D PHYSICS

CSIR-NET, GATE, SET, JEST, IIT-JAM, BARC, TIFR

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PHYSICAL SCIENCE

ELECTROMAGNETIC THEORY

Previous Year Questions [Topic-Wise]

With Answer Key

CSIR-NET/JRF I GATE I JEST I TIFR

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EMT Subject Expert

❖ EMT 01 : Electric Charge, Force, Field & Flux

❖ CSIR-NET PYQ's

1. Four equal point charges are kept fixed at the four vertices of a square. How many neutral points (i.e., points where the electric field vanishes will be found inside the square?

[CSIR DEC 2011]

(a) 3 (b) 4
(c) 5 (d) 7

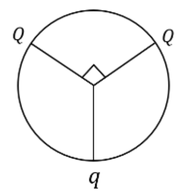
2. A static charge distribution gives rise to an electric field of the form $\vec{E} = \alpha\left(1 - e^{-r/R}\right)\frac{\hat{r}}{r^2}$, where α and R are positive constants. The charge contained within a sphere of radius R, centred at the origin is:

[CSIR DEC 2011]

(a) $\pi\alpha\varepsilon_0\frac{e}{R^2}$ (b) $\pi\alpha\varepsilon_0\frac{e^2}{R^2}$
(c) $4\pi\alpha\varepsilon_0(1-\frac{1}{e})$ (d) $\pi\alpha\varepsilon_0\frac{R^2}{e}$

3. Three charges are located on the circumference of a circle of radius ' R ' as shown in the figure below. The two charges Q subtend an angle 90° at the centre of the circle. The charge ' q ' is symmetrically placed with respect to the charges Q. If the electric field at the centre of the circle is zero, what is the magnitude of Q?

[CSIR DEC 2012]



(a) $q/\sqrt{2}$ (b) $\sqrt{2}q$
(c) 2q (d) 4q

4. Consider a hollow charged shell of inner radius ' a ' and outer radius ' b '. The volume charge density is $\rho(r) = \frac{k}{r^2}$ (where k is a constant) in the region $a < r < b$. The magnitude of the electric field produced at distance $r > a$ is:

[CSIR DEC 2012]

(a) $\frac{k(b-a)}{\varepsilon_0 r^2}$ for $r > a$
(b) $\frac{k(b-a)}{\varepsilon_0 r^2}$ for $a < r < b$ and $\frac{kb}{\varepsilon_0 r^2}$ for $r > b$
(c) $\frac{k(r-a)}{\varepsilon_0 r^2}$ for $a < r < b$ and $\frac{k(b-a)}{\varepsilon_0 r^2}$ for $r > b$
(d) $\frac{k(r-a)}{\varepsilon_0 a^2}$ for $a < r < b$ and $\frac{k(b-a)}{\varepsilon_0 a^2}$ for $r > b$

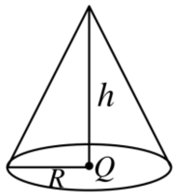
5. A solid sphere of radius R has a charge density, given by $\rho(r) = \rho_0\left(1 - \frac{ar}{R}\right)$, where r is the radial coordinate and ρ_0, a and R are positive constants. If the magnitude of the electric field at $r = R/2$ is 1.25 times that at $r = R$, then the value of a is

[CSIR DEC 2014]

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

6. Consider a charge Q at the origin of 3-dimensional coordinate system. The flux of the electric field through the curved surface of a cone that has a height h and a circular base of radius R (as shown in the figure) is

[CSIR DEC 2015]



(a) $\frac{Q}{\epsilon_0}$ (b) $\frac{Q}{2\epsilon_0}$

(c) $\frac{hQ}{R\epsilon_0}$ (d) $\frac{QR}{2h\epsilon_0}$

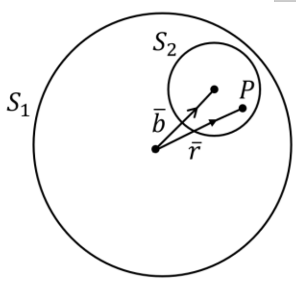
7. Four equal charges of $+Q$ each are kept at the vertices of a square of side R. A particle of mass m and charge $+Q$ is placed in the plane of the square at a short distance $a(\ll R)$ from the center. If the motion of the particle is confined to the plane, it will undergo small oscillations with an angular frequency

[CSIR JUNE 2016]

(a) $\sqrt{\frac{Q^2}{2\pi\varepsilon_0 R^3 m}}$ (b) $\sqrt{\frac{Q^2}{\pi\varepsilon_0 R^3 m}}$

(c) $\sqrt{\frac{\sqrt{2}Q^2}{\pi\varepsilon_0 R^3 m}}$ (d) $\sqrt{\frac{Q^2}{4\pi\varepsilon_0 R^3 m}}$

8. Consider a sphere S_1 of radius R which carries a uniform charge of density ρ. A smaller sphere S_2 of radius $a < \frac{R}{2}$ is cut out and removed from it. The centers of the two spheres are separated by the vector $\vec{b} = \hat{n}\frac{R}{2}$, as shown in the figure.



The electric field at a point P inside S_2 is

[CSIR JUNE 2016]

(a) $\frac{\rho R}{3\varepsilon_0}\hat{n}$ (b) $\frac{\rho R}{3\varepsilon_0 a}(\vec{r} - \hat{n}a)$

(c) $\frac{\rho R}{6\varepsilon_0}\hat{n}$ (d) $\frac{\rho a}{3\varepsilon_0 R}\vec{r}$

9. The charge per unit length of a circular wire of radius a in the xy-plane, with its center at the origin, is $\lambda = \lambda_0 \cos\ \theta$, where λ_0 is a constant and the angle θ is measured from the positive x-axis. The electric field at the center of the circle is

[CSIR DEC 2016]

(a) $\vec{E} = -\frac{\lambda_0}{4\varepsilon_0 a}\hat{\imath}$ (b) $\vec{E} = \frac{\lambda_0}{4\varepsilon_0 a}\hat{\imath}$

(c) $\vec{E} = -\frac{\lambda_0}{4\varepsilon_0 a}\hat{\jmath}$ (d) $\vec{E} = \frac{\lambda_0}{4\pi\varepsilon_0 a}\hat{k}$

10. A non-conducting thin ellipsoidal shell defined by the equation $x^2 + 2y^2 + 3z^2 = a^2$ has a net chareg Q spread uniformly over its surface. The flux passing through a hemispherical surface defined by $x^2 + y^2 + z^2 = a^2$ and $z > 0$, is

[NET Dec, 2019]

(a) $Q/(\sqrt{3}\epsilon_0)$ (b) Q/ϵ_0

(c) $Q/(2\epsilon_0)$ (d) $2/(3e_0)$.

11. The values of a and b for which the force $\vec{F} = (axy + z^3)\hat{\imath} + x^2\hat{\jmath} + bxz^2\hat{k}$ is conservative are

[CSIR DEC 2019]

(a) $a = 2, b = 3$ (b) $a = 1, b = 3$

(c) $a = 2, b = 6$ (d) $a = 3, b = 2$

12. Three point charges q are placed at the corners of an equilateral triangle. Another point charge $-Q$ is placed at the centroid of the triangle. If the force on each of the charges q vanishes, then the ratio Q/q is

[CSIR JUNE 2020]

(a) $\sqrt{3}$ (b) $\frac{1}{\sqrt{3}}$

(c) $\frac{1}{3\sqrt{3}}$ (d) $\frac{1}{3}$

❖ GATE PYQ's

1. Two point charges $Q_1 = 1nC$ and $Q_2 = 2nC$ are kept in free space such that the distance between them is 0.1 m.

[GATE 2001]

(a) The force on Q_2 is along the direction from Q_2 to Q_1

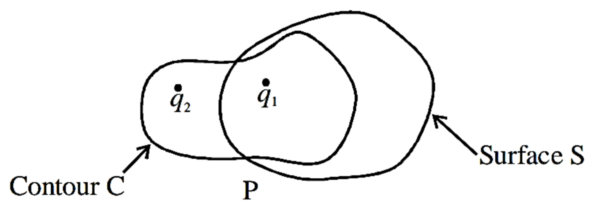
(b) The force on Q_2 is the same in magnitude as that on Q_1

(c) The force on Q_1 is attractive

(d) A point charge $Q_3 = -3nC$, placed at the midpoint between Q_1 and Q_2, experiences no net force

2. Consider a set of two stationary point charges q_1 and q_2 as shown in the figure. Which of the following statements is correct?

[GATE 2002]



(a) The electric field at P is independent of q_2

(b) The electric flux crossing the closed surface S is independent of q_2

(c) The line integral of the electric field $\vec{E}$ over the closed contour C depends on q_1 and q_2.

(d) $\vec{\nabla} \cdot \vec{E} = 0$ everywhere

3. A vector $\vec{A} = (5x + 2y)\hat{\imath} + (3y - z)\hat{\jmath} + (2x - az)\hat{k}$ is solenoidal if the constant a has a value

[GATE 2002]

(a) 4 (b) -4

(c) 8 (d) -8

4. A solid sphere of radius R carries a uniform volume charge density ρ. The magnitude of electric field inside the sphere at a distance r from the centre is

[GATE 2005]

(a) $\frac{r\rho}{3\varepsilon_0}$ (b) $\frac{R\rho}{2\varepsilon_0}$

(c) $\frac{R^2\rho}{r\varepsilon_0}$ (d) $\frac{R^3\rho}{r^2\varepsilon_0}$

5. A vector field is defined everywhere as $\vec{F} = \frac{y^2}{L}\hat{\imath} + z\hat{k}$. The net flux of $\vec{F}$ associated with a cube of side L, with one vertex at the origin and sides along the positive X, Y, and Z axes, is

[GATE 2007]

(a) $2L^3$ (b) $4L^3$

(c) $8L^3$ (d) $10L^3$

6. A charge distribution has the charge density given by $\rho = Q\{\delta(x - x_0) - \delta(x + x_0)\}$. For this charge distribution the electric field at $(2x_0, 0,0)$

[GATE. 2013]

(c) $\frac{Q\hat{x}}{4\pi\epsilon_0 x_0^2}$ (d) $\frac{Q\hat{x}}{16\pi\epsilon_0 x_0^2}$

7. The direction of $\vec{\nabla}f$ for a scalar field $f(x_i, y_* z) = \frac{1}{2}x^2 - xy + \frac{1}{2}z^2$ at the point $P(1,1,2)$ is

[GATE 2016]

(a) $\frac{(-\hat{\jmath}-2\hat{k})}{\sqrt{5}}$ (b) $\frac{(-\hat{\jmath}+2\hat{k})}{\sqrt{5}}$

(c) $\frac{(\hat{\jmath}-2\hat{k})}{\sqrt{5}}$ (d) $\frac{(\hat{\jmath}+2\hat{k})}{\sqrt{5}}$

8. An infinitely long thin cylindrical shell has its axis coinciding with the z-axis. It carries a surface charge density $\sigma_0 \cos\,\phi$, where ϕ is the polar angle and σ_0 is a constant. The magnitude of the electric field inside the cylinder is

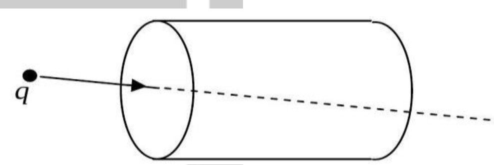
[GATE 2019]

(a) 0 (b) $\frac{\sigma_0}{2\epsilon_0}$

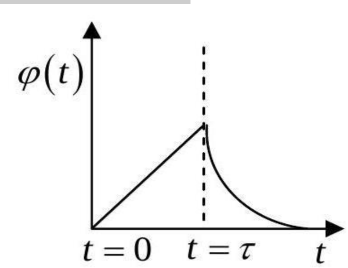
(c) $\frac{\sigma_0}{3\epsilon_0}$ (d) $\frac{\sigma_0}{4\epsilon_0}$

9. A charge q moving with uniform speed enters a cylindrical region in free space at $t = 0$ and exits the region at $t = \tau$ (see figure). Which one of the following options best describes the time dependence of the total electric flux $\varphi(t)$, through the entire surface of the cylinder?

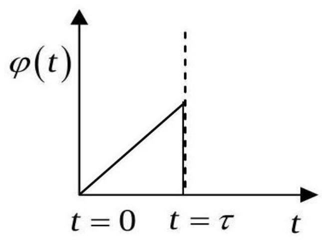
[GATE 2020]



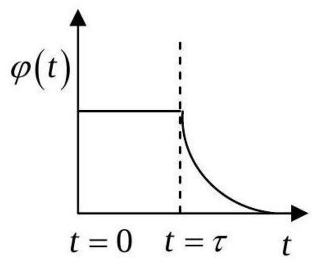
(a)



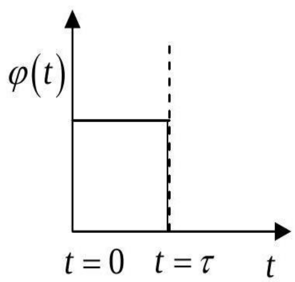
(b)



(c)



(d)



10. Electric field is measured along the axis of a uniformly charged disc of radius 25 cm . At a distance d from the centre, the field differs by 10% from that of an infinite plane having the same charge density. The value of d is (Round off to one decimal place) **[GATE 2023]**

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

[GATE 2023]

12. Consider the vector field $\vec{V}$ consisting of the velocities of points on a thin horizontal disc of radius $R=2$ m, moving anticlockwise with uniform angular speed $\omega=2$rad/sec about an axis passing through its center. If $V=|\vec{V}|$, then which of the following options is(are) CORRECT? (In the options, $\hat{r}$ and $\hat{\theta}$ are unit vectors corresponding to the plane polar coordinates r and θ).

You may use the fact that in cylindrical coordinates (s,ϕ,z) (s is the distance from the zaxis), the gradient, divergence, curl and Laplacian operators are: **[GATE 2023]**

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

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

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

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

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

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

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

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

13. The electric field in a region depends only on x and y coordinates as

$$\vec{E}=k\frac{(x\hat{x}+y\hat{y})}{x^2+y^2}$$

where k is a constant. The flux of $\vec{E}$ through the surface of a sphere of radius R with its center at the origin is $n\pi kR$, where the value of n is (in integer). **[GATE 2024]**

❖ JEST PYQ's

1. An electric field in a region is given by $\vec{E}(x,y,z)=ax\hat{\imath}+cz\hat{\jmath}+6by\hat{k}$. For which values of a, b, c does this represent an electrostatic field?

[JEST 2012]

(a) 13,1,12 (b) 17,6,1
(c) 13,1,6 (d) 45,6,1

2. If $\vec{E}_1=xy\hat{\imath}+2yz\hat{\jmath}+3xz\hat{k}$ and $\vec{E}_2=y^2\hat{\imath}+(2xy+z^2)\hat{\jmath}+2yz\hat{k}$ then **[JEST 2013]**

(a) Both are impossible electrostatic fields.

(b) Both are possible electrostatic fields.

(c) Only E_1 is a possible electrostatic field.
(d) E_2 is a possible electrostatic fields.

3. Two large non conducting sheets one with a fixed uniform positive charge and another with a fixed uniform negative charge are placed at a distance of 1 meter from each other. The magnitude of the surface charge densities are $\sigma_+ = 6.8\mu\text{C/m}^2$ for the positively charged sheet and $\sigma_- = 4.3\mu\text{C/m}^2$ for the negatively charged sheet. What is the electric field in the region between the sheets? **[JEST 2014]**

(a) 6.30×10^5 N/C (b) 3.84×10^5 N/C
(c) 1.40×10^5 N/C (d) 1.16×10^5 N/C

4. A circular loop of radius R carries a uniform line charge density λ. The electric field, calculated at a distance z directly above the center of the loop, is maximum if z is equal to, **[JEST 2015]**

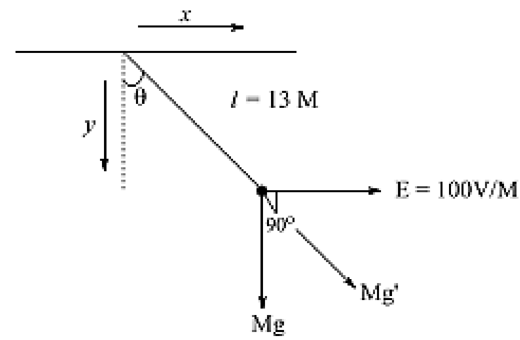
(a) $\frac{R}{\sqrt{3}}$ (b) $\frac{R}{\sqrt{2}}$
(c) $\frac{R}{2}$ (d) $2R$

5. Consider two points charges q and q located at the points, $x = a$ and xa, respectively. Assuming that the sum of the two charges is constant, what is the value of λ for which the magnitude of the electrostatic force is maximum? **[JEST 2015]**

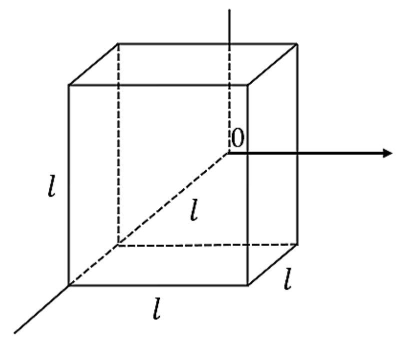
(a) μ (b) 1
(c) $\frac{1}{\mu}$ (d) $1 + \mu$

6. A sphere of inner radius 1 cm and outer radius 2 cm, centered at origins has a volume charge density $\rho_0 = \frac{k}{4\pi r}$, where K is a nonzero constant and r is the radial distance. A point charge of magnitude 10^{-3}C is placed at the origin. For what value of K in units of C/m^2, the electric field inside the shell is constant? **[JEST 2017]**

7. A simple pendulum has a bob of mass 1 kg and change 1 Coulomb. It is suspended by the massless string of length 13 m. The time period of small oscillations of this pendulum is T_0. if an electric field $\vec{E} = 100xV/m$ applied, the time period becomes T. What is the value of $(T_0/T)^4$? **[JEST 2017]**



8. For an electric field $\vec{E} = k\sqrt{x}x$ where k is an non - zero constant, total charge enclosed by the cube as shown below is **[JEST 2017]**



(a) 0 (b) $k\varepsilon_0 l^{5/2}(\sqrt{3} - 1)$
(c) $k\varepsilon_0 l^{5/2}(\sqrt{5} - 1)$ (d) $k\varepsilon_0 l^{5/2}(\sqrt{2} - 1)$

9. Two dielectric spheres of radius R are separated by a distance a such that $a >> R$. one of the spheres (sphere 1) has a charge q and the other is neutral. If the linear dimensions of the systems are scaled up by a factor two, by a factor two, by what factor should be charge on the sphere 1 be charged so that the force between the two spheres remain unchanged? **[JEST 2018]**

(a) 2 (b) $4\sqrt{2}$
(c) 4 (d) $2\sqrt{2}$

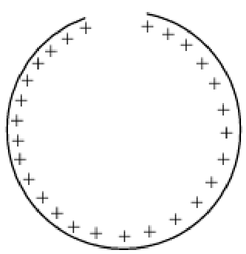
10. An electric charge distribution produces an electric field $\vec{E} = (1 - e^{-\alpha r})\frac{\vec{r}}{r^3}$, Where δ and α are constants. The net charge within a sphere of radius α^{-1} centered at the origin is **[JEST 2018]**

(a) $4\pi\varepsilon_0(1-e^{-1})$ (b) $4\pi\varepsilon_0(1+e^{-1})$
(c) $-4\pi\varepsilon_0 \frac{1}{\alpha e}$ (d) $4\pi\varepsilon_0 \frac{1}{\alpha e}$

11. The charge density as a function of the radial distance r is given by $\rho(r) = \rho_0 \frac{R^2-r^2}{R^2}$
For $r < R$ and zero otherwise. The electric flux over the surface of an ellipsoid with axes 3R, 4R and 5R centered at the origin is **[JEST 2018]**

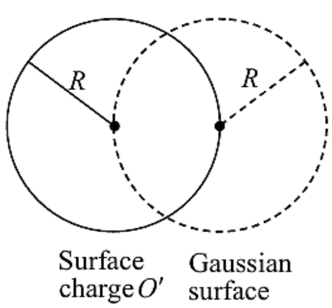
(a) $\frac{4}{3\varepsilon_0}\pi\rho_0 R^3$ (b) $\frac{8}{9\varepsilon_0}\pi\rho_0 R^3$
(c) $\frac{8}{15\varepsilon_0}\pi\rho_0 R^3$ (d) Zero

12. A ring of radius 0.5 m has a gap of 0.002πm. If the ring carries a charge of $+1.0$C distributed uniformly along it, then the electric field at the centre of the ring is **[JEST 2020]**



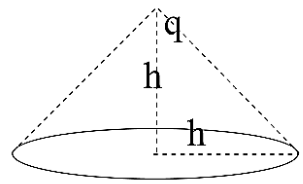
(a) $7.5 \times 10^7 \mathrm{NC}^{-1}$ (b) $7.2 \times 10^7 \mathrm{NC}^{-1}$
(c) $6.2 \times 10^7 \mathrm{NC}^{-1}$ (d) $6.5 \times 10^7 \mathrm{NC}^{-1}$

13. Consider a spherical shell of radius R having a uniform surface charge density σ. Suppose we construct a spherical Gaussian surface having the same radius R but its centre shifted from the charged sphere by a distance R (see the figure). What is the total electric flux $\oint \vec{E} \cdot d\vec{A}$ through the Gaussian surface? **[JEST 2021]**



(a) 0 (b) $\pi R^2\sigma$
(c) $2\pi R^2\sigma$ (d) $4\pi R^2\sigma$

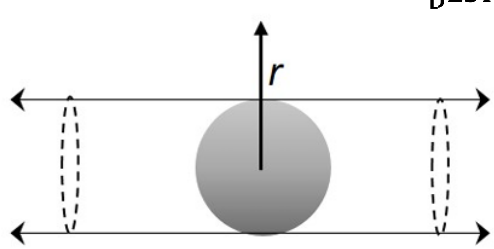
14. A point charge q is located at the apex of a cone of height h and base radius h. The flux of the electric field through the cone due to the point charge is **[JEST 2023]**



(a) $\left(1-\frac{1}{\sqrt{2}}\right)\frac{q}{2\pi\epsilon_0}$ (b) $\left(1-\frac{1}{\sqrt{2}}\right)\frac{\pi q}{2\epsilon_0}$
(c) $\frac{1}{\sqrt{2}}\frac{q}{2\epsilon_0}$ (d) $\left(1-\frac{1}{\sqrt{2}}\right)\frac{q}{2\epsilon_0}$

15. Three equal charges $+q$ are placed at the corners of an equilateral triangle. A test charge constrained to move on the plane of the triangle is placed at the centre of the triangle. Which of the following statements about the test charge is true? **[JEST 2024]**
(a) It is in a stable equilibrium.
(b) Stability of the equilibrium depends on the sign of the test charge.
(c) It is not in an equilibrium.
(d) It is in an unstable equilibrium.

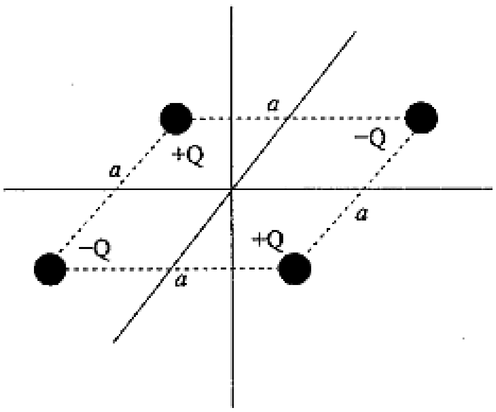
16. An infinitely long cylinder of radius R has uniform volume charge density. A spherical region of radius R is carved out of it, as shown in the figure. At what value of r (the radial coordinate in a cylindrical system, with origin at the center of the sphere) is the electric field maximum? **[JEST 2024]**



(a) $r = R$ (b) $r = \frac{4}{3}R$
(c) $r = \frac{2}{3}R$ (d) $r = \frac{3}{2}R$

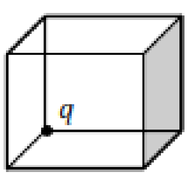
❖ TIFR PYQ

1. In the laboratory, four point charges $+Q, -Q, +Q, -Q$ are placed at the four ends of a horizontal square of side a, as shown in the figure below. The number of neutral points (where the electric field vanishes) is **[TIFR 2009]**



(a) ∞ (b) 4
(c) 1 (d) zero

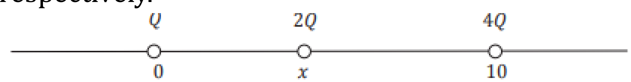
2. A point charge q sits at a corner of a cube of side a, as shown in the figure on the right. The flux of the electric field vector through the shaded side is **[TIFR 2013]**



(a) $\frac{q}{8\varepsilon_0}$ (b) $\frac{q}{16\varepsilon_0}$
(c) $\frac{q}{24\varepsilon_0}$ (d) $\frac{q}{6\varepsilon_0}$

3. In an ionization experiment conducted in the laboratory, different singly charged positive ions are produced and accelerated simultaneously using a uniform electric field along the x-axis. If we need to determine the masses of various ions produced, which of the following methods will NOT work **[TIFR 2016]**
(a) Detect them at a fixed distance from the interaction point along x-axis and measure their time of arrival.
(b) Apply a uniform magnetic field along y-axis and measure the deviation.
(c) Apply a uniform electric field along y-axis and measure the deviation.
(d) Apply a uniform electric field along y-axis and a (variable) uniform magnetic field along z-axis simultaneously and note the zero deviation.

4. Three positively charged particles lie on a straight line at positions $0, x$ and 10 as indicated in the figure below. Their charges are $Q, 2Q$, and $4Q$ cm respectively.



If the charges at $x = 0$ and $x = 10$ are fixed and the charge at x is movable, the system will be in equilibrium when $x =$ **[TIFR 2016]**
(a) 8 (b) 2
(c) 20/3 (d) 10/3

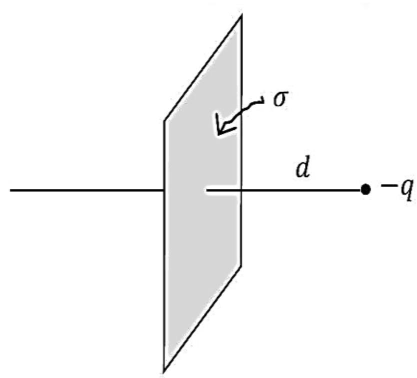
5. A common model for the distribution of charge in a hydrogen atom has a point-like proton of charge $+q_0$ at the centre and an electron with a static charge density distribution

$$\rho(r) = -\frac{q_0}{\pi a^3} e^{-2r/a}$$

where a is a constant. The electric field $\vec{E}$ at $r = a$ due to this system of charges will be **[TIFR 2017]**

(a) $-\frac{5q_0}{4\pi\epsilon_0 e^2 a^2}\hat{r}$ (b) $-\frac{5q_0}{4\pi\epsilon_0 e a^2}\hat{r}$
(c) $\frac{5q_0}{4\pi\epsilon_0 e^2 a^2}\hat{r}$ (d) $\frac{3q_0}{4\pi\epsilon_0 e^2 a^2}\hat{r}$

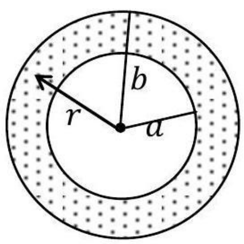
6. Consider an infinite plane with a uniform positive charge density σ as shown below.



A negative point charge $-q$ with mass m is held at rest at a distance d from the sheet and released. It

will then undergo oscillatory motion. What is the time period of this oscillation?
[You may assume that the point charge can move freely though the charged plane without disturbing the charge density.]. **[TIFR 2018]**

7. Consider two concentric spheres of radii a and b, where $a < b$ (see figure). The (shaded) space between the two spheres is filled uniformly with total charge Q. The electric field at any point between the two spheres at distance r from the centre is given by **[TIFR 2020]**



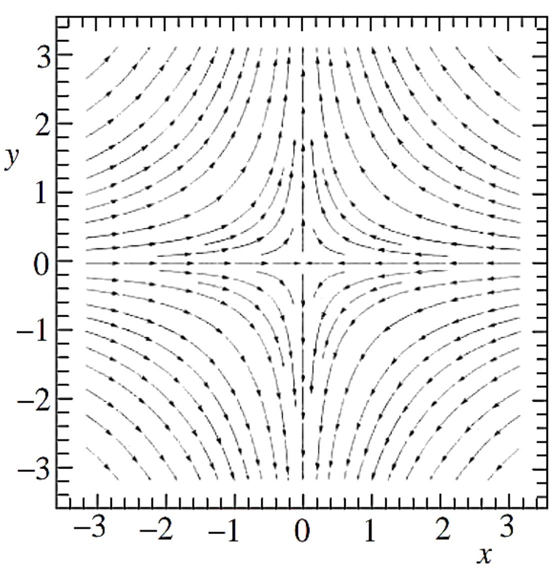
(a) $\frac{Q}{4\pi\epsilon_0}\frac{r^3-a^3}{r^2(b^3-a^3)}$ (b) $\frac{Q}{4\pi\epsilon_0}\frac{1}{r^2}$

(c) $\frac{Q}{4\pi\epsilon_0}\left(\frac{b}{r^4}-\frac{a}{r^4}\right)^{2/3}$ (d) zero

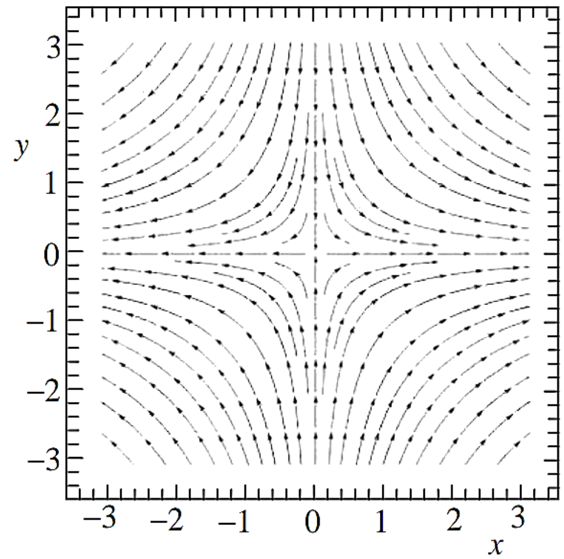
8. A two-dimensional electrostatic field is defined as
$\vec{E}(x,y) = -x\hat{\imath} + y\hat{\jmath}$

A correct diagram for the lines of force is **[TIFR 2020]**

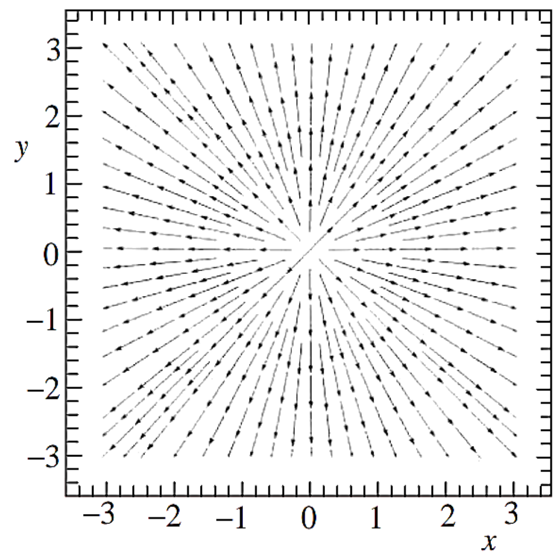
(a)



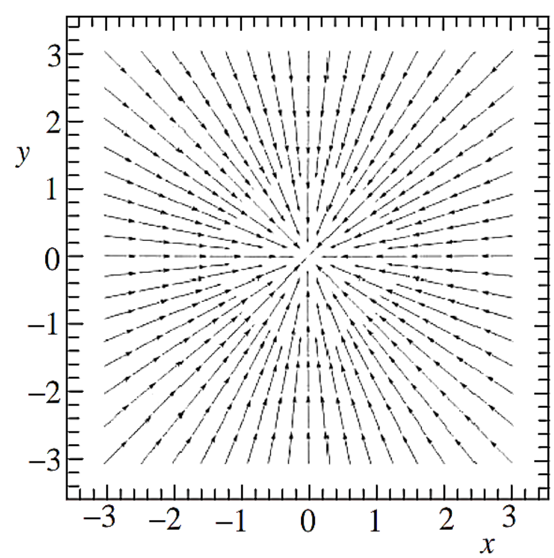
(b)



(c)



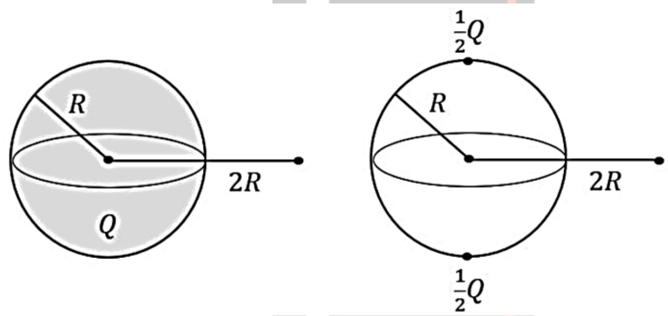
(d)



9. A falling raindrop, spherical in shape, with a diameter of 1μm, acquires a uniform negative charge due to friction with air. The electric field at a distance of 10μm from the surface of the droplet is measured to be 101 V m^{-1}.
The number of excess electrons acquired by the droplet is **[TIFR 2022]**

(a) 7 (b) 7.02×10^6
(c) 1.4×10^{23} (d) 1414

10. Consider a solid sphere of radius R with a total charge Q distributed uniformly throughout its volume (see figure, left). The electric field measured at a distance $x = 2R$ from the centre of the sphere along the equatorial plane is found to be E_1.



Next, the same charge is distributed differently, such that Q/2 is concentrated at the north pole, and the remaining Q/2 is concentrated at the south pole (see figure, right). The electric field is measured again at the same point on the equatorial plane and found to be E_2.
The value of E_2/E_1 is **[TIFR 2023]**

(a) $\frac{8}{5\sqrt{5}}$ (b) 1
(c) $\frac{2}{\sqrt{5}}$ (d) $\frac{4}{5}$

11. A thin spherical shell of radius R has a constant surface charge density σ. This shell is cut symmetrically into two pieces. What is the electrostatic force between the two halves? **[TIFR 2024]**

(a) $\frac{\pi}{2}\frac{\sigma^2 R^2}{\varepsilon_0}$ (b) $\frac{\pi}{4}\frac{\sigma^2 R^2}{\varepsilon_0}$
(c) $\pi\frac{\sigma^2 R^2}{\varepsilon_0}$ (d) $2\pi\frac{\sigma^2 R^2}{\varepsilon_0}$

❖ ANSWER KEY

❖ CSIR-NET PYQ				
1. c	2. c	3. a	4. c	5. b
6. b	7. c	8. c	9. a	10. c
11. a	12. b			

❖ GATE PYQ				
1. b	2. b	3. c	4. a	5. a
6. a	7. b	8. b	9. d	10. 2.4-2.6
11. 0.36to0.4	12. acd	13. 4		

❖ JEST PYQ				
1. c	2. d	3. a	4. b	5. b
6. 0020	7. 0101	8. d	9. d	10. a
11. c	12. b	13. b	14. d	15. b
16. b				

❖ TIFR PYQ				
1. a	2. c	3. c	4. d	5. c
6.	7. a	8. a	9. a	10. a
11. a				

❖ EMT 02 : Electric Potential & Conductor

❖ CSIR-NET PYQ's

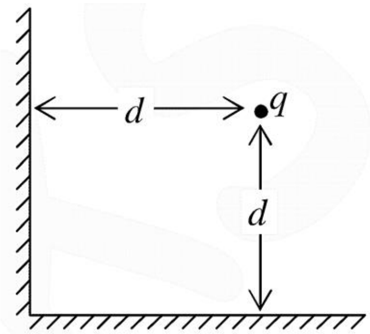
1. Consider an infinite line charge with linear charge density λ. At a distance r from the line, the electrostatic potential has the form **[CSIR NET 2008]**

(a) $\frac{\lambda a}{4\pi\varepsilon_0 r}$
(b) $\frac{\lambda}{2\pi\varepsilon_0}\exp\left(-\frac{r}{a}\right)$
(c) $\frac{-\lambda}{2\pi\varepsilon_0}\ln\left(\frac{r}{a}\right)$
(d) $\frac{\lambda}{4\pi\varepsilon_0}\frac{r}{a}$

2. A point charge ' q ' of mass ' m ' is kept at a distance ' d ' below a grounded infinite conducting sheet which lies in the xy-plane. What is the value of ' d ' for which the charge remains stationary? **[CSIR DEC 2012]**

(a) $q/4\sqrt{mg\pi\varepsilon_0}$
(b) $q/\sqrt{mg\pi\varepsilon_0}$
(c) There is no finite value of ' d '
(d) $\sqrt{mg\pi\varepsilon_0}/q$

3. A point charge q is placed symmetrically at a distance d from two perpendicularly placed grounded conducting infinite plates as shown in the figure. The net force on the charge (in units of $1/4\pi\epsilon_0$) is **[CSIR DEC 2013]**



(a) $\frac{q^2}{8d^2}(2\sqrt{2}-1)$ away from the corner
(b) $\frac{q^2}{8d^2}(2\sqrt{2}-1)$ towards the corner
(c) $\frac{q^2}{2\sqrt{2}d^2}$ towards the corner
(d) $\frac{3q^2}{8d^2}$ away from the corner

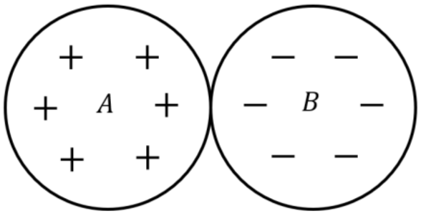
4. A charged particle is at a distance d from an infinite conducting plane maintained at zero potential. When released from rest, the particle reaches a speed u at a distance d/2 from the plane. At what distance from the plane will the particle reach the speed 2u ? **[NET June 2014]**

(a) d/6
(b) $d/3$
(c) d/4
(d) $d/5$

5. A charge (-e) is placed in vacuum at the point (d, 0,0), where d > 0. The region $x \leq 0$ is filled uniformly with a metal. The electric field at the point $\left(\frac{d}{2},0,0\right)$ is **[CSIR JUNE 2014]**

(a) $-\frac{10e}{9\pi\varepsilon_0 d^2}(1,0,0)$
(b) $\frac{10e}{9\pi\varepsilon_0 d^2}(1,0,0)$
(c) $\frac{e}{\pi\varepsilon_0 d^2}(1,0,0)$
(d) $-\frac{e}{\pi\varepsilon_0 d^2}(1,0,0)$

6. Two uniformly charged insulating solid spheres A and B, both of radius a, carry total charges $+Q$ and $-Q$, respectively. The spheres are placed touching each other as shown in the figure.



