-polarization (electric field parallel to plane of incidence), apply boundary conditions: continuity of tangential $\vec{E}$ and $\vec{H}$. Derive Fresnel's equations: reflection coefficient $r_p = \frac{n_2 \cos\theta_i - n_1 \cos\theta_t}{n_2 \cos\theta_i + n_1 \cos\theta_t}$, and transmission coefficient accordingly. Setting $r_p = 0$ gives Brewster's angle condition $\tan\theta_B = \frac{n_2}{n_1}$.	20	2023	C
345	**In spherical coordinates, $V = -25$ V on a conductor at $r = 2$ cm and $V = 150$ V on another conductor at $r = 35$ cm. The space between the conductors is a dielectric for which $\epsilon_r = 3.12$. Find the surface charge densities on the conductors.** **Hint:** Solve Laplace's equation $\nabla^2 V = 0$ in spherical coordinates (since $\rho = 0$ between conductors) with boundary conditions $V(r = 0.02\,\text{m}) = -25\,\text{V}$, $V(r = 0.35\,\text{m}) = 150\,\text{V}$. Assume $V(r) = A + \frac{B}{r}$, determine A and B using the conditions, and use $\epsilon = \epsilon_r\epsilon_0 = 3.12\epsilon_0$. Surface charge density $\sigma = \epsilon E_r$, where $E_r = -\frac{dV}{dr}$ evaluated at each conductor.	10	2024	A
346	**Find the magnetic field strength (H) at the centre of a square current loop of side L.** **Hint:** Apply the Biot-Savart law $d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l}\times\hat{r}}{r^2}$. For one side of the square, integrate along length L with $r = L/2$ (distance to center), yielding dB component perpendicular to the plane. Due to symmetry, sum contributions from all four sides, resulting in $B = \frac{2\sqrt{2}\mu_0 I}{\pi L}$ at the center.	10	2024	A
347	**The magnitude of the average electric field normally present in the Earth's atmosphere just above the surface of the Earth is about 150 N/C, directed radially inward, toward the centre of the Earth. What is the total net surface charge carried by the Earth? Assume the Earth to be a conductor. (The radius of the Earth is 6.37×10^6 m)** **Hint:** Use Gauss's law: total charge $Q = \epsilon_0 E \times 4\pi R^2$, where E is electric field and R is Earth's radius. Calculate Q carefully with correct units.	10	2024	A

Continued on next page...

#	Question	Marks	Year	Type
348	**Using Maxwell's equations, obtain Poisson's equation and Laplace's equation. The region** $-\frac{\pi}{2} < \frac{z}{z_0} < \frac{\pi}{2}$ **has a charge density** $\rho = 10^{-8} \cos\left(\frac{z}{z_0}\right)$ **C/m**^{3}**. Elsewhere the charge density is zero. Find the electric potential** V **and electric field** $\vec{E}$ **from the Poisson's equation.** **Hint:** Derive Poisson's equation from Gauss's law $\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0}$, and since $\vec{E} = -\nabla V$, obtain $\nabla^2 V = -\frac{\rho}{\epsilon_0}$. For Laplace's equation, set $\rho = 0$. For the given $\rho = 10^{-8} \cos\left(\frac{z}{z_0}\right)$ C/m^3 in $-\frac{\pi}{2} z_0 < z < \frac{\pi}{2} z_0$, assume $V(z) = A \cos\left(\frac{z}{z_0}\right) + B \sin\left(\frac{z}{z_0}\right) + C$ (due to symmetry), apply boundary conditions at $z = \pm\frac{\pi}{2} z_0$, and find $\vec{E} = -\frac{dV}{dz}\hat{z}$.	15	2024	C
349	**Consider a uniformly magnetized sphere of radius** a **and magnetization** $\vec{M} = M_0 \hat{z}$ **surrounded by a vacuum region. Obtain an expression for scalar magnetic potential for** $r < a$**.** **Hint:** Use the magnetic scalar potential approach $\vec{H} = -\nabla \phi_m$. Inside the sphere, $\nabla^2 \phi_m = \nabla \cdot \vec{M}$. For $\vec{M} = M_0 \hat{z}$, compute $\nabla \cdot \vec{M} = 0$ (uniform magnetization), but include bound surface currents at $r = a$. In spherical coordinates with axial symmetry, assume $\phi_m(r, \theta) = \sum_l (A_l r^l + B_l r^{-l-1}) P_l(\cos\theta)$, and solve for $r < a$ using $\phi_m \propto r \cos\theta$ (dipole-like term).	10	2024	A
350	**Define internal energy** U**, Helmholtz's function** F**, enthalpy** H**, Gibbs' potential** G **and hence obtain the four Maxwell's thermodynamic relations.** **Hint:** Define internal energy $U(S, V)$, Helmholtz function $F(T, V) = U - TS$, enthalpy $H(S, P) = U + PV$, and Gibbs potential $G(T, P) = U + PV - TS$. Write their differentials: $dU = TdS - PdV$, $dF = -SdT - PdV$, $dH = TdS + VdP$, $dG = -SdT + VdP$. Equate mixed partial derivatives (e.g., $\frac{\partial}{\partial V}\left(\frac{\partial F}{\partial T}\right)_V = \frac{\partial}{\partial T}\left(\frac{\partial F}{\partial V}\right)_T$) to obtain Maxwell's relations: $\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$, $\left(\frac{\partial T}{\partial P}\right)_S = \left(\frac{\partial V}{\partial S}\right)_P$, $\left(\frac{\partial S}{\partial V}\right)_T = \left(\frac{\partial P}{\partial T}\right)_V$, $\left(\frac{\partial S}{\partial P}\right)_T = -\left(\frac{\partial V}{\partial T}\right)_P$.	20	2024	C

Continued on next page...

#	Question	Marks	Year	Type
351	**Consider a situation shown in the figure below. The wire PQ has mass m, resistance r and can slide on the smooth, horizontal parallel rails separated by a distance l. The resistance of rails is negligible. A uniform magnetic field B exists in the rectangular region and a resistance R connects the rails outside the field region. At $t = 0$, the wire PQ is pushed towards right with a speed V_0. Find (i) the current in the loop at an instant when the speed of the wire PQ is V and (ii) the acceleration of the wire at this instant.**  **Hint:** Induced emf $\mathcal{E} = BlV$. Current $I = \frac{\mathcal{E}}{r+R}$. Magnetic force on wire $F = IlB$. Apply Newton's second law: $a = \frac{F}{m} = \frac{B^2l^2V}{m(r+R)}$.	20	2024	A
352	**Obtain the general boundary conditions for fields E, B, D and H at a boundary between two different media carrying charge density σ or a current density $\vec{K}$.** **Hint:** Apply Maxwell's equations in integral form over a small pillbox and a small loop straddling the boundary. Derive conditions: (i) Normal component of $\vec{D}$ has discontinuity equal to σ; (ii) Tangential component of $\vec{E}$ is continuous; (iii) Normal component of $\vec{B}$ is continuous; (iv) Tangential component of $\vec{H}$ has discontinuity equal to surface current density $\vec{K}$.	15	2024	C
353	**A uniform plane wave with $\vec{E} = E_x\hat{a}_x$ propagates in a lossless medium ($\epsilon_r = 4$, $\mu_r = 1$, $\sigma = 0$) in the z-direction. Assume that E_x is sinusoidal with a frequency 100 MHz and has a maximum value of 10^{-4} V/m at $t = 0$ and $z = \frac{1}{8}$ m. (i) Write the expression for instantaneous E for any t and z. (ii) Write the expression for instantaneous H. (iii) Determine the locations where E_x is a positive maximum when $t = 10^{-8}$ s.** **Hint:** The wave form is $E_x(z,t) = E_0\cos(\omega t - \beta z + \phi)$, with $E_0 = 10^{-4}$ V/m, $\omega = 2\pi \times 100 \times 10^6$ rad/s, and phase velocity $v = \frac{c}{\sqrt{\epsilon_r}} = 1.5 \times 10^8$ m/s, giving $\beta = \frac{\omega}{v}$. Adjust the phase ϕ using the initial condition at $t = 0$, $z = 1/8$ m. Then compute $H_y = \frac{E_x}{\eta}$ with $\eta = \sqrt{\frac{\mu_0}{\epsilon_r\epsilon_0}}$. For E_x to be a positive maximum at $t = 10^{-8}$ s, solve $\omega t - \beta z + \phi = 2n\pi$.	20	2024	A