If the potential at the center of the sphere A is V_A and that at the center of B is V_B, then the difference $V_A - V_B$ is **[CSIR DEC 2016]**

(a) $\frac{Q}{4\pi\varepsilon_0 a}$ (b) $\frac{-Q}{2\pi\varepsilon_0 a}$

(c) $\frac{Q}{2\pi\varepsilon_0 a}$ (d) $\frac{-Q}{4\pi\varepsilon_0 a}$

7. The yz-plane at $x = 0$ carries a uniform surface charge density σ. A unit point charge is moved from a point $(\delta, 0,0)$ on one side of the plane to a point $(-\delta, 0,0)$ on the other side. If δ is an infinitesimally small positive number, the work done in moving the charge is **[CSIR DEC 2019]**

(a) 0 (b) $\frac{\sigma}{\varepsilon_0}\delta$

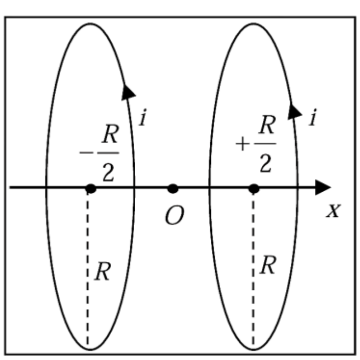
(c) $-\frac{\sigma}{\varepsilon_0}\delta$ (d) $\frac{2\sigma}{\varepsilon_0}\delta$

8. Two small metallic objects are embedded in a weakly conducting medium of conductivity σ and dielectric constant ε. A battery connected between them leads to a potential difference V_0. It is subsequently disconnected at time $t = 0$. The potential difference at later time t is **[NET June 2022]**

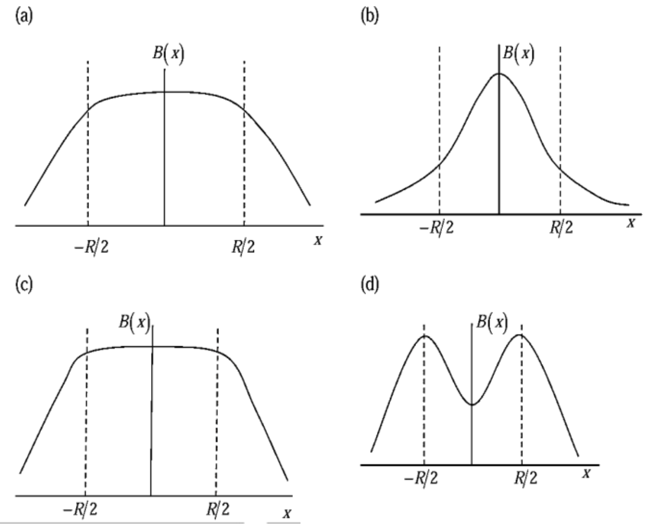
(a) $V_0 e^{-I\sigma/4\varepsilon}$ (b) $V_0 e^{-t\sigma/2\varepsilon}$

(c) $V_0 e^{-3\kappa\sigma/4\varepsilon}$ (d) $V_0 e^{-t\sigma/\varepsilon}$

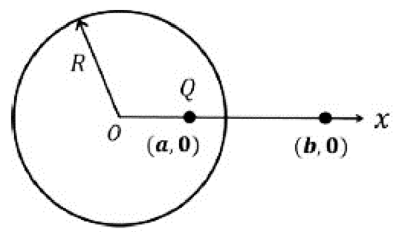
9. Two parallel conducting rings, both of radius R, are separated by a distance R. The planes of the rings are perpendicular to the line joining their centres, which is taken to be the x-axis.



If both the rings carry the same current i along the same direction, the magnitude of the magnetic field along the x axis is best represented by **[CSIR JUNE 2022]**



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



The electric field at a distance $b > R$ along the x-axis from the centre is **[CSIR DEC 2023]**

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

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

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

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

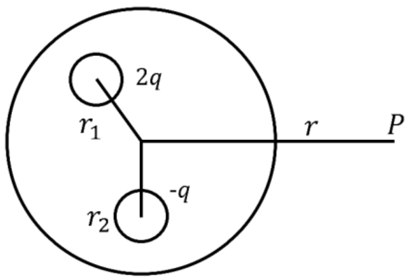
11. A one-dimensional infinite long wire with uniform linear charge density λ, is placed along the z-axis. The potential difference $\delta V = V(\rho + a) - V(\rho)$, between two points at radial distances $\rho + a$ and ρ from the z-axis, where $a \ll \rho$, is closest to **[CSIR DEC 2023]**

(a) $-\frac{\lambda}{2\pi\varepsilon_0}\frac{a^2}{\rho^2}$ (b) $-\frac{\lambda}{2\pi\varepsilon_0}\frac{a}{\rho}$

(c) $\frac{\lambda}{2\pi\varepsilon_0}\frac{a}{\rho}$ (d) $\frac{\lambda}{2\pi\varepsilon_0}\frac{a^2}{\rho^2}$

❖ GATE PYQ'S

1. A spherical conductor of radius R has two cavities centered at r_1 and r_2 respectively from the centre of the conductor. The cavities contain point charges $+2q$ and $-q$ at their respective centers as shown in the figure. The magnitude of the electric field at a point P is : **[GATE 1996]**



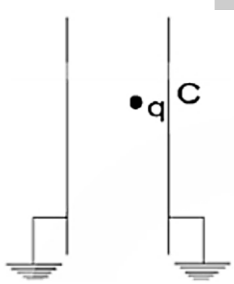
(a) $\frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$

(b) $\frac{1}{4\pi\varepsilon_0}\left[\left(\frac{2q}{(r-r_1)^2}\right)^2+\left(\frac{-q}{(r-r_2)^2}\right)^2\right]^{1/2}$

(c) $\frac{1}{4\pi\varepsilon_0}\frac{q}{(r-r_1-r_2)^2}$

(d) $\frac{1}{4\pi\varepsilon_0}\frac{q}{(r-r_1)^2+(r-r_2)^2}$

2. A point charge q is kept at the mid-point between two large parallel grounded conducting plates. Assume no gravity. The charge is displaced a little towards the right plate. The charge will now, **[GATE 2000]**



(a) Stay where it is
(b) Move towards the right plate
(c) Move towards the left plate
(d) Oscillate between the plates

3. The scalar potential corresponding to the force field $\vec{F} = \hat{\imath}(y+z)$ **[GATE 2002]**

(a) is $y^2/2$ (b) is 1
(c) is zero (d) does not exist

4. A conducting sphere of radius R has charge $+Q$ on its surface. If the charge on the sphere is doubled and its radius is halved, the energy associated with the electric field will be: **[GATE 2004]**

(a) Increase four times (b) Increase eight times
(c) Remain the same (d) Decrease four times

5. A charge $+q$ is kept at a distance of $2R$ from the centre of a grounded conducting sphere of radius R. The image charge and its distance from the centre are, respectively **[GATE 2004]**

(a) $-\frac{q}{2}$ and $\frac{R}{2}$ (b) $-\frac{q}{2}$ and $\frac{R}{4}$
(c) $-q$ and $\frac{R}{2}$ (d) $+\frac{q}{2}$ and $\frac{R}{2}$

6. The work done in bringing a charge $+q$ from infinity in free space, to a position at a distance d in front of a semi-infinite grounded metal surface is **[GATE 2005]**

(a) $-\frac{q^2}{4\pi\varepsilon_0(d)}$ (b) $-\frac{q^2}{4\pi\varepsilon_0(2d)}$
(c) $-\frac{q^2}{4\pi\varepsilon_0(4d)}$ (d) $-\frac{q^2}{4\pi\varepsilon_0(6d)}$

7. A sphere of radius R has uniform volume charge density. The electric potential at a point $r(r<R)$ is **[GATE 2006]**

(a) due to the charge inside a sphere of radius r only
(b) due to the entire charge of the sphere
(c) due to charge in the spherical shell of inner and outer radii r and R, only
(d) independent of r

8. At time $t=0$, a charge distribution $\rho(\vec{r},0)$ exist within an ideal homogeneous conductor of permittivity ε and conductivity σ. At a later time $\rho(\vec{r},t)$ is given by **[GATE 2008]**

(a) $\rho(\vec{r},t)=\rho(\vec{r},0)\exp\left(-\frac{\sigma t}{\varepsilon}\right)$

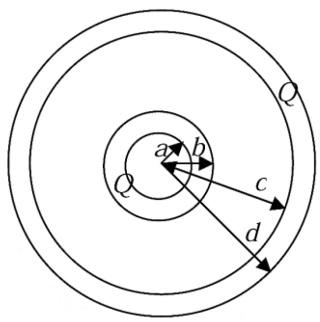
(b) $\rho(\vec{r},t)=\frac{\rho(\vec{r},0)}{1+(\sigma t/\varepsilon)^2}$

(c) $\rho(\vec{r},t) = \rho(\vec{r},0)\exp\left[-\left(\frac{\sigma t}{\varepsilon}\right)^2\right]$

(d) $\rho(\vec{r},t) = \rho(\vec{r},0)\frac{\varepsilon}{\sigma t}\sin\left(\frac{\sigma t}{\varepsilon}\right)$

Common data for Q. 9 and Q.10.

Consider two concentric conducting spherical shells with inner and outer radii a, b and c, d as shown in the figure. Both the shells are given Q amount of positive charges



9. The electric field in different regions are : **[GATE 2008]**

(a) $\vec{E} = 0$ for $r < a$; $\vec{E} = \frac{-Q}{4\pi\varepsilon_0 r^2}\hat{r}$ for $a < r < b$; $\vec{E} = 0$ for $\mathrm{b} < \mathrm{r} < \mathrm{c}$; $\vec{\mathrm{E}} = \frac{\mathrm{Q}}{4\pi\varepsilon_0 \mathrm{r}^2}\hat{\mathrm{r}}$ for $\mathrm{r} > \mathrm{d}$

(b) $\vec{\mathrm{E}} = \frac{-Q}{4\pi\varepsilon_0 r^2}\hat{\mathrm{r}}$ for $\mathrm{r} < \mathrm{a}$; $\vec{\mathrm{E}} = 0$ for $\mathrm{a} < \mathrm{r} < \mathrm{b}$; $\vec{\mathrm{E}} = \frac{Q}{4\pi\varepsilon_0 \mathrm{r}^2}\hat{\mathrm{r}}$ for $\mathrm{b} < \mathrm{r} < \mathrm{c}$; $\vec{\mathrm{E}} = \frac{\mathrm{Q}}{4\pi\varepsilon_0 \mathrm{r}^2}\hat{\mathrm{r}}$ for $\mathrm{r} < \mathrm{d}$

(c) $\vec{\mathrm{E}} = \frac{-Q}{4\pi\varepsilon_0 \mathrm{r}^2}\hat{\mathrm{r}}$ for $\mathrm{r} < \mathrm{a}$; $\vec{\mathrm{E}} = 0$ for $\mathrm{a} < \mathrm{r} < \mathrm{b}$; $\vec{\mathrm{E}} = 0$ for $\mathrm{b} < \mathrm{r} < \mathrm{c}$; $\dot{\mathrm{E}} = \frac{2\mathrm{Q}}{4\pi\varepsilon_0 \mathrm{r}^2}\hat{\mathrm{r}}$ for $\mathrm{r} > \mathrm{d}$

(d) $\vec{E} = 0$ for $r < a$; $\vec{E} = 0$ for $a < r < b$; $\dot{E} = \frac{Q}{4\pi\varepsilon_0 r^2}\hat{r}$ for $b < r < c$; $\dot{E} = \frac{2Q}{4\pi\varepsilon_0 r^2}\hat{r}$ for $r > d$

10. In order to have equal surface charge densities on the outer surfaces of both the shells, the following conditions should be satisfied **[GATE 2008]**

(a) $\mathrm{d} = 4\,\mathrm{b}$ and $\mathrm{c} = 2\mathrm{a}$

(b) $-\mathrm{d} = 2\,\mathrm{b}$ and $\mathrm{c} = \sqrt{2}\mathrm{a}$

(c) $\mathrm{d} = \sqrt{2}\,\mathrm{b}$ and $\mathrm{c} > \mathrm{a}$

(d) $d > b$ and $c = \sqrt{2}a$

11. An electric charge, +Q is placed on the surface of a solid, conduction sphere of radius a. The distance measured from the centre of the sphere is denoted as r. Then : **GATE 2008]**

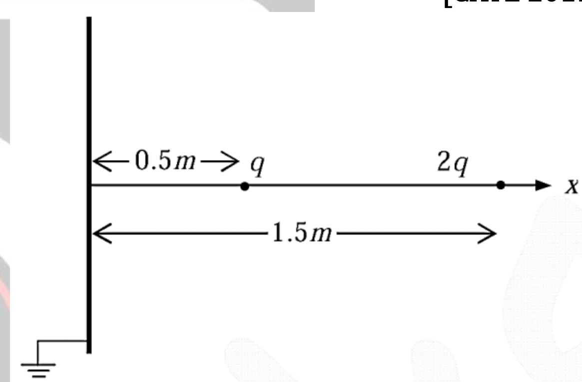
(a) The charge gets distributed uniformly through the volume of the sphere

(b) The electrostatic potential has the same value for $r < a$

(c) An equal and opposite charge gets induced in the bottom half of the sphere

(d) The electric field is given by $1/(4\pi\varepsilon_0 \mathrm{r}^2)$ for $\mathrm{r} < \mathrm{a}$

12. Two charges q and $2q$ are placed along the x-axis in front of a grounded, infinite conducting plane, as shown in the figure. They are located respectively at a distance of 0.5 m and 1.5 m from the plane. The force acting on the charge q is **[GATE 2011]**



(a) $\frac{1}{4\pi\varepsilon_0}\frac{7q^2}{2}$

(b) $\frac{1}{4\pi\varepsilon_0}2q^2$

(c) $\frac{1}{4\pi\varepsilon_0}q^2$

(d) $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2}$

13. A point charge is placed between two semi-infinite conducting plates which are inclined at an angle of 30° with respect to each other. The number of image charges is **[GATE 2015]**

14. Identical charges q are placed at five vertices of a regular hexagon of side a. The magnitude of the electric field and the electrostatic potential at the centre of the hexagon are respectively **[GATE 2017]**

(a) 0,0

(b) $\frac{q}{4\pi\varepsilon_0 a^2}, \frac{q}{4\pi\varepsilon_0 a}$

(c) $\frac{q}{4\pi\varepsilon_0 a^2}, \frac{5q}{4\pi\varepsilon_0 a}$

(d) $\frac{\sqrt{5}q}{4\pi\varepsilon_0 a^2}, \frac{\sqrt{5}q}{4\pi\varepsilon_0 a}$

15. A uniform volume charge density is placed inside a conductor (with resistivity $10^{-2}\Omega\mathrm{m}$). The charge density becomes 1/(2.718) of its original value after time_____ femto seconds. (up to two decimal places) ($\varepsilon_0 = 8.854 \times 10^{-12}$ F/m)

[GATE 2017]

16. A conducting sphere of radius 1 m is placed in air. The maximum number of electrons that can be put on the sphere to avoid electrical breakdown is about 7×10^n, where n is an integer. The value of n is ..... Assume:

Breakdown electric field strength in air is $|\vec{E}| = 3 \times 10^6$ V/m **[GATE 2020]**

Permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-12}$ F/m

Electron charge $e = 1.60 \times 10^{-19}$C

17. Two point charges of charge $+q$ each are placed a distance $2d$ apart. A grounded solid conducting sphere of radius a is placed midway between them. Assume $a^2 \ll d^2$. Which of the following statement is/are true? **[GATE 2024]**

(a)The potential at the center of the sphere is non-zero

(b)Total induced charge on the sphere is $\left(-\frac{2aq}{d}\right)$

(c) If $a > \frac{d}{8}$, the net force acting on the charges is directed towards each other

(d) The potential at the surface of the sphere is zero

❖ JEST PYQ

1 A point charge $+q$ placed at $(0,0,d)$ above a grounded infinite conducting plane defined by $z = 0$. There are no charges present anywhere else. What is the magnitude of electric field at $(0,0,-\mathrm{d})$? **[JEST 2012]**

(a) $q/(8\pi\varepsilon_0\, \mathrm{d}^2)$ (b) $-\infty$

(c) 0 (d) $\frac{q}{(16\pi\varepsilon_0\, \mathrm{d}^2)}$

2 A point charge q of mass m is released from rest at a distance d from an infinite grounded conducting plane (ignore gravity). How long does it takes for the charge to hit the plane?

[JEST 2016]

(a) $\frac{\sqrt{2\pi^3\epsilon_0 m d^3}}{q}$ (b) $\frac{\sqrt{2\pi^3\epsilon_0 m d}}{q}$

(c) $\frac{\sqrt{\pi^3\epsilon_0 m d^3}}{q}$ (d) $\frac{\sqrt{\pi^3\epsilon_0 m d}}{q}$

3 Consider a grounded conducting plane which is infinitely extended perpendicular to the $y-$ axis at $y = 0$. If an infinite line of charge per unit length λ runs parallel to x-axis at $y = d$, then surface charge density on the conducting plane is

[JEST 2017]

(a) $\frac{-\lambda d}{(x^2+d^2+z^2)}$ (b) $\frac{-\lambda d}{(x^2+d^2+z^2)}$

(c) $\frac{-\lambda d}{\pi(x^2+d^2+z^2)}$ (d) $\frac{-\lambda d}{2\pi(x^2+d^2+z^2)}$

4 A solid, insulating sphere of radius 1 cm has charge 10^{-7}C distributed uniformly over its volume. It is surrounded concentrically by a conducting thick spherical shell of inner radius 2 cm, outer radius 2.5 cm and is charged with -2×10^{-7}C. What is the electrostatic potential in Volts on the surface of the sphere?

[JEST 2017]

5 An apparatus is made from two concentric conducting cylinders of radii a and b respectively, where a < b. the inner cylinder is grounded and the outer cylinder is at a positive potential V. the space between the cylinders has a uniform magnetic field H directed along the axis of the cylinders. Electrons leave the inner cylinder with zero speed and travel towards the outer cylinder. What is the threshold value of V below which the electrons cannot reach the outer cylinder?

[JEST 2018]

(a) $\frac{eH^2(b^2-a^2)}{8mc^2}$ (b) $\frac{eH^2(b^2-a^2)^2}{8mc^2b^2}$

(c) $\frac{eH^2(b^2-a^2)^2}{8mc^2a^2}$ (d) $\frac{eH^2b\sqrt{(b^2-a^2)}}{8mc^2}$

6 Consider two concentric spherical metal shells of radii r_1 and $r_2 (r_2 > r_1)$. The outer shell has a charge q and the inner shell is grounded. What is the charge on the inner shell? **[JEST 2019]**

(a) $\frac{r_1}{r_2}q$ (b) $\frac{r_1}{r_2}q$

(c) 0 (d) $\frac{r_2}{r_1}q$

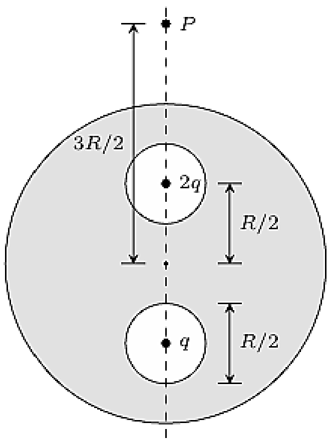
7 A point charge q is kept d distance above an infinite conducting plane. What is the energy stored in the configuration?

[JEST 2022]

(a) $-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{4d}$ (b) $-\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2d}$

(c) $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{2d}$ (d) $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{4d}$

8 Two point charges $2q$ and q are placed inside two spherical cavities of equal radii $R/4$ in a solid conducting sphere of radius R, as shown in the figure. The cavities are placed along a diagonal at distances $R/2$ from the center of the solid sphere. The electrical potential at a point P, $3R/2$ distance away from the center along the same diagonal, is given by **[JEST 2022]**



(a) $\frac{1}{4\pi\epsilon_\circ}\frac{2q}{R}$ (b) $\frac{1}{4\pi\epsilon_\circ}\frac{5q}{2R}$

(c) 0 (d) $\frac{1}{4\pi\epsilon_\circ}\frac{3q}{R}$

9 A point charge q is fixed at point A inside a hollow grounded conducting spherical shell of radius R, at a distance a from the center C. The force on the sphere due to the presence of the point charge is **[JEST 2022]**

(a) $\frac{1}{4\pi\epsilon_0}\frac{q^2aR}{(R+a)^2(R-a)^2}$ in magnitude and along $\overrightarrow{AC}$.

(b) $\frac{1}{4\pi\epsilon_0}\frac{q^2aR}{(R+a)^2(R-a)^2}$ in magnitude and along $\overrightarrow{CA}$.

(c) $\frac{1}{4\pi\epsilon_0}\frac{q^2}{(R-a)^2}$ in magnitude and along $\overrightarrow{AC}$.

(d) $\frac{1}{4\pi\epsilon_0}\frac{q^2}{(R-a)^2}$ in magnitude and along $\overrightarrow{CA}$.

10 Calculate the magnitude of the force experienced by a point charge $+q$ placed at a distance d from the center of a grounded conducting sphere of radius $a(< d)$.

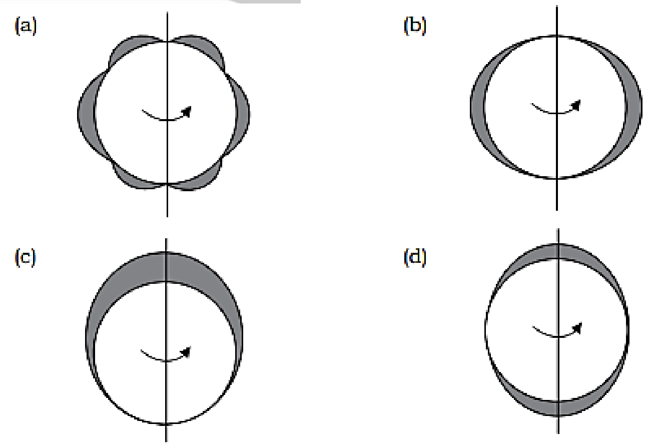
[JEST 2023]

(a) $\frac{q^2ad}{4\pi\epsilon_0(d^2-a^2)^2}$ (b) $\frac{q^2}{4\pi\epsilon_0(d-a)^2}$

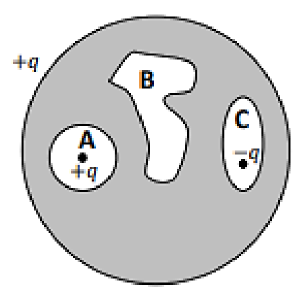
(c) $\frac{q^2}{4\pi\epsilon_0 d^2}$ (d) 0

❖ TIFR PYQ

1 A spherical conductor, carrying a total charge Q, spins uniformly and very rapidly about an axis coinciding with one of its diameters. In the diagrams given below, the equilibrium charge density on its surface is represented by the thickness of the shaded region. Which of these diagrams is correct? **[TIFR 2014]**

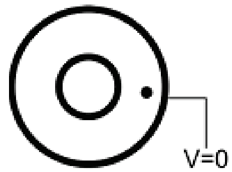


2 A solid spherical conductor encloses 3 cavities, a cross-section of which are as shown in the figure. A net charge $+q$ resides on the outer surface of the conductor. Cavities A and C contain point charges $+q$ and $-q$, respectively.
The net charges on the surfaces of these cavities are **[TIFR 2015]**

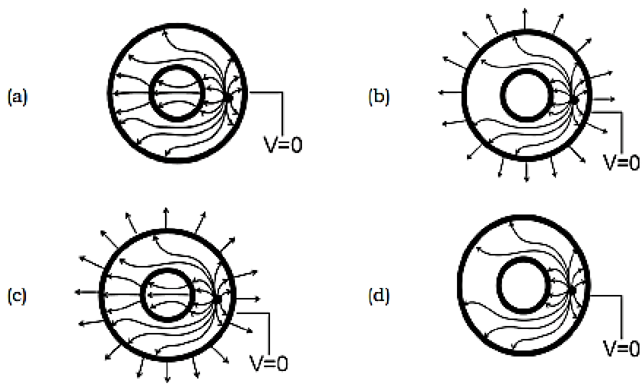


(a) $A=-q, B=q, C=0$
(b) $A=-q, B=0, C=-q$
(c) $A=+q, B=0, C=-q$
(d) $A=-q, B=0, C=+q$

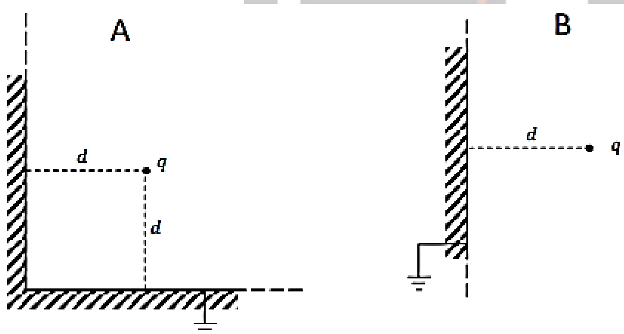
3 Two long hollow conducting cylinders, each of height h, are placed concentrically on the ground, as shown in the figure (top view). The outer cylinder is grounded, while the inner cylinder is insulated. A positive charge (the black dot in the figure) is placed between the cylinders at a height $h/2$ from the ground.



Which of the following figures gives the most accurate representation (top view) of the lines of force? **[TIFR 2017]**

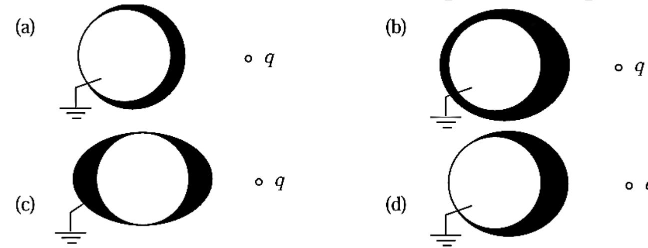


4 Consider the following situations.

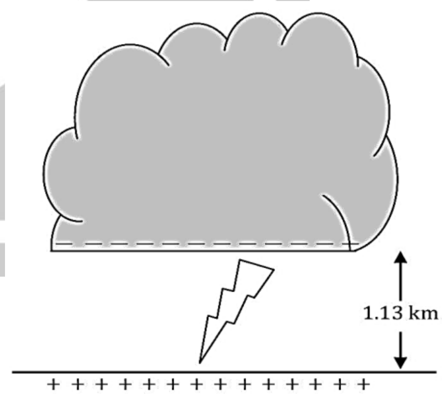


In situation A, two semi-infinite earthed conducting planes meet at right-angles. A point charge q, is placed at a distance d from each plane, as shown in the figure A. The magnitude of the force exerted on the charge q is denoted F_A.
In situation B, the same charge q is kept at the same distance d from an infinite earthed conducting plane, as shown in the figure B. The magnitude of the force exerted on the charge q is denoted F_B.
Find the numerical ratio F_A/F_B **[TIFR 2017]**

5 A point charge $q < 0$ is brought in front of a grounded conducting sphere. If the induced charge density on the sphere is plotted such that that the thickness of the black shading is proportional to the charge density, the correct plot will most closely resemble **[TIFR 2019]**



6 A monsoon cloud has a flat bottom of surface area 125 km^2. It floats horizontally over the ground at a level such that the base of the cloud is 1.13 km above the ground (see figure). Due to friction with the air below, the base of the cloud acquires a uniform electric charge density. This keeps increasing slowly with time.
When the uniform electric field below the cloud reaches the value $2.4\mathrm{MVm}^{-1}$ a lightning discharge occurs, and the entire charge of the cloud passes to the Earth below - which, in this case, behaves like a grounded conductor.

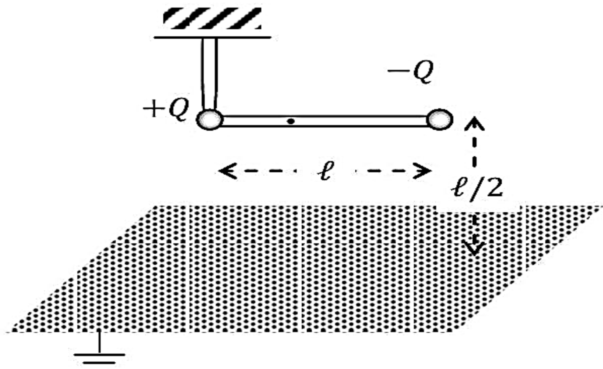


Neglecting edge effects and inhomogeneities inside the cloud and the air below, the energy released in this lightning discharge can be estimated, in kilowatt-hours (kWh), as about **[TIFR 2019]**

(a) 10^9 (b) 10^5
(c) 10 (d) 10^{-1}

7 A light rigid insulating rod of length ℓ is suspended horizontally from a rigid frictionless

pivot at one of the ends (see figure). At a vertical distance h below the rod there is an infinite plane conducting plane, which is grounded.
If two small, light spherical conductors are attached at the ends of the rod and given charges $+Q$ and $-Q$ as indicated in the figure, the torque on the rod will be **[TIFR 2020]**

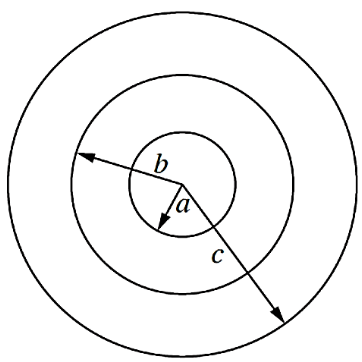


(a) $\frac{Q^2}{4\pi\epsilon_0\ell}\hat{k}$ (b) $-\frac{Q^2}{4\pi\epsilon_0\ell}\hat{k}$

(c) $\frac{(4-\sqrt{2})}{16\pi\epsilon_0}\frac{Q^2}{\ell}\hat{k}$ (d) $-\frac{(4-\sqrt{2})}{16\pi\epsilon_0}\frac{Q^2}{\ell}\hat{k}$

8 Three concentric spherical metallic shells with radii $c > b > a$ (see figure) are charged with charges e_e, e_b, and e_o respectively. The outermost shell (of radius c) is at a potential V_c^0.

[TIFR 2021]



Now, the innermost shell (of radius a) is grounded, and the potential of the outermost shell becomes V_c^g The difference $V_c^g - V_c^0$ will be

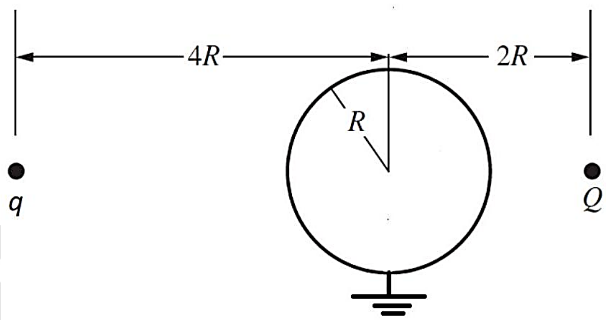
(a) $-\frac{1}{4\pi\varepsilon_0}\frac{a}{c}\left(\frac{e_c}{c-a}+\frac{e_b}{b}\right)$

(b) $-\frac{1}{4\pi\varepsilon_0}\frac{c}{a}\left(\frac{e_a}{a}+\frac{e_b}{b}+\frac{e_c}{c}\right)$

(c) $-\frac{1}{4\pi\varepsilon_0}\frac{c}{a}\left(\frac{e_a}{c}+\frac{e_b}{b}+\frac{e_c}{a}\right)$

(d) $-\frac{1}{4\pi\varepsilon_0}\frac{a}{c}\left(\frac{e_a}{a}+\frac{e_b}{b}+\frac{e_c}{c}\right)$

9 Two positive charges Q and q are placed on opposite sides of a grounded sphere of radius R at distances of $2R$ and $4R$ respectively, from the centre of the sphere, as shown in the diagram below.



The charge q feels a force AWAY from the centre of the sphere if **[TIFR 2021]**

(a) $\frac{q}{Q} < \frac{25}{36}$ (b) $\frac{q}{Q} < \frac{25}{16}$

(c) $\frac{q}{Q} < \frac{25}{144}$ (d) $\frac{q}{Q} < \frac{49}{144}$

10 Three concentric spherical metallic shells with radii $c > b > a$ (see figure) are charged with charges e_c, e_b, and e_a respectively. The outermost shell (of radius c) is at a potential V_c^0. Now, the innermost shell (of radius a) is grounded, and the potential of the outermost shell becomes V_c^g.The difference $V_c^g - V_c^0$ will be

[TIFR 2021]

11 A falling raindrop, spherical in shape, with a diameter of 1μm, acquires a uniform negative charge due to friction with air. The electric field at a distance of 10μm from the surface of the droplet is measured to be 101Vm^{-1}. The number of excess electrons acquired by the droplet is

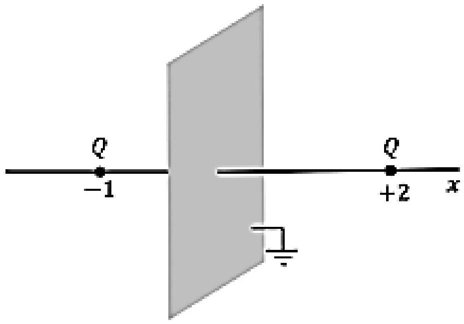
(a) 7 (b) 7.02×10^6

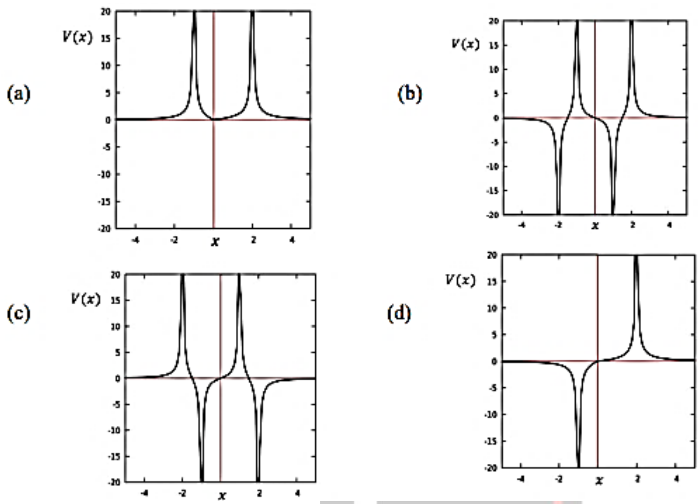
(c) 1.4×10^{23} (d) 1414

[TIFR 2022]

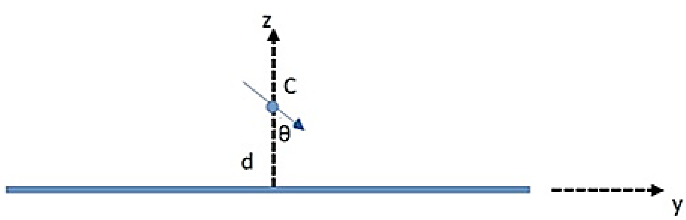
12 Two equal positive point charges $Q = +1$ are placed on either side of an x-axis normal to a grounded infinite conducting plane at distances of $x = +2$ units and $x = -1$ unit respectively (see figure) w.r.t. the point of intersection of the axis

with the conducting plane as origin. The electrostatic potential along the axis will correspond to the graph in **[TIFR 2022]**





13. Consider an electric dipole of strength p placed near a grounded infinite conducting sheet in the xy plane at a distance d from it in the z direction as shown below. The centre of the dipole (C) is fixed to a pivot but the dipole is free to rotate about the x axis (coming out of the page). **[TIFR 2024]**



What is the magnitude of the torque on the dipole when the angle between the dipole and the positive z axis is $(\pi - \theta)$ as shown?