Thermodynamics

Key: C = Conceptual, A = Applied

#	Question	Marks	Year	Type
354	**1kmol of an ideal gas is compressed isothermally at 400 K from 100 kPa to 1000 kPa in a piston and cylinder arrangement. Calculate the entropy change of the gas, the entropy change of the surroundings and the total entropy change resulting from the process if the process is mechanically reversible and the surroundings consist of a heat reservoir at 400 K.** 💡 **Hint:** Use the isothermal entropy change formula $\Delta S = nR\ln\left(\frac{V_f}{V_i}\right)$ or equivalently $\Delta S = -nR\ln\left(\frac{P_f}{P_i}\right)$ for isothermal reversible compression. For surroundings, consider $Q = -W$ and use $\Delta S = \frac{Q}{T}$. Add system and surroundings entropy for total.	10	2010	A
355	**Calculate the change in pressure for a change in freezing point of water equal to -0.91°C. Given, the increase of specific volume when 1 gm of water freezes into ice is 0.091 cc/gm and latent heat of fusion of ice is 80 cal/gm.** 💡 **Hint:** Apply the Clausius-Clapeyron equation $\frac{dP}{dT} = \frac{L}{T\Delta v}$, where $T = 273\,\mathrm{K}$ is the normal freezing point of water. Convert the latent heat $L = 80\,\mathrm{cal/g}$ to $334400\,\mathrm{J/kg}$ and $\Delta v = 0.091\,\mathrm{cm^3/g}$ to $9.1\times10^{-5}\,\mathrm{m^3/kg}$. Use $\Delta T = -0.91\,^{\circ}\mathrm{C}$ to compute $\Delta P \approx \frac{dP}{dT}\Delta T$.	10	2010	A
356	**Consider one mole of an ideal gas whose pressure changes with volume as $P = \alpha/V$, where α is a constant. If it is expanded such that its volume increases m times, find the change in internal energy, work done by the gas and heat capacity of the gas.** 💡 **Hint:** For an ideal gas with $P = \alpha/V$, apply the first law $\Delta U = Q - W$. Compute work via $W = \int_{V_i}^{mV_i} \frac{\alpha}{V}\,dV = \alpha\ln m$. Use the ideal gas law $PV = nRT$ to relate $\alpha = nRT$, and determine the temperature change. Internal energy is $\Delta U = nC_V\Delta T$. For heat capacity, compute $C = \frac{dQ}{dT}$ using the process path and ideal gas relations.	25	2010	C

Continued on next page...

#	Question	Marks	Year	Type
357	**Derive an expression for the thermal efficiency of a reversible heat engine operating on the Diesel cycle with an ideal gas of constant heat capacity as the working medium.** 💡 **Hint:** Analyze the Diesel cycle: isentropic compression, isobaric heat addition, isentropic expansion, and isochoric heat rejection. For an ideal gas, compute heat input $Q_{\text{in}} = nC_P(T_3 - T_2)$ during the isobaric stage and heat output $Q_{\text{out}} = nC_V(T_4 - T_1)$. Use isentropic relations and the compression ratio $r = V_1/V_2$ and cutoff ratio $r_c = V_3/V_2$ to express temperatures. Derive efficiency as $\eta = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$.	25	2010	C
☐ 358	**What led van der Waals to modify the ideal gas equation? Using the concepts of critical temperature T_c, pressure P_c and volume V_c, show that the critical constant for a real gas is $8/3$.** 💡 **Hint:** Van der Waals modified the ideal gas law to include intermolecular attractions (via a) and finite molecular volume (via b), yielding $\left(P + \frac{a}{V^2}\right)(V - b) = RT$. At the critical point, solve $\left(\frac{\partial P}{\partial V}\right)_T = 0$ and $\left(\frac{\partial^2 P}{\partial V^2}\right)_T = 0$. Substitute $V = V_c$, $P = P_c$, $T = T_c$ into the van der Waals equation and critical conditions to derive $\frac{P_c V_c}{RT_c} = \frac{3}{8}$.	15	2011	C
359	**Find out the expressions for van der Waals constants a and b.** 💡 **Hint:** Use the van der Waals equation at the critical point. Apply $\left(\frac{\partial P}{\partial V}\right)_T = 0$ and $\left(\frac{\partial^2 P}{\partial V^2}\right)_T = 0$ at $T = T_c$ to derive $a = \frac{27R^2T_c^2}{64P_c}$ and $b = \frac{RT_c}{8P_c}$.	20	2011	C
360	**Calculate the values of van der Waals constants a and b for oxygen with $T_c = 154.2$ K, $P_c = 49.7$ atmosphere and $R = 80$ cm^3 atmosphere/K.** 💡 **Hint:** Use the van der Waals relations $a = \frac{27R^2T_c^2}{64P_c}$ and $b = \frac{RT_c}{8P_c}$. Given $R = 80\,\text{cm}^3\text{atm}/(\text{K}\cdot\text{mol})$, $T_c = 154.2\,\text{K}$, and $P_c = 49.7\,\text{atm}$, ensure consistent units. Convert outputs to appropriate units (e.g., a in $\text{cm}^6\text{atm}/\text{mol}^2$, b in cm^3/mol) by checking dimensional consistency.	20	2011	A
361	**Show that the Helmholtz free energy of a system never increases in any isothermal-isochoric transformation.** 💡 **Hint:** For an isothermal-isochoric process, the Helmholtz free energy is $F = U - TS$. With $dT = 0$ and $dV = 0$, the differential is $dF = dU - TdS$. From the first law, $dU = dQ - dW$, and at constant volume, $dW = PdV = 0$, so $dU = dQ$. The second law gives $dQ \leq TdS$, thus $dF = dQ - TdS \leq 0$, proving F never increases in a spontaneous process.	12	2012	C

Continued on next page...

#	Question	Marks	Year	Type
362	**Establish the relation** $\left(\frac{\partial T}{\partial V}\right)_P = -\left(\frac{\partial P}{\partial S}\right)_T$ **and then derive** $\left(\frac{\partial C_P}{\partial P}\right)_T = -T\left(\frac{\partial^2 V}{\partial T^2}\right)_P$. **Hence show that the heat capacity** C_P **of an ideal gas is independent of pressure** P. **Hint:** Start with the Gibbs potential to derive the Maxwell relation $\left(\frac{\partial T}{\partial V}\right)_P = -\left(\frac{\partial P}{\partial S}\right)_T$. For the second part, use $C_P = \left(\frac{\partial H}{\partial T}\right)_P$, where $H = U + PV$. Compute $\left(\frac{\partial C_P}{\partial P}\right)_T$ using $\left(\frac{\partial V}{\partial T}\right)_P$, leading to $\left(\frac{\partial C_P}{\partial P}\right)_T = -T\left(\frac{\partial^2 V}{\partial T^2}\right)_P$. For an ideal gas, $V = \frac{nRT}{P}$, so $\left(\frac{\partial^2 V}{\partial T^2}\right)_P = 0$, implying C_P is pressure-independent.	20	2012	C
363	**The Einstein theory of specific heat of solids gives the expression** $C_V = \frac{3Nk_B x^2 e^x}{(e^x-1)^2}$, **where** $x = \frac{\theta_E}{T}$ **with** θ_E **as the Einstein temperature.** (i) Mention Einstein's assumptions in deriving it. Also obtain low- and high-temperature limiting expressions for it. (ii) Give schematic plot of $\frac{C_V}{3Nk_B}$ versus $\frac{T}{\theta_E}$ and comment on the validity of expressions in (i) in comparison with experiments. **Hint:** Einstein assumed that each atom in a solid acts as an independent 3D quantum harmonic oscillator with a single characteristic frequency, leading to quantized energy levels. For part (i), derive the high-temperature limit by expanding $e^x \approx 1 + x$ for small $x = \frac{\theta_E}{T}$, yielding $C_V \approx 3Nk_B$ (Dulong–Petit law). For the low-temperature limit, when $T \ll \theta_E$, the term $e^x \gg 1$, so $C_V \approx 3Nk_B\left(\frac{\theta_E}{T}\right)^2 e^{-\theta_E/T}$. For part (ii), plot $\frac{C_V}{3Nk_B}$ versus $\frac{T}{\theta_E}$: it rises from near zero at low $\frac{T}{\theta_E}$ to approach 1 at high $\frac{T}{\theta_E}$. The Einstein model matches experiments at high temperatures but underestimates C_V at low temperatures, where experiments show $C_V \propto T^3$. The Debye model corrects this by accounting for a distribution of vibrational frequencies.	15	2012	C
364	**A thermally insulated ideal gas is compressed quasi-statically from an initial state with volume** V_0 **and pressure** P_0 **to a final state of volume** V_f **and pressure** P_f. **Show that the work done on the gas in the process is given by** $W = \frac{C_V}{R}(P_f V_f - P_0 V_0)$, **where** C_V **and** R **have their standard meanings.** **Hint:** Use the first law of thermodynamics $\Delta U = Q - W$. Since the gas is thermally insulated, $Q = 0$, so $\Delta U = -W$. For an ideal gas, $\Delta U = nC_V\Delta T$. Use the ideal gas law $PV = nRT$ to eliminate T, and integrate accordingly to get the expression for work.	10	2013	C

Continued on next page...