(a) $\tau = \frac{p^2}{(64\pi\epsilon_0 d^3)}\sin(2\theta)$

(b) $\tau = \frac{p^2}{(16\pi\epsilon_0 d^3)}\cos(2\theta)$

(c) $\tau = \frac{p^2}{(64\pi\epsilon_0 d^3)}\cos(\theta)$

(d) $\tau = \frac{p^2}{(16\pi\epsilon_0 d^3)}\sin(\theta)$

❖ Answer Key

CSIR-NET PYQ				
1. c	2. b	3. b	4. d	5. b
6. c	7. a	8. d	9. a	
10. a	11. b			
GATE PYQ				
1. a	2. b	3. d	4. b	5. a
6. c	7. b	8. a	9. d	10. c
11. b	12. a	13. 11	14. c	15. 88.50
16. 14	17. bcd			
JEST PYQ				
1. c	2. a	3. c	4. 9000	5. b
6. a	7. a	8. a	9. a	10. a
TIFR PYQ				
1. b	2. d	3. c	4.	5. b
6. a	7. d	8. d	9. c	10.
11. a	12. a	13. a		

❖ EMT 03 : Laplace & Poisson's Equations , Dielectrics , Capacitor

❖ CSIR-NET PYQ's

1. Consider a parallel plate capacitor connected to an AC voltage source (as shown in fig.1). A conductin slab is introduced in the space between the plates from above (as shown in fig.2)

[NET 2008]

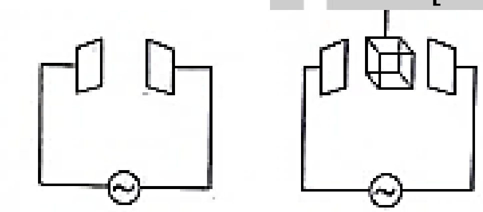


Fig. 1 Fig. 2

The capacitance of the parallel plate capacitor.

(a) Goes to zero.

(b) Increases to a finite value

(c)decreases to a non zero value

(d) becomes infinite

2. A dielectric sphere of radius R carries a polarization $\vec{P} = k\vec{r}$ throughout its volume. The volume charge density ρ_b of the bound charges is **[NET June 2009]**

(a) $-3k$ (b) 3k

(c)k (d) k

3. The electrostatic potential V(x, y) in free space in a region where the charge density ρ is zero is given by $V(x,y) = 4e^{2x} + f(x) - 3y^2$. Given that the x-component of the electric field, E_x, and V are zero at the origin, $f(x)$ is:

[NET June 2011]

(a) $3x^2 - 4e^{2x} + 8x$ (b) $3x^2 - 4e^{2x} + 16x$

(c) $4e^{2x} - 8$ (d)$3x^2 - 4e^{2x}$

4. A static, spherically symmetric charge distribution is given by $\rho(r) = \frac{A}{r}e^{-kr}$ where A and k are positive constants. The electrostatic potential corresponding to this charge distribution varies with r as

[CSIR JUNE 2011]

(a) re^{-kr} (b) $\frac{1}{r}e^{-kr}$

(c) $\frac{1}{r^2}e^{-k}$ (d) $\frac{1}{r}(1 - e^{-kr})$

5. If the electrostatic potential $V(r,\theta,\phi)$ in a charge free region has the form $V(r,\theta,\phi) = f(r)\cos\,\theta$, then the functional form of $f(r)$ (in the following a and b are constants) is **[NET Dec, 2013]**

(a) $ar^2 + \frac{b}{r}$ (b) $ar + \frac{b}{r^2}$

(c) $ar + \frac{b}{r}$ (d) $a\ln\left(\frac{r}{b}\right)$

6. If the electrostatic potential in spherical polar coordinates is $\varphi(r) = \varphi_0 e^{-r/r_0}$ where φ_0 and r_0 are constants, then the charge density at a distance $r = r_0$ will be

[NET June 2014]

(a) $\frac{\varepsilon_0\varphi_0}{er_0^2}$ (b) $\frac{\varepsilon\varepsilon_0\varphi_0}{2r_0^2}$

(c) $-\frac{\varepsilon_0\varphi_0}{er_0^2}$ (d) $-\frac{2\varepsilon\varepsilon_0\varphi_0}{r_0^2}$

7. A hollow metallic sphere of radius a, which is kept at a potential V_0, has a charge Q at its centre. The potential at a point outside the sphere, at a distance r from the centre, is

[CSIR DEC 2015]

(a) V_0 (b) $\frac{Q}{4\pi\epsilon_0 r} + \frac{V_0 a}{r}$

(c) $\frac{Q}{4\pi\epsilon_0 r} + \frac{V_0 a^2}{r^2}$ (d) $\frac{V_0 a}{r}$

8. Two parallel plate capacitors, separated by distances x and $1{,}1x$ respectively, have a dielectric material of dielectric constant 3.0 inserted between the plates, and are connected to a battery of voltage V. The difference in charge on the second capacitor compared to the first is

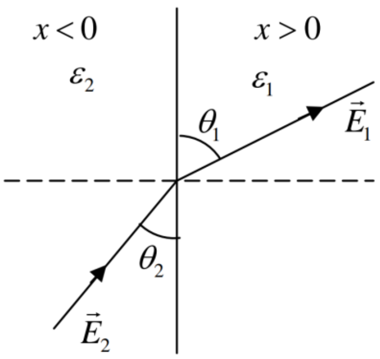
[CSIR JUNE 2016]

(a) $+66\%$ (b) $+20\%$

(c) -3.3% (d) -10%

9. The half space regions $x > 0$ and $x < 0$ are filled with dielectric media of dielectric constants ε_1 and ε_2 respectively. There is a uniform electric field in each part. In the right half, the electric field makes an angle θ_1 to the interfice. The corresponding angle θ_2 in the left half satisfies

[NET June 2016]



(a) $\varepsilon_1 \sin\,\theta_2 = \varepsilon_2 \sin\,\theta_1$

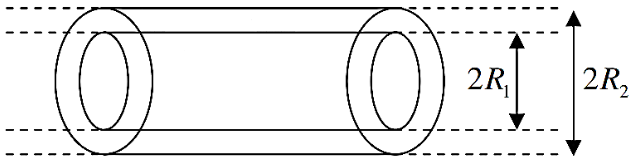
(b) $\varepsilon_1 \tan\,\theta_2 = \varepsilon_2 \tan\,\theta_1$

(c) $\varepsilon_1 \tan\,\theta_1 = \varepsilon_2 \tan\,\theta_2$

(d) $\varepsilon_1 \sin\,\theta_1 = \varepsilon_2 \sin\,\theta_2$

10. Two long hollow co-axial conducting cylinders of radii R_1 and $R_2 (R_1 < R_2)$ are placed in vacuum as shown in the figure below.

[NET June 2017]



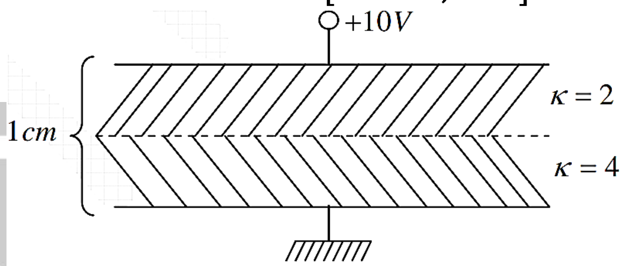
the inner cylinder carries a charge $+\lambda$ per unit length and the outer cylinder carries a charge $-\lambda$ per unit length. The electrostatic energy per unit length of this system is

(a) $\frac{\lambda^2}{\pi\varepsilon_0}\ln$ (b) $\frac{\lambda^2}{4\pi\varepsilon_0}\left(\frac{R_2^2}{R_1^2}\right)$

(c) $\frac{\lambda^2}{4\pi\varepsilon_0}\ln\left(\frac{R_2}{R_1}\right)$ (d) $\frac{\lambda^2}{2\pi\varepsilon_0}\ln\left(\frac{R_2}{R_1}\right)$

11. A parallel plate capacitor, with 1 cm separation between the plates, has two layers of dielectric with dielectric constants $\kappa = 2$ and $\kappa = 4$, as shown in the figure below. If a potentialdifference of 10 V is applied between the plates, the magnitude of the bound surface charge density (in units of $\mathrm{C/m^2}$) at the junction of the diclectrics is.

[NET Dec, 2019]

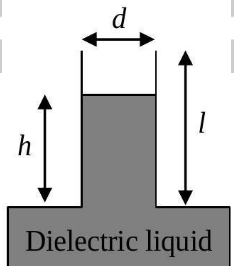


(a) $250\varepsilon_0$ (b) $2000\varepsilon_0 3$

(c) $2000\varepsilon_0$ (d) $200\varepsilon_0/3$

12. A parallel plate capacitor with rectangular plates of length l, breadth b and plate separation d, is held vertically on the surface of a dielectric liquid of dielectric constant κ and density ρ as shown in the figure. The length and breadth are large enough for edge effects to be neglected. The plates of the capacitor are kept at a constant voltage difference V. Ignoring effects of surface tension, the height h upto which the liquid level rises inside the capacitor, is

[CSIR JUNE 2020]



(a) $\frac{V^2\varepsilon_0(\kappa-1)}{\rho g b d}$ (b) $\frac{V^2\varepsilon_0(\kappa-1)}{2\rho g b^2}$

(c) $\frac{V^2\varepsilon_0(\kappa-1)}{2\rho g d^2}$ (d) $\frac{V^2\varepsilon_0(\kappa-1)}{\rho g d^2}$

13. The electric potential on the boundary of a spherical cavity of radius R as a function of the polar angle θ is $V_0 \cos^2\frac{\theta}{2}$. The charge density inside the cavity is zero everywhere. The potential at a distance $\frac{R}{2}$ from the center of the sphere is **[CSIR JUNE 2023]**

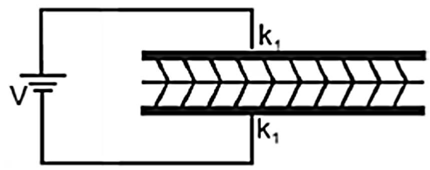
(a) $\frac{V_0}{2}\left(1 + \frac{\cos(\theta)}{2}\right)$ (b) $\frac{V_0}{2}\cos(\theta)$

(c) $\frac{V_0}{2}\left(1+\frac{Sin(\theta)}{2}\right)$ (d) $\frac{V_0}{2}\sin(\theta)$

❖ GATE PYQ's

1. The space between the plates of a parallel plate capacitor is filled with two dielectric slabs of dielectric constants k_1 and k_2 as shown in the figure. If the capacitor is charged to a potential V, then at the interface between the two dielectrics.

[GATE 2000]



(a) $\vec{E}$ is discontinuous and $\vec{D}$ is continuous
(b) $\vec{E}$ is discontinuous and $\vec{D}$ is discontinuous
(c) $\vec{E}$ is continuous and $\vec{D}$ is continuous
(d) $\vec{E}$ is continuous and $\vec{D}$ is discontinuous

2. Consider an electric field $\vec{E}$ existing in the interface between a conductor and free space. Then the electric field $\vec{E}$ is : **[GATE 2001]**
(a) External to the conductor and normal to the conductor's surface
(b) Internal to the conductor and normal to the conductor's surface
(c) External to the conductor and tangential to the conductor's surface
(d) Both external and internal to the conductor and normal to the conductor's surface

3. A coaxial cable of uniform cross-section contains an insulating material of dielectric constant 3.5. The radius of the central wire is 0.01 m and that of the sheath is 0.02 m. The capacitance per kilo meter of a cable is :

[GATE 2001]

(a) 280.5nF (b) 28.05nF
(c) 56.10nF (d)2.805nF

4. An electric field applied along the length of a long cylinder produces a polarization P. The depolarization field produced in this configuration is

[GATE 2003]

(a) $4\pi P/3$ (b) $-4\pi P/3$
(c) $2\pi P$ (d) 0

5. A conducting sphere of radius R is placed in a uniform electric field $\vec{E}_0$ directed along $+z$ axis. The electric potential for outside points is given as $V_{\text{out}} = -E_0\left(1-\frac{R^3}{r^3}\right)r\cos\theta$, where r is the distance from the centre and θ is the polar angle. The charge density on the surface of the sphere is

[GATE 2004]

(a) $3\varepsilon_0 E_0\cos\theta$ (b) $\varepsilon_0 E_0\cos\theta$
(c) $3\varepsilon_0 E_0\cos\theta$ (d) $\frac{\varepsilon_0}{3}E_0\cos\theta$

6. A conducting sphere of radius R has charge $+Q$ on its surface. If the charge on the sphere is doubled and its radius is halved, the energy associated with the electric field will

[GATE 2004]

(a) increase four times
(b) increase eight times
(b) remain the same
(d) decrease four times

7. If the electrostatic potential were given by $\phi = \phi_0(x^2+y^2+z^2)$, where ϕ_0 is constant, then the charge density giving rise to the above potential would be :

[GATE 2005]

(a) 0 (b) $-6\phi_0\varepsilon_0$
(c) $-2\phi_0\varepsilon_0$ (d) $-\frac{6\phi_0}{\varepsilon_0}$

Statement for Linked Answer Q. 8 and Q. 9 :
A dielectric sphere of radius R carries polarization $\vec{P} = kr^2\hat{r}$, where r is the distance from the centre and k is a constant. In the spherical polar coordinate system, $\hat{r}, \hat{\theta}$ and $\hat{\varphi}$ are the unit vectors.

8. The bound volume charge density inside the sphere at a distance r from the centre is

[GATE 2006]

(a) $-4k\mathrm{R}$ (b) $-4kr$
(c) $-4kr^2$ (d) $-4kr^3$

9. The electric field inside the sphere at a distance d from the centre is

[GATE 2006]

(a) $\frac{-kd^2}{\varepsilon_0}\hat{r}$ (b) $\frac{-k\mathrm{R}^2}{\varepsilon_0}\hat{r}$
(c) $\frac{-kd^2}{\varepsilon_0}\hat{\theta}$ (d) $\frac{-k\mathrm{R}^2}{\varepsilon_0}\hat{\theta}$

Statement for Linked Answer Questions 10 & 11:

A sphere of radius R carries a polarization $\vec{P} = k\vec{r}$, where k is a constant and $\vec{r}$ is measured from the centre of the sphere.

10. The bound surface and volume charge densities are given, respectively, by **[GATE 2007]**

(a) $-k|\vec{r}|$ and $3k$ (b) $k|\vec{r}|$ and $-3k$

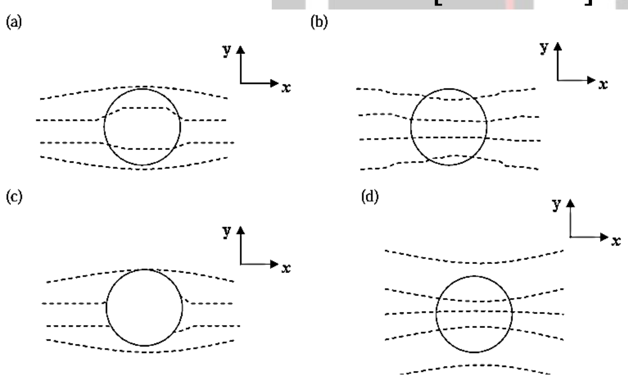
(c) $k|\vec{r}|$ and $-4\pi kR$ (d) $-k|\vec{r}|$ and $4\pi kR$

11. The electric field $\vec{E}$ at a point $\vec{r}$ outside the sphere is given by **[GATE 2007]**

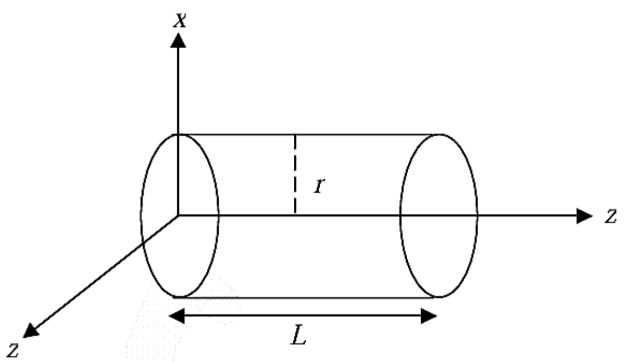
(a) $\vec{E} = 0$ (b) $\vec{E} = \frac{kR(R^2-r^2)}{\varepsilon_0 r^3}\hat{r}$

(c) $\vec{E} = \frac{kR(R^2-r^2)}{\varepsilon_0 r^5}\hat{r}$ (d) $\vec{E} = \frac{3k(r-R)}{4\pi\varepsilon_0 r^4}\hat{r}$

12. A dielectric sphere is placed in a uniform electric field directed along the positive y-axis. Which one of the following represents the correct equal potential surfaces? **[GATE 2008]**



13. A cylindrical rod of length L and radius r, made of an inhomogeneous dielectric is placed with its axis along the z direction with one end at the origin as shown below

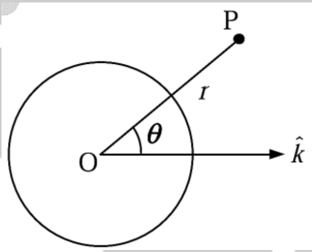


If the rod carries a polarization, $\vec{P} = (5z^2 + 7)\hat{k}$, the volume bound charge inside the dielectric is **[GATE 2009]**

(a) zero (b) $10\pi r^2 L$

(c) $-5\pi r^2 L$ (d) $-5\pi r^2 L^2$

14. A spherical conductor of radius a is placed in a uniform electric field $\vec{E} = E_0\hat{k}$. The potential at a point $P(r,\theta)$ for $r > a$, is given by $\varphi(r,\theta) = \text{Constant} - E_0 r\cos\theta + \frac{E_0 a^3}{r^2}\cos\theta$ where r is the distance of P from the centre O of the sphere and θ is the angle OP makes with the z-axis



The charge density on the sphere at $\theta = 30°$ is **[GATE 2011]**

(a) $3\sqrt{3}\varepsilon_0 E_0/2$ (b) $3\varepsilon_0 E_0/2$

(c) $\sqrt{3}\varepsilon_0 E_0/2$ (d) $\varepsilon_0 E_0/2$

15. For a scalar function φ satisfying the Laplace equation, $\nabla\varphi$ has **[GATE 2013]**

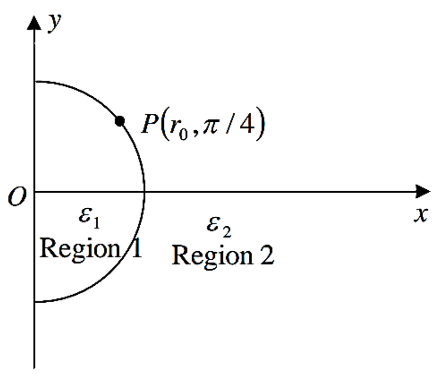
(a) zero curl and non-zero divergence

(c) non-zero curl and zero divergence

(c) zero curl and zero divergence

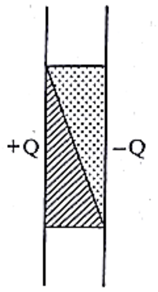
(d) non-zero curl and non-zero divergence

16. A ray of light inside Region 1 in the xy-plane is incident at the semicircle boundary that carries no free charges. The electric field at the point $P(r_0, \pi/4)$ in plane polar coordinates is $\vec{E}_1 = 7\hat{e}_r - 3\hat{e}_\varphi$, where $\hat{e}_r$ and $\hat{e}_\varphi$ are the unit vectors. The emerging ray in Region 2 has the electric field $\vec{E}_2$ parallel to x-axis. If ε_1 and ε_2 are the dielectric constants of Region 1 and Region 2 respectively, then $\frac{\varepsilon_2}{\varepsilon_1}$ is **[GATE 2014]**



17. The space between two plates of a capacitor carrying charges $+Q$ and $-Q$ is filled with two different dielectric materials, as shown in the figure. Across the interface of the two dielectric materials, which one of the following statements is correct?

[GATE 2015]



(a) $\vec{E}$ and $\vec{D}$ are continuous
(b) $\vec{E}$ is continuous and $\vec{D}$ is discontinuous
(c) $\vec{D}$ is continuous and $\vec{E}$ is discontinuous
(d) $\vec{E}$ and $\vec{D}$ are discontinuous

18. An infinite, conducting slab kept in a horizontal plane carries a uniform charge density σ. Another infinite slab of thickness t, made of a linear dielectric material of dielectric constant k, is kept above the conducting slab. The bound charge density on the upper surface of the dielectric slab is

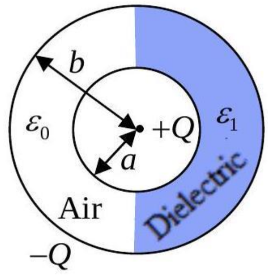
[GATE 2016]

(a) $\frac{\sigma}{2k}$ (b) $\frac{\sigma}{k}$
(c) $\frac{\sigma(k-2)}{2k}$ (d) $\frac{\sigma(k-1)}{k}$

19. A parallel plate capacitor with square plates of side 1 m separated by 1 micro meter is filled with medium of dielectric constant of 10 . If the charges on the two plates are 1C and -1C, the voltage across the capacitor is ________ kV. (up to two decimal places).
($\varepsilon_0 = 8.854 \times 10^{-12}$ F/m) -

[GATE 2017]

20. Two concentric shells as shown in the figure. The inner shell has a radius a and carries a charge $+Q$. The outer shell has a radius b and carries a charge $-Q$. The empty space between them is half-filled by a hemispherical shell of a dielectric having permittivity ε_1. The remaining space between the shells is filled with air having the permittivity ε_0.



The electric field at a radial distance r from the center and between the shells ($a < r < b$) is

[GATE 2021]

(a) $\frac{Q}{2\pi(\varepsilon_0+\varepsilon_1)}\frac{\hat{r}}{r^2}$ everywhere
(b) $\frac{Q}{4\pi\varepsilon_0}\frac{\hat{r}}{r^2}$ on the air side and $\frac{Q}{4\pi\varepsilon_1}\frac{\hat{r}}{r^2}$ on the dielectric side
(c) $\frac{Q}{2\pi\varepsilon_0}\frac{\hat{r}}{r^2}$ on the air side and $\frac{Q}{2\pi\varepsilon_1}\frac{\hat{r}}{r^2}$ on the dielectric side
(d) $\frac{Q}{4\pi(\varepsilon_0+\varepsilon_1)}\frac{\hat{r}}{r^2}$ everywhere

21. A parallel plate capacitor with spacing d and area of cross-section A is connected to a source of voltage V. If the plates are pulled apart quasistatically to a spacing of $2d$, then which of the following statements are correct?

[GATE 2022]

(a) The force between the plates at spacing $2d$ is $\frac{1}{8}\left(\frac{\varepsilon_0 A V^2}{d^2}\right)$.
(b) The work done in moving the plates is $\frac{1}{8}\left(\frac{\varepsilon_0 A V_i^2}{d}\right)$.
(c) The energy transferred to the voltage source is $\frac{1}{2}\left(\frac{\varepsilon_0 A V^2}{d}\right)$.
(d) The energy of the capacitor reduces by $\frac{1}{4}\left(\frac{\varepsilon_0 A V^2}{d}\right)$.

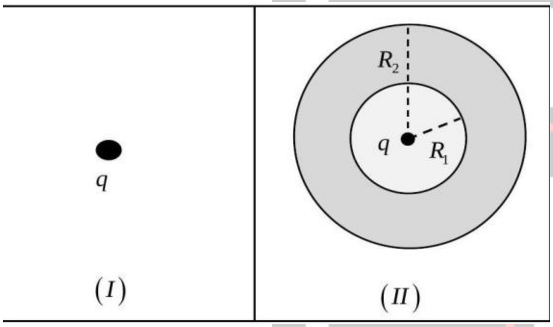
22. On the surface of a spherical shell enclosing a charge free region, the electrostatic potential values are as follows: One quarter of the area has potential ϕ_0, another quarter has potential $2\phi_0$ and the rest has potential $4\phi_0$. The potential at the Centre of the shell is
(You can use a property of the solution of Laplace's equation

[GATE 2022]

(a) $\frac{11}{4}\phi_0$ (b) $\frac{11}{2}\phi_0$
(c) $\frac{7}{3}\phi_0$ (d) $\frac{7}{4}\phi_0$

23. Two independent electrostatic configurations are shown in the figure. Configuration (I) consists of an isolated point charge $q = 1$C, C, and configuration (II) consists of another identical charge surrounded by a thick conducting shell of inner radius $R_1 = 1$ m and outer radius $R_2 = 2$ m, with the charge being at the centre of the shell. $W_I = \frac{\epsilon_0}{2}\int E_I^2 dV$ and $W_{II} = \frac{\epsilon_0}{2}\int E_{II}^2 dV$, where E_I and E_{II} are the magnitudes of the electric fields for configurations (I) and (II) respectively, ϵ_0 is the permittivity of vacuum, and the volume integrations are carried out over all space. If $\frac{8\pi}{\epsilon_0}|W_I - W_{II}| = \frac{1}{2}$, what is the value of the integer n?

[GATE 2023]



24. In a parallel plate capacitor, the plate at $x = 0$ is grounded and the plate at $x = d$ is maintained at a potential V_0. The space between the two plates is filled with a linear dielectric of permittivity $\epsilon = \epsilon_0\left(1 + \frac{x}{d}\right)$, where ϵ_0 is the permittivity of free space.
Neglecting the edge effects, the electric field $(\vec{E})$ inside the capacitor is **[GATE 2024]**

(a) $-\frac{V_0}{(d+x)\ln 2}\hat{x}$ (b) $-\frac{V_0}{d}\hat{x}$
(c) $-\frac{V_0}{(d+x)}\hat{x}$ (d) $-\frac{V_0 d}{(d+x)x}\hat{x}$

❖ JEST PYQ's

1. A cube has a constant electric potential V on its surface. If there are no charges inside the cube, the potential at the centre of the cube is

[JEST 2012]

(a) V (b) V/8
(c) 0 (d) V/6

2. A charge q is placed at the centre of an otherwise neutral dielectric sphere of radius a and relative pernitivity ϵ_r. We denote the expression $q/4\pi\epsilon_0 r^2$ by $E(r)$. Which of the following statements is false

[JEST 2013]

(a) The electric field inside the sphere, $r < a$, is given by $E(r)/\epsilon_r$.
(b) The field outside the sphere, $r > a$, is given by $E(r)$.
(c) The total charge inside a sphere of radius $r > a$ is given by q.
(d) The total charge inside a sphere of radius $r < a$ is given by q.

3. The electric fields outside $(r > R)$ and inside $(r < R)$ a solid sphere with a uniform volume charge density are given by $\vec{E}_{r>R} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$ and $\vec{E}_{r<R} = \frac{1}{4\pi\varepsilon_0}\frac{q}{R^3}r\hat{r}$ respectively, while the electric field outside a spherical shell with a uniform surface charge density is given by $\vec{E}_{r\propto R} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r}$, q bing the total charge. The correct ratio of the electrostatic energies for the second case to the first case is

[JEST 2013]

(a) 1:3 (b) 9:16
(c) 3:8 (d) 5:6

4. A spherical shell of inner and outer radii a and b, respectively, is made of a dielectric material with frozen polarization $\vec{P}(r) = \frac{k}{r}\hat{r}$, where k is a constant and r is the distance from the it's centre. The electric field in the region $a < r < b$ is, **[JEST 2015]**

(a) $\vec{E} = \frac{k}{\epsilon_0 r}\hat{r}$ (b) $\vec{E} = -\frac{k}{\epsilon_0 r}\hat{r}$
(c) $\vec{E} = 0$ (d) $\vec{E} = \frac{k}{\epsilon_0 r^2}\hat{r}$

5. The electrostatic potential due to a change distribution is given by $V(r) = A\frac{e^{-\lambda r}}{r}$ where A and λ are constants. The total charge enclosed within a sphere of radius $\frac{1}{\lambda}$, with its origin at $r = 0$ is given by, **[JEST 2015]**

(a) $\frac{8\pi\epsilon_0 A}{e}$ (b) $\frac{4\pi\epsilon_0 A}{e}$
(c) $\frac{\pi\epsilon_0 A}{e}$ (d) 0

6. Two conductors are embedded in a material of conductivity 10^{-4}ohm − m and dielectric constant $\varepsilon = 80_{\varepsilon 0}$. The resistance between the two conductors is 10^6ohm. What is the capacitance (in pF) between the tow conductors? ignore the decimal part of the answer.

[JEST 2018]

7. A rectangular dielectric slab partly fills two identical rectangular parallel plate capacitors which are maintained at potentials V_1 and V_2 with $V_1 > V_2$. The slab can freely move in the space between the capacitor plates without any friction. Which of the following is true?

[JEST 2022]

(a) The slab will not move.
(b) The slab will move towards lower potential.
(c) The slab will move towards higher potential.
(d) The slab will position itself at $1/V_1 : 1/V_2$ ratio between capacitors 1 and 2.

8. A conducting sphere of radius R is placed in a uniform electric field E_0 directed along $+z$ axis. The electric potential for outside points is given by $V_{\text{out}} = -E_0(1-(R/r)^3) r\cos\,\theta$, where r is the distance from the center and θ is the polar angle. The charge density on the surface of the sphere is

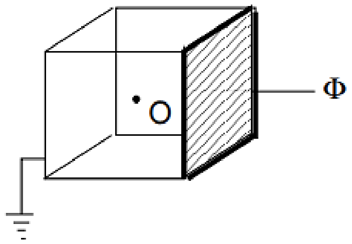
[JEST 2022]

(a) $3\varepsilon_0 E_0 \cos\,\theta$ (b) $\varepsilon_0 E_0 \cos\,\theta$
(c) $-3\varepsilon_0 E_0 \cos\,\theta$ (d) $\frac{1}{3}\varepsilon_0 E_0 \cos\,\theta$

❖ TIFR PYQ's

1. Three equal charges Q are successively brought from infinity and each is placed at one of the three vertices of an equilateral tringle. Assuming the rest of the Universe as a whole to be neutral, the energy E_0 of the electrostatic field will increase, successively, to
$E_0 + \Delta_1, E_0 + \Delta_1 + \Delta_2, E_0 + \Delta_1 + \Delta_2 + \Delta_3$
Where $\Delta_1 : \Delta_2 : \Delta_3 =$ **[TIFR 2012]**
(a) $1:2:3:$ (b) $1:1:1$
(c) $0:1:1$ (d) $0:1:2$

2. Five sides of a hollow metallic cube are grounded and the sixth side is insulated from the rest and is held at a potential Φ (see figure).



The potential at the center O of the cube is

[TIFR 2012]

(a) 0 (b) $\Phi/6$
(c) $\Phi/5$ (d) $2\Phi/3$

3. A parallel plate capacitor of circular cross section with radius $r \gg d$, where d is the spacing between the plates, is charged to a potential V and then disconnected from the charging circuit. If, now, the plates are slowly pulled apart (keeping them parallel) so that their separation is increased from d to d', the work done will be

[TIFR 2013]

(a) $\frac{\pi\varepsilon_0 r^2 V^2}{2d}\left(1-\frac{d}{d'}\right)$ (b) $\frac{\pi\varepsilon_0 r^2 V^2}{2d}\frac{d'}{d}$
(c) $\frac{\pi\varepsilon_0 r^2 V^2}{2d}\left(\frac{d'}{d}-1\right)$ (d) $\frac{\pi\varepsilon_0 r^2 V^2}{2d}\frac{d}{d'}$

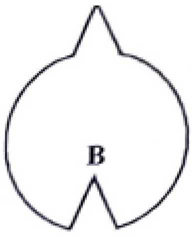
4. Solving Poisson's equation $\nabla^2\varphi = -\rho_0/\varepsilon_0$ for the electrostatic potential $\varphi(\vec{x})$ in a region with a constant charge density ρ_0, two students find different answers, viz.

$$\varphi_1(\vec{x}) = -\frac{1}{2}\frac{\rho_0 x^2}{\varepsilon_0} \quad \text{and} \quad \varphi_2(\vec{x}) = -\frac{1}{2}\frac{\rho_0 y^2}{\varepsilon_0}$$

The reason why these different solutions are both correct is because **[TIFR 2014]**
(a) space is isotropic and hence x and y are physically equivalent.
(b) we can add solutions of Laplace's equation to both $\varphi_1(\vec{x})$ and $\varphi_2(\vec{x})$.
(c) the electrostatic energy is infinite for a constant charge density.
(d) the boundary conditions are different in the two cases.

5. A solid spherical conductor has a conical hole made at one end, ending in a point B, and a small conical projection of the same shape and size at the opposite side, ending in a point A. A cross-section through the Centre of the conductor is shown in the figure on the right.