#	Question	Marks	Year	Type
365	**In a tungsten filament lamp, thermionic emission takes place at 1.2×10^3 K. Calculate the ratio of spontaneous emission to stimulated emission for non-degenerate energy levels. Interpret your result physically. Take $\lambda = 550$ nm, $k_B = 1.38 \times 10^{-23}$ J K^{-1}, $h = 6.67 \times 10^{-34}$ J s and $c = 3 \times 10^8$ m s^{-1}.** **Hint:** The ratio of spontaneous to stimulated emission is $\frac{A_{21}}{B_{21}\rho(\nu)} = e^{h\nu/k_BT} - 1$. Calculate $\nu = \frac{c}{\lambda}$ with $\lambda = 550\,\text{nm}$, then compute $\frac{h\nu}{k_BT}$ using $T = 1.2 \times 10^3\,\text{K}$. A large ratio indicates that spontaneous emission dominates at optical frequencies due to the high energy of photons relative to thermal energy.	10	2013	A
366	**The vapour pressure, in mm of Hg, of a substance in solid state is given by the relation $\ln p = 23.03 - \frac{3754}{T}$, where T is in Kelvin. The vapour pressure, in mm of Hg, of the substance in liquid state is given by $\ln p = 19.49 - \frac{3063}{T}$. Calculate (i) the coordinates of the triple point, and (ii) the latent heat of vaporisation at the triple point. Take Gas constant $R = 8.314$ J mol^{-1} K^{-1}.** **Hint:** At the triple point, both phases coexist, so equate the two expressions: $\ln p_{\text{solid}} = \ln p_{\text{liquid}}$ to find T. Then use Clausius–Clapeyron equation: $L = RT^2\left(\frac{d(\ln p)}{dT}\right)$ using the slope of the liquid line at the triple point to calculate latent heat.	15	2013	A
367	**In Leh, temperature of ice on a cold winter night is measured as -20°C. Calculate the change in entropy when 1 kg of ice is converted into steam at 100°C. Given: specific heat capacity of ice is 500 cal kg^{-1} K^{-1}, latent heat of ice is 3.36×10^5 J kg^{-1}, latent heat of steam is 2.26×10^6 J kg^{-1} and 1 J = 4.2 cal.** **Hint:** Compute the entropy change in four steps: (1) heat 1 kg of ice from 253 K to 273 K using $C_{\text{ice}} = 500\,\text{cal}/(\text{kg}\cdot\text{K}) = 2100\,\text{J}/(\text{kg}\cdot\text{K})$, with $\Delta S = \int_{253}^{273}\frac{mC_{\text{ice}}dT}{T}$; (2) melt ice at 273 K using $L_{\text{ice}} = 3.36 \times 10^5\,\text{J/kg}$, with $\Delta S = \frac{mL_{\text{ice}}}{T}$; (3) heat water from 273 K to 373 K using $C_{\text{water}} = 4200\,\text{J}/(\text{kg}\cdot\text{K})$, with $\Delta S = \int_{273}^{373}\frac{mC_{\text{water}}dT}{T}$; (4) vaporize water at 373 K using $L_{\text{steam}} = 2.26 \times 10^6\,\text{J/kg}$, with $\Delta S = \frac{mL_{\text{steam}}}{T}$. Sum all contributions in SI units.	15	2013	A
368	**Define Enthalpy and show that it remains constant in a throttling process.** **Hint:** Enthalpy is defined as $H = U + PV$. In throttling (Joule–Thomson process), there is no heat exchange or work done other than pressure-volume work. Apply steady-flow energy equation under adiabatic conditions with no shaft work: $h_1 = h_2$, showing enthalpy remains constant.	10	2014	C

Continued on next page...

#	Question	Marks	Year	Type
369	**In deriving radiation laws, we consider a cubical container of volume V containing a photon gas in equilibrium. Calculate the differential number of allowed normal modes of frequency ω.** **Hint:** Use the idea of electromagnetic standing waves in a cube of side L. The number of modes between ω and $\omega + d\omega$ is given by $g(\omega)d\omega = \frac{V\omega^2}{\pi^2 c^3} d\omega$. This is derived using density of states in 3D spherical k-space.	10	2014	C
370	**One kg of water at 20°C is converted into ice at -10°C at constant pressure. Heat capacity of water is $4,200$ J/kg·K and that of ice is $2,100$ J/kg·K. Heat of fusion of ice at 0°C is 335×10^3 J/kg. Calculate the total change in entropy of the system.** **Hint:** Break into three steps: (1) cool water from 20°C to 0°C, (2) freeze at 0°C, (3) cool ice from 0°C to −10°C. Use $\Delta S = \int \frac{CdT}{T}$ or $\Delta S = \frac{Q}{T}$ accordingly. Sum entropy changes to get total.	15	2014	A
371	**Consider a system of free gas particles having f degrees of freedom. Use equipartition theorem to establish the relation $f = \frac{2}{\left(\frac{C_P}{C_V} - 1\right)}$, where C_P and C_V are molar specific heats at constant pressure and constant volume respectively. Obtain the values of $\frac{C_P}{C_V}$ for diatomic and triatomic gases.** **Hint:** Equipartition theorem states each quadratic degree of freedom contributes $\frac{1}{2}kT$ to energy. For f degrees of freedom, $C_V = \frac{f}{2}R$, and $C_P = C_V + R$. Use these to derive $\frac{C_P}{C_V}$ and solve for f. Typical values: $f = 5$ (diatomic), $f = 6$ (triatomic linear), $f = 6+$ (nonlinear triatomic).	15	2014	C
372	**Explain the four thermodynamic relations of Maxwell. Using the same, obtain the Clausius–Clapeyron equation $\frac{dP}{dT} = \frac{L}{T(V_2 - V_1)}$.** **Hint:** Start from thermodynamic potentials (U, H, F, G) and derive Maxwell's relations using their total differentials. For Clausius–Clapeyron, equate chemical potentials (μ) across coexisting phases: $dG = VdP - SdT \Rightarrow \frac{dP}{dT} = \frac{\Delta S}{\Delta V} = \frac{L}{T(V_2 - V_1)}$.	15	2014	C

Continued on next page...

#	Question	Marks	Year	Type
373	**A Van der Waals gas undergoes Joule–Kelvin expansion with a pressure drop of 50 atm. If its initial temperature is 300 K, determine its final temperature. (Given Van der Waals constant $a = 0.136$ Pa m^6 mol^{-1}, $b = 36.5 \times 10^{-6}$ m^3 mol^{-1}, $C_P = 30$ J K^{-1} mol^{-1}, $R = 8.3$ J K^{-1} mol^{-1}).** 💡 **Hint:** For a van der Waals gas, the Joule-Thomson coefficient is $\mu = \left(\frac{\partial T}{\partial P}\right)_H = \frac{1}{C_P}\left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]$. Use the van der Waals equation $\left(P + \frac{a}{V^2}\right)(V - b) = RT$ to compute $\left(\frac{\partial V}{\partial T}\right)_P = \frac{R}{P - \frac{a}{V^2} + \frac{2a(V-b)}{V^3}}$. Evaluate at initial $T = 300\,\text{K}$, P, and V (solved from the equation of state). Estimate $\Delta T = \mu \Delta P$ with $\Delta P = -50\,\text{atm}$, ensuring consistent SI units.	10	2015	A
374	**The vapour pressure of an organic substance is 50×10^3 Pa at 40°C. Its normal boiling point is 80°C. If the substance in vapour phase can be treated like an ideal gas, find the latent heat of vaporization of the substance.** 💡 **Hint:** Use Clausius–Clapeyron in logarithmic form: $\ln\left(\frac{P_2}{P_1}\right) = -\frac{L}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$. Convert temperatures to Kelvin and solve for L.	15	2015	A
375	**For a Van der Waals gas, write down the equation of state. Determine the coefficient of critical expansion β.** 💡 **Hint:** The van der Waals equation is $\left(P + \frac{a}{V^2}\right)(V - b) = RT$. Use definition of $\beta = \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$ and differentiate the equation of state with respect to T at constant P to derive β.	15	2015	C
376	**m gram of water at temperature T_1 is isobarically and adiabatically mixed with an equal mass of water at temperature T_2. Show that the change in entropy is given by $\Delta S = 2mC_P \ln\left(\frac{T_{\text{av}}}{T_{\text{geo}}}\right)$, where $T_{\text{av}} = \frac{T_1+T_2}{2}$ and $T_{\text{geo}} = \sqrt{T_1 T_2}$.** 💡 **Hint:** For isobaric and adiabatic mixing of two equal masses of water, the final temperature is the arithmetic mean $T_{\text{av}} = \frac{T_1+T_2}{2}$ due to energy conservation under adiabatic conditions. Compute the entropy change for each mass: $\Delta S_1 = mC_P \ln\left(\frac{T_{\text{av}}}{T_1}\right)$, $\Delta S_2 = mC_P \ln\left(\frac{T_{\text{av}}}{T_2}\right)$. Sum them to get $\Delta S = mC_P \ln\left(\frac{T_{\text{av}}^2}{T_1 T_2}\right) = 2mC_P \ln\left(\frac{T_{\text{av}}}{\sqrt{T_1 T_2}}\right)$, where $T_{\text{geo}} = \sqrt{T_1 T_2}$.	10	2016	C

Continued on next page...