[TIFR 2014]



If now, a positive charge Q is transferred to the sphere, then
(a) The charge density at both A and B will be undefined.
(b) The charge density at A will be the same as the charge density at B.
(c) The charge density at A will be more than the charge density at B.
(d) The charge density at B will be more than the charge density at A

6. Consider an infinitely long cylinder of radius R, placed along the z-axis, which carries a static charge density $\rho(r) = kr$, where r is the perpendicular distance from the axis of the cylinder and k is a constant. The electrostatic potential $\phi(r)$ inside the cylinder is proportional to **[TIFR 2015]**

(a) $-\frac{2}{3}\left(\frac{r^3}{R^3}+1\right)$ (b) $-2\ln\left(\frac{r}{R}\right)$
(c) $-\frac{2}{3}\left(\frac{r^3}{R^3}-1\right)$ (d) $-2\ln\left(\frac{R}{r}\right)$

7. A long, solid dielectric cylinder of radius a is permanently polarized so that the polarization is everywhere radially outward, with a magnitude proportional to the distance from the axis of the cylinder, i.e., $\vec{P} = \frac{1}{2}P_0 r\hat{r}$. The bound charge density in the cylinder is given by **[TIFR 2016]**

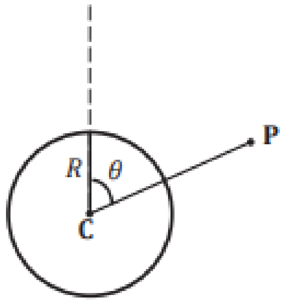
(a) $-P_0$ (b) P_0
(c) $-P_0/2$ (d) $P_0/2$

8. A beam of plane microwaves of wavelength 12 cm strikes the surface of a dielectric at 45°. If the refractive index of the dielectric is 4/3, what will be the wavelength, in units of mm, of the microwaves inside the dielectric? **[TIFR 2017]**

9. Consider a spherical shell with radius R such that the potential on the surface of the shell in spherical coordinates is given by,

$$V(r = R, \theta, \varphi) = V_0 \cos^2\theta$$

where the angle θ is shown in the figure. There are no charges except for those on the shell. The potential outside the shell at the point P a distance $2R$ away from its center C (see figure) is **[TIFR 2017]**



(a) $V = \frac{V_0}{8}(1+\cos^2\theta)$
(b) $V = \frac{V_0}{8}(1+2\cos^2\theta)$
(c) $V = \frac{V_0}{4}(1-\cos^2\theta)$
(d) $V = \frac{V_0}{2}(-2\cos\theta+\cos^3\theta)$

10. The electrostatic charge density $\rho(r)$ corresponding to the potential

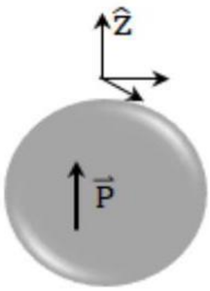
$$\varphi(r) = \frac{q}{4\pi\epsilon_0}\frac{1}{r}\left(1+\frac{\alpha r}{2}\right)\exp(-\alpha r)$$

is $\rho =$ **[TIFR 2018]**
(a) $q\delta(r) - 2q\alpha^3\exp(-\alpha r)$
(b) $q\delta(r) - q\frac{\alpha^3}{4}\exp(-\alpha r)$
(c) $q\delta(r) - q\frac{\alpha^3}{2}\exp(-\alpha r)$
(d) $-q\delta(r) - 2q\alpha^3\exp(-\alpha r)$

11. Calculate the self-energy, in Joules, of a spherical conductor of radius 8.5 cm, which carries a charge 100μC **[TIFR 2018]**

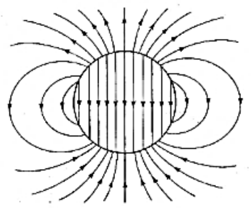
12. An atom of atomic number Z can be modelled as a point positive charge surrounded by a rigid uniformly negatively charged solid sphere of radius R. The electric polarisability α of this system is defined as $\alpha = \frac{p_E}{E}$ where p_E is the dipole moment induced on application of electric field E which is small compared to the binding electric field inside the atom. It follows that $\alpha =$ **[TIFR 2018]**
(a) $\frac{8\pi\epsilon_0}{R^3}$ (b) $\frac{4\pi\epsilon_0}{R^3}$
(c) $8\pi\epsilon_0 R^3$ (d) $4\pi\epsilon_0 R^3$

13. The electric field lines due to a uniformly polarized dielectric sphere (polarization along the positive z-axis as shown in the figure)

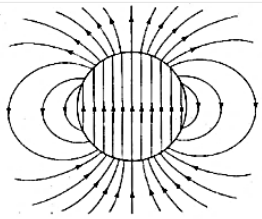


will look like **[TIFR 2023]**

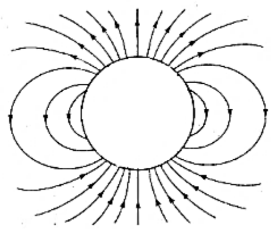
(a)



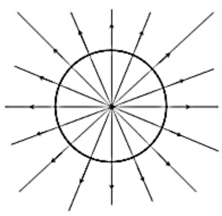
(c)



(b)



(d)



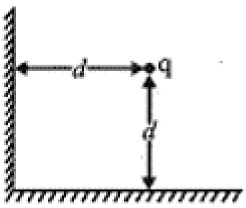
❖ Answer Key				
CSIR PYQ				
1. b	2. a	3. d	4. b	5. b
6. a	7. d	8. d	9. c	10. c
11. b	12. c	13. a		
GATE PYQ				
1. b	2. a	3. a	4. d	5. c
6. b	7. b	8. b	9. a	10. b
11. a	12. d	13. c	14. a	15. c
16. 2.33	17. d	18. d	19. 11.3	20. a
21. acd	22. a	23. MTA	24. a	
JEST PYQ				
1. a	2. d	3. d	4. b	5. a
6. *	7. c	8. a		
TIFR PYQ				
1. d	2. b	3. b	4. d	5. c
6. c	7. a	8. 090	9. a	10. c
11. 529	12. d	13. a		

❖ EMT 04 : Multipole Expansion

❖ CSIR-NET PYQ's

1. An electric point charge +q is placed at the point (1,1) of the xy-plane in which two grounded semiinfinite conducting plates along the positive x and y-axes meet see figure. The electric potential in the positive quadrant at a large distance r goes as

[NET 2008]

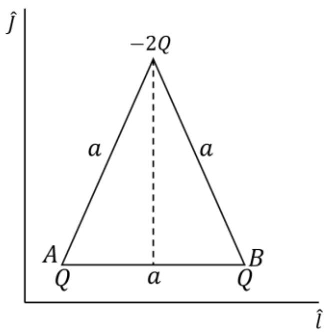


(a) $V(r) \sim r^{-1}$ (b) $V(r) \sim r^{-2}$

(c) $V(r) \sim r^{-3}$ (d) $V(r) \sim r^{-4}$

2. Charges Q, Q and $-2Q$ are placed on the vertices of an equilateral triangle ABC of sides of length a, as shown in the figure
The dipole moment of this configuration of charges, irrespective of the choice of origin, is

[CSIR JUNE 2012]

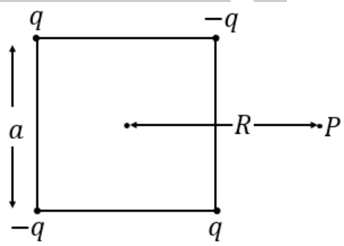


(a) $+2aQ_{\hat{\imath}}$ (b) $+\sqrt{3}aQ\hat{j}$

(c) $-\sqrt{3}aQ\hat{j}$ (d) 0

3. Four charges (two $+q$ and two $-q$) are kept fixed at the four vertices of a square of side ' a ' as shown At the point P which is at a distance R from the centre $(R >> a)$, the potential is proportional to

[CSIR DEC 2012]

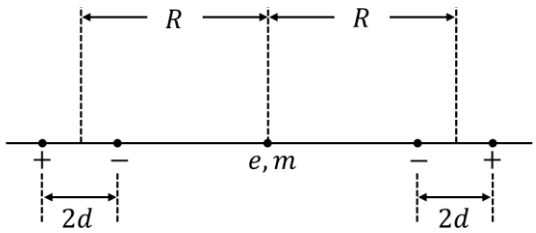


(a) $\frac{1}{R}$ (b) $\frac{1}{R^2}$

(c) $\frac{1}{R^3}$ (d) $\frac{1}{R^4}$

4. A particle of charge e and mass m is located at the midpoint of the line joining two mixed collinear dipoles with unit charges as shown in the figure. (The particle is constrained to move only along the line joining the dipoles). Assuming that the length of the dipoles is much shorter than their separation, the natural frequency of oscillation of the particle is

[CSIR JUNE 2013]



(a) $\sqrt{\frac{6e^2R^2}{\pi\varepsilon_0 md^5}}$ (b) $\sqrt{\frac{6e^2R}{\pi\varepsilon_0 md^4}}$

(c) $\sqrt{\frac{6e^2\, d^2}{\pi\varepsilon_0\, mR^5}}$ (d) $\sqrt{\frac{6e^2\, d}{\pi\varepsilon_0 mR^4}}$

5. Consider an axially symmetric static charge distribution of the form,

$\rho = \rho_0 \left(\frac{r_0}{r}\right)^2 e^{-r/r_0} \cos^2 \varphi$.

The radial component of the dipole moment due to this charge distribution is

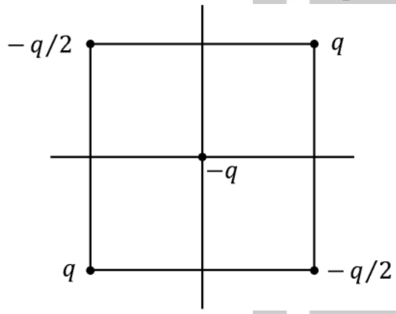
[CSIR JUNE 2013]

(a) $2\pi\rho_0 r_0^4$ (b) $\pi\rho_0 r_0^4$

(c) $\rho_0 r_0^4$ (d) $\pi\rho_0 r_0^4/2$

6. Let four point charges $q, -q/2, q$ and $-q/2$ be placed at the vertices of a square of side a. Let another point charge $-q$ be placed at the centre of the square (see the figure). Let $V(r)$ be the electrostatic potential at a point P at a distance $r \gg a$ from the centre of the square. Then $V(2r)/V(r)$ is

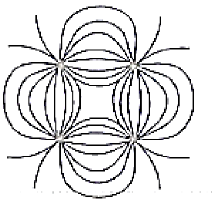
[CSIR DEC 2013]



(a) 1 (b) $\frac{1}{2}$

(c) $\frac{1}{4}$ (d) $\frac{1}{8}$

7. The electrostatic lines of force due to a system of four point charges is sketched below.



At a large distance r, the leading asymptotic behaviour of the electrostatic potential is proportional to

[NET Dec. 2014]

(a) r (b) r^{-1} (c) r^{-2} (d) r^{-3}

8. Two point charges $+3Q$ and $-Q$ are placed at $(0,0,d)$ and $(0,0,2d)$ respectively, above an infinite grounded conducting sheet kept in the xy-plane. At a point $(0,0,z)$, where $z \gg d$, the electrostatic potential of this charge configuration would approximately be

[CSIR DEC 2017]

(a) $\frac{1}{4\pi\varepsilon_0}\frac{d^2}{z^3}Q$ (b) $\frac{1}{4\pi\varepsilon_0}\frac{2d}{z^2}Q$

(c) $\frac{1}{4\pi\varepsilon_0}\frac{3d}{z^2}Q$ (d) $-\frac{1}{4\pi\varepsilon_0}\frac{d^2}{z^3}Q$

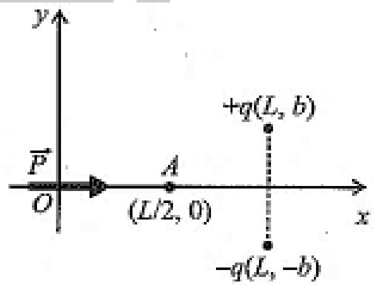
9. Two points charges $+2Q$ and $-Q$ are kept at points with Cartesian coordinates (1,0,0) and (2,0, 0), respectively, in front of an infinite grounded conducting plate at $x = 0$. The potential at $(x, 0,0)$ for $x \geqslant 1$ depends on x as

[CSIR JUNE 2018]

(a) x^{-3} (b) x^{-5}

(c) x^{-2} (d) x^{-4}

10. An electric dipole of dipole moment $\vec{P} = qb\hat{\imath}$ is placed at the origin in the vicinity of two charges $+q$ and $-q$ at (L, b) and $(L, -b)$, respectively, as shown in the figure below.



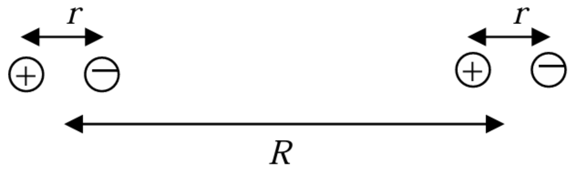
The electrostatic potential at the point $\left(\frac{L}{2}, 0\right)$ is

[CSIR DEC 2018]

(a) $\frac{qb}{\pi\varepsilon_0}\left(\frac{1}{L^2} + \frac{2}{L^2+4b^2}\right)$ (b) $\frac{4qbL}{\pi\varepsilon_0[L^2+4b^2]^{3/2}}$

(c) $\frac{qb}{\pi\varepsilon_0 L^2}$ (d) $\frac{3qb}{\pi\varepsilon_0 L^2}$

11. A linear diatomic molecule consists of two identical small electric dipoles with an equilibrium separation R, which is assumed to be a constant. Each dipole has charges $+q$ of mass m separated by r when the molecule is at equilibrium. Each dipole can execute simple harmonic motion of angular frequency ω.



Recall that the interaction potential between two dipoles of moments p_1 and p_2, separated by $R_{12} = R_{12}\hat{n}$ is . $\left(p_1 \cdot p_2 - 3(p_1 \cdot \hat{n})(p_2 \cdot \hat{n})\right)/(4\pi\varepsilon_0 R_{12}^3)$.

Assume that $R \gg r$ and let $\Omega^2 = \frac{q^2}{4\pi\varepsilon_0 m R^3}$. The angular frequencies of small oscillations of the diatomic molecule are

[CSIR JUNE 2021]

(a) $\sqrt{\omega^2+\Omega^2}$ and $\sqrt{\omega^2-\Omega^2}$

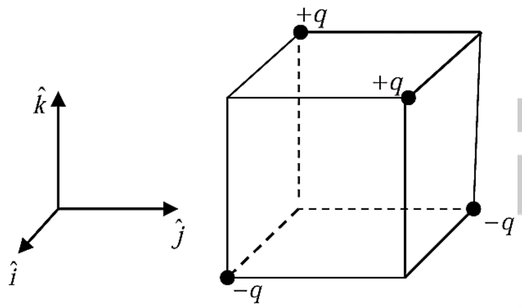
(b) $\sqrt{\omega^2+3\Omega^2}$ and $\sqrt{\omega^2-3\Omega^2}$

(c) $\sqrt{\omega^2+4\Omega^2}$ and $\sqrt{\omega^2-4\Omega^2}$

(d) $\sqrt{\omega^2+2\Omega^2}$ and $\sqrt{\omega^2-2\Omega^2}$

12. Two positive and two negative charges of magnitude q are placed on the alternate vertices of a cube of side a (as shown in the figure).

[CSIR JUNE 2022]

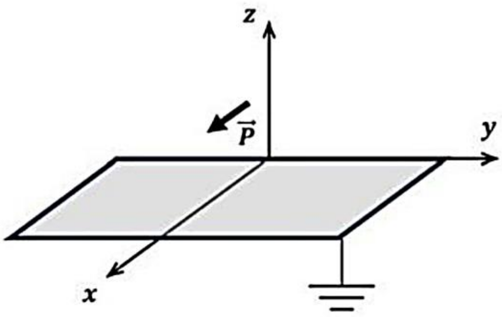


The electric dipole moment of this charge configuration is **[CSIR JUNE 2022]**

(a) $-2qa\hat{k}$ (b) $2qa\hat{k}$

(c) $2qa(\hat{\imath}+\hat{\jmath})$ (d) $2qa(\hat{\imath}-\hat{\jmath})$

13. A point electric dipole $\vec{P}=p_x\hat{\imath}$ is placed at a vertical distance d above a grounded infinite conducting xy plane as shown in the figure.



At a point $\vec{r}(r\gg d, z>0)$ far away from the dipole, the electrostatic potential $V(r)$ varies approximately as **[CSIR JUNE 2024]**

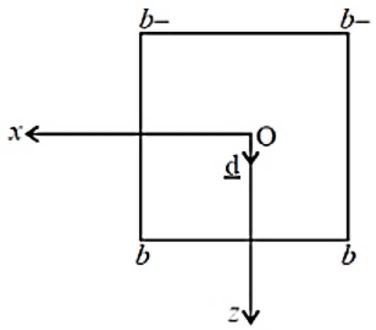
(a) $\frac{1}{r^2}$ (b) $\frac{1}{r^6}$

(c) $\frac{1}{r^3}$ (d) $\frac{1}{r^4}$

❖ GATE PYQ's

1. Four point charges are placed at the corners of a square whose center is at the origin of a Cartesian coordinate system. A point dipole $\vec{p}$ is placed at the centre of the square as shown in the figure. Then,

[GATE 2001]



(a) there is no force acting on the dipole

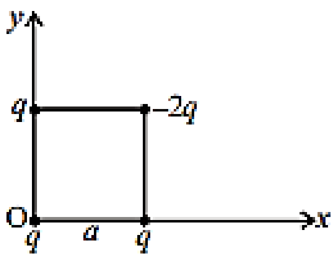
(b) there is no torque about the centre of O on the dipole

(c) the dipole has minimum energy if it is in $\hat{e}_x$ direction

(d) the force on the dipole is increased if the medium is replaced by another medium with larger dielectric constant

2. Four charges are placed at the four corners of a square of side a as shown in the figure. The electric dipole moment of this configuration is

[GATE 2002]



(a) $\vec{p}=qa\hat{\imath}+qa\hat{\jmath}$ (b) $\vec{p}=-qa\hat{\imath}+qa\hat{\jmath}$

(c) $\vec{p}=-qa\hat{\imath}-qa\hat{\jmath}$ (d) $\vec{p}=qa\hat{\imath}-qa\hat{\jmath}$

3. Three point charges q, q and $-2q$ are located at $(0,-a,a),(0,a,a)$ and $(0,0,-a)$, respectively. The net dipole moment of this charge distribution is

[GATE 2006]

(a) $4qa\hat{k}$ (b) $2qa\hat{k}$

(c) $-4qa\hat{\imath}$ (d) $-2qa\hat{\jmath}$

4. Four point charges are placed in a plane at the following positions: $+Q$ at $(1,0), -Q$ at $(-1,0), +Q$ at $(0,1)$ and $-Q$ at $(0,-1)$. At large distances the electrostatic potential due to this charge distribution will be dominated by the

[GATE 2007]

(a) monopole moment

(b) dipole moment
(c) quadrupole moment
(d) octopole moment

5. A circular disc of radius a on the xy plane has a surface charge density $\sigma = \frac{\sigma_0 r\cos\theta}{a}$. The electric dipole moment of this charge distribution is

[GATE 2008]

(a) $\frac{\sigma_0 \pi a^4}{4}\hat{x}$ (b) $\frac{\sigma_0 \pi a^3}{4}\hat{x}$
(c) $-\frac{\sigma_0 \pi a^3}{4}\hat{x}$ (d) $-\frac{\sigma_0 \pi a^4}{4}\hat{x}$

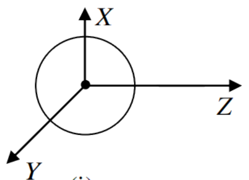
6. An insulating sphere of radius a carries a charge density $\rho(\vec{r}) = \rho_0(a^2 - r^2)\cos\theta, r < a$. The leading order term for the electric field at a distance d, far away from the charge distribution, is proportional to

[GATE 2010]

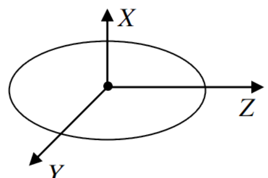
(a) d^{-1} (b) d^{-2}
(c) d^{-3} (d) d^{-4}

7. A charge $-q$ is distributed uniformly over a sphere, with a positive charge q at its center in (i) also in (ii), a charge $-$q is distributed uniformly over an ellipsoid with a positive charge q at its center. With respect to the origin of the coordinate system, which one of the following statements is correct?

[GATE 2015]



(i)

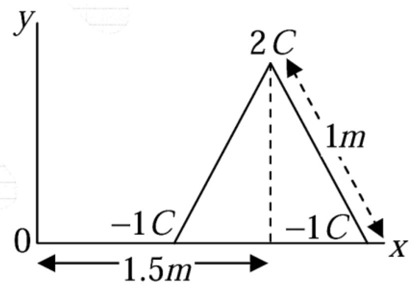


(ii)

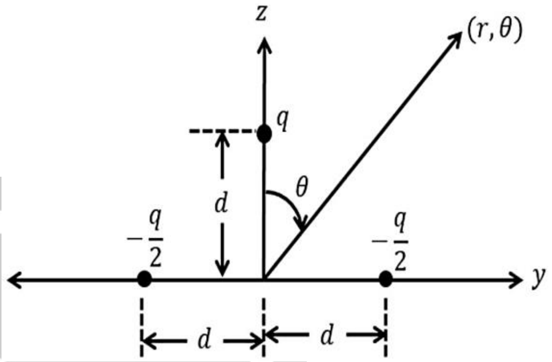
(a) The dipole moment is zero in both (i) and (ii)
(b) The dipole moment is non-zero in (i) but zero in (ii)
(c) The dipole moment is zero in (i) but non-zero in (ii)
(d) The dipole moment is non-zero in both (i) and (ii)

8. Three charges $(2\text{C}, -1\text{C}, -1\text{C})$ are placed at the vertices of an equilateral triangle of side 1 m as shown in the figure. The component of the electric dipole moment about the marked origin along the $\hat{y}$ direction is________ Cm.

[GATE 2017]



9. Consider a system of three charges as shown in the figure below:



For $r = 10$ m; $\theta = 60$ degrees; $q = 10^{-6}$ Coulomb, and $d = 10^{-3}$ m, the electric dipole potential in volts (rounded off to three decimal places) at a point (r, θ) is

[GATE 2019]

$$[\text{ Use : } \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}\ ]$$

❖ JEST PYQ's

1 Two equal positive charges of magnitude $+q$ separated by a distance d are surrounded by a uniformly charged thin spherical shell of radius $2d$ bearing a total charge $-2q$ and centred at the midpoint between the two positive charges. The net electric field at distance r from the midpoint $(\gg d)$ is

[JEST 2017]

(a) zero
(b) proportional to d
(c) proportional to $1/r^3$
(d) proportional to $1/r^4$

2 Charges are placed as follows: q at $(a, a, 0)$ and $(-a, -a, 0)$ and $-q$ at $(a, -a, 0)$ and $(-a, a, 0)$. At large distances, how does the electrostatic potential behave as a function of the distance r from the centre (0,0,0)?

[JEST 2020]

(a) $1/r^3$ (b) $1/r^2$ (c) $1/r$ (d) $1/r^4$

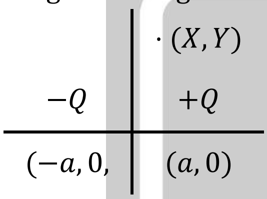
3 A solid sphere of radius R has a volume charge density $\rho = \rho_0 \sin 2\theta$. How does the leading term in the electrostatic potential depend on the distance r far away from the charged sphere? **[JEST 2024]**

(a) Does not depend on r (b) $\frac{1}{r}$

(c) r (d) $\frac{1}{r^2}$

❖ TIFR PYQ

1. Consider two charges $+Q$ and $-Q$ placed at the points $(a, 0)$ and $(-a, 0)$ in a plane, as shown in the figure on the right. If the origin is moved to the point (X, Y), the magnitude of the dipole moment of the given charge distribution with



respect to this origin will be **[TIFR 2013]**

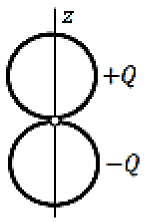
(a) $Q\sqrt{(a-X)^2+y^2} - Q\sqrt{(a+X)^2+y^2}$

(c) $Q(a-X) - Q(-a+X)$

(b) $2Qa$

(d) $2Qa\sqrt{X^2+Y^2}$

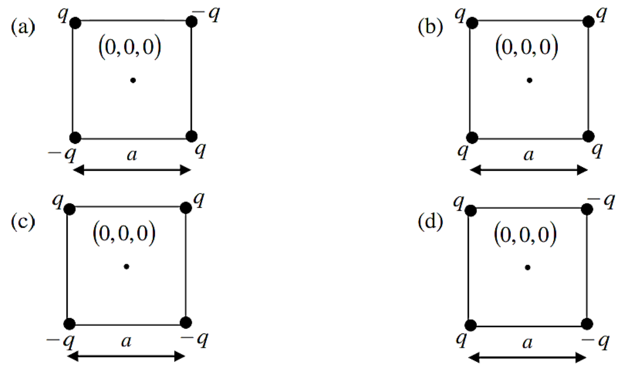
2. An electric dipole is constructed by fixing two circular charged rings, each of radius a, with an insulating contact (see figure). One of these rings has total charge $+Q$ and the other has total charge $-Q$. If the charge is distributed uniformly along each ring, the dipole moment about the point of contact will be **[TIFR 2014]**



(a) $\frac{Qa}{\pi}\hat{z}$ (b) $4\pi Q a\hat{z}$

(c) $2Qa\hat{z}$ (d) zero

3. The electrostatic potential $\varphi(r)$ of a distribution of point charges has the form $\varphi(r) \propto r^{-3}$ at a distance r from the origin (0,0,0), where $r \gg a$. Which of the following distributions can give rise to this potential? **[TIFR 2015]**

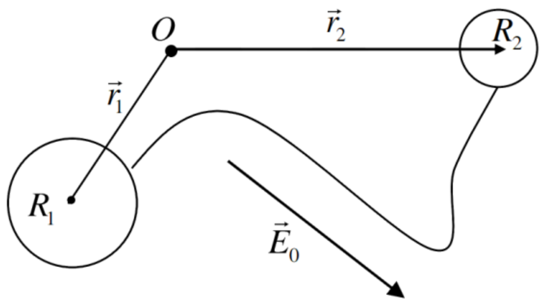


4. A grounded conducting sphere of radius a is placed with its centre at the origin. A point dipole of dipole moment $\vec{p} = p\hat{k}$ is placed at a distance d along the x-axis, where $\hat{\imath}, \hat{k}$ are the units vector along the x and z-axes respectively. This leads to the formation of an image dipole of strength $\vec{p}'$ at a distance d' from the centre along the x-axis. If $d' = a^2/d$, then $\vec{p}' =$ **[TIFR 2016]**

(a) $-\frac{a^4 p}{d^4}\hat{k}$ (b) $-\frac{a^3 p}{d^3}\hat{k}$

(c) $-\frac{a^2 p}{d^2}\hat{k}$ (d) $-\frac{ap}{d}\hat{k}$

5. Two conducting uncharged spheres of radii R_1 and R_2 are connected by an infinitesimally thin wire. The centres of the spheres are located at $\vec{\boldsymbol{r}}_1$ and $\vec{\boldsymbol{r}}_2$ respectively with respect to the origin O. The system is subjected to an uniform external electric field $\vec{\boldsymbol{E}}_0$.



If the wire cannot support a net charge and the two spheres are separated by distance much larger than the radii of each of them, the induced dipole moment in the system would be **[TIFR 2020]**

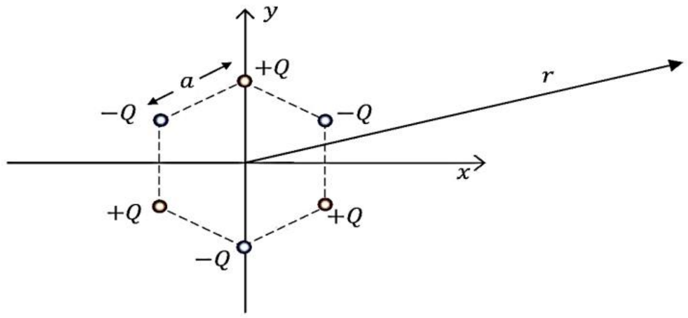
(a) $4\pi\epsilon_0 \frac{R_1 R_2}{R_1 + R_2}\{\vec{E_0}\cdot(\vec{r_2}-\vec{r_1})\}(\vec{r_2}-\vec{r_1})$

(b) $\frac{1}{4\pi\epsilon_0}\frac{R_1 R_2}{(R_1 + R_2)}\{\vec{E_0}\cdot(\vec{r_2}-\vec{r_1})\}(\vec{r_2}-\vec{r_1})$

(c) $4\pi\epsilon_0 \frac{R_1 + R_2}{R_1 R_2}\{\vec{E_0}\cdot(\vec{r_2}-\vec{r_1})\}(\vec{r_2}-\vec{r_1})$

(d) zero

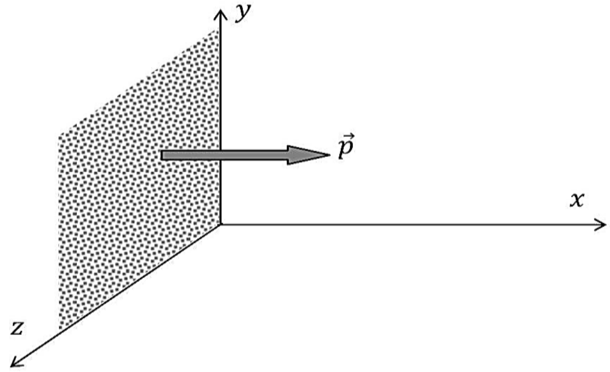
6. Consider 6 charges fixed at the vertices of a regular hexagon of side a, as shown in the figure below.



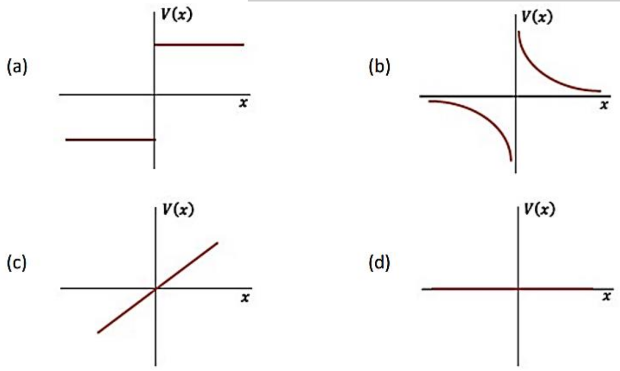
The behavior of the electrostatic potential at distance $r \to \infty$ in the xy plane is proportional to **[TIFR 2021]**

(a) $1/r^5$ (b) $1/r^4$
(c) $1/r^3$ (d) $1/r^2$

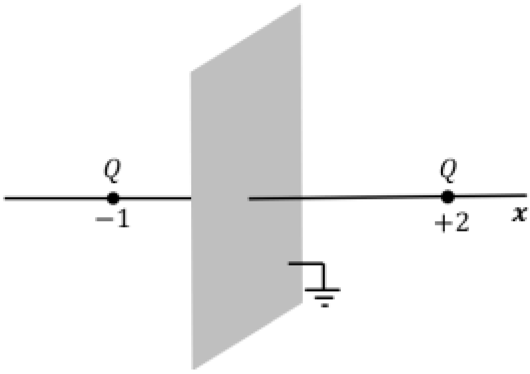
7. Consider an infinite uniform layer of point-like dipoles, placed in the $y-z$ plane, with a constant dipole strength $\vec{p} = p\hat{x}$ per unit area, as shown in figure below.

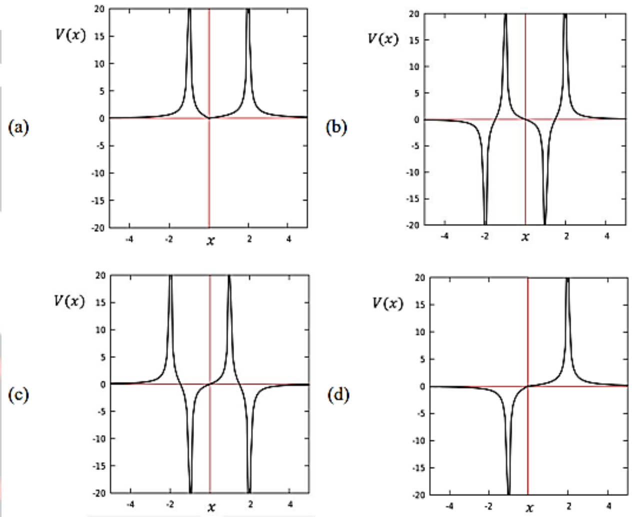


Which graph best represents the variation of potential along the x direction? **[TIFR 2021]**

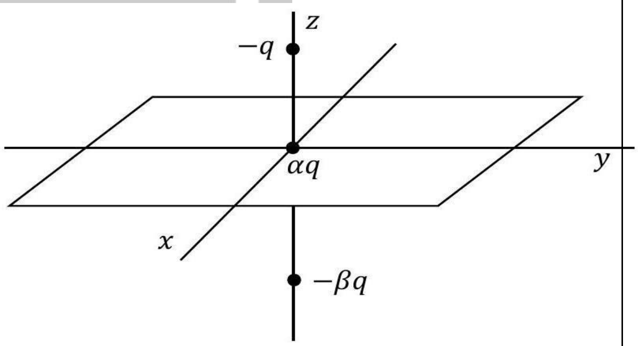


8. Two equal positive point charges $Q = +1$ are placed on either side of an x-axis normal to a grounded infinite conducting plane at distances of $x = +2$ units and $x =$ -1 unit respectively (see figure) w.r.t. the point of intersection of the axis with the conducting plane as origin.
The electrostatic potential along the axis will correspond to the graph in **[TIFR 2022]**





9. Consider a system of three electric charges: (i) a charge $-q$ placed at the point $(x, y, z) = (0,0,d)$, (ii) a charge $+\alpha q$ placed at the origin and (iii) a charge $-\beta q$ placed at the point $(x, y, z) = (0,0,-d)$.



The values of α and β are such that the monopole and dipole terms vanish in the multipole expansion of the electrostatic potential. What is the quadrupole term of the potential at a point $(x, y, 0)$? **[TIFR 2024]**

(a) $\frac{q}{2\pi\epsilon_0}\frac{d^2}{(x^2+y^2)^{3/2}}$ (b) $\frac{q}{4\pi\epsilon_0}\frac{d^2}{(x^2+y^2)^{3/2}}$

(c) 0 (d) $\frac{q}{4\pi\epsilon_0}\frac{1}{(x^2+y^2)^{1/2}}$

❖ Answer Key

CSIR PYQ				
1. c	2. c	3. c	4. d	5. a
6. d	7. d	8. b	9. d	10. c
11. c	12. b	13. c		
GATE PYQ				
1 b	2 d	3 b	4 c	5 b
6 c	7 a	8 1.73	9 0.045	
JEST PYQ				
1 a	2 a	3 d		
TIFR PYQ				
1. b	2. c	3. c	4. b	5. c
6. b	7. a	8. a	9. b	

❖ EMT 05 : Magnetic Field Induction & Trajectories

❖ CSIR-NET PYQ's

1. The magnetic field at a distance R from a long straight wire carrying a steady current I is proportional to

[CSIR JUNE 2012]

(a) IR (b) I/R^2
(c) I^2/R^2 (d) I/R

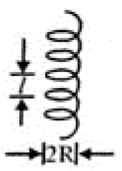
2. The force between two long and parallel wires carrying currents I_1 and I_2 and separated by a distance D is proportional to

[CSIR DEC 2013]

(a) I_1I_2/D (b) $(I_1+I_2)/D$
(c) $(I_1I_2/D)^2$ (d) I_1I_2/D^2

3. A charged particle moves in a helical path under the influence of a constant magnetic field. The initial velocity such that the component along the magnetic field is twice the component in the plane normal to the magnetic field. The ratio l/R of the pitch l to the radius R of the helical path is

[NET Dec. 2014]



(a) $\pi/2$ (b) 4π
(c) 2π (d) π

4. A proton moves with a speed of 300 m/s in a circular orbit in the xy-plane in a magnetic field I tesla along the positive z-direction. When an electric field of IV/m is applied along the positive y-direction, the center of the circular orbit

[NET June 2015]

(a) remains stationary
(b) moves at 1 m/s along the negative x-direction
(c) moves at 1 m/s along the positive z-direction
(d) moves at 1 m/s along the positive x-direction

5. The x - and z-components of a static magnetic field in a region are $B_x = B_0(x^2-y^2)$ and $B_z = 0$, respectively Which of the following solutions for its y-component is consistent with the Maxwell equations?

[NET June 2016]

(a) $B_y = B_0xy$
(b) $B_y = -2B_0xy$
(c) $B_y = -B_0(x^2-y^2)$
(d) $B_y = B_0\left(\frac{1}{3}x^3 - xy^2\right)$

6. A parallel plate capacitor is formed by two circular conducting plates of radius a separated by a distance d, where $d \ll a$. It is being slowly charged by a current that is nearly constant. At an instant when the current is I, the magnetic induction between the plates at a distance $a/2$ from the centre of the plate, is

[CSIR DEC 2016]

(a) $\frac{\mu_0 I}{\pi a}$ (b) $\frac{\mu_0 I}{2\pi a}$
(c) $\frac{\mu_0 I}{a}$ (d) $\frac{\mu_0 I}{4\pi a}$

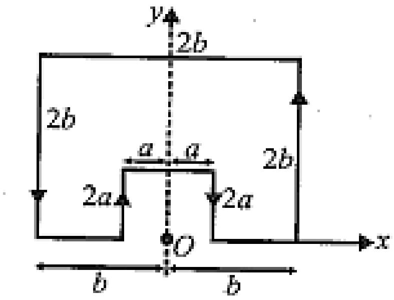
7. A set N concentric circular loops of wire, each carrying a steady current I in the same direction, is arranged in a plane. The radius of the first loop is $r_1 = a$ and the radius of the n^{hi} loop is given by $r_n = nr_{n-1}$. The magnitude B of the magnetic field at the centre of the circles in the limit $N \to \infty$, is

[CSIR JUNE 2017]

(a) $\frac{\mu_0 I(e^2-1)}{4\pi a}$ (b) $\frac{\mu_0 I(e-1)}{\pi a}$

(c) $\frac{\mu_0 I(e^2-1)}{8a}$ (d) $\frac{\mu_0 I(e-1)}{2a}$

8. A constant current I is flowing in a piece of wire that is bent into a loop as shown in the figure.



The magnitude of the magnetic field at the point O is **[CSIR JUNE 2017]**

(a) $\frac{\mu_0 I}{4\pi\sqrt{5}} \ln\left(\frac{a}{b}\right)$ (b) $\frac{\mu_0 I}{4\pi\sqrt{5}} \ln\left(\frac{1}{a} - \frac{1}{b}\right)$

(c) $\frac{\mu_0 I}{4\pi\sqrt{5}}\left(\frac{1}{a}\right)$ (d) $\frac{\mu_0 I}{4\pi\sqrt{5}}\left(\frac{1}{b}\right)$

9. A circular current carrying loop of radius a carries a steady current. A constant electric charge is kept at the centre of the loop. The electric and magnetic fields, $\vec{E}$ and $\vec{B}$ respectively, at a distance d vertically above the centre of the loop satisfy

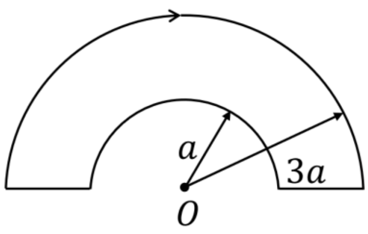
[NET Dec. 2017]

(a) $\vec{E} \perp \vec{B}$ (b) $\vec{E} = 0$

(c) $\vec{\nabla}(\vec{E} \cdot \vec{B}) = 0$ (d) $\vec{\nabla} \cdot (\vec{E} \times \vec{B}) = 0$

10. The loop shown in the figure below carries a steady current I. The magnitude of the magnetic field at the point O is

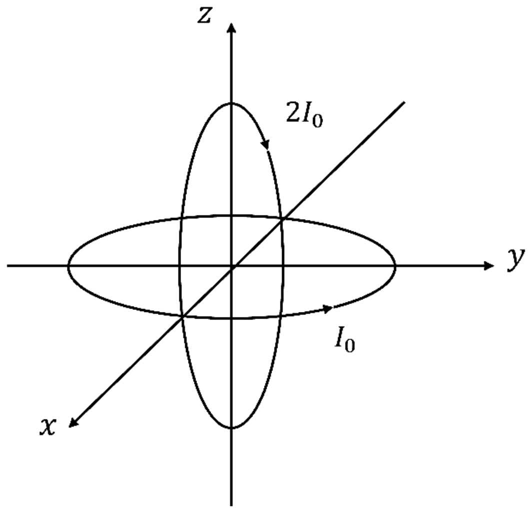
[CSIR JUNE 2018]



(a) $\frac{\mu_0 I}{2a}$ (b) $\frac{\mu_0 I}{6a}$

(c) $\frac{\mu_0 I}{4a}$ (d) $\frac{\mu_0 I}{3a}$

11. Two current-carrying circular loops, each of radius R, are placed perpendicular to each other, as shown in the figure below.



The loop in the xy-plane carries a current I_0 while that in the xz-plane carries a current $2I_0$. The resulting magnetic field $\vec{B}$ at the origin is

[CSIR DEC 2018]

(a) $\frac{\mu_0 I_0}{2R}[2\hat{j} + \hat{k}]$ (b) $\frac{\mu_0 I_0}{2R}[2\hat{j} - \hat{k}]$

(c) $\frac{\mu_0 I_0}{2R}[-2\hat{j} + \hat{k}]$ (d) $\frac{\mu_0 I_0}{2R}[-2\hat{j} - \hat{k}]$

12. Consider a planar wire loop as an n-sided regular polygon, in which R is the distance from the centre to a vertex. If a steady current I flows through the wire, the magnitude of the magnetic field at the centre of the loop is

[CSIR JUNE 2019]

(a) $\frac{\mu_0 I}{2R} \sin\left(\frac{2\pi}{n}\right)$ (b) $\frac{\mu_0 nI}{4\pi R} \sin\left(\frac{\pi}{n}\right)$

(c) $\frac{\mu_0 nI}{2\pi R} \tan\left(\frac{2\pi}{n}\right)$ (d) $\frac{\mu_0 nI}{2\pi R} \tan\left(\frac{\pi}{n}\right)$

13. A positively charged particle is placed at the origin (with zero initial velocity) in the presence of a constant electric and a constant magnetic field along the positive z and x-directions, respectively. At large times, the overall motion of the particle is adrift along the

[CSIR DEC 2019]

(a) positive y-direction
(b) negative z-direction
(c) positive z-direction
(d) negative y-direction

14. Three infinitely long wires, each carrying equal current are placed in the xy-plane along $x = 0, +d$ and $-d$. On the xy-plane, the magnetic field vanishes at **[CSIR JUNE 2020]**

(a) $x = \pm\frac{d}{2}$ (b) $x = \pm d\left(1+\frac{1}{\sqrt{3}}\right)$

(c) $x = \pm d\left(1-\frac{1}{\sqrt{3}}\right)$ (d) $x = \pm\frac{d}{\sqrt{3}}$

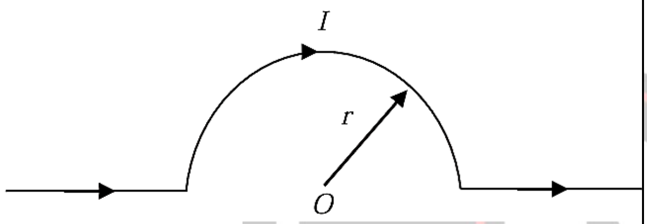
15. In an experiment to measure the charge to mass ratio e/m of the electron by Thomson's method, the value of the deflecting electric field and the accelerating potential are 6×10^6 N/C (Newton per coulomb) and 150 V, respectively. The magnitude of the magnetic field that leads to zero deflection of the electron beam is closest to

[NET June 2021]

(a) 0.6 T (b) 1.2 T

(c) 0.4 T (d) 0.8 T

16. A part of an infinitely long wire, carrying a current I, is bent in a semicircular arc of radius r (as shown in the figure).



The magnetic field at the centre 0 of the arc is

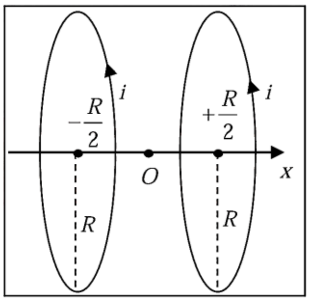
[CSIR JUNE 2022]

(a) $\frac{\mu_0 I}{4r}$ (b) $\frac{\mu_0 I}{4\pi r}$

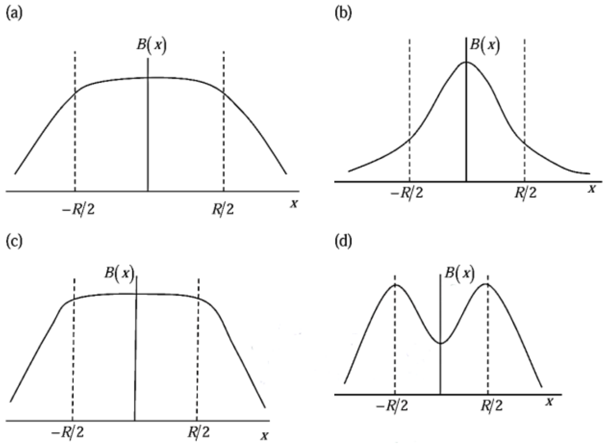
(c) $\frac{\mu_0 I}{2r}$ (d) $\frac{\mu_0 I}{2\pi r}$

17. Two parallel conducting rings, both of radius R, are separated by a distance R. The planes of the rings are perpendicular to the line joining their centers, which of is taken to be the x-axis.

[NET June 2022]



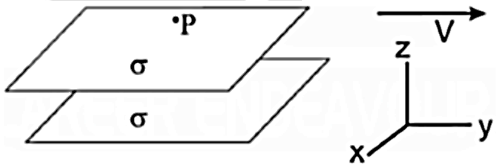
If both the rings carry the same current i along the same direction, the magnitude of the magnetic field along the x-axis is best represented by



❖ **GATE PYQ's**

1. Two large parallel plates move with a constant speed v in the positive y-direction as shown in the figure. If both the plates have a surface charge density $\sigma > 0$, the magnetic field at the point P just above the top plate will have:

[GATE 2000]



(a) Larger magnitude than the field at the mid-point between the plates and point towards $-\hat{x}$
(b) Smaller magnitude than the field at the mid-point between the plates and point towards $+\hat{x}$.
(c) Larger magnitude than the field at the mid-point between the plates and point towards $+\hat{x}$
(d) Smaller magnitude than the field at the mid-point between the plates and point towards $-\hat{x}$

2. The xoy plane carries a uniform surface current of density $\vec{K} = 50\hat{e}_z$ A/m. The magnetic field at the point $z = -0.5$ m is

[GATE 2001]

(a) 10×10^{-6} Wb (b) 1×10^{-6} Wb

(c) $\pi \times 10^{-6}$ Wb (d) $10\pi \times 10^{-6}$ Wb

3. A current I flows in the anticlockwise direction through a square loop of side a lying in the xoy plane with its center at the origin. The magnetic induction at the center of the square loop is :

[GATE 2001]

(a) $\frac{2\sqrt{2}\mu_0 I_1}{\pi a}\hat{e}_x$ (b) $\frac{2\sqrt{2}\mu_0 I_2}{\pi a}\hat{e}_z$

(c) $\frac{2\sqrt{2}\mu_0 I}{\pi a^2}\hat{e}_z$ (d) $\frac{2\sqrt{2}\mu_0 I}{\pi a^2}\hat{e}_x$

4. Consider an infinitely long straight cylindrical conductor of radius R with its axis along the z-direction, which carries a current of 1 A uniformly distributed over its cross section. Which of the following statements is correct?

[GATE 2002]

(a) $\vec{\nabla}\times\vec{B} = 0$ everywhere

(b) $\vec{\nabla}\times\vec{B} = \frac{\mu_0}{\pi R^2}\hat{z}$ everywhere

(c) $\vec{\nabla}\times\vec{B} = 0$ for $r > R$

(d) $\vec{\nabla}\times\vec{B} = \frac{\mu_0}{\pi R^2}\hat{z}$ for $r > R$

where r is the radial distance from the axis of the cylinder.

5. An infinite conducting sheet in the $x-y$ plane carries a surface current density K along the y-axis. The magnetic field B for $z > 0$ is

[GATE 2003]

(a) $B = 0$

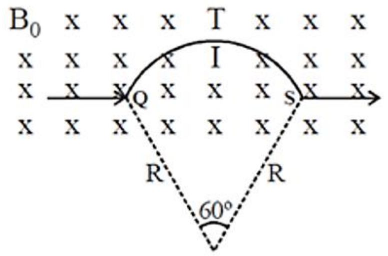
(b) $B = \mu_0 K\hat{k}/2$

(c) $B = \mu_0 K\hat{\imath}/2$

(d) $B = \mu_0 \hat{K} J/(x^2 + z^2)^{0.5}$

6. A circular arc QTS is kept in an external magnetic field $\vec{B}_0$ as shown in figure. The arc carries a current I. The magnetic field is directed normal and into the page. The force acting on the arc is

[GATE 2004]



(a) $2IB_0R\hat{\jmath}$ (b) $IB_0R\hat{\jmath}$

(c) $-2IB_0R\hat{\jmath}$ (d) $-IB_0R\hat{\jmath}$

7. Three infinitely long wires are placed equally apart on the circumference of a circle of radius a, perpendicular to its plane. Two of the wires carry current I each, in the same direction, while the third carries current $2I$ along the direction opposite to the other two. The magnitude of the magnetic induction $\vec{B}$ at a distance r from the centre of the circle, for $r > a$, is

[GATE 2005]

(a) 0 (b) $\frac{2\mu_0}{\pi}\frac{I}{r}$

(c) $-\frac{2\mu_0}{\pi}\frac{I}{r}$ (d) $\frac{2\mu_0}{\pi}\frac{Ia}{r^2}$

8. A long cylindrical kept along z-axis carries a current density $\hat{J} = J_0 r\hat{k}$, where J_0 is a constant and r is the radial distance form the axis of the cylinder. The magnetic induction $\hat{B}$ inside the conductor at a distance d from the axis of the cylinder is : **[GATE 2006]**

(a) $\mu_0 J_0\hat{\phi}$ (b) $\frac{\mu_0 J0\ d}{2}\hat{\phi}$

(c) $\frac{\mu_0 J_0 d^2}{3}\hat{\phi}$ (d) $-\frac{\mu_0 J_0 d^3}{4}\hat{\phi}$

9. A toroidal coil has N closely-wound turns. Assume the current through the coil to be I and the toroid is filled with a magnetic material of relative permittivity μ_r. The magnitude of magnetic induction $\vec{B}$ inside the toroid, at a radial distance r from the axis, is given by

[GATE 2007]

(a) $\mu_r\mu_0 NIr$ (b) $\frac{\mu_r\mu_0 NI}{r}$

(c) $\frac{\mu_r\mu_0 NI}{2\pi r}$ (d) $2\pi\mu_r\mu_0 NIr$

10. The magnetic field (in Am^{-1}) inside a long solid cylindrical conductor of radius $a = 0.1$ m is, $\vec{H} = \frac{10^4}{r}\left[\frac{1}{\alpha^2}\sin(\alpha r) - \frac{r}{\alpha}\cos(\alpha r)\right]\hat{\phi}$ where $\alpha = \frac{\pi}{2a}$. What is the total current (in A) in the conductor?

[GATE 2009]

(a) $\frac{\pi}{2a}$ (b) $\frac{800}{\pi}$

(c) $\frac{400}{\pi}$ (d) $\frac{300}{\pi}$

11. A uniform surface current is flowing in the positive y-direction over in infinite sheet lying in $x-y$ plane. The direction of the magnetic field is

[GATE 2011]

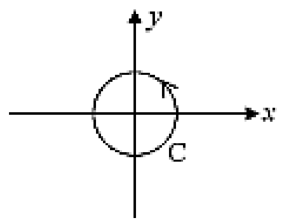
(a) along $\hat{\imath}_{\text{for}}\ z > 0$ and along $-\hat{\imath}$ for $z < 0$

(b) along $\hat{k}_{\text{for}}\ z > 0$ and along $-\hat{k}_{\text{for}}\ z < 0$

(c) along $-\hat{\imath}_{\text{for}}\ z > 0$ and along $\hat{\imath}_{\text{for}}\ z < 0$

(d) along $-\hat{k}_{\text{for}}\ z > 0$ and along $\hat{k}_{\text{for}}\ z < 0$

12. Given $\vec{F} = \vec{r}\times\vec{B}$, where $\vec{B} = B_0(\hat{\imath}+\hat{\jmath}+\hat{k})$ is a constant vector and $\vec{r}$ is the position vector. The value of $\oint_C \vec{F}\cdot d\vec{r}$, where C is a circle of unit radius centered at origin is **[GATE 2012]**



(a) 0 (b) $2\pi B_0$
(c) $-2\pi B_0$ (d) 1

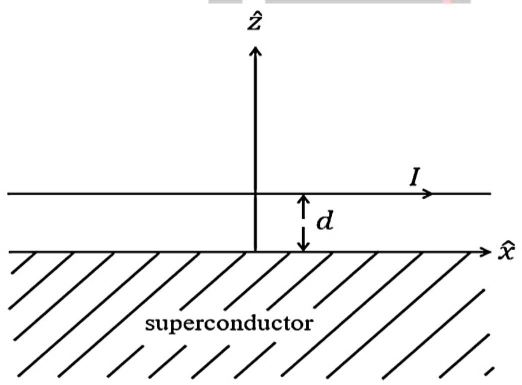
13. The value of the magnetic field required to maintain non-relativistic protons of energy 1MeV in a circular orbit of radius 100 mm is Tesla.

[GATE 2014]

(Given: $m_p = 1.67 \times 10^{-27} kg, e = 1.6 \times C$

14. An infinitely long wire parallel to the x-axis is kept at $z = d$ and carries a current I in the positive x direction above a superconductor filling the region $z \leq 0$ (see figure). The magnetic field $\vec{B}$ inside the superconductor is zero so that the field just outside the superconductor is parallel to its surface. The magnetic field due to this configuration at a point $(x, y, z > 0)$ is

[GATE 2019]



(a) $\left(\frac{\mu_0 I}{2\pi}\right)\frac{-(z-d)\hat{\jmath}+y\hat{k}}{[y^2+(z-d)^2]}$

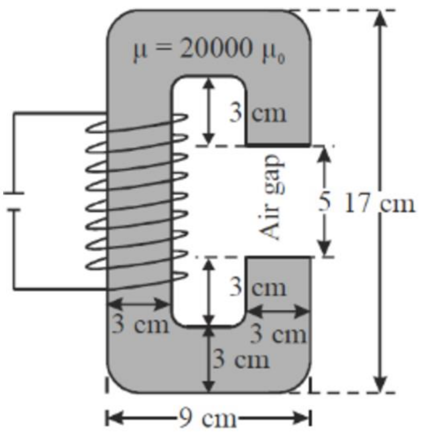
(b) $\left(\frac{\mu_0 I}{2\pi}\right)\left[\frac{-(z-d)\hat{\jmath}+y\hat{k}}{y^2+(z-d)^2}+\frac{(z+d)\hat{\jmath}-y\hat{k}}{y^2+(z+d)^2}\right]$

(c) $\left(\frac{\mu_0 I}{2\pi}\right)\left[\frac{-(z-d)\hat{\jmath}+y\hat{k}}{y^2+(z-d)^2}-\frac{(z+d)\hat{\jmath}-y\hat{k}}{y^2+(z+d)^2}\right]$

(d) $\left(\frac{\mu_0 I}{2\pi}\right)\left[\frac{y\hat{\jmath}+(z-d)\hat{k}}{y^2+(z-d)^2}+\frac{y\hat{\jmath}-(z+d)\hat{k}}{y^2+(z+d)^2}\right]$

15. Consider a cross-section of an electromagnet having an air-gap of 5 cm as shown in the figure. It consists of a magnetic material ($\mu = 20000\mu_0$) and is driven by a coil having $NI = 10^4$ A, where N is the number of tums and I is the current in Ampere.

[GATE 2021]



Ignoring the fringe fields, the magnitude of the magnetic field $\vec{B}$ (in Tesla, rounded off to two decimal places) in the air-gap between the magnetic poles is………………

❖ JEST PYQ's

1. A magnetic field $\vec{B} = B_0(\hat{\imath} + 2j - 4k)$ exists at point. If a test charge moving with a velocity, $\vec{v} = v_0(3\hat{\imath} - j + 2k)$ experiences no force at a certain point, the electric field at that point in SI units is

[JEST 2012]

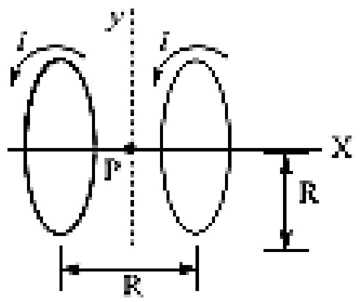
(a) $\vec{E} = v_0 B_0(3\hat{\imath} + 2j - 4k)$
(b) $\vec{E} = -v_0 B_0(\hat{\imath} + j + 7k)$
(c) $\vec{E} = v_0 B_0(14j + 7k)$
(d) $\vec{E} = -v_0 B_0(14j + 7k)$

2. Consider a particle of electric charge ' e ' and mass ' m ' moving under the influence of a constant horizontal electric field E and constant vertical gravitational field described by acceleration due to gravity g. If the particle starts from rest, what will be its trajectory?

[JEST 2012]

(a) parabolic (b) elliptic
(c) straight line (d) circular

3. A system of two circular co-axial coils carrying equal currents I along same direction having equal radius R and separated by a distance R (as shown in figure below). The magnetic field at the midpoint P is given by **[JEST 2014]**



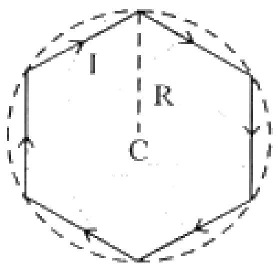
(a) $\frac{\mu_0 I}{2\sqrt{2}R}$ (b) $\frac{4\mu_0 I}{5\sqrt{5}R}$

(c) $\frac{8\mu_0 I}{5\sqrt{5}R}$ (d) 0

4. A charged particle is released at time $t = 0$, from the origin in the presence of uniform static electric and magnetic fields given by $E = E_0 y$ and $B = B_0 \hat{z}$, respectively. Which of the following statements is true for $t > 0$? **[JEST 2015]**

(a) The particle moves along the x-axis
(b) The particle moves in a circular orbit
(c) The particle moves in the (x, y) plane
(d) the particle moves in the (y, z) plane

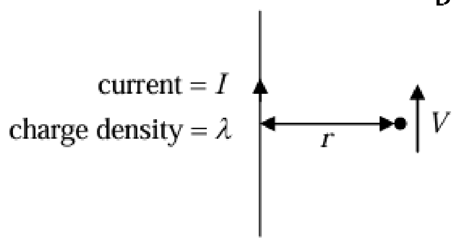
5. A conducting wire is in the shape of a regular hexagon, which is inscribed inside an imaginary circle of radius R, as shown. A current I flows through the wire. The magnitude of the magnetic field at the centre of the circle is **[JEST 2016]**



(a) $\frac{\sqrt{3}\mu_0 I}{2\pi R}$ (b) $\frac{\mu_0 I}{2\sqrt{3}\pi R}$

(c) $\frac{\sqrt{3}\mu_0 I}{\pi R}$ (d) $\frac{3\mu_0 I}{2\pi R}$

6. A wire with uniform line charge density λ per unit length carries a current I as shown in the figure. Take the permittivity and permeability of the medium to be $\varepsilon_0 = \mu_0 = 1$. A particle of charge q is at a distance r and is travelling along a trajectory parallel to the wire. What is the speed of the charge? **[JEST 2019]**



(a) $\frac{\lambda}{I}$ (b) $\frac{\lambda}{2I}$

(c) $\frac{\lambda}{3I}$ (d) $\frac{4\lambda}{I}$

7. A very long solenoid (axis along z-direction) of n turns per unit length carries a current which increases linearly with time, $i = Kl$. What is the magnetic field inside the solenoid at a given time t ? **[JEST2019]**

(a) $B = \mu_0 nKt\hat{z}$ (b) $B = \mu_0 nk\hat{z}$

(c) $B = \mu_0 nKt(\hat{x} + \hat{y})$ (d) $B = \mu_0 cnKtz$

8. Consider three infinitely long, straight, and coplanar wires which are placed parallel to each other. The distance between the adjacent wires is d. Each wire carries a current I in the same direction. Consider points on either side of the middle wire where the magnetic field vanishes. What is the distance of these points from the middle wire? **[JEST 2020]**

(a) $\frac{2d}{3}$ (b) $\frac{2d}{\sqrt{3}}$

(c) $\frac{d}{3}$ (d) $\frac{d}{\sqrt{3}}$

9. A circular ring of radius R with total charge Q_{ring} has uniform linear charge density. It rotates about an axis passing through its centre and perpendicular to its plane with a constant angular speed ω. The magnetic field at the centre is found to be B_0. Another thin circular disk of the same radius R has a constant surface charge density with a total charge Q_{disk}. This disk too rotates about the same axis as the ring with the same constant angular speed ω. The magnetic field at the centre in this case is found to be $10^{-3}B_0$. What is the value of $Q_{\text{ring}}/Q_{\text{disk}}$? **[JEST 2021]**

10. An electron of kinetic energy 100MeV moving in a region of uniform magnetic field penetrates a layer of lead. In the process it looses half of its kinetic energy. The radius of curvature of the path has changed by a factor

[JEST 2022]

11. Two semi-infinite wires are placed on the x - axis, one from $-\infty$ to the $-d$, and the the other from d to ∞. Both wires carry a steady current I in the same direction. The magnitude of the magnetic field at a distance d away from the center of this gap in the $y-z$ plane (ignore the charge accumulation) is: **[JEST 2023]**

(a) $\frac{\mu_0 I}{\pi d}\sqrt{2}$ (b) $\frac{\mu_0 I}{2\pi d}\left(1-\frac{1}{\sqrt{2}}\right)$

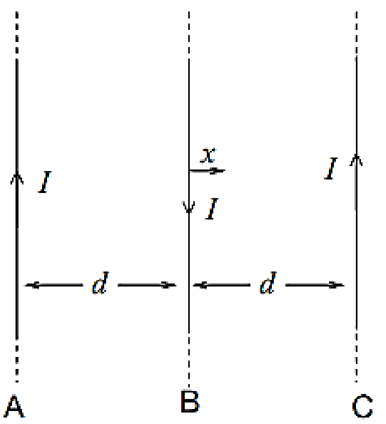
(c) $\frac{\mu_0 I}{\pi d}\frac{1}{\sqrt{2}}$ (d) $\frac{\mu_0 I}{\pi d}\frac{1}{2}$

12. A semi-infinite, thin wire extending from $-\infty$ to zero along the z-axis carries a constant current I in the positive z-direction. The wire is charge-neutral except at $z=0$, where the inflowing charge is accumulate(d) What is the absolute value of the line integral $\frac{4}{\mu_0 I}\oint \vec{B}\cdot d\vec{l}$ along the circle $x^2+y^2=1$? $\vec{B}$ is the magnetic field and μ_0 is the permeability in free space. Assume that the accumulated charge at $z=0$ is a point charge.

[JEST 2024]

❖ TIFR PYQ

1. Consider three identical infinite straight wires A, B and C arranged in parallel on a plane as shown in the figure.



The wires carry equal currents I with directions as shown in the figure and have mass per unit length m. If the wires A and C are held fixed and the wire B is displaced by a small distance x from its position, then it (B) will execute simple harmonic motion with a time period

[TIFR 2012]

(a) $2\pi\sqrt{\frac{m}{\pi\mu_0}}\left(\frac{d}{T}\right)$ (b) $2\pi\sqrt{\frac{2\pi m}{\mu_0}}\left(\frac{d}{T}\right)$

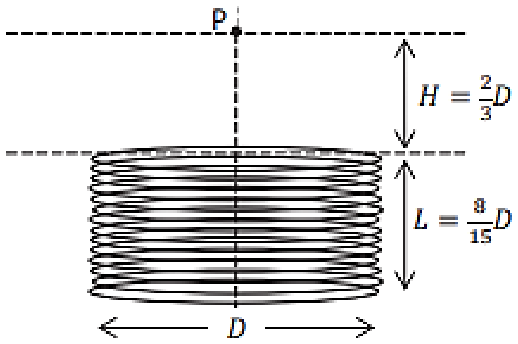
(c) $2\pi\sqrt{\frac{\pi m}{\mu_0}}\left(\frac{d}{T}\right)$ (d) $2\pi\sqrt{\frac{m}{2\pi\mu_0}}\left(\frac{d}{I}\right)$

2. A short solenoid with n turns per unit length has diameter D and length $L=8D/15$, as shown in the figure, and it carries a constant current I.

The magnetic field B at a point P on the axis of the solenoid at a distance $H=2D/3$ from its near end (see figure) is

[use $\int dx(1+x^2)^{-3/2} = x(1+x^2)^{-1/2}$]

[TIFR 2014]



(a) $\frac{4}{65}\mu_0 nI$ (b) $\frac{4}{13}\mu_0 nI$

(c) $\frac{24}{15}\mu_0 nI$ (d) $\frac{112}{65}\mu_0 nI$

3. A circular loop of fine wire of radius R carrying a current I is placed in a uniform magnetic field B perpendicular to the plane of the loop. If the breaking tension of the wire is T_b, the wire will break when the magnetic field exceeds

[TIFR 2016]

(a) T_b/IR (b) $T_b/2\pi IR$

(c) $\mu_0 T_b/2\pi IR$ (c) $\mu_0 T_b/4\pi IR$

4. Consider three straight, coplanar, parallel wires of infinite length where the distance between adjacent wires is d. Each wire carries a current I in the same direction. The perpendicular distance from the middle wire (on either side) where the magnetic field vanishes is

[TIFR 2019]

(a) $d/\sqrt{3}$ (b) $2d/3$
(c) $d/3$ (d) $2d/\sqrt{3}$

5. An electromagnet is made by winding N turns of wire around a wooden cylinder of diameter d and passing a current I through it. When the current flows, a magnetic field of magnitude B is produced at a perpendicular distance z_0 from the axis of the cylinder, where $z_0 \gg d$.
If the number of turns N, the diameter of the wooden cylinder d and the current I are all doubled, then the magnitude of the magnetic field will be $B/2$ at a distance $z =$ **[TIFR 2022]**
(a) $2.4z_0$ (b) $0.5z_0$
(c) $4.8z_0$ (d) $3.2z_0$

6. Two particles, as specified in the table below, both enter a region of uniform magnetic field in a direction perpendicular to the field direction.

Particle	Rest Mass	Kinetic Energy
Alpha	3.7GeV	11.2GeV
Deuteron	1.9GeV	20.0MeV

If both the particles then follow circular trajectories in the magnetic field, the ratio of their time periods for one full revolution must be

[TIFR 2022]

(a) 3.0 (b) 4.0
(c) 2.0 (d) 1.0

7. An electromagnet is made by winding N turns of wire around a wooden cylinder of diameter d and passing a current I through it. When the current flows, a magnetic field of magnitude B is produced at a perpendicular distance z_0 from the axis of the cylinder, where $z_0 \gg d$. If the number of turns N, the diameter of the wooden cylinder d and the current I are all doubled, then the magnitude of the magnetic field will be $B/2$ at a distance z is equal to

[TIFR 2022]

(a) $0.5z_0$ (b) $2.4z_0$
(c) $3.2z_0$ (d)$4.8z_0$

Answer Key

CSIR PYQ				
1. d	2. a	3. b	4. d	5. b
6. d	7. d	8. b	9. d	10. b
11. c	12. d	13. a	14. b	15. d
16. a	17. a			

GATE PYQ				
1. c	2. d	3. b	4. c	5. c
6. b	7. a	8. c	9. c	10. b
11. a	12. c	13. 1.44	14. b	15. 0.25

JEST PYQ				
1. d	2. c	3. c	4. c	5. c
6. a	7. a	8. d	9. 2000	10. 0.71
11. b	12. 2			

TIFR PYQ				
1. c	2. a	3. a	4. a	5. d
6. b	7. c			

❖ EMT 06 : Magnetic Vector potential & Magnetic Material

❖ CSIR-NET PYQ's

1. A current carrying loop lying in the plane of the paper is in the shape of an equilateral triangle of side a. It carries a current I in the clockwise sense. If $\hat{k}$ denotes the outward normal to the plane of the paper, the magnetic moment $\hat{m}$ due to the current loop is

[CSIR NET 2008]

(a) $\vec{m} = a^2 I\hat{k}$

(b) $\vec{m} = -\frac{1}{2}a^2 I\hat{k}$

(c) $\vec{m} = \frac{\sqrt{3}}{2}a^2 I\hat{k}$

(d) $\vec{m} = -\frac{\sqrt{3}}{4}a^2 I\hat{k}$

2. The magnetic field corresponding to the vector potential, $\vec{A} = \frac{1}{2}\vec{F}\times\vec{r} + \frac{10}{r^3}\vec{r}$ where $\vec{F}$ is a constant vector, is

[CSIR JUNE 2012]

(a) $\vec{F}$

(b) $-\vec{F}$

(c) $\vec{F} + \frac{30}{r^4}\vec{r}$

(d) $\vec{F} - \frac{30}{r^4}\vec{r}$

3. The vector potential $\vec{A}$ due to a magnetic moment ' m ' at a point ' r ' is given by $\vec{A} = \frac{\vec{m}\times\vec{r}}{r^3}$. If $\vec{m}$ is directed along the positive z-axis, the x-component of the magnetic field, at the point r, is

[CSIR JUNE 2012]

(a) $\frac{3myz}{r^5}$

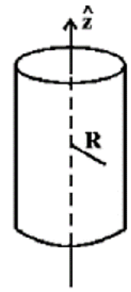
(b) $-\frac{3mxy}{r^5}$

(c) $\frac{3mxz}{r^5}$

(d) $\frac{3\,m(z^2-xy)}{r^5}$

4. An infinite solenoid with its axis of symmetry along the z-direction carries a steady current I.

[NET Dec, 2012]



The vector potential $\vec{A}$ at a distance R from the axis.

(a) Is constant inside and varies as R outside the solenoid.

(b) Varies as R inside and is constant outside the solenoid.

(c) Varies as $1/R$ inside and as R outside the solenoid.

(d) Varies as R inside and as $1/R$ outside the solenoid.

5. A thin infinitely long solenoid placed along the z-axis contains a magnetic flux ϕ. Which of the following vector potentials corresponds to the magnetic field at an arbitrary point (x, y, z) ?

[CSIR JUNE 2014]

(a) $(A_x, A_y, A_z) = \left(-\frac{\phi}{2\pi}\frac{y}{x^2+y^2}, \frac{\phi}{2\pi}\frac{x}{x^2+y^2}, 0\right)$

(b) $(A_x, A_y, A_z) = \left(-\frac{\phi}{2\pi}\frac{y}{x^2+y^2+z^2}, \frac{\phi}{2\pi}\frac{x}{x^2+y^2+z^2}, 0\right)$

(c) $(A_x, A_y, A_z) = \left(-\frac{\phi}{2\pi}\frac{x+y}{x^2+y^2}, \frac{\phi}{2\pi}\frac{x+y}{x^2+y^2}, 0\right)$

(d) $(A_x, A_y, A_z) = \left(-\frac{\phi}{2\pi}\frac{x}{x^2+y^2}, \frac{\phi}{2\pi}\frac{y}{x^2+y^2}, 0\right)$

6. Given a uniform magnetic field $\boldsymbol{B} = B_0\hat{k}$ (where B_0 is a constant), a possible choice for the magnetic vector potential $\boldsymbol{A}$ is

[CSIR DEC 2015]

(a) $B_0 y\hat{\imath}$ (b) $-B_0 y\hat{\imath}$

(c) $B_0(x\hat{\jmath}+y\hat{\imath})$ (d) $B_0(x\hat{\imath}-y\hat{\jmath})$

7. A small magnetic needle is kept at (0,0) with its moment along the x-axis. Another small magnetic needle is at the point (1,1) and is free to rotate in the xy-plane. In equilibrium the angle θ between their magnetic moments is such that

[CSIR DEC 2015]

(a) $\tan\,\theta = 1/3$ (b) $\tan\,\theta = 0$

(c) $\tan\,\theta = 3$ (d) $\tan\,\theta = 1$

8. A loop of radius a, carrying a current I, is placed in a uniform magnetic field $\boldsymbol{B}$. If the normal to the loop is denoted by $\hat{n}$, the force F and the torque T on the loop are

[CSIR JUNE 2016]

(a) $F=0$ and $T=\pi a^2 I\hat{n}\times B$

(b) $F=\frac{\mu_0}{4\pi}I\times B$ and $T=0$

(c) $F=\frac{\mu_0}{4\pi}I\times B$ and $T=I\hat{n}\times B$

(d) $F=0$ and $T=\frac{1}{\mu_0\varepsilon_0}IB$

9. A rotating spherical shell of uniform surface charge and mass density has total mass M and charge Q. If its angular momentum is L and magnetic moment is μ, then the ratio μ/L is

[CSIR DEC 2018]

(a) $Q/3M$ (b) $2Q/3M$

(c) $Q/2M$ (d) $3Q/4M$

10. The vector potential for an almost point like magnetic dipole located at the origin is $A=\frac{\mu\sin\,\theta}{4\pi r^2}\hat{\phi}$, where (r,θ,ϕ) denote the spherical polar coordinates and $\hat{\phi}$ is the unit vector along ϕ. A particle of mass m and charge q, moving in the equatorial plane of the dipole, starts at time $= t = 0$ with an initial speed v_0 and an impact parameter b. Its instantaneous speed at the point of closest approach is [CSIR JUNE 2021]

(a) v_0 (b) 0/0

(c) $v_0+\frac{\mu q}{4\pi m b^2}$ (d) $\sqrt{v_0^2+\left(\frac{\mu q}{4\pi m b^2}\right)^2}$

11. A stationary magnetic dipole $\mathbf{m}=\mathrm{m}\hat{\mathbf{k}}$ is placed above an infinite surface $(\mathrm{z}=0)$ carrying a uniform surface current density $\boldsymbol{\kappa}=\kappa\hat{\mathbf{i}}$. The torque on the dipole is Options:-

[CSIR JUNE 2022]

(a)$\frac{\mu_0}{2}\mathrm{m}\kappa\hat{\mathbf{i}}$, (b)$-\frac{\mu_0}{2}\mathrm{m}\kappa\hat{\mathbf{i}}$

(c)$\frac{\mu_0}{2}\mathrm{m}\kappa\hat{\jmath}$ (d)$-\frac{\mu_0}{2}\mathrm{m}\kappa\hat{\jmath}$

12. A small bar magnet is placed in a magnetic field $B(\vec{r})=B(x)\hat{z}$. The magnet is initially at rest with its magnetic moment along $\hat{y}$. At later times, it will undergo [CSIR DEC 2023]

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

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

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

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

❖ GATE PYQ's

STATEMENT FOR LINKED ANSWER Q.1 AND Q. 2

An infinitely long hollow cylinder of radius R carrying a surface charge density σ is rotated about its cylindrical axis with a constant angular speed w Then

1. magnitude of the surface current is:

[GATE 2005]

(a) $\sigma R\omega$ (b) $2\sigma R\omega$

(c) $\pi\sigma R\omega$ (d) $2\pi\sigma R\omega$

2. The magnitude of vector potential inside the cylinder at a distance from its axis is:

[GATE 2005]

(a) $2\mu_0\sigma\mathrm{R}\omega r$ (b) $\mu_0\sigma\mathrm{R}\omega r$

(c) $\frac{1}{2}\mu_0\sigma R\omega\mathrm{r}$ (d) $\frac{1}{4}\mu_0\sigma R\omega r$

3. The vector potential in a region is given as $\vec{A}(x,y,z)=-y\hat{\imath}+2x\hat{\jmath}$. The associated magnetic induction is $\vec{B}$ is [GATE 2006]

(a) $\hat{\imath}+\hat{k}$ (b) $3\hat{k}$

(c) $-\hat{\imath}+2\hat{\jmath}$ (d) $-\hat{\imath}+\hat{\jmath}+\hat{k}$

4. The value of $\oint \vec{A} \cdot d\vec{\ell}$ along a square loop of side L in a uniform field $\vec{A}$ is : **[GATE 2006]**

(a) 0 (b) 2LA

(c) 4LA (d) L^2 A

5. An atom with net magnetic moment $\vec{\mu}$ and net angular momentum $\vec{L}(\vec{\mu} = \gamma\vec{L})$ is kept in a uniform magnetic induction $\vec{B} = B_0\hat{k}$. The magnetic moment $\vec{\mu}(= \mu_x)$ is

[GATE 2006]

(a) $\frac{d^2\mu_x}{dt^2} + \gamma B_0 \mu_x = 0$

(b) $\frac{d^2\mu_x}{dt^2} + \gamma B_0 \frac{d\mu_x}{dt} + \mu_x = 0$

(c) $\frac{d^2\mu_x}{dt^2} + \gamma^2 B_0^2 \mu_x = 0$

(d) $\frac{d^2\mu_x}{dt^2} + 2\gamma B_0 \mu_x = 0$

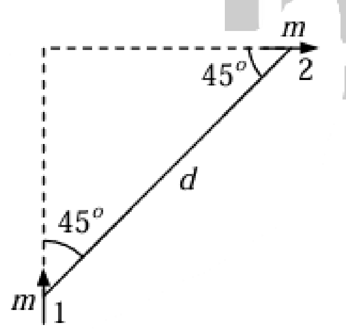
6. Which one of the following current densities, j, can generate the magnetic vector potential $\hat{A} = (y^2\hat{\imath} + x^2\hat{\jmath})$? **[GATE 2009]**

(a) $\frac{2}{\mu_0}(x\hat{\imath} + y\hat{\jmath})$ (b) $\frac{-2}{\mu_0}(\hat{\imath} + \hat{\jmath})$

(c) $\frac{2}{\mu_0}(\hat{\imath} - \hat{\jmath})$ (d) $\frac{2}{\mu_0}(x\hat{\imath} - y\hat{\jmath})$

7. Two magnetic dipoles of magnitude m each are placed in a plane as shown The energy of interaction is given by

[GATE 2010]



(a) 0 (b) $\frac{\mu_0}{4\pi}\frac{m^2}{d^3}$

(c) $\frac{3\mu_0}{2\pi}\frac{m^2}{d^3}$ (d) $-\frac{3\mu_0}{8\pi}\frac{m^2}{d^3}$

8. A magnetic dipole of dipole moment $\vec{m}$ is placed in a non-uniform magnetic field $\vec{B}$. If the position vector of the dipole is $\vec{r}$, the torque acting on the dipole about the origin is

[GATE 2011]

(a) $\vec{r} \times (\vec{m} \times \vec{B})$

(b) $\vec{r} \times \vec{\nabla}(\vec{m} \cdot \vec{B})$

(c) $\vec{m} \times \vec{B}$

(d) $\vec{m} \times \vec{B} + \vec{r} \times \vec{\nabla}(\vec{m} \cdot \vec{B})$

9. Which of the following expressions for a vector potential $\vec{A}$ does not represent a uniform magnetic field of magnitude B_0 along the z-direction?