#	Question	Marks	Year	Type
377	**Write down van der Waals' equation of state for n moles of a gas and calculate the temperature at which 5 moles of the gas at 5 atm pressure will occupy a volume of 20 litres.** **Given, $R = 8.31 \times 10^7$ erg mol^{-1} K^{-1}, $a = 1.34 \times 10^{12}$ dyne cm^4 mol^{-2}, $b = 31.2$ cm^3 mol^{-1} and 1 atm = 1.013×10^6 dyne cm^{-2}.** **Hint:** The van der Waals equation for n moles is $\left(P + \frac{an^2}{V^2}\right)(V - nb) = nRT$. For $n = 5\,\text{mol}$, $P = 5\,\text{atm} = 5.065 \times 10^6\,\text{dyne/cm}^2$, $V = 20\,\text{L} = 20 \times 10^3\,\text{cm}^3$, $a = 1.34 \times 10^{12}\,\text{dynecm}^4/\text{mol}^2$, $b = 31.2\,\text{cm}^3/\text{mol}$, and $R = 8.31 \times 10^7\,\text{erg}/(\text{mol} \cdot \text{K})$, compute the left-hand side: $\frac{an^2}{V^2}$, $V - nb$, and solve for $T = \frac{\left(P+\frac{an^2}{V^2}\right)(V-nb)}{nR}$. Ensure all units are consistent before calculation.	10	2016	A
378	**A student is working in a physics laboratory, which is at temperature 27°C, on a sonometer to study formation of stationary waves. The cross-sectional area of the sonometer wire is 0.85×10^{-6} m^2 and a tension of 20 N is applied on it. If the rigid supports are 1.2 m apart and the temperature of the wire drops by 7°C, calculate the (i) final tension and (ii) fundamental frequency of vibration of the wire. Take, coefficient of linear expansion and isothermal Young's modulus as 1.5×10^{-5} K^{-1} and 2.0×10^{11} N m^{-2} respectively.** **Hint:** For a temperature drop of $\Delta T = -7^\circ$C, compute the thermal strain using $\Delta L/L = \alpha \Delta T$, with $\alpha = 1.5 \times 10^{-5}\,\text{K}^{-1}$. Use Young's modulus $Y = \frac{F/A}{\Delta L/L}$ to find the new tension F, where $A = 0.85 \times 10^{-6}\,\text{m}^2$, $Y = 2.0 \times 10^{11}\,\text{N/m}^2$. For the fundamental frequency, use $f = \frac{1}{2L}\sqrt{\frac{F}{\mu}}$, where $L = 1.2\,\text{m}$, and $\mu = \rho A$ requires the wire's density (assume a typical value, e.g., steel $\rho \approx 7800\,\text{kg/m}^3$, or note if provided). Ensure SI units throughout.	10	2016	A

Continued on next page...

#	Question	Marks	Year	Type
379	**What do you understand by the term 'phase transition'? Using Clausius–Clapeyron equation, show that for first-order phase transitions, vapour pressure decreases exponentially with temperature. You can assume that the vapour behaves like an ideal gas and latent heat remains constant with temperature.** **Hint:** A first-order phase transition involves discontinuous changes in entropy and volume. For the Clausius-Clapeyron equation, use $\frac{dP}{dT} = \frac{L}{T\Delta V}$. Assuming the vapor is an ideal gas, $\Delta V \approx V_{\text{gas}} = \frac{RT}{P}$, so $\frac{dP}{dT} = \frac{LP}{RT^2}$. Integrate $\frac{d\ln P}{dT} = \frac{L}{RT^2}$ to get $\ln P = -\frac{L}{RT} + \text{const}$, implying $P \propto e^{-L/(RT)}$, showing vapor pressure decreases exponentially with increasing $1/T$ (or decreasing T).	15	2016	C
380	**1 litre of hydrogen at 127°C and 10^6 dynes/cm^2 pressure expands isothermally until its volume is doubled and then expands adiabatically until its volume is redoubled. Calculate the resulting pressure.** ($\gamma = 1.42$) **Hint:** First use the isothermal law: $PV = \text{const}$ for doubling volume. Then apply adiabatic relation $PV^\gamma = \text{const}$ for the next doubling. Chain both to find final pressure.	10	2017	A
381	**Derive Clausius–Clapeyron equation. How does it explain the effect of pressure on melting point of solids and boiling point of liquids?** **Hint:** Start from $dG = VdP - SdT$ for two-phase equilibrium and equate $dG_1 = dG_2$. This leads to $\frac{dP}{dT} = \frac{L}{T\Delta V}$. A positive ΔV (as in liquids to gas) implies boiling point increases with pressure; negative ΔV (solid to liquid) implies melting point decreases with pressure.	10	2017	C
382	**Calculate the critical temperature for helium, given the values for critical constants, $a = 6.15 \times 10^{-5}$, $b = 9.95 \times 10^{-4}$, where the unit of pressure is atm and the sample is kept at NTP.** **Hint:** For a van der Waals gas, the critical temperature is $T_c = \frac{8a}{27Rb}$. Given $a = 6.15\times10^{-5}$ (units unclear, assume atm-related), $b = 9.95 \times 10^{-4}$ (units unclear, assume volume-related), and assuming standard $R = 0.0821\,\text{L atm}/(\text{mol}\cdot\text{K})$, convert a and b to consistent units (e.g., a in L^{2}atm/mol^2, b in L/mol). At NTP ($P = 1$ atm, $T = 273$ K), compute T_c, ensuring dimensional consistency.□□	10	2017	A

Continued on next page...

#	Question	Marks	Year	Type
383	**A reversible engine converts $1/6$ of the heat input into work. When the temperature of the sink is reduced by $62°$C, its efficiency is doubled. Find the temperatures of source and sink.** **Hint:** Use efficiency of Carnot engine: $\eta = 1 - \frac{T_C}{T_H}$. Set up two equations for the two cases and solve them simultaneously.	10	2017	A
384	**One mole of a gas obeys the following equation of state: $\left(P + \frac{a}{v^2}\right)(v - b) = RT$, where v is the molar volume and a, b are constants. Show that internal energy of the gas increases as the volume increases, with the temperature remaining constant.** **Hint:** Use thermodynamic identity $\left(\frac{\partial U}{\partial V}\right)_T = T\left(\frac{\partial P}{\partial T}\right)_V - P$. Differentiate the equation of state with respect to T and substitute to show positive derivative.	10	2018	C
385	**At $4°$C temperature, the density of water is found to be maximum. Prove that heat capacity at the constant pressure (C_P) is equal to the heat capacity at constant volume (C_V) for water at $4°$C.** **Hint:** Use relation $C_P - C_V = \frac{TV\beta^2}{\kappa_T}$, where β is thermal expansion and κ_T compressibility. At $4°$C, $\beta = 0$ since density is maximum $\Rightarrow C_P = C_V$.	10	2018	C
386	**If the temperature variation of heat capacity is known, how do you calculate the change of entropy during an isochoric process? According to Debye's theory of specific heat of a solid, the molar heat capacity of diamond crystal at constant volume varies with temperature (T) as follows: $c_v = \frac{12}{5}\pi^4 R\left(\frac{T}{\theta}\right)^3$, where R is the molar gas constant $= 8.315$ J/mol·K and $\theta = 2230$ K for diamond. Calculate the change in entropy of diamond of 0.36 g mass when it is heated at constant volume from 0 K to 300 K.** **Hint:** For an isochoric process with temperature-dependent molar heat capacity $c_v(T)$, the entropy change is given by $\Delta S = n\int_{T_1}^{T_2} \frac{c_v(T)}{T}\, dT$, where n is the number of moles. Substitute $c_v(T) = \frac{12}{5}\pi^4 R\left(\frac{T}{\theta}\right)^3$ to obtain $\Delta S = n\frac{12}{5}\pi^4 R\theta^{-3}\int_0^{300} T^2\, dT$. Evaluate the integral $\int_0^{300} T^2\, dT$ analytically. Convert the molar entropy to the entropy for 0.36 g of diamond using the molar mass of carbon (12 g/mol). Note that integrating from 0 K is an approximation valid in Debye's model, as the entropy of a perfect crystal at 0 K is zero per the third law of thermodynamics.	20	2018	A

Continued on next page...

#	Question	Marks	Year	Type
387	**The pressure on 100 g of solid copper is increased quasi-statically and isothermally at 0°C from 0 to 0.5×10^8 Pa. Assuming the density and isothermal compressibility to remain at constant values of 8.96 g/cm^3 and 7.16×10^{-12} Pa^{-1}, respectively, calculate the work done. Comment on the sign and magnitude of work.** **Hint:** For isothermal compression, the work done is $W = -\int_{P_1}^{P_2} V(P)\, dP$. Given constant isothermal compressibility κ, the volume varies as $V = V_0[1 - \kappa(P - P_1)]$. Substitute into the integral and evaluate from $P_1 = 0$ to $P_2 = 0.5 \times 10^8$ Pa, using the initial volume from the given mass and density. The negative work reflects compression, consistent with the system's volume reduction.	15	2018	A
388	**What are the conditions for the change in temperature of a van der Waals gas passing through a porous plug? Prove that the ideal gas passing through the porous plug does not show any change in temperature.** **Hint:** For the Joule–Thomson effect, the coefficient is $\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H = \frac{1}{C_P}\left[T\left(\frac{\partial V}{\partial T}\right)_P - V\right]$. For an ideal gas, use $PV = nRT$ to show $\mu_{JT} = 0$, implying no temperature change. For a van der Waals gas, compute $\left(\frac{\partial V}{\partial T}\right)_P$ using the equation of state and determine conditions where μ_{JT} is positive, negative, or zero, referencing the inversion temperature.	10	2019	C
389	**What is Gibbs' phase rule? Find the values of degrees of freedom when: (i) only the liquid CO_2 is in equilibrium with the gaseous CO_2, (ii) water is in the vapour-liquid saturation region, (iii) water is in a single-phase region, (iv) water is at the triple point.** **Hint:** Gibbs phase rule: $F = C - P + 2$. For pure substances, $C = 1$. Evaluate F for different phases: $P = 2$ for coexistence, $P = 1$ for single phase, $P = 3$ for triple point.	15	2019	A
	Continued on next page...			

#	Question	Marks	Year	Type
390	**Einstein's molar specific heat capacity of a solid is given by $C_V = 3R\left(\frac{\theta_E}{T}\right)^2 \frac{e^{\theta_E/T}}{(e^{\theta_E/T}-1)^2}$, where $\theta_E = \frac{\hbar\omega}{k_B}$. Obtain the expressions for the cases: (i) when $T \gg \theta_E$, (ii) when $T \ll \theta_E$. What is the discrepancy of Einstein model to explain the variation of specific heat capacities of solids with the temperature? The molar specific heat capacity of a solid at constant volume is 2.77 J K^{-1} at 36.8 K. Determine the Debye temperature of the solid.** **Hint:** For $T \gg \theta_E$, apply a Taylor expansion to the exponential terms in $C_V = 3R\left(\frac{\theta_E}{T}\right)^2 \frac{e^{\theta_E/T}}{(e^{\theta_E/T}-1)^2}$ to show $C_V \approx 3R$. For $T \ll \theta_E$, approximate the denominator to derive $C_V \approx 3R\left(\frac{\theta_E}{T}\right)^2 e^{-\theta_E/T}$. The Einstein model assumes a single oscillator frequency, unlike the Debye model's frequency distribution, leading to discrepancies at low temperatures. To find θ_E, solve $C_V = 2.77\,\mathrm{J\,K^{-1}mol^{-1}}$ at $T = 36.8\,\mathrm{K}$ numerically, using the full expression.	20	2019	A
391	**What is Carnot's theorem? Prove that Carnot's reversible engine is the most efficient one and no other engine can be more efficient than Carnot's engine.** **Hint:** Carnot's theorem: No engine operating between two heat reservoirs can be more efficient than a reversible one. Use contradiction by assuming a more efficient engine and combining it with Carnot's in a cycle to violate second law.	15	2019	C
392	**If the partition function for a perfect gas is given by $Z = \frac{V}{h^3}(2\pi mkT)^{3/2}$, calculate (i) average kinetic energy per molecule and (ii) specific heat of the gas.** **Hint:** For a perfect gas, the internal energy is $U = -\left(\frac{\partial \ln Z}{\partial \beta}\right)_{\beta=1/(k_BT)}$, where $Z = \frac{V}{h^3}(2\pi mk_BT)^{3/2}$. Compute $\ln Z$ and its derivative to find U, then determine the average kinetic energy per molecule as $\langle E\rangle = U/N$. For specific heat, use $C_V = \left(\frac{\partial U}{\partial T}\right)_V$ per molecule, accounting for the number of particles.	15	2019	A

Continued on next page...

#	Question	Marks	Year	Type
393	**Explain the effect of pressure on the melting and boiling points of a substance using Clapeyron's latent heat equation. Calculate under what pressure, water will boil at 120°C, if the change in specific volume when 1 gram of water is converted into steam is 1676 cm^3. Latent heat of steam = 540 cal/g, 1 atmospheric pressure = 10^6 dynes/cm^2.** **Hint:** Apply the Clausius–Clapeyron equation, $\frac{dP}{dT} = \frac{L}{T\Delta V}$, to relate pressure and temperature changes during phase transitions. For the boiling point, approximate the pressure change as $\Delta P \approx \frac{L\Delta T}{T\Delta V}$, using the given latent heat, temperature change, and specific volume change. Convert units consistently (e.g., cal to erg, cm^3 to cm^2 for pressure). Higher pressure raises the boiling point. For melting, the sign of ΔV determines whether pressure increases or decreases the melting point, per the Clapeyron equation.	15	2019	A
394	**The melting point of tin is 232°C, its latent heat of fusion is 14 cal/g and the specific heat of solid and molten tin are 0.055 and 0.064 cal/g$^\circ$C respectively. Calculate the change in entropy when 1.0 gm of tin is heated from 100°C to 300°C.** **Hint:** Divide the process into three stages: (1) heating solid tin from 100°C to 232°C, (2) melting at 232°C, and (3) heating liquid tin from 232°C to 300°C. For heating, use $\Delta S = mc\int_{T_1}^{T_2}\frac{dT}{T} = mc\ln\left(\frac{T_2}{T_1}\right)$ with specific heats in J/g·K. For melting, use $\Delta S = \frac{mL}{T_m}$, where L is the latent heat. Convert all units to joules (1 cal = 4.184 J) and sum the entropy changes, assuming constant specific heats.	10	2021	A
395	**Calculate the efficiency of an engine having compression ratio 13.8 and expansion ratio 6 and working on diesel cycle. Given $\gamma = 1.4$.** **Hint:** The efficiency of a diesel cycle is $\eta = 1 - \frac{1}{r_c^{\gamma-1}} \cdot \frac{\rho^{\gamma}-1}{\gamma(\rho-1)}$, where r_c is the compression ratio and ρ is the cutoff ratio (volume after heat addition divided by volume before). Given the compression ratio $r_c = 13.8$ and expansion ratio $r_e = 6$, compute ρ using the relationship between compression and expansion volumes in the diesel cycle. Substitute $\gamma = 1.4$ and evaluate numerically.	5	2021	A
396	**Assume that the Earth's atmosphere is pure nitrogen in thermodynamic equilibrium at a temperature of 300 K. Calculate the height above sea level at which the density of the atmosphere is one-half its sea level value. (Molecular weight of N_2 is 28 gm/mole)** **Hint:** Use barometric formula $\rho(h) = \rho_0 e^{-Mgh/RT}$. Set $\rho(h)/\rho_0 = 1/2$, solve for h. Use $M = 0.028$ kg/mol, $g = 9.8$ m/s^2, $R = 8.314$ J/mol·K.	10	2022	A

Continued on next page...