[GATE 2011]

(a) $\vec{A} = (0, B_0 x, 0)$ (b) $\vec{A} = (-B_0 y, 0, 0)$

(c) $\vec{A} = \left(\frac{B_0 x}{2}, \frac{B_0 x}{2}, 0\right)$ (d) $\vec{A} = \left(-\frac{B_0 y}{2}, \frac{B_0 x}{2}, 0\right)$

10. At a surface current, which one of the magneto static boundary condition is NOT CORRECT?

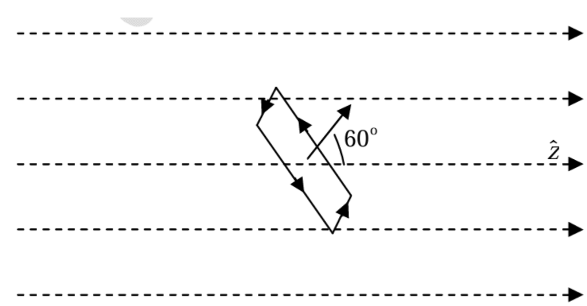
(a) Normal component of the magnetic field is continuous. **[GATE 2013]**

(b) Normal component of the magnetic vector potential is continuous.

(c) Tangential component of the magnetic vector potential is continuous.

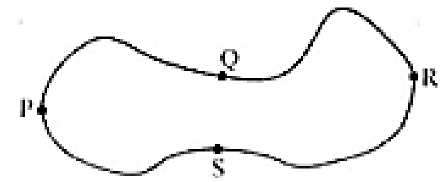
(d) Tangential component of the magnetic vector potential is not continuous.

11. In a constant magnetic field of 0.6 Tesla along the z direction, find the value of the path integral $\oint \vec{A} \cdot d\vec{\ell}$ in the units of (Tesla m^2) on a square loop of side length $(1/\sqrt{2}$) meters. The normal to the loop makes, an angle of 60° to the z-axis, as shown in the figure. The answer should be up to two decimal places. **[GATE 2013]**



12. Given that magnetic flux through the closed loop PQRSP is ϕ. If $\int_P^R \vec{A} \cdot \vec{dl} = \phi_1$ along PQR, the value of $\int_A^R \vec{A} \cdot dl$ along PSR is

|GATE 2015|



(a) $\phi - \phi_1$ (b) $\phi_1 - \phi$
(c) $-\phi_1$ (d) ϕ_1

13. The magnitude of the magnetic dipole moment associated with a square shaped loop carrying a steady current I is m. If this loop is changed to a circular shape with the same current I passing through it, the magnetic dipole moment becomes $\frac{pm}{\pi}$. The value of p is______________.

[GATE 2016]

14. The $x - y$ plane is the boundary between free space and a magnetic material with relative permeability μ_r. The magnetic field in the free space is $B_x\hat{\imath} + B_z\hat{k}$. The magnetic field in the magnetic material is **[GATE 2016]**

(a) $B_x\hat{\imath} + B_z\hat{k}$ (b) $B_x\hat{\imath} + \mu_r B_z\hat{k}$
(c) $\frac{1}{\mu_r}B_x\hat{\imath} + B_z\hat{k}$ (d) $\mu_r B_x\hat{\imath} + B_z\hat{k}$

15. Which of the following magnetic vector potentials gives rise to a uniform magnetic field $B_0\hat{k}$?

[GATE 2016]

(a) $B_0 z\hat{k}$ (b) $-B_0 x\hat{\jmath}$
(c) $\frac{B_0}{2}(-y\hat{\imath} + x\hat{\jmath})$ (d) $\frac{B_0}{2}(y\hat{\jmath} + x\hat{\jmath})$

16. A solid cylinder of radius R has total charge Q distributed uniformly over its volume. It is rotating about its axis with angular speed ω. The magnitude of the total magnetic moment of the cylinder is

[GATE 2019]

(a) $QR^2\omega$ (b) $\frac{1}{2}QR^2\omega$
(c) $\frac{1}{4}QR^2\omega$ (d) $\frac{1}{8}QR^2\omega$

17. Far from the Earth, the Earth's magnetic field can be approximated as due to a bar magnet of magnetic pole strength 4×10^{14}Am. Assume this magnetic field is generated by a current carrying loop encircling the magnetic equator. The current required to do so is about 4×10^n A, where n is an integer. The value of n is………. (Earth's circumference: 4×10^7 m)

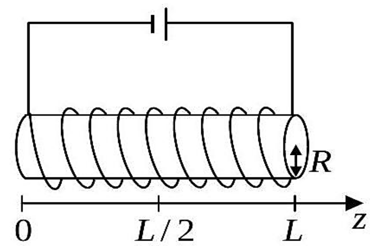
[GATE 2020]

18. A material is placed in a magnetic field intensity H. As a result, bound current density J_b is induced and magnetization of the material is M. The magnetic flux density is B. Choose the correct option(s) valid at the surface of the material

[GATE 2021]

(a) $\nabla \cdot M = 0$ (b) $\nabla \cdot B = 0$
(c) $\nabla \cdot H = 0$ (d) $\nabla \cdot J_b = 0$

19. Consider a solenoid of length L and radius R, where $R \ll L$. A steady-current flows through the solenoid. The magnetic field is uniform inside the solenoid and zero outside.

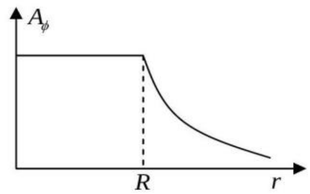


Among the given options, choose the one that best represents the variation in the magnitude of the vector potential, $(0, A_\varphi, 0)$ at $z = L/2$, as a function of the radial distance (r) in cylindrical coordinates.

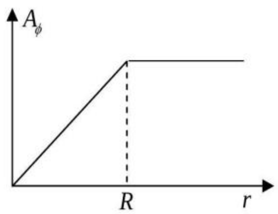
Useful information: The curl of a vector $\vec{F}$, in cylindrical coordinates is $\vec{\nabla} \times \vec{F}(r, \varphi, z) = \hat{r}\left[\frac{1}{r}\frac{\partial F_z}{\partial \varphi} - \frac{\partial F_\varphi}{\partial z}\right] + \hat{\varphi}\left[\frac{\partial F_r}{\partial z} - \frac{\partial F_z}{\partial r}\right] + \hat{z}\frac{1}{r}\left[\frac{\partial (rF_\varphi)}{\partial r} - \frac{\partial F_r}{\partial \varphi}\right]$

[GATE 2021]

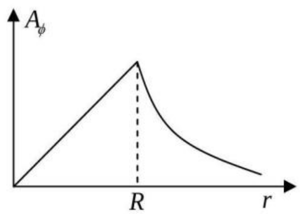
(a)



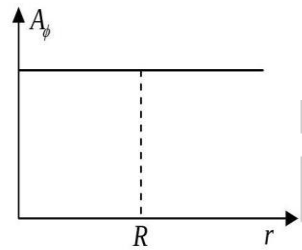
(b)



(c)



(d)



20. Consider an isolated magnetized sphere of radius R with a uniform magnetization $\vec{M}$ along the positive z-direction, with the north and south poles of the sphere lying on the z axis. It is given that the magnetic field inside the sphere is $\vec{B} = \frac{2\mu_0}{3}\vec{M}$, where μ_0 is the permeability of vacuum. Which of the following statements is (are) CORRECT? **[GATE 2023]**

(a) The bound volume current density is zero

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

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

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

21. An infinitely long cylinder of radius R carries a frozen-in magnetization $\vec{M} = ke^{-s}\hat{z}$, where k is a constant and s is the distance from the axis of cylinder. The magnetic permeability of free space is μ_0. There is no free current present anywhere. The magnetic flux density ($\vec{B}$) inside the cylinder is

[GATE 2024]

(a) 0 (b) $\mu_0 ke^{-R}\hat{Z}$

(c) $\mu_0 ke^{-s}\hat{Z}$ (d) $\mu_0 ke^{-s}\left(\frac{R}{s}\right)\hat{Z}$

❖ JEST PYQ

1. A spherical shell of radius R carries a constant surface charge density σ and is rotating about one of its diameters with an angular velocity ω. The magnitude of the magnetic moment of the shell is: **[JEST 2016]**

(a) $4\pi\sigma\omega R^4$ (b) $\frac{4\pi\sigma\omega R^4}{3}$

(c) $\frac{4\pi\sigma\omega R^4}{15}$ (d) $\frac{4\pi\sigma\omega R^4}{9}$

2. Two identical magnetic dipoles of length ℓ, which are free to rotate, are kept fixed at a distance $d(d \gg \ell)$. In their minimum energy configuration, they will orient themselves **[JEST 2023]**

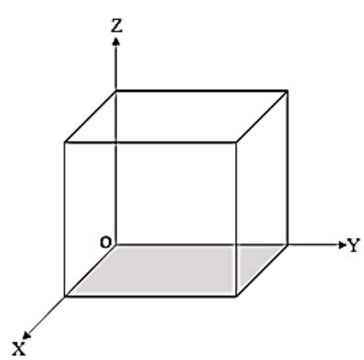
(a) anti-parallel to each other and perpendicular to the line joining them

(b) parallel to each other and aligned to the line joining them

(c) anti-parallel to each other and aligned to the line joining them

(d) parallel to each other and perpendicular to the line joining them

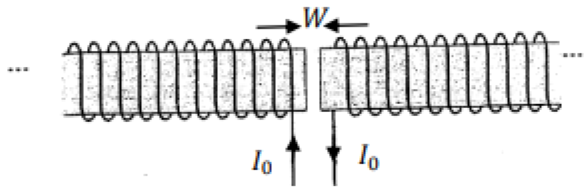
3. A magnetic vector potential is given as $\vec{A} = 6\hat{\imath} + yz^2\hat{\jmath} + (3y+z)\hat{k}$. Find the corresponding outgoing magnetic flux through the five faces (excluding the shaded one) of a unit cube with one corner at the origin, as shown in the figure.



[JEST 2024]

❖ TIFR PYQ

1. Two semi-infinite solenoids placed next to each other are separated by a small gap of width W as shown in the figure.



The current I_0 in the solenoids flows in the direction as shown. If the solenoids have a circular cross-section of radius R and are filled with a magnetic material of permeability $\mu(\mu > \mu_0)$, then the magnetic energy densities u_i inside the solenoid and u_g in the gap are best related by **[TIFR 2015]**

(a) $u_g > u_i$ (b) $u_g < u_i$

(c) $u_g = cu_i$ (d) $u_g > cu_i$

2. Four students were asked to write down possible forms for the magnetic vector potential $\vec{\boldsymbol{A}}(\vec{\boldsymbol{x}})$ corresponding to a uniform magnetic field of magnitude B along the positive z direction. Three returned correct answers and one returned an incorrect answers. Their answers are reproduced below. Which was the incorrect answer? **[TIFR 2020]**

(a) $Bx\hat{\boldsymbol{j}}$ (b) $-By\hat{\imath}$

(c) $\frac{1}{2}(Bx\hat{\imath} - By\hat{\jmath})$ (d) $\frac{1}{2}(-By\hat{\imath} + Bx\hat{\jmath})$

3. The magnetic vector potential $\vec{A} \equiv A_x\hat{\imath} + A_y\hat{\jmath} + A_z\hat{k}$ is defined in a region R of space by

$A_x = 5\cos\,\pi y\ A_y = 2 + \sin\,\pi x\ A_z = 0$

in an appropriate unit.

If L be a square loop of wire in the $x - y$ plane, with its ends at

(0 0) (0, 0.25) (0.25,0.25) (0.25,0)

in an appropriate unit and it lies entirely in the region R, the numerical value of the flux of the above magnetic field (in the same units) passing through L is **[TIFR 2020]**

(a) 0.543 (b) 3.31

(c) -0.75 (d) zero

Answer Key				
CSIR NET PYQ				
1. d	2. a	3. c	4. d	5. a
6. b	7. c	8. a	9. c	10. a
11. a	12. b			
GATE PYQ				
1. a	2. c	3. b	4. a	5. c
6. b	7. d	8. d	9. b	10. d
11. 0.15	12. a	13. 4	14. d	15. c
16. c	17. 7	18. bd	19. c	20. ab
21. c				
JEST PYQ				
1. b	2. b	3. 0		
TIFR PYQ				
1. a	2. d	3. a		

❖ EMT 07: EMF, Displacement Current

❖ CSIR-NET PYQ's

1. Consider a solenoid of radius R with n turns per unit length, in which a time dependent current $I = I_0 \sin \omega t$ (where $\omega R/c\&1$) flows. The magnitude of the electric field at a perpendicular distance r < R from the axis of symmetry of the solenoid, is:

[CSIR DEC 2011]

(a) 0

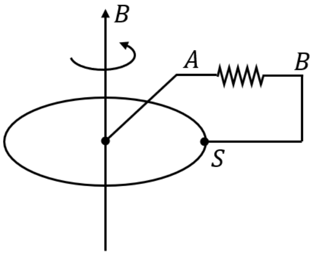
(b) $\frac{1}{2r}\omega\mu_0 n I_0 R^2 \cos\,\omega t$

(c) $\frac{1}{2}\omega\mu_0 n I_0 r \sin\,\omega t$

(d) $\frac{1}{2}\omega\mu_0 n I_0 r \cos\,\omega t$

2. A horizontal metal disc rotates about the vertical axis in a uniform magnetic field pointing up as shown in the figure. A circuit is made by connecting one end A of a resistor to the centre of the disc and the other end B to its edge through a sliding contact S. The current that flows through the resistor is

[CSIR DEC 2013]



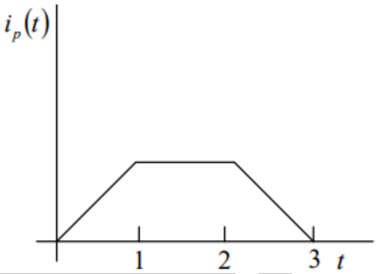
(a) zero

(b) DC from A to B

(c) DC from B to A

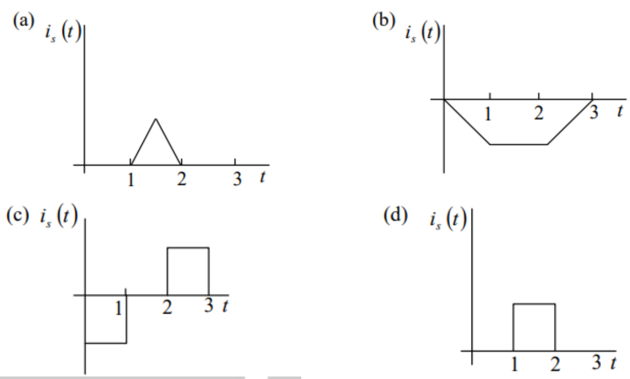
(d) AC

3. A current i_p flows through the primary coil of a transformer. The graph of $i_p(t)$ as a function of time ' t ' is shown in figure below Which of the following graph represents the current i_s in the secondary coil?



Which of the following graph represents the current i_s in the secondary coil?

[CSIR JUNE 2014]



4. A uniform magnetic field in the positive z-direction passes through a circular wire loop of radius 1 cm and resistance 1Ω lying in the xy-plane. The field strength is reduced from 10 tesla to 9 tesla in 1 s. The charge transferred across any point in the wire is approximately

[NET June 2015]

(a) 3.1×10^{-4} coulomb

(b) 3.4×10^{-4} coulomb

(c) 4.2×10^{-4} coulomb

(d) 5.2×10^{-4} coulomb

5. A magnetic field B is Bz in the region $x > 0$ and zero elsewhere. A rectangular loop, in the xy-plane, of sides / (along the x-direction) and h (along the y-direction) is inserted into the $x > 0$ region from the $x < 0$ region at a constant velocity v v $\hat{x}$. Which of the following values of l and h will generate the larged EMF ?

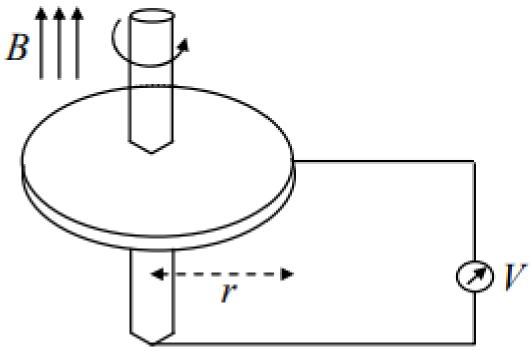
[NET June 2016]

(a) $l = 8, h = 3$ (b) $l = 4, h = 6$

(c) $l = 6, h = 4$ (d) $l = 12, h = 2$

6. A conducting circular disc of radius r and resistivity ρ rotates with an angular velocity ω in a magnetic field B perpendicular to it. A voltmeter is connected as shown in the figure below.

[CSIR DEC 2016]



Assuming its internal resistance to be infinite, the reading on the voltmeter

(a) depends on ω, B, r and ρ

(b) depends on ω, B and r, but not on ρ

(c) is zero because the flux through the loop is not changing

(d) is zero because a current flows in the direction of B

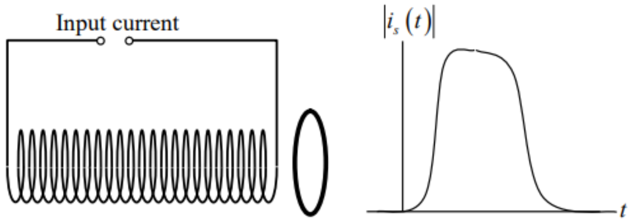
7. A parallel plate capacitor is formed by two circular conducting plates of radius a separated by a distance d, where $d \ll a$. It is being slowly charged by a current that is nearly constant. At an instant when the current is I, the magnetic induction between the plates at a distance $a/2$ from the centre of the plate, is

[NET Dec. 2016]

(a) $\frac{\mu_0 I}{\pi a}$ (b) $\frac{\mu_0 I}{2\pi a}$

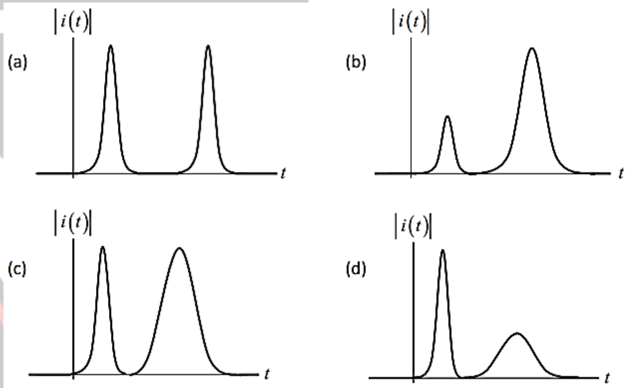
(c) $\frac{\mu_0 I}{a}$ (d) $\frac{\mu_0 I}{4\pi a}$

8. A circular conducting wire loop is placed close to a solenoid as shown in the figure below. Also shown is the current through the solenoid as a function of time.

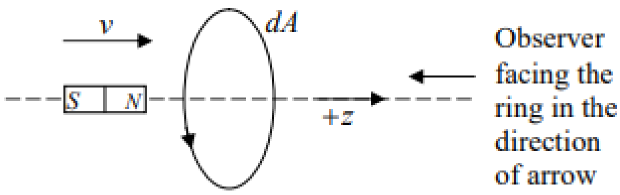


The magnitude $|i(t)|$ of the induced current in the wire loop, as a function of time t, is best represented as

[NET Dec. 2019]

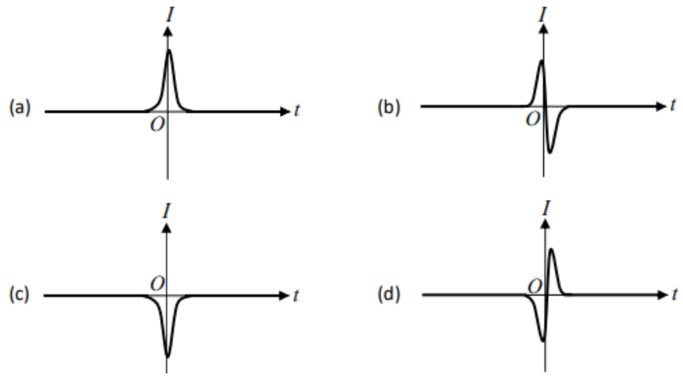


9. A conducting wire in the shape of a circle lies on the (x, y)-plane with its centre at the origin. A bar magnet moves with a constant velocity towards the wire along the z-axis (as shown in the figure below)



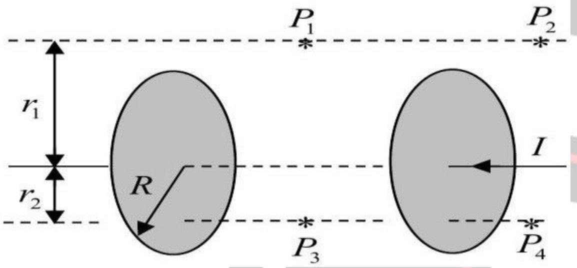
We take $t = 0$ to be the instant at which the midpoint of the magnet is at the centre of the wire loop and the induced current to be positive when it is counter-clockwise as viewed by the observer facing the loop and the incoming magnet. In these conventions, the best schematic representation of the induced current $I(t)$ as a function of t, is

[CSIR JUNE 2021]



10. The figure below shows an ideal capacitor consisting of two parallel circular plates of radius R. Points P_1 and P_2 are at a transverse distance $r_1 > R$ from the line joining the centres of the plates, while points P_3 and P_4 are at a transverse distance $r_2 < R$.

[CSIR JUNE 2021]



If $B(x)$ denotes the magnitude of the magnetic fields at these points, which of the following holds while the capacitor is charging?

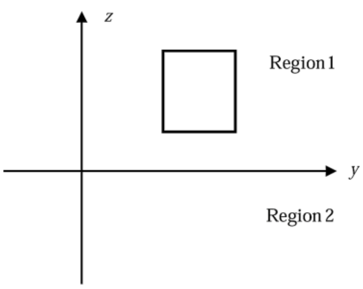
(a) $B(P_1) < B(P_2)$ and $B(P_3) < B(P_4)$

(b) $B(P_1) > B(P_2)$ and $B(P_3) > B(P_4)$

(c) $B(P_1) = B(P_2)$ and $B(P_3) < B(P_4)$

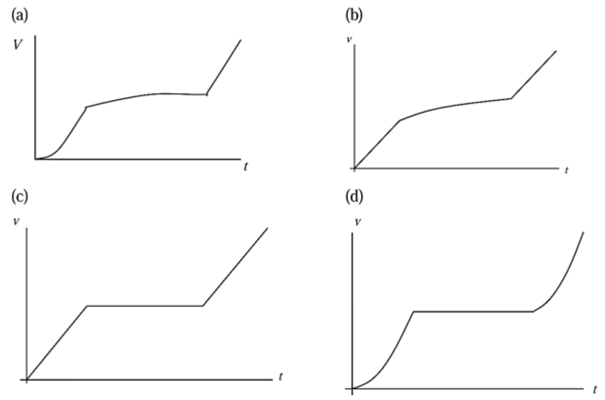
(d) $B(P_1) = B(P_2)$ and $B(P_3) > B(P_4)$

11. A square conducting loop in the yz-plane, falls downward under gravity along the negative z-axis. Region 1, defined by $z > 0$ has a uniform magnetic field $\mathbf{B} = B_0\hat{1}$, while region 2 (defined by $z < 0$) has no magnetic field.



The time dependence of the speed v(t) of the loop, as it starts to fall from well within the region 1 and passes into the region 2, is best represented by

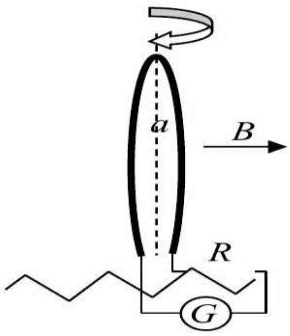
[CSIR JUNE 2022]



12. A small circular wire loop of radius a and number of turns N, is oriented with its axis parallel to the direction of the local magnetic field B.A resistance and Galvano meter are connected to the coil as shown in then figure

When the coil is flipped (i.e. the direction of its axis is reversed) the galvanometer measures the total charge Q that flow through it. If the induce emf through the coil $E_F = IR$ then Q is

[CSIR JUNE 2023]



(a) $\pi N a^2 B/2R$ (b) $\pi N a^2 B/R$

(c) $\sqrt{2}\pi N a^2 B/R$ (d) $2\pi N a^2 B/R$

13. An infinitely long solenoid of radius r_0 centred at origin which produces a timedependent magnetic field $\frac{\alpha}{\pi r_0^2}\cos\,\omega t$ (where α and ω are constants) is placed along the z-axis. A circular loop of radius R, which carries unit line charge density is placed, initially at rest, on the xy-plane with its centre on the z-axis. If $R > r_0$, the magnitude of the angular momentum of the loop is **[CSIR DEC 2023]**

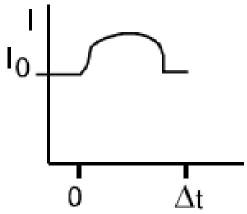
(a)$\alpha R(1 - \cos\,\omega t)$ (b)$\alpha R\sin\,\omega t$

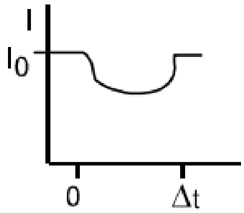
(c)$\frac{1}{2}\alpha R(1 - \cos\,2\omega t)$ (d)$\frac{1}{2}\alpha R\sin\,2\omega t$

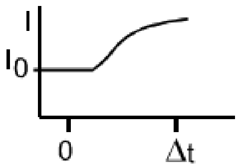
❖ GATE PYQ's

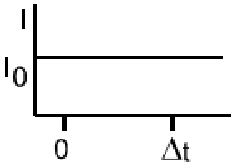
1. A solenoid with an iron core is connected in series with a battery of emf V and it is found that a constant current I_0 passes through the solenoid. If at $t = 0$, the iron core is pulled out from the solenoid quickly in a time Δt, which one of the following could be a correct description of the current passing through the solenoid?

[GATE 2000]

(a) 

(b) 

(c) 

(d) 

2. A current I flows in the anticlockwise direction through a square loop of side a lying in the xoy plane with its centre at the origin. The magnetic induction at the centre of the square loop is

[GATE 2001]

(a) $\frac{2\sqrt{2}\mu_0 I}{\pi a}\hat{e}_x$ (b) $\frac{2\sqrt{2}\mu_0 I}{\pi a}\hat{e}_z$

(c) $\frac{2\sqrt{2}\mu_0 I}{\pi a^2}\hat{e}_z$ (d) $\frac{2\sqrt{2}\mu_0 I}{\pi a^2}\hat{e}_x$

3. A thin conducting wire is bent into a circular loop of radius r and placed in a time dependent magnetic field of magnetic induction.

$$\vec{B}(t) = B_0 e^{-\alpha t}\hat{e}_z, (B_0 > 0 \text{ and } \alpha > 0),$$

such that, the plane of the loop is perpendicular to $\vec{B}(t)$. Then the induced emf in the loop is

[GATE 2001]

(a) $\pi r^2 \alpha B_0 e^{-\alpha t}$ (b) $\pi r^2 B_0 e^{-\alpha r}$

(c) $-\pi r^2 \alpha B_0 e^{-\alpha r}$ (d) $-\pi r^2 B_0 e^{-\alpha r}$

4. An infinitely long closely wound solenoid carries a sinusoidally varying current. The induced electric field is

[GATE 2002]

(a) zero everywhere

(b) non-zero inside and zero outside the solenoid

(c) non-zero inside as well as outside the solenoid

(d) zero inside and non-zero outside the solenoid

5. Consider a parallel plate air filled capacitor with a plate area of 10 cm^2 separated by a distance of 2 mm. The potential difference across the plates varies as

$$V = 360\sin(2\pi \times 10^6 t) \text{ volts,}$$

where t is measured in seconds. Neglecting fringe effects, calculate the displacement current flowing through the capacitor.

[GATE 2002]

6. A large circular coil of N turns and radius R carries a time varying current $i = i_0\sin(wt)$. A small circular coil of n turns and radius $r(r << R)$ is placed at the center of the large coil such that the coils are concentric and coplanar. The induced emf in the small coil

[GATE 2002]

(a) Leads the current in the large coil by $\pi/2$

(b) Lags the current in the large coil by π

(c) Is in phase with the current in the large coil

(d) lags the current in the large coil by $\pi/2$

7. Which one of the following Maxwell's equations implies the absence of magnetic monopoles?

[GATE 2003]

(a) $\nabla . E = \frac{\pi}{\varepsilon_0}$

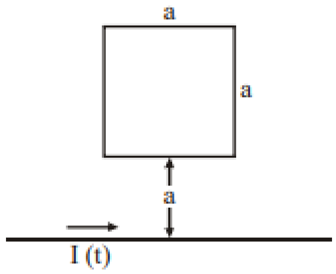
(b) $\nabla \cdot B = 0$

(c) $\nabla \times E = -\partial B/\partial t$

(d) $\nabla \times B = (1/c^2)\,\partial B/\partial t + \mu_0 J$

8. An infinitely long wire carrying a current $I(t) = I_0\cos(\omega t)$ is placed at a distance a froma square loop of side a as shown in the figure. If the resistance of the loop is R, then the amplitude of the induced current in the loop is

[GATE 2005]



(a) $\frac{\mu_0}{2\pi}\frac{aI_0\omega}{R}\ln\ 2$ (b) $\frac{\mu_0}{\pi}\frac{aI_0\omega}{R}\ln\ 2$

(c) $\frac{2\mu_0}{\pi}\frac{aI_0\omega}{R}\ln\ 2$ (d) $\frac{\mu_0}{2\pi}\frac{aI_0\omega}{R}$

9. A charge capacitor (C) is connected in series with an inductor (L). When the displacement current reduces to zero, the energy of the LC circuit is

[GATE 2007]

(a) stored entirely in its magnetic field

(b) stored entirely in its electric field

(c) distributed equally among its electric and magnetic fields.

(d) radiated out of the circuit.

10. A conducting loop L of surface area S is moving with a velocity $\vec{v}$ in a magnetic field $\vec{B}(\vec{r},t)=\vec{B}_0t^2, B_0$ is a positive constant of suitable dimensions. The emf induced, V_{emf}, in the loop is given by :

[GATE 2009]

(a) $-\int_s\frac{\partial\vec{B}}{\partial t}\cdot d\vec{S}$

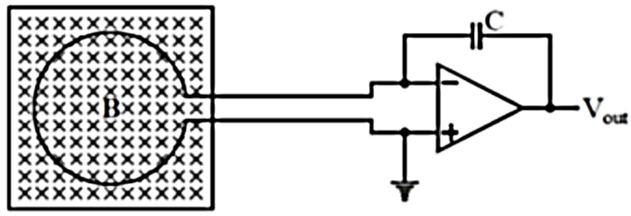
(b) $\oint_L(\vec{v}\times\vec{B})\cdot d\vec{L}$

(c) $-\int_s\frac{\partial\vec{B}}{dt}\cdot d\vec{S}-\oint_L(\vec{v}\times\vec{B})\cdot d\vec{L}$

(d) $-\int_s\frac{\partial\vec{B}}{dt}\cdot d\vec{S}+\oint_L(\vec{v}\times\vec{B})\cdot d\vec{L}$

11. Consider a conducting loop of radius a and total loop resistance R placed in a region with a magnetic field B thereby enclosing a flux ϕ_0. The loop is connected to an electronic circuit as shown, the capacitor being initially uncharged. If the loop is pulled out of the region of the magnetic field at a constant speed ' u ', the final output voltage V_{out} is independent of

[GATE 2010]



(a) ϕ_0 (b) u
(c) R (d) C

12. A long solenoid is embedded in a conducting medium and is insulated from the medium. If the current through the solenoid is increased at a constant rate, the induced current in the medium as a function of the radial distance r from the axis of the solenoid is proportional to

[GATE 2015]

(a) r^2 inside the solenoid and $\frac{1}{r}$ outside

(b) r inside the solenoid and $\frac{1}{r^2}$ outside

(c) r^2 inside the solenoid and $\frac{1}{r^2}$ outside

(d) r inside the solenoid and $\frac{1}{r}$ outside

13. An infinite solenoid carries a time varying current $I(t)=At^2$, with $A\neq 0$. the axis of the solenoid is along the $\hat{z}$ direction. $\hat{r}$ and $\hat{\theta}$ are the usual radial and polar directions in cylindrical polar coordinates. $\vec{B}=B_r\hat{r}+B_0\hat{\theta}+B_z\hat{z}$ is the magnet ic field at a point outside the solenoid. Which one of the following statements is true?