#	Question	Marks	Year	Type
397	**A body of constant heat capacity C_P and a temperature T_i is put into contact with a reservoir at temperature T_f. Equilibrium between the body and the reservoir is established at constant pressure. Determine the total entropy change and prove that it is positive for either sign of $\left(\frac{T_f-T_i}{T_f}\right)$. Consider $\left\lvert\frac{T_f-T_i}{T_f}\right\rvert < 1$.** 💡 **Hint:** For a body at constant pressure with heat capacity C_P, the entropy change is $\Delta S_{\text{body}} = C_P \ln\left(\frac{T_f}{T_i}\right)$. The reservoir's entropy change is $\Delta S_{\text{res}} = -\frac{Q}{T_f} = -\frac{C_P(T_f-T_i)}{T_f}$. Sum these to obtain the total entropy change: $\Delta S_{\text{total}} = C_P\left[\ln\left(\frac{T_f}{T_i}\right) - \frac{T_f-T_i}{T_f}\right]$. Prove $\Delta S_{\text{total}} > 0$ for $T_i \neq T_f$ using a series expansion of the logarithm for $\left\lvert\frac{T_f-T_i}{T_f}\right\rvert < 1$, confirming the second law.	10	2022	C
398	**One mole of gas obeys van der Waals equation of state. If its molar internal energy is given by $u = cT - \frac{a}{V}$ (in which V is the molar volume, a is one of the constants in the equation of state and c is a constant), calculate the molar heat capacities C_V and C_P.** 💡 **Hint:** Given the molar internal energy $u = cT - \frac{a}{V}$, compute $C_V = \left(\frac{\partial u}{\partial T}\right)_V = c$. For C_P, use $C_P = C_V + T\left(\frac{\partial P}{\partial T}\right)_V\left(\frac{\partial V}{\partial T}\right)_P$. From the van der Waals equation $\left(P + \frac{a}{V^2}\right)(V-b) = RT$, compute $\left(\frac{\partial P}{\partial T}\right)_V = \frac{R}{V-b}$. Then, differentiate the equation implicitly to find $\left(\frac{\partial V}{\partial T}\right)_P$, and substitute to obtain C_P. Ensure all terms are expressed in terms of V, T, and constants.	10	2022	C
399	**A compressor designed to compress air is used instead to compress helium. It is found that the compressor overheats. Explain this effect, assuming that the compression is approximately adiabatic and the starting pressure is same for both the gases.** **[$\gamma_{\text{He}} = \frac{5}{3}$, $\gamma_{\text{Air}} = \frac{7}{5}$]** 💡 **Hint:** In adiabatic process, $T_f \propto P^{(\gamma-1)/\gamma}$. Since $\gamma_{\text{He}} > \gamma_{\text{Air}}$, helium's temperature rises more on compression, causing overheating.	10	2022	C

Continued on next page...

#	Question	Marks	Year	Type
400	**A gas of interacting atoms has an equation of state and heat capacity at constant volume given by the expressions:** $p(T,V) = aT^{1/2} + bT^3 + cV^{-2}$ $C_V(T,V) = dT^{1/2} + eT^2V + fT^{1/2}$ **where a through f are constants which are independent of T and V. Find the differential of the internal energy $dU(T,V)$ in terms of dT and dV.** **Hint:** Use thermodynamic identity: $dU = C_V dT + \left[T\left(\frac{\partial P}{\partial T}\right)_V - P\right] dV$. Compute $\left(\frac{\partial P}{\partial T}\right)_V$ from $p(T,V)$ expression and simplify.	15	2022	C
401	**A thermally insulated cylinder, closed at both ends, is fitted with a frictionless heat-conducting piston which divides the cylinder in two parts. Initially, the piston is clamped in the centre, with one litre of air at 200 K and 2 atm pressure on one side and one litre of air at 300 K and 1 atm pressure on the other side. The piston is released and the system reaches equilibrium in pressure and temperature, with the piston at a new position. Compute the final pressure and temperature.** **Hint:** For an ideal gas, the total internal energy is $U = nC_VT$. Calculate initial moles in each compartment using $PV = nRT$. After the piston is released, the system reaches a common final pressure P_f and temperature T_f. Apply conservation of total internal energy: $U_{\text{initial},1} + U_{\text{initial},2} = U_{\text{final},1} + U_{\text{final},2}$. Use $P_fV_1/T_f = n_1R$ and $P_fV_2/T_f = n_2R$, with $V_1 + V_2 = 2\,\text{L}$, to form a system of equations. Solve for P_f and T_f, assuming C_V is constant.	15	2022	A
402	**In a partially conducting medium, $\varepsilon_r = 18.5$, $\mu_r = 800$ and $\sigma = 1$ S m^{-1}. Find α, β, η and the velocity u, for a frequency of 10^9 Hz. Determine $\vec{H}(z,t)$. Given, $\vec{E}(z,t) = 50e^{-\alpha z}\cos(\omega t - \beta z)\hat{a}_y$ V m^{-1}.** **Hint:** For a conducting medium, the complex propagation constant is $\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$, where $\alpha = \text{Re}(\gamma)$ and $\beta = \text{Im}(\gamma)$. Compute γ using $\varepsilon = \varepsilon_r\varepsilon_0$, $\mu = \mu_r\mu_0$, $\sigma = 1\,\text{S/m}$, and $\omega = 2\pi \times 10^9\,\text{rad/s}$. The wave velocity is $u = \omega/\beta$, and the intrinsic impedance is $\eta = \sqrt{\frac{j\omega\mu}{\sigma + j\omega\varepsilon}}$. For $\vec{H}$, use $\vec{H} = \frac{1}{\eta}(\hat{k} \times \vec{E})$, where $\hat{k} = -\hat{a}_z$ for the given $\vec{E}$. Verify if the good conductor approximation ($\sigma \gg \omega\varepsilon$) applies to simplify calculations.	20	2022	A

Continued on next page...

#	Question	Marks	Year	Type
403	**Calculate the number of different arrangements of 10 indistinguishable particles in 15 cells of equal a priori probability, considering that one cell contains only one particle.** **Hint:** Use combinatorics for placing indistinguishable particles in distinguishable boxes: $\binom{15}{10}$ since each cell can hold only one particle.	10	2010	A
404	**Consider the following statement: "The Fermi energy of a given material is the energy of that quantum state which has the probability equal to $\frac{1}{2}$ of being occupied by the conduction electrons."** **Is the above statement correct? Give reasons for your answer.** **Hint:** The Fermi energy is the energy at which the Fermi-Dirac distribution is $\frac{1}{2}$ only at $T = 0$. At non-zero temperatures, the probability becomes less sharp. Clarify that E_F is defined as the highest occupied energy level at $T = 0$.	10	2010	C
405	**Write down the expressions for Bose–Einstein and Fermi–Dirac distribution functions, and show how Fermi–Dirac distribution leads to the explanation of Pauli's exclusion principle.** **Hint:** The Fermi-Dirac distribution is $f_{FD}(\epsilon) = \frac{1}{e^{(\epsilon-\mu)/k_BT}+1}$, and the Bose-Einstein distribution is $f_{BE}(\epsilon) = \frac{1}{e^{(\epsilon-\mu)/k_BT}-1}$. For Fermi-Dirac, $f_{FD} \leq 1$ ensures that each quantum state has at most one fermion, reflecting the Pauli exclusion principle due to the antisymmetric wavefunction of fermions. Contrast this with Bose-Einstein, where f_{BE} allows multiple bosons per state. Demonstrate the exclusion principle by analyzing f_{FD} at $T = 0$, where states up to the Fermi energy are fully occupied.	10	2011	C
406	**Consider non-equilibrium situation for a system in which the population inversion has been achieved. Explain that such a system can be treated as if it has negative absolute temperature.** **Hint:** Population inversion occurs when more particles occupy higher energy states, as in laser systems with bounded energy levels. Thermodynamically, temperature is defined via $\frac{1}{T} = \frac{\partial S}{\partial U}$. For inversion, the entropy S decreases with increasing energy U, yielding $\frac{\partial S}{\partial U} < 0$, implying a negative absolute temperature. This is valid only in isolated systems with a maximum energy bound, such as two-level systems in lasers. Illustrate using a simple two-level system to compute $\frac{\partial S}{\partial U}$.	12	2012	C

Continued on next page...

#	Question	Marks	Year	Type
407	**Show that both Fermi–Dirac and Bose–Einstein distributions reduce under certain condition in a form which gives the total number of particles as** $N = A\int_0^\infty \sqrt{\varepsilon}e^{-\beta\varepsilon}d\varepsilon$ **where** A **is a constant and** $\beta = 1/k_BT$**. Further show that this expression is just the same as that obtained from the Maxwellian speed distribution.** **Hint:** In the high-temperature or low-density limit, both Fermi-Dirac and Bose-Einstein distributions approximate the Maxwell-Boltzmann form: $f(\epsilon) \approx e^{-(\epsilon-\mu)/k_BT}$. For the number of particles, use $N = \int_0^\infty g(\epsilon)f(\epsilon)\,d\epsilon$, where the density of states is $g(\epsilon) \propto \sqrt{\epsilon}$ for a 3D free particle gas. Evaluate the integral $N = A\int_0^\infty \sqrt{\epsilon}e^{-\beta\epsilon}\,d\epsilon$, and show equivalence to the Maxwell-Boltzmann distribution by computing the partition function and density of states for classical statistics.	15	2012	C
408	**The coefficient of viscosity of helium at** 27°**C is** 2×10^{-5} **kg m**$^{-1}$ **s**$^{-1}$**. Calculate (i) the average speed and (ii) the diameter of a helium molecule, if it is assumed that the gas obeys Maxwell–Boltzmann distribution. Given Boltzmann constant** $k_B = 1.38\times10^{-23}$ **J K**$^{-1}$ **and mass of helium atom =** 6.67×10^{-27} **kg.** **Hint:** (i) Average speed: $\bar{v} = \sqrt{\frac{8kT}{\pi m}}$. (ii) Use relation for viscosity: $\eta = \frac{1}{3}\rho\bar{v}\lambda$ and mean free path $\lambda = \frac{1}{\sqrt{2}\pi d^2 n}$ to solve for d.	10	2013	A
409	N **particles obeying Classical Statistics are distributed among three states having energies** $\epsilon_1 = 0$, $\epsilon_2 = k_BT$ **and** $\epsilon_3 = 2k_BT$**, where** k_B **is Boltzmann constant. If the total equilibrium energy of the system is** $1000k_BT$**, calculate the value of** N**.** **Hint:** Use Boltzmann distribution: $P_i = \frac{e^{-\beta\epsilon_i}}{Z}$, compute $Z = 1 + e^{-1} + e^{-2}$. Average energy per particle: $\bar{\epsilon} = \sum P_i\epsilon_i$. Multiply $\bar{\epsilon}$ by N and equate to $1000k_BT$ to solve for N.	10	2013	A

Continued on next page...