[GATE 2017]

(a) $B_r=0,\dot{B}_0=0,B_z=0$

(b) $B_r\neq 0,B_0\neq 0,B_z=0$

(c) $B_r\neq 0,B_0\neq 0,B_z\neq 0$

(d) $B_r=0,B_0=0,B_z\neq 0$

14. Consider an infinitely long solenoid with N turns per unit length, radius R and carrying a current $I(t)=\alpha\cos\ \omega t$, where α is a constant and ω is the angular frequency. The magnitude of electric field at the surface of the solenoid is

[GATE 2018]

(a) $\frac{1}{2}\mu_0NR\omega\alpha\sin\ \omega t$ (b) $\frac{1}{2}\mu_0\omega NR\cos\ \omega t$

(c) $\mu_0NR\omega\alpha\sin\ \omega t$ (d) $\mu_0\omega NR\cos\ \omega t$

15. A circular loop made of a thin wire has radius 2 cm and resistance 2Ω. It is placed perpendicular to a uniform magnetic field of magnitude $|\vec{B}_0| = 0.01$ Tesla. At time $t = 0$ the field starts decaying as $\vec{B} = \vec{B}_0 e^{-t/t_0}$, where $t_0 = 1$ s. The total charge that passes through a cross section of the wire during the decay is Q. The value of Q in μC (rounded off to two decimal places) is

[GATE 2019]

16. A sinusoidal voltage of the form $V(t) = V_0 \cos(\omega t)$ is applied across a parallel plate capacitor placed in vacuum. Ignoring the edge effects, the induced emf within the region between the capacitor plates can be expressed as a power series in ω. The lowest non vanishing exponent in ω is

[GATE 2020]

17. A medium ($\varepsilon_r > 1, \mu_r = 1, \sigma > 0$) is semi-transparent to an electromagnetic wave when

(a) Conduction current ≫ Displacement current

(b) Conduction current ≪ Displacement current

(c) Conduction current = Displacement current

(d) Both Conduction current and Displacement current are zero **[GATE 2020]**

18. A plane electromagnetic wave of wavelength λ is incident on a circular loop of conducting wire. The loop radius is $a (a \ll \lambda)$. The angle (in degrees), made by the Poynting vector with the normal to the plane of the loop to generate a maximum induced electrical signal, is

[GATE 2020]

❖ JEST PYQ

1. A circular conducting ring of radius R rotates with constant angular velocity ω about its diameter placed along the x-axis. A uniform magnetic field B is applied along the y-axis. If at time $t = 0$ the ring is entirely in the xy plane, the emf induced in the ring at time t > 0 is

[JEST 2012]

(a) $B\omega^2\pi R^2 t$ (b) $B\omega^2\pi R^2 \tan(\omega t)$

(c) $B\omega^2\pi R^2 \sin(\omega t)$ (d) $B\omega^2\pi R^2 \cos(\omega t)$

2. A time-dependent magnetic field $\vec{B}(t)$ is produced in a circular region of space, infinitely long and of radius R, The magnetic field is given as $\vec{B} = B_0 t \hat{z}$ for $0 \le r < R$ and is zero for $r > R$. Where B_0 is a positive constant, The electric field for $r > R$ is

[JEST 2012]

(a) $\frac{B_0 R^2}{r}\hat{r}$ (b) $\frac{B_0 R^2}{2r}\hat{\theta}$

(c) $-\frac{B_0 R^2}{r}\hat{r}$ (d) $-\frac{B_0 R^2}{2r}\hat{\theta}$

3. Which of the following expressions represents an electric field due to a time varying magnetic field?

[JEST 2015]

(a) $K(x\hat{x} + y\hat{y} + z\hat{z})$ (b) $K(x\hat{x} + y\hat{y} - z\hat{z})$
(c) $K(x\hat{x} - y\hat{y})$ (d) $K(y\hat{y} - x\hat{y} + 2z\hat{z})$

4. Self-inductance per unit length of a long solenoid of radius R with n turns per unit length is:

[JEST 2016]

(a) $\mu_0 \pi R^2 n^2$ (b) $2\mu_0 \pi R^2 n$

(c) $2\mu_0 \pi R^2 n^2$ (d) $\mu_0 \pi R^2 n$

5. Two parallel rails of a railroad track are insulated from each other and from the ground. The distance between the rails is 1 meter. A voltmeter is electrically connected between the rails. Assume the vertical components of the earth's magnetic field to be 0.2 gauss. What is the voltage developed between the rails when a train travels at a speed of 180 km/h along the track ? give the answer in milli-volts.

[JEST 2018]

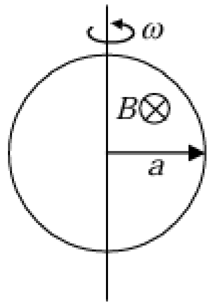
6. Two conductors are embedded in a material of conductivity 10^{-4} ohm − m and dielectric constant $\epsilon = 80\epsilon_0$. The resistance between the two conductors is 10^6ohm. What is the capacitance (in pF) between the conductors? Ignore the decimal part of the answer.

[JEST 2018]

7. A circular metal loop of radius $a = 1$ m spins with a constant angular velocity $\omega = 20\pi$rad/s in a magnetic field $B = 3$ Tesla, as shown in the figure. The resistance of the loop is 10 ohms. Let

P be the power dissipated in one complete cycle. What is the value of $\frac{P}{\pi^3}$ in Watts?

[JEST 2019]



8. A very long solenoid (axis along z direction) of n turns per unit length carries a current which increases linearly with time, $i = Kt$. What is the magnetic field inside the solenoid at a given time t ? **[JEST 2019]**

(a) $B = \mu_0 nKt\hat{z}$ (b) $B = \mu_0 nK\hat{z}$

(c) $B = \mu_0 nKt(\hat{x} + \hat{y})$ (d) $B = \mu_0 cnKt\hat{z}$

9. Two rails of a railroad track are insulated from each other and from the ground, and are connected by a millivoltmeter. What is the reading of the millivoltmeter when a train travels at the speed 90 km/hr down the track? Assume that the vertical component of the earth's magnetic field is 0.2 gauss and that the tracks are separated by two meters. Use 1 gauss $= 10^{-4}$ Tesla $= 10^{-4} V \cdot \mathrm{sec/m^2}$

[JEST 2020]

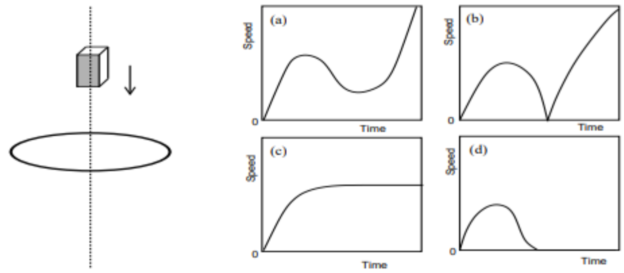
(a) 10 (b) 1

(c) 0.2 (d) 180

❖ TIFR PYQ

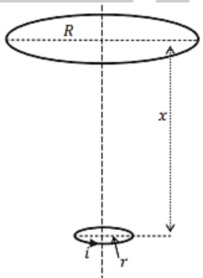
1. A small but very powerful bar magnet falls from rest under gravity through the centre of a horizontal ring of conducting wire, as shown in the figure below (on the left). The speed-versus-time graph, in arbitrary units, of the magnet will correspond most closely to which of the four plots below (on the right)?

[TIFR 2011]



2. Consider the following system. Two circular loops of wire are placed horizontally, having a common axis passing vertically through the centre of each coil (see figure). The lower loop has radius r and carries a current i as shown in the figure. The upper loop has a radius $R (R \gg r)$ and is at distance $x (x \gg R)$ above it.
If the lower loop is held fixed and the upper loop moves upwards with a uniform velocity $v = dx/dt$, then the induced e.m.f. and the direction of the induced current in this loop will be

[TIFR 2016]



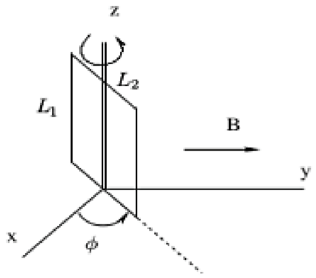
(a) $3i\mu_0\pi^2 r^2 R^2 v/2x^4$; anti-clockwise

(b) $2i\mu_0\pi^2 r^2 R^2 v/2x^4$; clockwise

(c) $3i\mu_0\pi^2 r^2 R^2 v/2x^3$; anti-clockwise

(d) $2i\mu_0\pi^2 r^2 R^2 v/3x^3$; clockwise

3. A rectangular metallic loop with sides L_1 and L_2 is placed in the vertical plane, making an angle φ with respect to the x-axis, as shown in the figure, and a spatially uniform magnetic field $\vec{B} = B\hat{y}$ is applied. The loop is free to rotate about the $\hat{z}$ axis (shown in the figure with a double line). The magnetic field changes with time at a constant rate $\frac{dB}{dt} = \kappa$



If the resistance of the loop is R, the torque τ required to prevent the loop from rotating will be

[TIFR 2017]

(a) $-\kappa B\frac{(L_1L_2)^2}{2R}\sin\ 2\varphi\hat{z}$

(b) $\kappa B\frac{(L_1L_2)^2}{R}\sin\ \varphi\cos\ \varphi\hat{z}$

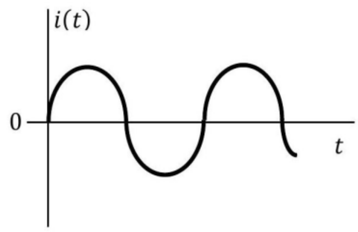
(c) $\kappa B\frac{(L_1L_2)^2}{2R}\sin\ \varphi\hat{z}$

(d) $-\kappa B\frac{(L_1L_2)^2}{R}\sin\ \varphi 2$

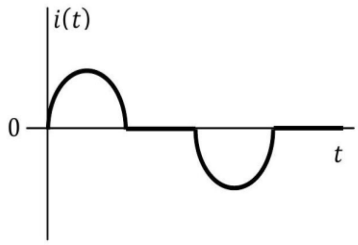
4. A circular coil of conducting wire, of radius a and n turns, is placed in a uniform magnetic field $\vec{B}$ along the axis of the coil and is then made to undergo simple harmonic oscillations along the direction of the axis. The current through the coil will be best described by

[TIFR 2019]

(a)



(b)



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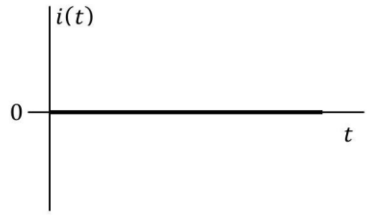
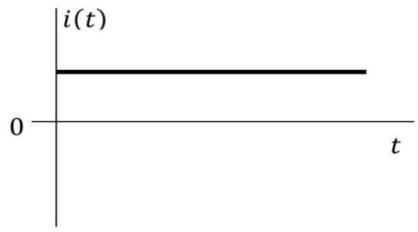


(d)



5. A metallic wire of uniform cross-section and resistance R is bent into a circle of radius a. The circular loop is placed in a magnetic field $\vec{B}(t)$ which is perpendicular to the plane of the wire. This magnetic field is uniform over space, but its magnitude decreases with time at a constant rate k, where $k = \frac{d|\vec{\boldsymbol{B}}(t)|}{dt}$ The tension in the metallic wire is **[TIFR 2020]**

(a) $\frac{\pi a^3 k}{2R}|\vec{B}(t)|$ (b) $\frac{\pi a^3 k}{R}|\vec{B}(t)|$

(c) $\frac{2\pi a^3 k}{R}|\vec{B}(t)|$ (d) $|\vec{B}(t)|$

6. Two co-axial solenoids A and B, one placed completely inside the other, have the following parameters:

Solenoid	No of turns	Length	Diameter
A	1000	50 cm	2 cm
B	2000	50 cm	4 cm

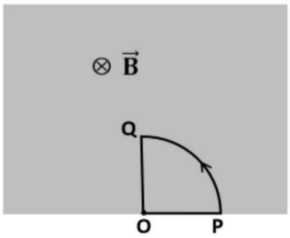
The mutual inductance between the solenoids is

[TIFR 2022]

(a) 395.0mH (b) 125.7mH

(c) 1.58mH (d) 12.57mH

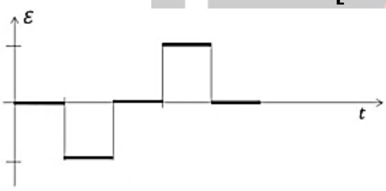
7. Consider the following situation. A uniform magnetic field $\vec{B}$ pointing into the plane of the paper is present everywhere inside the rectangular region shown shaded in the adjoining figure. Outside the rectangular region, there is no magnetic field.



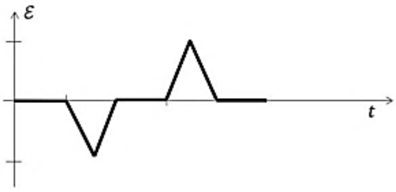
A closed loop of conducting wire is placed inside the rectangular region as shown in the figure at time $t = 0$. The loop is then rotated counterclockwise with a uniform angular velocity ω about an axis perpendicular to the paper passing through the point O.
If the direction along PQOP is taken to be positive, then a correct graph for the EMF $\mathcal{E}$ generated in the loop is

[TIFR 2023]

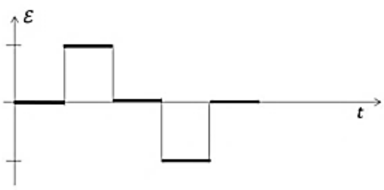
(a)



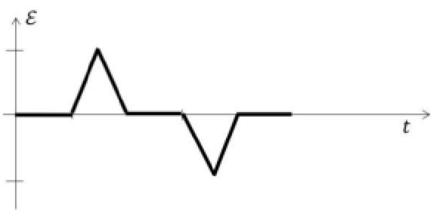
(b)



(c)



(d)



Answer Key

		CSIR-NET PYQ		
1. D	2. c	3. c	4. a	5. b
6. b	7. b	8. d	9. d	10. c
11. b	12. d	13. a		
		GATE PYQ		
1.	2. b	3. a	4. c	5.
6. D	7. d	8. b	9. b	10. d
11. b	12. d	13. d	14. a	15. 6.28
16. **2**	17. b	18. 90		
		JEST PYQ		
1. C	2. d	3. d	4. a	5. 1Mv
6. 7080	7. 18	8. a	9. b	
		TIFR PYQ		
1. a	2. a	3. a	4. c	5. a
6. c	7. a			

❖ EMT 08 : Applications Of Maxwell's Equations , Wave In Matter

❖ CSIR-NET PYQ's

1 In a certain region R, Maxwell's equations for the electric and magnetic fields are given by

$$\nabla \cdot \vec{E} = 0, \nabla \cdot \vec{B} = 0, \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t},$$
$$\nabla \times \vec{B} = \mu_0 \varepsilon_0 \frac{\partial \vec{E}}{\partial t}$$

We may conclude that **[CSIR NET 2008]**

(a) Both the scalar and the vector potential are necessarily constant in the region R.

(b) The electric field $\vec{E}$ and the magnetic field $\vec{B}$ must necessarily be uniform in R.

(c) There are no sources for electric charges and currents in R.

(d) The electric field $\vec{E}$ is necessarily perpendicular to the magnetic field $\vec{B}$ at every point in R.

2 A plane electromagnetic wave is propagating in a lossless dielectric. The electric field is given by $E(x, y, z, t) = E_0(\hat{x} + A\hat{z})\exp\left[ik_0\{-ct + (x + \sqrt{3}z)\}\right]$, where c is the speed of light in vacuum, E_0, A and k_0 are constants and $\hat{x}$ and $\hat{z}$ are unit vectors along the x - and z-axes. The relative dielectric constant of the medium, ε_r and the constant A are

[CSIR JUNE 2011]

(a) $\varepsilon_r = 4$ and $A = -\frac{1}{\sqrt{3}}$

(b) $\varepsilon_r = 4$ and $A = +\frac{1}{\sqrt{3}}$

(c) $\varepsilon_r = 4$ and $A = \sqrt{3}$

(d) $\varepsilon_r = 4$ and $A = -\sqrt{3}$

3 The electric field of an electromagnetic wave is given by $\vec{E} = E_0 \cos[\pi(0.3x + 0.4y - 1000t)]\hat{k}$. The associated magnetic field $\vec{B}$ is

[CSIR DEC 2013]

(a) $10^{-3}E_0 \cos[\pi(0.3x + 0.4y - 1000t)]\hat{k}$

(b) $10^{-4}E_0 \cos[\pi(0.3x + 0.4y - 1000t)](4\hat{\imath} - 3\hat{\jmath})$

(c) $E_0 \cos[\pi(0.3x + 0.4y - 1000t)](0.3\hat{\imath} + 0.4\hat{\jmath})$

(d) $10^2 E_0 \cos[\pi(0.3x + 0.4y - 1000t)](3\hat{\imath} + 4\hat{\jmath})$

4 An electromagnetically-shielded room is designed so that at a frequency $\omega = 10^7$ rad/s the intensity of the external radiation that penerates the room is 1% of the incident radiation. If $\sigma = \frac{1}{2\pi} \times 10^6 (\Omega\text{m})^{-1}$ is the conductivity of the shielding material, its minimum thickness should be (given that $\ln 10 = 2.3$)

[CSIR JUNE 2014]

(a) 4.60 mm (b) 2.30 mm

(c) 0.23 mm (d) 0.46 m

5 Consider an electromagnetic wave at the interface between two homogeneous dielectric media of the dielectric constants ε_1 and ε_2. Assuming $\varepsilon_2 > \varepsilon_1$ and non charges on the surfice, the electric field vector $\vec{E}$ and the displacement vector $\vec{D}$ in the two media satisfy the following inequalities

[CSIR JUNE 2014]

(a) $|\vec{E}_2| > |\vec{E}_1|$ and $|\vec{D}_2| > |\vec{D}_1|$

(b) $|\vec{E}_2| < |\vec{E}_1|$ and $|\vec{D}_2| < |\vec{D}_1|$

(c) $|\vec{E}_2| < |\vec{E}_1|$ and $|\vec{D}_2| > |\vec{D}_1|$

(d) $|\vec{E}_2| > |\vec{E}_1|$ and $|\vec{D}_2| < |\vec{D}_1|$

6 Suppose that free charges are present in a material of dielectric constant $\varepsilon = 10$ and resistivity $\rho = 10^{11}\Omega - \text{m}$. Using Ohm's law and the equation of continuity for charge, the time required for the charge density inside the material to decay by $\frac{1}{e}$ is closest to

[NET DEC 2016]

(a) 10^{-6} s (b) 10^{6} s

(c) 10^{12} s (d) 10 s

7 An electromagnetic wave (of wavelength λ_0 in free space) travels through an absorbing medium with dielectric permittivity given by $\varepsilon = \varepsilon_R + i\varepsilon_J$, where $\frac{\varepsilon_I}{\varepsilon_R} = \sqrt{3}$. If the skin depth is $\frac{\lambda_0}{4\pi}$, the ratio of the amplitude of electric field E to that of the magnetic field B, in the medium (in ohms) is

[CSIR JUNE 2017]

(a) 120π (b) 377

(c) $30\sqrt{2}\pi$ (d) 30π

8 The charge distribution inside a material of conductivity σ and permittivity ε at initial tine $t = 0$ is $\rho(r, 0) = \rho_0$. constant. At subsequent times $\rho(r, t)$ is given by **[NET JUNE 2017]**

(a) $\rho_0 \exp\left(-\frac{\sigma t}{\varepsilon}\right)$ (b) $\frac{1}{2}\rho_O\left[1 + \exp\left(\frac{\sigma t}{\varepsilon}\right)\right]$

(c) $\frac{\rho_0}{\left[1 - \exp\left(\frac{\sigma l}{\varepsilon}\right)\right]}$ (d) $P_O, \cosh\frac{\sigma l}{\varepsilon}$

9 The electric field of a plane wave in a conducting medium is given by

$$\vec{E}(z,t) = \hat{\imath}E_0 e^{-s/3a}\cos\left(\frac{z}{\sqrt{3a}} - \omega t\right)$$

where ω is the angular frequency and $a > 0$ is a constant. The phase difference between the magnetic field $\vec{B}$ and the electric field $\vec{E}$ is

[CSIR JUNE 2018]

(a) 30° and $\vec{E}$ lags behind $\vec{B}$

(b) 30° and $\vec{B}$ lags behind $\vec{E}$

(c) 60° and $\vec{E}$ lags behind $\vec{B}$

(d) 60° and $\vec{B}$ lags behind $\vec{E}$

10 An electromagnetic wave propagates in a nonmagnetic medium with relative permittivity $\varepsilon = 4$. The magnetic field for this wave is

$$\vec{H}(x,y) = \hat{k}H_0\cos(\omega t - \alpha x - \alpha\sqrt{3}y),$$

where H_0 is a constant. The corresponding electric field $\vec{E}(x,y)$ is **[CSIR DEC 2018]**

(a) $\frac{1}{4}\mu_0 H_0 c(-\sqrt{3}\hat{\imath} + \hat{\jmath})\cos(\omega t - \alpha x - \alpha\sqrt{3}y)$

(b) $\frac{1}{4}\mu_0 H_0 c(\sqrt{3}\hat{\imath} + \hat{\jmath})\cos(\omega t - \alpha x - \alpha\sqrt{3}y)$

(c) $\frac{1}{4}\mu_0 H_0 c(\sqrt{3}\hat{\imath} - \hat{\jmath})\cos(\omega t - \alpha x - \alpha\sqrt{3}y)$

(d) $\frac{1}{4}\mu_0 H_0 c(-\sqrt{3}\hat{\imath} - \hat{\jmath})\cos(\omega t - \alpha x - \alpha\sqrt{3}y)$

11 Which of the following is not a correct boundary condition at an interface between two homogeneous dielectric media? (In the following $\hat{n}$ is a unit vector normal to the interface, σ and $\mathbf{j}_s$ are the surface charge and current densities, respectively).

[CSIR JUNE 2019]

(a) $\hat{n} \times (\mathrm{D}_1 - \mathrm{D}_2) = 0$ (b) $\hat{n} \times (\mathrm{H}_1 - \mathrm{H}_2) = \mathrm{j}_s$

(c) $\hat{n} \cdot (\mathrm{D}_1 - \mathrm{D}_2) = \sigma$ (d) $\hat{n} \cdot (\mathrm{B}_1 - \mathrm{B}_2) = 0$

12 The permittivity tensor of a uniaxial anisotropic medium, in the standard Cartesian basis, is

$\begin{pmatrix} 4\varepsilon_0 & 0 & 0 \\ 0 & 4\varepsilon_0 & 0 \\ 0 & 0 & 9\varepsilon_0 \end{pmatrix}$, where ε_0 is a constant.

The wave number of an electromagnetic plane wave polarized along the x-direction, and propagating along the y-direction in this medium (in terms of the wave number k_0 of the wave in vacuum) is **[NET June 2019]**

(a) $4k_o$ (b) $2k_0$ (c) $9k_0$ (d) $3k$

13 Let $\vec{E}(x,y,z,t) = \vec{E}_0 \cos(2x + 3y - \omega t)$, where ω is a constant, be the electric field of an electromagnetic wave travelling in vacuum. Which of the following vectors is a valid choice for $\vec{E}_0$? **[CSIR JUNE 2020]**

(a) $\hat{\imath} - \frac{3}{2}\hat{\jmath}$ (b) $\hat{\imath} + \frac{3}{2}\hat{\jmath}$

(c) $\hat{\imath} + \frac{2}{3}\hat{\jmath}$ (d) $\hat{\imath} - \frac{2}{3}\hat{\jmath}$

14 A perfectly conducting fluid, of permittivity ε and permeability μ, flows with a uniform velocity $\mathcal{V}$ in the presence of time dependent electric and magnetic fields E and B, respectively. If there is a finite current density in the fluid, then

[CSIR JUNE 2021]

(a) $\nabla \times (v \times B) = \frac{\partial B}{\partial t}$

(b) $\nabla \times (v \times B) = -\frac{\partial B}{\partial t}$

(c) $\nabla \times (v \times B) = \sqrt{\varepsilon\mu}\frac{\partial E}{\partial t}$

(d) $\nabla \times (v \times B) = -\sqrt{\varepsilon\mu}\frac{\partial E}{\partial t}$

15 An electromagnetic wave is incident from vacuum normally on a planar surface of a non-magnetic medium. If the amplitude of the electric field of the incident wave is E_0 and that of the transmitted wave is $\frac{2E_0}{3}$, then neglecting any loss, the refractive index of the medium is

[NET June 2022]

(a) 1.5 (b) 2.0 (c) 2.4 (d) 2.7

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

[CSIR DEC 2023]

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

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

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

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

17 In a non-magnetic material with no free charges and no free currents, the permittivity ϵ is a function of position. If $\vec{E}$ represents the electric field and μ_0, ϵ_0 are free space permeability and permittivity respectively, which one of the following expressions is correct?

[CSIR JUNE 2024]

(a) $\nabla^2\vec{E} - \mu_0\frac{\partial^2(\epsilon\vec{E})}{\partial t^2} - \frac{1}{\epsilon_0}\vec{\nabla}(\vec{E}\cdot\vec{\nabla}\epsilon) = 0$

(b) $\nabla^2\vec{E} - \mu_0\frac{\partial^2(\epsilon\vec{E})}{\partial t^2} + \frac{1}{\epsilon_0}\vec{\nabla}(\vec{E}\cdot\vec{\nabla}\epsilon) = 0$

(c) $\nabla^2\vec{E} - \mu_0\frac{\partial^2(\epsilon\vec{E})}{\partial t^2} + \vec{\nabla}\left(\frac{1}{\epsilon}\vec{E}\cdot\vec{\nabla}\epsilon\right) = 0$

(d) $\nabla^2\vec{E} - \mu_0\frac{\partial^2(\epsilon\vec{E})}{\partial t^2} - \vec{\nabla}\left(\frac{1}{\epsilon}\vec{E}\cdot\vec{\nabla}\epsilon\right) = 0$

❖ GATE PYQ's

1. The region $z > 0$ of a Cartesian coordinate system contains a linear isotropic dielectric of dielectric constant 2.0. The region $z < 0$ is the free space. A free space charge density of 5nC/m^2 is at the interface $z = 0$. If the displacement vector in the dielectric is $\vec{D}_2 = 3\hat{e}_x + 4\hat{e}_y + 6\hat{e}_z \text{nC/m}^2$, find the corresponding displacement vector $\vec{D}_1$ in the free space.

[GATE 2001]

2. The electric field $E(r,t)$ at a point r at time t in a metal due to the passage of electrons can be described by the equation

$$\nabla^2\vec{E}(\vec{r},t) = \frac{1}{c^2}\left[\frac{\partial^2\vec{E}(\vec{r},t)}{\partial t^2} + \omega'^2\vec{E}(\vec{r},t)\right]$$

where ω' is a characteristic associated with the metal and c is the speed of light in vacuum. The dispersion relation corresponding to the plane wave solutions of the form $\exp\,[i(\vec{k}\cdot\vec{r} - \omega t)]$ is given by **[GATE 2001]**

(a) $\omega^2 = c^2k^2 - \omega'^2$ (b) $\omega^2 = c^2k^2 + \omega'^2$

(c) $\omega = ck - \omega'$ (d)

3. Consider an infinitely long straight cylindrical conductor of radius R with its axis along the z-direction, which carries a current of 1 A uniformly distributed over its cross section. Which of the following statements is correct?

[GATE 2002]

(a) $\vec{\nabla} \times \vec{B} = 0$ everywhere

(b) $\vec{\nabla} \times \vec{B} = \frac{\mu_0}{\pi R^2}\hat{z}$ everywhere,

(c) $\vec{\nabla} \times \vec{B} = 0$ for $r > R$,

(d) $\vec{\nabla} \times \vec{B} = \frac{\mu_0}{\pi R^2}\hat{z}$ for $r > R$

where r is the radial distance from the axis of the cylinder.

4. Consider a plane electromagnetic wave propagating in free space and having an electric field distribution given by

$$\vec{E} = E_0\left(\frac{\sqrt{3}}{2}\hat{\jmath} - \frac{1}{2}\hat{\imath}\right)\exp\left[i\left(\omega t - \frac{\sqrt{3}}{2}\alpha x - \frac{1}{2}\alpha y\right)\right],$$

where E_0, ω and a constants. Calculate the corresponding magnetic field $\vec{B}$. **[GATE 2002]**

5. Which one of the following Maxwell's equations implies the absence of magnetic monopoles?

[GATE 2003]

(a) $\nabla \cdot E = \pi/\varepsilon_0$

(b) $\nabla \cdot B = 0$

(c) $\nabla \times E = -\partial B/\partial t$

(d) $\nabla \times B = (1/c^2)\,\partial B/\partial t + \mu_0 J$

6. An electromagnetic wave is propagating in free space in the z-direction. If the electric field is given by $E = \cos\,(\omega t - kz)i$, where $\omega t = ck$, then the magnetic field is given by

[GATE 2003]

(a) $B = (1/c)\cos\,(\omega t - kz)j$

(b) $B = (1/c)\sin\,(\omega t - kz)j$

(c) $B = (1/c)\cos\,(\omega t - kz)i$

(d) $B = (1/c)\cos\,(\omega t - kz)j$

Data for Q. No. 7 to 8

Consider two conducting plates of infinite extent, one plate at $z = 0$ and the other at $z = L$, both parallel to the xy plane. The vector and scalar potential in the region between the plates is given by

$$A(r,t) = A_0\hat{\imath}\cos\,(kz + \alpha)\cos\,(kct)$$
$$\phi(r,t) = 0$$

7. For this to represent a standing wave in the empty region between the plates **[GATE 2003]**

(a) $k = \pi/L$ and $\alpha = 0$

(b) $k = 2\pi/L$ and $\alpha = \pi/2$

(c) $k = \pi/(2L)$ and $\alpha = \pi/2$

(d) $k = \pi/2L$ and $\alpha = 0$

8. The energy density at $z = 0$ and $t = 0$ is

[GATE 2003]

(a) 0

(b) $\varepsilon_0 c^2 k^2 A_0^2$

(c) $(1/2)\mu_0 A_0{}^2 k^2$

(d) $(1/2)\mu_0 A_0{}^2 k^2 + (1/2)\varepsilon_0 c^2 k^2 A_0{}^2$

9. Consider the given statements about E(r, t) and B(r, t), the electric and magnetic vectors respectively in a region of free space

[GATE 2003]

P. Both E and B are conservative vector fields
Q. Both E and B are central force fields
R. E and B are mutually perpendicular in the region
S. Work done by B on a moving charge in the region is zero
Choose the right combination of correct statements from the following :

(a) P and R (b) R and S

(c) S only (d) P and Q

10. The electric field of a plane e.m. wave is $\vec{E} = \vec{E}_0 \exp\,[i(xk\cos\,\alpha + yk\sin\,\alpha - \omega t)]$. If $\hat{x}, \hat{y}$ and $\hat{z}$ are cartesian unit vectors, the wave vector k of the e.m. wave is

[GATE 2004]

(a) $\hat{z}k$ (b) $\hat{x}k\sin\,\alpha + \hat{y}k\cos\,\alpha$

(c) $\hat{x}k\cos\,\alpha + \hat{y}k\sin\,\alpha$ (d) $-\hat{z}k$

11. The dispersion relation for a low density plasma is $\omega^2 = \omega_0^2 + c^2k^2$, where ω_0 is the plasma frequency and c is the speed of light in free space. The relationship between the group velocity (v_g) and phase velocity (v_p) is

[GATE 2004]

(a) $v_p = v_g$ (b) $v_p = v_g^{1/2}$

(c) $v_p v_g = c^2$ (d) $v_g = v_p^{1/2}$

Common Data for Q. 12 and Q. 13

Let $\tilde{E} = \hat{x}E_0 \exp\,[i\vec{k}\cdot\vec{r} - \omega t]$, where $\vec{k} = \hat{z}(k\cos\,\phi + ik\sin\,\phi), k = 1|\vec{k}|$ and $\hat{x}, \hat{y}$ and $\hat{z}$ are cartesian unit vectors, represent an electric field of plane electro magnetic wave of frequency ω.

12. Which one of the following statements is TRUE?

[GATE 2004]

(a) The magnitude of the electric field is attenuated as the wave propagates
(b) The energy of the e.m. wave flows along the x-direction
(c) The magnitude of the electric field of the wave is a constant
(d) The speed of the wave is the same as c (speed of light in free space)

13. The magnetic field $\tilde{B}$ of the wave is

[GATE 2004]

(a) $\hat{y}\frac{k}{\omega}E_0 \exp\,(-zk\sin\,\phi)\exp\,[i(zk\cos\,\phi - \omega t)]$

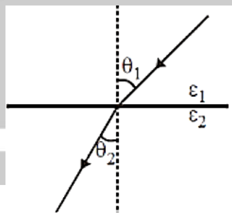
(b) $\hat{y}\frac{k}{\omega}E_0 \exp\,(-zk\sin\,\phi)\exp\,[i(zk\cos\,\phi - \omega t + \phi)]$

(c) $\hat{y}\frac{k}{\omega}E_0 \exp\,[i(zk\cos\,\phi - \omega t + \phi)]$

(d) $\hat{y}\frac{k}{\omega}E_0 \exp\,(-zk\cos\,\phi)\exp\,[i(zk\sin\,\phi - \omega t)]$

14. At the interface between two linear dielectrics (with dielectric constants ε_1 and ε_2), the electric field lines bend, as shown in the figure. Assume that there are no free charges at the interface. The ratio $\varepsilon_1/\varepsilon_2$ is

[GATE 2006]



(a) $\frac{\tan\,\theta_1}{\tan\,\theta_2}$ (b) $\frac{\cos\,\theta_1}{\cos\,\theta_2}$

(c) $\frac{\sin\,\theta_1}{\sin\,\theta_2}$ (d) $\frac{\cot\,\theta_1}{\cot\,\theta_2}$

15. Which one of the following sets of Maxwell's equations for time-independent charge density ρ and current density $\hat{\mathbf{J}}$ is correct?