#	Question	Marks	Year	Type
410	**Show that both Fermi–Dirac and Bose–Einstein distribution functions at an energy E are given by:** $f(E) \simeq \exp[(\mu - E)/k_B T]$, **where $f(E)$ is much smaller than unity, μ and $k_B T$ are the chemical potential and thermal energy of the atom.** **Hint:** In the classical limit, where the occupation number $f(E) \ll 1$, both Fermi-Dirac and Bose-Einstein distributions approximate the Maxwell-Boltzmann form. For $f_{FD} = \frac{1}{e^{(E-\mu)/k_B T}+1}$ and $f_{BE} = \frac{1}{e^{(E-\mu)/k_B T}-1}$, assume $e^{(E-\mu)/k_B T} \gg 1$ (due to large negative μ) to neglect the ± 1 terms, yielding $f(E) \approx e^{-(E-\mu)/k_B T}$. This occurs in high-temperature or low-density regimes, where quantum effects are minimal.	10	2014	C
411	**Using Maxwell–Boltzmann distribution law prove that there cannot be any negative absolute temperature.** **Hint:** The Maxwell-Boltzmann distribution, $f(E) \propto e^{-E/k_B T}$, implies that higher energy states have exponentially decreasing populations, requiring positive T. A negative temperature would imply increasing populations with energy, which is thermodynamically inconsistent with the unbounded energy spectrum of classical systems. Since temperature is defined via $\frac{1}{T} = \frac{\partial S}{\partial U}$, and entropy S increases with energy U in unbounded systems, $\frac{\partial S}{\partial U} > 0$, prohibiting negative T. Contrast this with bounded systems, where negative T is possible.	10	2014	C
412	**The molecules of a gas obey Maxwell–Boltzmann distribution. Calculate the fraction of molecules of the gas within 1% of the most probable speed at STP. Interpret your result.** **Hint:** For a gas obeying the Maxwell-Boltzmann distribution, the speed distribution is $f(v) = 4\pi \left(\frac{m}{2\pi k_B T}\right)^{3/2} v^2 e^{-mv^2/2k_B T}$. The most probable speed is $v_p = \sqrt{\frac{2k_B T}{m}}$. To find the fraction of molecules within 1% of v_p, integrate $f(v)$ from $v_p - 0.005v_p$ to $v_p + 0.005v_p$. Approximate the integral for small Δv, noting the narrow peak at v_p implies a small fraction, reflecting the distribution's sharp maximum at STP.	10	2016	C

Continued on next page...

#	Question	Marks	Year	Type
413	**Consider a system of N particles and a phase space consisting of only two states with energies 0 and ε (> 0). Obtain the expressions for the partition function and the internal energy of the system, if it obeys M–B statistics.** **Hint:** For N particles obeying Maxwell-Boltzmann statistics in a system with two energy states (0 and ε), the single-particle partition function is $Z_1 = 1 + e^{-\varepsilon/k_BT}$. For N distinguishable particles, the system partition function is $Z = Z_1^N$. The internal energy is $U = -\frac{\partial \ln Z}{\partial \beta} = N\frac{\varepsilon e^{-\varepsilon/k_BT}}{1+e^{-\varepsilon/k_BT}}$, where $\beta = 1/k_BT$. Derive U by computing the average energy per particle using the Boltzmann probabilities for each state.	20	2016	C
414	**The viscosity in a liquid arises due to friction between adjacent layers. What causes viscosity in a gas? Explain.** **Hint:** In gases, viscosity arises from the transfer of momentum between adjacent layers due to molecular motion across them. Molecules moving from a faster-moving layer to a slower one transfer momentum, creating a shear force. This is modeled in kinetic theory via the viscosity coefficient $\eta \approx \frac{1}{3}\rho\bar{v}\lambda$, where ρ is density, $\bar{v}$ is average speed, and λ is the mean free path determined by molecular collisions. Explain how frequent collisions (short λ) reduce viscosity compared to liquids, where cohesive forces dominate.	5	2016	C
415	**The molecules of a gas obeying Maxwell–Boltzmann distribution move with an average speed of 450 m/s. If the coefficient of viscosity of the gas η is 16.6×10^{-6} N s m^{-2}, density of the gas is 1.25 kg m^{-3} and number density is 2.7×10^{25} m^{-3}, calculate the mean free path and diameter of the gas molecules.** **Hint:** In a gas obeying Maxwell-Boltzmann statistics, the viscosity is related to the mean free path by $\eta = \frac{1}{3}\rho\bar{v}\lambda$, where ρ is density and $\bar{v}$ is the average speed. Solve for λ using the given η, ρ, and $\bar{v}$. Then, use the mean free path expression $\lambda = \frac{1}{\sqrt{2}\pi d^2 n}$, where n is the number density, to compute the molecular diameter d. Ensure consistency in unitsitado and note that the viscosity formula assumes a hard-sphere model in kinetic theory.	10	2016	A
416	**Write and explain the Maxwell–Boltzmann distribution. Using this distribution, find the expressions for the most probable speed, mean speed and root-mean-square speed.** **Hint:** State $f(v) = 4\pi\left(\frac{m}{2\pi kT}\right)^{3/2} v^2 e^{-mv^2/2kT}$. Then derive: $v_p = \sqrt{2kT/m}$, $v_{avg} = \sqrt{8kT/\pi m}$, $v_{rms} = \sqrt{3kT/m}$.	15	2017	C

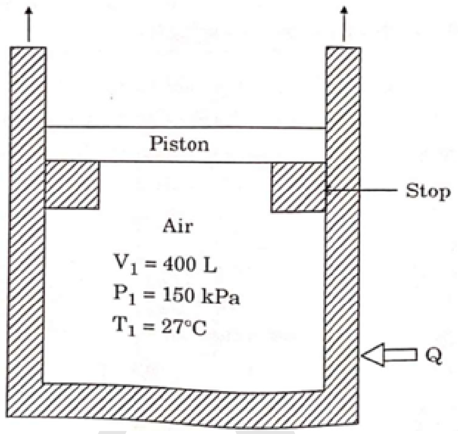
Continued on next page...

#	Question	Marks	Year	Type
417	**Explain Bose–Einstein distribution and obtain the same from the grand canonical ensemble.** 💡 **Hint:** Derive the Bose-Einstein distribution using the grand canonical ensemble for indistinguishable bosons. The grand partition function for a single state with energy ϵ is $\Xi = \sum_{n=0}^{\infty} e^{-n(\epsilon-\mu)/k_BT} = \frac{1}{1-e^{-(\epsilon-\mu)/k_BT}}$. The average occupancy is $f(\epsilon) = -\frac{1}{\beta}\frac{\partial \ln \Xi}{\partial \mu} = \frac{1}{e^{(\epsilon-\mu)/k_BT}-1}$. Sum over all states, accounting for the statistical weighting of bosonic states, to obtain the distribution. Explain the role of the chemical potential μ.	15	2017	C
418	**A system having two energy levels, $-\frac{1}{2}\Delta$ and $+\frac{1}{2}\Delta$ with $\Delta = 10$ meV is populated by 1000 particles at a low temperature close to 100 K. Obtain the average energy per particle using classical distribution law.** 💡 **Hint:** Use $P_i = \frac{e^{-\beta\epsilon_i}}{Z}$ with $\epsilon_1 = -\Delta/2$, $\epsilon_2 = +\Delta/2$, $Z = 2\cosh(\beta\Delta/2)$. Then $U/N = -\frac{\Delta}{2}\tanh(\beta\Delta/2)$.	15	2018	A
419	**Schematically, show the variation of density of states, $D(\epsilon)$ and distribution function, $f(\epsilon, T)$, of particles in a non-relativistic Fermi gas at high temperatures. At a temperature T, an electron occupies a state with energy 100 meV above the Fermi energy (ϵ_F) with the probability of 1%. Find the temperature T.** 💡 **Hint:** Use Fermi–Dirac distribution: $f(\epsilon) = \frac{1}{e^{(\epsilon-\mu)/kT}+1}$ and solve for T from given probability. For $\epsilon - \epsilon_F = 0.1$ eV, $f = 0.01$, solve for T.	20	2018	C
420	**A gas has only two particles, a and b. With the help of a diagram, show how these two particles can be arranged in the three quantum series 1, 2, 3 using (i) Maxwell–Boltzmann, (ii) Fermi–Dirac, and (iii) Bose–Einstein statistics.** 💡 **Hint:** MB: Particles are distinguishable → all $3^2 = 9$ combinations valid. FD: Identical fermions → Pauli principle forbids same state → choose 3C2 = 3. BE: Identical bosons → both can occupy same state → allow repetitions. Use diagrams to show occupation number representation.	10	2019	C
421	**Starting from Maxwell–Boltzmann distribution for a free particle in 3-dimension, obtain the expression for root mean square (rms) speed of a particle. Calculate the rms speed of nitrogen (N_2) molecule at room temperature (27°C).** 💡 **Hint:** Use $v_{rms} = \sqrt{3kT/m}$. For N_2, $m = \frac{28}{6.022\times10^{23}}$ kg. Convert temperature to Kelvin and plug in values.	20	2020	A

Continued on next page...

#	Question	Marks	Year	Type
422	**Eight indistinguishable balls are to be arranged in six distinguishable boxes. Calculate the total number of ways in which the above can be done.** 💡 **Hint:** This is a partition problem: number of integer solutions of $x_1 + x_2 + \cdots + x_6 = 8$ where $x_i \geq 0$. Use stars and bars: $\binom{8+6-1}{6-1} = \binom{13}{5}$.	10	2021	C
423	**Write the expression for the Fermi–Dirac distribution. Plot the Fermi–Dirac distribution at $T = 0$ and for $T_1 > T_2 > 0$. Now from the plot propose two alternative definitions of the Fermi level.** 💡 **Hint:** The Fermi-Dirac distribution is $f(\epsilon) = \frac{1}{e^{(\epsilon-\mu)/k_BT}+1}$. At $T = 0$, $f(\epsilon)$ is a step function, with $f = 1$ for $\epsilon < \epsilon_F$ and $f = 0$ for $\epsilon > \epsilon_F$. For $T_1 > T_2 > 0$, the curve softens around μ. Plot these to propose two Fermi level definitions: (1) the energy where $f(\epsilon) = 1/2$, typically μ at finite T, and (2) the energy separating predominantly occupied ($f \approx 1$) from predominantly unoccupied ($f \approx 0$) states, approximating ϵ_F at low T.	15	2021	C
424	**Calculate the probability of an electron occupying an energy level 0.02 eV above the Fermi level at $T = 300$ K.** 💡 **Hint:** Use $f(\epsilon) = \frac{1}{e^{(\epsilon-\mu)/kT}+1}$, with $\epsilon - \mu = 0.02$ eV. Plug $kT = 0.0259$ eV and evaluate.	5	2021	A
425	**What do you understand by negative temperature? Write and explain various restrictions on a system for the concept of negative temperature to be meaningful.** 💡 **Hint:** Negative temperatures occur in systems with a bounded energy spectrum, where population inversion leads to more particles in higher energy states. Thermodynamically, temperature is defined via $\frac{1}{T} = \frac{\partial S}{\partial U}$. For bounded systems in thermal equilibrium, increasing energy U can decrease entropy S, yielding $\frac{\partial S}{\partial U} < 0$, hence $T < 0$. Restrictions include: (1) an isolated system to maintain equilibrium, (2) a finite upper energy bound, and (3) inverted populations, as in nuclear spin systems or lasers. Illustrate with a two-level system to clarify.	15	2022	C

Continued on next page...

#	Question	Marks	Year	Type
426	**A piston-cylinder device initially contains air at 150 kPa and 27°C. At this state, the piston is resting on a pair of stops, as shown in the figure, and the enclosed volume is 400 L. The mass of the piston is such that a 350 kPa pressure is required to move it. The air is now heated until the volume is doubled. Determine:** **a. the final temperature,** **b. the work done by the air, and** **c. the total heat transferred to air.** **Given:** $U_{300\,\text{K}} = 214$ **kJ/kg and** $U_{\text{final}} = 1113$ **kJ/kg;** **Gas constant of air,** $R = 0.287$ **kPa·m³/kg·K.**  **Hint:** The process occurs in two stages due to the piston resting on stops: (1) isochoric heating from 150 kPa to 350 kPa at constant volume (400 L), and (2) isobaric expansion at 350 kPa as the volume doubles to 800 L. First, use the ideal gas law $PV = mRT$ to find the mass m of air at the initial state (150 kPa, 27°C = 300 K, 400 L = 0.4 m³). For stage 1 (isochoric), compute the intermediate temperature at 350 kPa using $P_1/T_1 = P_2/T_2$. For stage 2 (isobaric), find the final temperature using $V_2/T_2 = V_3/T_3$ with $V_3 = 800\,\text{L}$. For work (part b), calculate $W = P(V_{\text{final}} - V_{\text{initial}})$ during the isobaric stage (zero work in isochoric stage). For heat transfer (part c), apply the first law $Q = \Delta U + W$, where $\Delta U = m(U_{\text{final}} - U_{300\,\text{K}})$ using the given internal energy values. Ensure all units are consistent (e.g., convert volumes to m³).	20	2023	A

Continued on next page...

#	Question	Marks	Year	Type
427	**Prove that the work done by a perfect gas during a quasi-static adiabatic expansion is given by** $W = \frac{P_i V_i}{\gamma - 1}\left[1 - \left(\frac{P_f}{P_i}\right)^{\frac{\gamma-1}{\gamma}}\right]$, **where γ is the ratio of specific heats.** **Hint:** For a quasi-static adiabatic process, use $PV^\gamma =$ constant and the first law, $dU = -P\,dV$. Express pressure as $P = P_i(V_i/V)^\gamma$ and compute the work via $W = \int_{V_i}^{V_f} P\,dV$. To express the result in terms of pressures, use $P_f V_f^\gamma = P_i V_i^\gamma$ to relate volumes to pressures.	10	2024	C
428	**Calculate the Fermi energy in electron-volt for sodium assuming that it has one free electron per atom. The density of sodium = 0.97 gm/cc and the atomic weight of sodium is 23.** **Hint:** Use $E_F = \frac{\hbar^2}{2m}\left(3\pi^2 n\right)^{2/3}$ where $n = \frac{N_A \rho}{M}$. Convert density to kg/m^3, use Avogadro's number, and electron mass. Final result in joules, convert to eV.	10	2024	A
429	**Define internal energy U, Helmholtz's function F, enthalpy H, Gibbs' potential G and hence obtain the four Maxwell's thermodynamic relations.** **Hint:** Define the thermodynamic potentials: $F = U - TS$, $H = U + PV$, $G = H - TS$. Compute their total differentials using natural variables: $U(S,V)$, $F(T,V)$, $H(S,P)$, $G(T,P)$. Derive the four Maxwell relations by equating mixed partial derivatives of dU, dF, dH, and dG, ensuring consistency with thermodynamic identities.	20	2024	C
430	**What do you understand by macrostates and microstates? Briefly explain.** **Hint:** A macrostate is specified by macroscopic variables such as pressure, volume, and temperature. A microstate is a distinct quantum or classical configuration of the system's particles consistent with the macrostate. The number of microstates, Ω, determines the statistical weight of the macrostate, related to entropy via $S = k \ln \Omega$ in the microcanonical ensemble.	5	2024	C
431	**Explain the T–s diagram for the reversible Carnot cycle and hence obtain the expression for the efficiency of the Carnot engine.** **Hint:** Construct the T-s diagram for a reversible Carnot cycle with isotherms at T_H and T_C and two adiabats. The enclosed area represents net work. Derive the efficiency, $\eta = 1 - \frac{T_C}{T_H}$, by analyzing heat transfers: Q_H and Q_C, with entropy changes $\Delta S = Q_H/T_H = Q_C/T_C$ during isotherms.	10	2024	C

Continued on next page...

#	Question	Marks	Year	Type
432	**The specific heat of a solid at low temperatures is given by the relation $C_V = AT^3$, where A is a constant and T is the absolute temperature. How much heat will be required to raise the temperature of m gm of the solid from 300 K to 500 K?** **Hint:** Calculate the heat required via $Q = \int_{T_1}^{T_2} mC_V(T)\,dT$, where $C_V = AT^3$. Evaluate $Q = mA\int_{300}^{500} T^3\,dT = mA\left[\frac{T^4}{4}\right]_{300}^{500}$. Note that the $C_V = AT^3$ model is typically valid at low temperatures (e.g., $T \ll \Theta_D$), so verify its applicability for 300–500 K.	5	2024	A