[GATE 2006]

(a) $\vec{\nabla}\cdot\vec{E}=\rho/\varepsilon_0$
$\vec{\nabla}\cdot\vec{B}=0$
$\vec{\nabla}\times\vec{E}=-\dfrac{\partial\vec{B}}{\partial t}$
$\vec{\nabla}\times\vec{B}=\mu_0\varepsilon_0\dfrac{\partial\vec{E}}{\partial t}$

(b) $\vec{\nabla}\cdot\vec{E}=\rho/\varepsilon_0$
$\vec{\nabla}\cdot\vec{B}=0$
$\vec{\nabla}\times\vec{E}=0$
$\vec{\nabla}\times\vec{B}=\mu_0\hat{J}$

(c) $\vec{\nabla}\cdot\vec{E}=0$
$\vec{\nabla}\cdot\vec{B}=0$
$\vec{\nabla}\times\vec{E}=0$
$\vec{\nabla}\times\vec{B}=\mu_0\hat{J}$

(d) $\vec{\nabla}\cdot\vec{E}=\rho/\varepsilon_0$
$\vec{\nabla}\cdot\vec{B}=\mu_0\hat{J}$
$\vec{\nabla}\times\vec{E}=0$
$\vec{\nabla}\times\vec{B}=\mu_0\varepsilon_0\dfrac{\partial\vec{E}}{\partial t}$

16. A plane electromagnetic wave is given by $E_0(\hat{x}+e^{l\delta}\hat{y})\exp\{i(kz-\omega t)\}$. At a given location, that number of times $\vec{E}$ vanishes in one second is

[GATE 2008]

(a) An integer near $\frac{\omega}{\pi}$ when $\delta=n\pi$ and zero when $\delta\neq n\pi, n$ is integer
(b) An integer near $\frac{\omega}{\pi}$ and is independent of δ
(c) An integer near $\frac{\omega}{2\pi}$ when $\delta=n\pi$ and zero when $\delta\neq n\pi, n$ is integer
(d) An integer near $\frac{\omega}{2\pi}$ and is independent of δ

17. In a non-conducting medium characterized by $\varepsilon=\varepsilon_0, \mu=\mu_0$ and conductivity $\sigma=0$, the electric field (in $\mathrm{Vm^{-1}}$) is given by $\vec{E}=20\sin[10^8\mathrm{t}-\mathrm{kz}]\hat{\jmath}$. The magnetic field, $\vec{H}$ (in $\mathrm{Am^{-1}}$), is given by:

[GATE 2009]

(a) $20\,\mathrm{k}\cos[10^8\mathrm{t}-\mathrm{kz}]\hat{\imath}$

(b) $\frac{20\mathrm{k}}{10^8\mu_0}\sin[10^8\mathrm{t}-\mathrm{kz}]\hat{\jmath}$

(c) $-\frac{20\mathrm{k}}{10^8\mu_0}\sin[10^8\mathrm{t}-\mathrm{kz}]\hat{\imath}$

(d) $-20\,\mathrm{k}\cos[10^8\mathrm{t}-\mathrm{kz}]\hat{\jmath}$

18. Consider the propagation of electromagnetic waves in a linear, homogenous and isotropic material medium with electric permittivity ε, and magnetic permeability μ.
For a plane wave of angular frequency ω and propagation vector $\vec{k}$ propagating in the medium Maxwell's equations reduce to

[GATE 2010]

(a) $\vec{k},\vec{E}=0;\vec{k}\cdot\bar{H}=0;\vec{k}\times\vec{E}=\omega\varepsilon\bar{H};\vec{k}\times\bar{H}=-\omega\mu\vec{E}$

(b) $\vec{k}\cdot\vec{E}=0;\ \vec{k}\cdot\bar{H}=0;\ \vec{k}\times\vec{E}=-\omega\varepsilon\bar{H};\vec{k}\times\bar{H}=\omega\mu\vec{E}$

(c) $\vec{k}\cdot\vec{E}=0;\vec{k}\cdot\bar{H}=0;\vec{k}\times\vec{E}=-\omega\varepsilon\bar{H};\vec{k}\times\bar{H}=\omega\mu\vec{E}$

(d) $\vec{k}\cdot\vec{E}=0;\ \vec{k}\cdot\bar{H}=0;\ \vec{k}\times\vec{E}=\omega\mu\bar{H};\ \vec{k}\times\bar{H}=-\omega\varepsilon\vec{E}$

19. A plane polarized electromagnetic wave in free space at time $t=0$ is given by $\vec{E}(x,z)=10\hat{\jmath}\exp[i(6x+8z)]$. The magnetic field $\vec{B}(x,z,t)$ is given by

[GATE 2012]

(a) $\vec{B}(x,z,t)=\frac{1}{c}(6\hat{k}-8\hat{\imath})\exp[i(6x+8z-10ct)]$

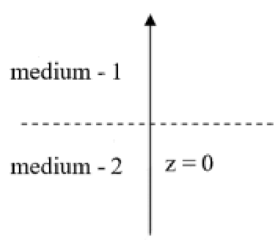
(b) $\vec{B}(x,z,t)=\frac{1}{c}(6x+8\hat{\imath})\exp[i(6x+8z-10ct)]$

(c) $\vec{B}(x,z,t)=\frac{1}{c}(6x-8\hat{\imath})\exp[i(6x+8z-ct)]$

(d) $\vec{B}(x,z,t)=\frac{1}{c}(6x+8\hat{\imath})\exp[i(6x+8z+10ct)]$

20. Two infinitely extended homogeneous isotropic dielectric media (medium-1 and medium-2 with dielectric constants $\frac{\varepsilon_1}{\varepsilon_0}=2$ and $\frac{\varepsilon_2}{\varepsilon_0}=5$, respectively) meet at the z = 0 plane as shown in the figure. A uniform electric field exists everywhere. For $z\geq 0$, the electric field is given by $\vec{E}_1=2\hat{\imath}-3\hat{\jmath}+5\hat{k}$. The interface separating the two media is charge free. The electric displacement vector in the medium-2 is given by

[GATE 2012]



(a) $\vec{D}_2 = \varepsilon_0[10\hat{\imath} + 15j + 10k]$

(b) $\vec{D}_2 = \varepsilon_0[10\hat{\imath} - 15\hat{\jmath} + 10\hat{k}]$

(c) $\vec{D}_2 = \varepsilon_0[4\hat{\imath} - 6j + 10k]$

(d) $\vec{D}_2 = \varepsilon_0[4\hat{\imath} + 6j + 10k]$

21. The electric field of a uniform plane wave propagating in a dielectric, non-conducting medium is given by

$$\vec{E} = \hat{x}10\cos(16\pi \times 10^7 t - 0.4\pi z)\text{V/m}$$

The phase velocity of the wave is……….. $\times 10^8$ m/s.

[GATE 2014]

22. A uniform volume charge density is placed inside a conductor (with resistivity $10^{-2}\Omega$m). The charge density becomes $\frac{1}{2.718}$ of its original value after time femto seconds. (up to two decimal places)

[GATE 2017]

$$\left(\varepsilon_0 = 8.854 \times \frac{10^{-12}\text{ F}}{\text{m}}\right)$$

23. Consider a metal with free electron density of 6×10^{22} cm^{-3}. The lowest frequency electromagnetic radiation to which this metal is transparent is 1.38×10^{16} Hz. If this metal had a free electron density of 1.8×10^{23} cm^{-3} instead, the lowest frequency electromagnetic radiation to which it would be transparent is 10^{16} Hz (up to two decimal places).

[GATE 2017]

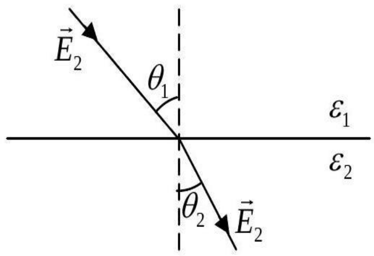
24. An electromagnetic plane wave is propagating with an intensity $I = 1.0 \times 10^5\text{Wm}^{-2}$ in a medium with $\epsilon = 3\epsilon_0$ and $\mu = \mu_0$. The amplitude of the electric field inside the medium is $\times 10^3\text{Vm}^{-1}$ (up to one decimal place).

[GATE 2018]

$$(\epsilon_0 = 8.85 \times 10^{-12}C^2N^{-1}\text{ m}^{-2}, \mu_0 = 4\pi \times 10^{-7}NA^{-2}, c = 3 \times 10^8\text{ ms}^{-1})$$

25. Which one of the following relations determines the manner in which the electric field lines are refracted across the interface between two dielectric media having dielectric constants ε_1 and ε_2 (see figure)?

[GATE 2020]



(a) $\varepsilon_1\sin\,\theta_1 = \varepsilon_2\sin\,\theta_2$

(b) $\varepsilon_1\cos\,\theta_1 = \varepsilon_2\cos\,\theta_2$

(c) $\varepsilon_1\tan\,\theta_1 = \varepsilon_2\tan\,\theta_2$

(d) $\varepsilon_1\cot\,\theta_1 = \varepsilon_2\cot\,\theta_2$

26. A matter wave is represented by the wave function

$$\Psi(x, y, z, t) = Ae^{i(4x+3y+5z-10\pi t)}$$

where A is a constant. The unit vector representing the direction of the propagation of this matter wave is **[GATE 2021]**

(a) $\frac{4}{5\sqrt{2}}\hat{x} + \frac{3}{5\sqrt{2}}\hat{y} + \frac{1}{\sqrt{2}}\hat{z}$

(b) $\frac{3}{5\sqrt{2}}\hat{x} + \frac{4}{5\sqrt{2}}\hat{y} + \frac{1}{5\sqrt{2}}\hat{z}$

(b) $\frac{1}{5\sqrt{2}}\hat{x} + \frac{3}{5\sqrt{2}}\hat{y} + \frac{1}{\sqrt{2}}\hat{z}$

(d) $\frac{1}{5\sqrt{2}}\hat{x} + \frac{4}{5\sqrt{2}}\hat{y} + \frac{3}{5\sqrt{2}}\hat{z}$

27. For the refractive index $n = n_r(\omega) + in_{im}(\omega)$ of a material, which of the following statements are correct? **[GATE 2022]**

(a) n_r can be obtained from n_{im} and vice-versa.
(b) n_{im} could be zero.
(c) n is an analytic function in the upper half of the complex ω plane.
(d) n is independent of ω for some materials.

❖ JEST PYQ's

1. An electromagnetic wave of frequency ω travels in the x-direction through vacuum. It is polarized in the y direction and the amplitude of the electric field is E_0. With $k = \omega/c$ where c is the speed of light in vacuum, the electric and the magnetic fields are then conventionally given by

[JEST 2013]

(a) $\vec{E} = E_0 \cos(ky - \omega x)\hat{y}$ and $\vec{B} = \frac{E_0}{c}\cos(ky - \omega x)\hat{z}$

(b) $\vec{E} = E_0 \cos(kx - \omega x)\hat{y}$ and $\vec{B} = \frac{E_0}{c}\cos(kx - \omega x)\hat{z}$

(c) $\vec{E} = E_0 \cos(kx - \omega x)\hat{z}$ and $\vec{B} = \frac{E_0}{c}\cos(ky - \omega x)\hat{y}$

(d) $\vec{E} = E_0 \cos(kx - \omega x)\hat{x}$ and $\vec{B} = \frac{E_0}{c}\cos(ky - \omega x)\hat{y}$

2. At 'equilibrium' there can not be any free charge inside a metal. However, if you forcibly put charge in the interior then it takes some finite time to 'disappear', i.e. move to the surface. If the conductivity, σ, of a metal is $10^6 (\Omega\text{m})^{-1}$ and the dielectric constant $\epsilon_0 = 8.85 \times \frac{10^{-12}\text{Farad}}{\text{m}}$, this time will be approximately:

[JEST 2013]

(a) 10^{-5}sec (b) 10^{-11}sec

(c) 10^{-9}sec (d) 10^{-17}sec

3. Which of the following expressions represents an electric field due to a time varying magnetic field? **[JEST 2015]**

(a) $K(x\hat{x} + y\hat{y} + z\hat{z})$ (b) $K(x\hat{x} + y\hat{y} - z\hat{z})$

(c) $K(x\hat{x} - y\hat{y})$ (d) $K(y\hat{y} - x\hat{y} + 2z\hat{z})$

4. The skin depth of a metal is dependent on the conductivity (σ) of the metal and the angular frequency ω of the incident field. For a metal of high conductivity, which of the following relations is correct? (Assume that $\sigma \gg \in \omega$, where $\in$ is the electrical permittivity of the medium)

[JEST 2015]

(a) $d \propto \sqrt{\frac{\sigma}{\omega}}$ (b) $d \propto \sqrt{\frac{1}{\sigma\omega}}$

(c) $d \propto \sqrt{\sigma\omega}$ (d) $d \propto \sqrt{\frac{\omega}{\sigma}}$

5. Suppose yz-plane forms the boundary between two linear dielectric media I and II with dielectric constant $\epsilon_1 = 3$ and $\epsilon_2 = 4$, respectively. If the electric field in region. I at the interface is given by $\vec{E}_1 = 4\hat{x} + 3\hat{y} + 5\hat{z}$, then the electric field $\vec{E}_{II}$ at the interface in region I is:

[JEST 2016]

(a) $4\hat{x} + 3\hat{y} + 5\hat{z}$

(b) $4\hat{x} + 0.75\hat{y} - 1.25\hat{z}$

(c) $-3\hat{x} + 3\hat{y} + 5\hat{z}$

(d) $3\hat{x} + 3\hat{y} + 5\hat{z}$

6. A plane electromagnetic wave propagating in air with $\vec{E} = (8\hat{\imath} + 6\hat{\jmath} + 5\hat{k})e^{i(\omega t+3x-4y)}$ is incident on a perfectly conducting slab positioned at $x = 0$. $\vec{E}$ field of the reflected wave is

[JEST 2017]

(a) $(-8\hat{\imath} - 6\hat{\jmath} - 5\hat{k})e^{i(\omega t+3x-4y)}$

(b) $(-8\hat{\imath} + 6\hat{\jmath} - 5\hat{k})e^{i(\omega t+3x-4y)}$

(c) $(-8\hat{\imath} + 6\hat{\jmath} - 5\hat{k})e^{i(\omega t-3x-4y)}$

(d) $(-8\hat{\imath} - 6\hat{\jmath} - 5\hat{k})e^{i(\omega t-3x-4y)}$

7. The magnetic field (Gaussian units) in an empty space is described by

$$B = B_0 \exp(ax)\sin(ky - \omega t)\hat{z}$$

What is the y-component of the electric field?

[JEST 2019]

(a) $-\frac{ac}{\omega}B_0 \sin(ky - \omega t)$

(b) $-\frac{ac}{\omega}B_0 \exp(ax)\cos(ky - \omega t)$

(c) $-B_0 \sin(ky - \omega t)$

(d) 0

8. An electromagnetic field is given by

$$\vec{E}(\vec{r},t) = -\frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\theta(vt-r)\dot{r}, \quad \vec{B}(\vec{r},t) = 0, \text{ where } \theta(x) = \begin{cases} 1 & \text{for } x > 0 \\ 0 & \text{for } x \le 0 \end{cases}$$

The corresponding charge density ρ and current density $\vec{J}$ are given by **[JEST 2020]**

(a) $\rho = -q\delta^3(\vec{r})\theta(vt-r) + \frac{q}{4\pi r^2}\theta(vt-r); \vec{J} = 0$

(b) $\rho = -q\delta^3(\vec{r})\theta(vt-r); \vec{J} = 0$

(c) $\rho = \frac{q}{4\pi r^2}\delta(vt-r); \vec{J} = \frac{qv}{4\pi r^2}\delta(vt-r)\hat{r}$

(d) $\rho = -q\delta^3(\vec{r})\theta(vt-r) + \frac{q}{4\pi r^2}\delta(vt-r); \vec{J} = \frac{qv}{4\pi r^2}\delta(vt-r)\hat{r}$

❖ TIFR PYQ

1. Measurement of the electric field (E) and the magnetic field (B) in a plane-polarized electromagnetic wave in vacuum led to the following:

$$\frac{\partial E}{\partial x} = \frac{\partial E}{\partial y} = 0 \quad \frac{\partial E}{\partial z} = -\frac{\partial B}{\partial t}$$
$$\frac{\partial B}{\partial x} = \frac{\partial B}{\partial y} = 0 \quad \frac{\partial B}{\partial z} = +\frac{\partial E}{\partial t}$$

It follows that **[TIFR 2009]**

(a) $\vec{E} = E\hat{\imath}, \vec{B} = B\hat{\jmath}$ and the wave was travelling along $\hat{k}$

(b) $\vec{E} = E\hat{\jmath}, \vec{B} = B\hat{\imath}$ and the wave was travelling along022. $\hat{k}$

(c) $\vec{E} = E\hat{\jmath}, \vec{B} = B\hat{k}$ and the wave was travelling along $-\hat{\imath}$

(d) $\vec{E} = E\hat{k}, \vec{B} = B\hat{\imath}$ and the wave was travelling along $\hat{\jmath}$

(e) $\vec{E} = E\hat{\imath}, \vec{B} = B\hat{k}$ and the wave was travelling along $-\hat{\jmath}$

(f) the wave was travelling along $\pm\hat{k}$ but directions of $\vec{E}$ and $\vec{B}$ are not uniquely defined

2. A plane electromagnetic wave travelling in a vacuum is characterized by the electric and magnetic fields **[TIFR 2013]**

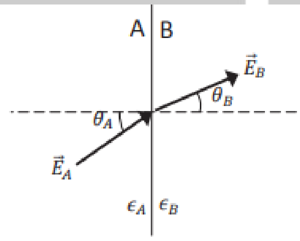
$$\vec{E} = \hat{\imath}(30\pi \text{Vm}^{-1})\exp\, i(\omega t + kz)$$
$$\vec{H} = \hat{\jmath}(H_0 \text{Am}^{-1})\exp\, i(\omega t + kz)$$

If $\omega, k > 0$, the value of H_0 must be

(a) 2π (b) 0.67

(c) 0.25 (d) 0.94

3. Two semi-infinite slabs A and B of dielectric constant ϵ_A and ϵ_B meet in a plane interface, as shown in the figure below.



If the electric field in slab A makes an angle θ_A with the normal to the boundary and the electric field in slab B makes an angle θ_B with the same normal (see figure), then **[TIFR 2016]**

(a) $\cos\,\theta_A = \frac{\epsilon_A}{\epsilon_B}\cos\,\theta_B$

(b) $\sin\,\theta_A = \frac{\epsilon_A}{\epsilon_B}\sin\,\theta_B$

(c) $\tan\,\theta_A = \frac{\epsilon_A}{\epsilon_B}\tan\,\theta_B$

(d) $\sin\,\theta_A = \frac{\epsilon_B}{\epsilon_A}\sin\,\theta_B$

4. A beam of plane microwaves of wavelength 12 cm strikes the surface of a dielectric at 45°. If the refractive index of the dielectric is $\frac{4}{3}$, what will be the wavelength, in units of mm, of the microwaves inside the dielectric? **[TIFR 2017]**

5. The components of the electric and magnetic fields corresponding to a plane electromagnetic field propagating in vacuum satisfy

$$E_x = E_y = -E_z = \frac{|\vec{E}|}{\sqrt{3}} \; B_x = -B_y = \frac{|\vec{B}|}{\sqrt{2}} \; B_z = 0$$

A unit vector along the direction of propagation of the plane wave is **[TIFR 2020]**

(a) $\frac{\hat{\imath}+\hat{\jmath}+2\hat{k}}{\sqrt{6}}$ (b) $-\frac{\hat{\imath}+\hat{\jmath}+2\hat{k}}{\sqrt{6}}$

(c) $\frac{2\hat{\imath}-2\hat{\jmath}+\hat{k}}{\sqrt{3}}$ (d) $-\frac{2\hat{\imath}-2\hat{\jmath}+\hat{k}}{\sqrt{3}}$

Answer Key				
CSIR-NET PYQ				
1. d	2. a	3. b	4. b	5. c
6. d	7. d			
8. a	9. b	10. a	11. a	12. b
13. d	14. a	15. b	16.c	17.c
GATE PYQ				
1.	2. b	3. c	4. b	5. b
6. a	7. b	8. a	9. b	10. c
11. c	12. a	13. b	14. a	15. b
16. a	17. c	18. d	19. a	
20. b	21. 1.5	22. 88.50	23. 2.39	
24. 6.6	25. d	26. a	27. a,c	
JEST PYQ				
1. b	2. d	3. d	4. b	5. d
6. c	7. d	8. d		
TIFR PYQ				
1.	2. c	3. c	4. 90	5. b

❖ EMT 09 : Poynting Vector , Radiation

❖ CSIR-NET PYQ's

1. When a charged particle emits electromagnetic radiation, the electric field $\vec{E}$ and the Poynting vector $\vec{S}=\frac{1}{\mu_0}\vec{E}\times\vec{B}$ at a large distance ' r 'from the emitter vary as $\frac{1}{r^n}$ and $\frac{1}{r^m}$ respectively. Which of the following choices for ' n ' and ' m ' are correct?

[CSIR DEC 2012]

(a) $n=1$ and $m=1$ (b) $n=2$ and $m=2$

(c) $n=1$ and $m=2$ (d) $n=2$ and $m=4$

2. Consider the interference of two coherent electromagnetic waves whose electric field vectors are given by $\vec{E}_1=\hat{i}E_0\cos\omega t$ and $\vec{E}_2=\hat{j}E_0\cos(\omega t+\varphi)$ where φ is the phase difference. The intensity of the resulting wave is given by $\frac{\varepsilon_0}{2}\langle E^2\rangle$, where $\langle E^2\rangle$ is the time average of E^2. The total intensity is

[CSIR Dec. 2012]

(a) 0 (b) $\varepsilon_0 E_0^2$

(c) $\varepsilon_0 E_0^2\sin^2\varphi$ (d) $\varepsilon_0 E_0^2\cos^2\varphi$

3. A current I is created by a narrow beam of protons moving in vacuum with constant velocity $\bar{u}$. The direction and magnitude, respectively, of the Poynting vector $\vec{S}$ outside the beam at a radial distance r (much larger than the width of the beam) from the axis, are

[CSIR JUNE 2013]

(a) $\vec{S}\perp\bar{u}$ and $|\vec{S}|=\frac{I^2}{4\pi^2\epsilon_0|\bar{u}|r^2}$

(b) $\vec{S}\parallel(-\bar{u})$ and $|\vec{S}|=\frac{I^2}{4\pi^2\epsilon_0|\bar{u}|r^4}$

(c) $\bar{S}\parallel\bar{u}$ and $|\bar{S}|=\frac{I^2}{4\pi^2\epsilon_0|\bar{u}|r^2}$

(d) $\vec{S}||\vec{u}$ and $|\vec{S}|=\frac{I^2}{4\pi^2\epsilon_0|\vec{u}|r^4}$

4. An oscillating current in the direction of the y-axis through a thin metal sheet of area $1.0\ \mathrm{cm}^2$ kept in the xy-plane. The rate of total energy radiated per unit area from the surfaces of the metal sheet at a distance of 100 m is

[CSIR JUNE 2013]

(a) $I_0\omega/(12\pi\varepsilon_0 c^3)$ (b) $I_0{}^2\omega^2/(12\pi\varepsilon_0 c^3)$

(c) $I_0^2\omega/(12\pi\varepsilon_0 c^3)$ (d) $I_0\omega^2/(24\pi\varepsilon_0 c^3)$

5. A non-relativistic particle of mass m and charge e, moving with a velocity $\vec{v}$ and acceleration $\vec{a}$, emits radiation of intensity I. What is the intensity of the radiation emitted by a particle of mass $m/2$, charge $2e$, velocity $\vec{v}/2$ and acceleration $2\vec{a}$?

[CSIR DEC 2014]

(a) $16I$ (b) $8I$

(c) $4I$ (d) $2I$

6. A plane electromagnetic wave is travelling along the positive z-direction. The maximum electric field along the x-direction is $10\ \mathrm{V/m}$. The approximate maximum values of the power per unit area and the magnetic induction B, respectively, are

[CSIR JUNE 2015]

(a) 3.3×10^{-7} watts $/\mathrm{m}^2$ and 10 tesla

(b) 3.3×10^{-7} watts/ $/\mathrm{m}^2$ and 3.3×10^{-4} tesla

(c) 0.265 watts $/\mathrm{m}^2$ and 10 tesla

(d) 0.265watts$/\mathrm{m}^2$ and 3.3×10^{-8} tesla

7. A dipole of moment $\vec{p}$, oscillating at frequency ω, radiates spherical waves. The vector potential at large distance is $\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} i\omega \frac{e^{ikr}}{r}\vec{p}$. To order $(1/r)$ the magnetic field $\vec{B}$ at a point $\vec{r} = r\hat{n}$ is

[CSIR Dec. 2015]

(a) $-\frac{\mu_0}{4\pi}\frac{\omega^2}{c}(\hat{n}\cdot\dot{p})\hat{n}\frac{4\pi}{r}$

(b) $-\frac{\mu_0}{4\pi}\frac{\omega^2}{c}(\hat{n}\times\dot{p})\frac{e^{ikr}}{r}$

(c) $-\frac{\mu_0}{4\pi}\omega^2 k(\hat{n}\cdot\dot{p})\dot{p}\frac{e^{ikr}}{r}$

(d) $-\frac{\pi_0}{4\pi}\frac{\omega}{c}p\frac{e^{ikr}}{r}$

8. The electric and magnetic fields in the charge free region $z > 0$ are given by

$\dot{E}(\dot{r},t) = E_0 e^{-k_1 z}\cos(k_2 x - \omega t)\hat{\jmath}$

$\dot{B}(\dot{r},t) = \frac{E_0}{\omega}e^{-k_1 z}$

$\left|k_1 \sin(k_2 x - \omega t)\hat{\imath} + k_2\cos(k_2 x - \omega t)\hat{k}\right|$

where $\omega, k_1 \& k_2$ are positive constants. The average energy flow in the x-direction is

[CSIR June 2015]

(a) $\frac{E_0^2 k_2}{2\mu_0(1)}e^{-2k_1 z}$

(b) $\frac{E_0^2 k_2}{\mu_0\omega}e^{-2k_1 z}$

(c) $\frac{E_0^2 k_1}{2\mu_0\omega}e^{-2k_1 z:}$

(d) $\frac{1}{2}c\varepsilon_0 E_0^2 e^{-2x_1 z}$

9. A particle with charge $-q$ moves with a uniform angular velocity ω in a circular orbit of radius a in the xy-plane, around a fixed charge $+q$, which is at the centre of the orbit at (0,0,0). Let the intensity of radiation at the point $(0,0,R)$ be I_1 and at $(2R,0,0)$ be I_2. The ratio I_2/I_1, for $R \gg a$, is

[CSIR DEC 2016]

(a) 4

(b) $\frac{1}{4}$

(c) $\frac{1}{8}$

(d) 8

10. An electron is decelerated at-a constant rate starting from an initial velocity u (where $u \ll c$) to $u/2$ during which it travels a distance s. The amount of energy lost to radiation is

[CSIR JUNE 2017]

(a) $\frac{\mu_0 e^2 u^2}{3\pi mc^2 s}$

(b) $\frac{\mu_0 e^2 u^2}{6\pi mc^2 s}$

(c) $\frac{\mu_0 e^2 u}{8\pi mcs}$

(d) $\frac{\mu_0 e^2 u}{16\pi mcs}$

11. An electromagnetic wave is travelling in free space (of permittivity E_0) with electric field $\vec{E} = \hat{k}E_0\cos\, q(x - ct)$. The average power (per unit area) crossing planes parallel to $4x + 3y = 0$ will be

[CSIR DEC 2017]

(a) $\frac{4}{5}\varepsilon_0 c E_0^2$

(b) $\varepsilon_0 c E_0^2$

(c) $\frac{1}{2}\varepsilon_0 c E_0^2$

(d) $\frac{16}{25}\varepsilon_0 c E_0^2$

12. In the region far from a source, the time dependent electric field at a point (r,θ,ϕ) is $\vec{E}(r,\theta,\phi) = \hat{\phi}E_0\omega^2\left(\frac{\sin\theta}{r}\right)\cos\left[\omega\left(t - \frac{r}{c}\right)\right]$ where ω is angular frequency of the source. The total power radiated (average over a cycle) is

[CSIR JUNE 2018]

(a) $\frac{2\pi}{3}\frac{E_0^2\omega^4}{\mu_0 c}$

(b) $\frac{4\pi}{3}\frac{E_0^2\omega^4}{\mu_0 c}$

(c) $\frac{4}{3\pi}\frac{E_0^2\omega^4}{\mu_0 c}$

(d) $\frac{2}{3}\frac{E_0^2\omega^4}{\mu_0 c}$

13. The electric field of an electromagnetic wave is $\vec{E} = \hat{\imath}\sqrt{2}\sin(kz - \omega t)\text{Vm}^{-1}$. The average flow of energy per unit area per unit time, due to this wave, is

[CSIR DEC 2019]

(a) $27\times10^4\ \text{W/m}^2$

(b) $27\times10^{-4}\ \text{W/m}^2$

(c) $27\times10^{-2}\ \text{W/m}^2$

(d) $27\times10^2\ \text{W/m}^2$

14. An alternating current $I(t) = I_0\cos(\omega t)$ flows through a circular wire loop of radius R, lying in the xy-plane, and centered at the origin. The electric field $\vec{E}(\vec{r},t)$ and the magnetic field $\vec{B}(\vec{r},t)$ are measured at a point $\vec{r}$ such that $r \gg \frac{c}{\omega} \gg R$, where $\vec{r} = |\vec{r}|$. Which one of the following statements is correct?

[CSIR DEC 2019]

(a) The time-averaged $|\vec{E}(\vec{r},t)| \propto \frac{1}{r^2}$.

(b) The time-averaged $|\vec{E}(\vec{r},t)| \propto \omega^2$.

(c) The time-averaged $|\vec{B}(\vec{r},t)|$ as a function of the polar angle θ has a minimum at $\theta = \frac{\pi}{2}$.

(d) $|\vec{B}(\vec{r},t)|$ is along the azimuthal direction

15. A spacecraft of mass $m = 1000$ kg has a fully reflecting sail that is oriented perpendicular to the direction of the sun. The sun radiates 10^{26} W and has a mass $M = 10^{30}$ kg. Ignoring the effect of the planets, for the gravitational pull of the sun to balance the radiation pressure on the sail, the area of the sail will be

[CSIR JUNE 2020]

(a) $10^2 m^2$ (b) 10^4 m^2

(c) $10^8 m^2$ (d) $10^6 m^2$

16. The electric and magnetic fields at a point due to two independent sources are $E_1 = E(\alpha\hat{\imath} + \beta\hat{\jmath})$, $\mathrm{B}_1 = B\hat{k}$ and $\mathrm{E}_2 = E\hat{\imath}$, $\mathrm{B}_2 = -2B\hat{k}$, where α, β, E and B are constants. If the Poynting vector is along $\hat{\imath} + \hat{\jmath}$, then

[CSIR JUNE 2023]

(a) $\alpha + \beta + 1 = 0$ (b) $\alpha + \beta - 1 = 0$

(c) $\alpha + \beta + 2 = 0$ (d) $\alpha + \beta - 2 = 0$

17. A long cylindrical wire of radius R and conductivity σ, lying along the z-axis, carries a uniform axial current density I. The Poynting vector on the surface of the wire is (in the following $\hat{\rho}$ and $\hat{\varphi}$ denote the unit vectors along the radial and azimuthal directions respectively)

[CSIR JUNE 2023]

(a) $\frac{I^2 R}{2\sigma}\hat{\rho}$ (b) $-\frac{I^2 R}{2\sigma}\hat{\rho}$

(c) $-\frac{I^2 \pi R}{4\sigma}\hat{\varphi}$ (d) $\frac{I^2 \pi R}{4\sigma}\hat{\varphi}$

18. An infinitely long solenoid of radius r_0 centred at origin which produces a time-dependent magnetic field $\frac{\alpha}{\pi {r_0}^2}\cos(\omega t)$ (where α and ω are constants) is placed along the z-axis. A circular loop of radius R, which carries unit line charge density is placed, initially at rest, on the xy-plane with its centre on the z-axis. If $R > r_0$, the magnitude of the angular momentum of the loop is

[CSIR JUNE 2023]

(a) $\alpha R(1 - \cos \omega t)$ (b) $\alpha R \sin(\omega t)$

(c) $\frac{\alpha R}{2}(1 - \cos 2\omega t)$ (d) $\frac{\alpha R}{2}\sin(2\omega t)$

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

[CSIR DEC 2023]

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

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

20. The electric field of an electromagnetic wave in free space is given by

$$\vec{E} = E_0 \sin(\omega t - k_z z)\hat{\jmath}$$

The magnetic field $\vec{B}$ vanishes for $t = \frac{k_z z}{\omega}$. The Poynting vector of the system is

[CSIR JUNE 2024]

(a) $\frac{k_z}{2\mu_0\omega}E_0^2 \sin^2(\omega t - k_z z)\hat{k}$

(b) $\frac{4k_z}{\mu_0\omega}E_0^2 \sin^2(\omega t - k_z z)\hat{k}$

(c) $\frac{2k_z}{\mu_0\omega}E_0^2 \sin^2(\omega t - k_z z)\hat{k}$

(d) $\frac{k_z}{\mu_0\omega}E_0^2 \sin^2(\omega t - k_z z)\hat{k}$

21. A radio station antenna on the earth's surface radiates 50 kW power isotropically. Assume the electromagnetic waves to be sinusoidal and the ground to be a perfect absorber. Neglecting any transmission loss and effects of earth's curvature, the peak value of the magnetic field (in Tesla) detected at a distance of 100 km is closest to

[CSIR JUNE 2024]

(a) 1.5×10^{-11} (b) 5.5×10^{-11}

(c) 8.5×10^{-11} (d) 3.5×10^{-11}

❖ GATE PYQ's

1. The electric (E) and magnetic (B) field amplitudes associated with an electromagnetic radiation from a point source behave at a distance r from the source as

[GATE 2005]

(a) $E =$ constant, $B =$ constant

(b) $E \propto \frac{1}{r}, B \propto \frac{1}{r}$

(c) $E \propto \frac{1}{r^2}, B \propto \frac{1}{r^2}$

(d) $E \propto \frac{1}{r^3}, B \propto \frac{1}{r^3}$

2. Consider the following three independent cases:
(i) Particle A of charge $+q$ moves in free space with a constant velocity $\vec{v}$ ($v \ll$ speed of light)
(ii) Particle B of charge $+q$ moves in free space in a circle of radius R with same speed v as in case (i)
(iii) Particle C having charge $-q$ moves as in case (ii)
If the power radiated by A, B and C are P_A, P_B and P_C, respectively, then

[GATE 2005]

(a) $P_A = 0, P_B > P_C$ (b) $P_A = 0, P_B = P_C$

(c) $P_A > P_B > P_C$ (d) $P_A = P_B = P_C$

3. An electromagnetic wave with $\vec{E}(z,t) = E_0 \cos(\omega t - kz)\hat{\imath}$ is travelling in free space and crosses a disc of radius 2 m placed perpendicular to the z-axis. If $E_0 = 60\text{Vm}^{-1}$, the average power, in Watt, crossing the disc along the z-direction is

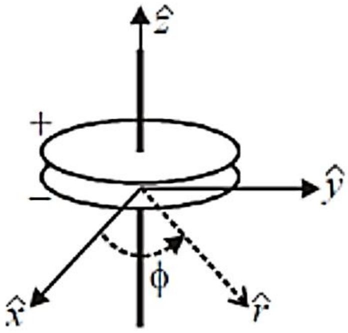
[GATE 2007]

(a) 30 (b) 60

(c) 120 (d) 270

4. A parallel plate capacitor is being discharged. What is the direction of the energy flow in terms of the poynting vector in the space between the plates?

[GATE 2008]



(a) Along the wire in the positive z axis

(b) Radially inward $(-\hat{r})$

(c) Radially outward $(\hat{r})$

(d) Circumferential (ϕ)

Statement for Linked Answer Q.5 and Q. 6:
A plane electromagnetic wave has the magnetic field given by
$\vec{B}(x,y,z,t) = B_0 \sin\left[(x+y)\frac{k}{\sqrt{2}} + \omega t\right]\hat{k}$
Where k is the wave number and $\hat{\imath}, \hat{\jmath}$ and $\hat{k}$ are the Cartesian unit vectors is x, y and z directions, respectively.

5. The electric field $\dot{E}(x,y,z,t)$ corresponding to the above wave is given by

[GATE 2011]

(a) $cB_0 \sin\left[(x+y)\frac{k}{\sqrt{2}} + \omega t\right]\frac{(\hat{\imath}-\hat{\jmath})}{\sqrt{2}}$

(b) $cB_0 \sin\left[(x+y)\frac{k}{\sqrt{2}} + \omega t\right]\frac{(\hat{\imath}+\hat{\jmath})}{\sqrt{2}}$

(c) $cB_0 \sin\left[(x+y)\frac{k}{\sqrt{2}} + \omega t\right]\hat{\imath}$

(d) $cB_0 \sin\left[(x+y)\frac{k}{\sqrt{2}} + \omega t\right]j$

6. The average Poynting vector is given by

[GATE 2011]

(a) $\frac{cB_0^2}{2\mu_0}\frac{(\hat{\imath}-\hat{\jmath})}{\sqrt{2}}$ (b) $-\frac{cB_0^2}{2\mu_0}\frac{(\hat{\imath}-\hat{\jmath})}{\sqrt{2}}$

(c) $\frac{cB_0^2}{2\mu_0}\frac{(\hat{\imath}+\hat{\jmath})}{\sqrt{2}}$ (d) $-\frac{cB_0^2}{2\mu_0}\frac{(\hat{\imath}+\hat{\jmath})}{\sqrt{2}}$

7. The space-time dependence of the electric field of a linearly polarized light in free space is given by $\hat{x}_0 \cos(\omega t - kz)$ where E_0, ω and k are the amplitude, the angular frequency and the wave vector, respectively. The time averaged energy density associated with the electric field is

[GATE 2012]

(a) $\frac{1}{4}\varepsilon_0 E_0^2$ (b) $\frac{1}{2}\varepsilon_0 \mathrm{E}_0^2$

(c) $\varepsilon_0 \mathrm{E}_0^2$ (d) $2\varepsilon_0 \mathrm{E}_0^2$

8. The intensity of a laser in free space is $\frac{150\ \mathrm{mW}}{\mathrm{m}^2}$. The corresponding amplitude of the electric field of the laser is $\frac{\mathrm{V}}{\mathrm{m}}$.

[GATE 2014]

$$\left(\varepsilon_0 = 8.854 \times \frac{10^{-12} C^2}{N}.m^2\right)$$

9. The electric field component of a plane electromagnetic wave travelling in vacuum is given by $\vec{E}(z,t) = E_0 \cos(kz - \omega t)\hat{\imath}$. The pointing vector for the wave is

[GATE 2016]

(a) $(c\varepsilon_0/2)E_0^2 \cos^2(kz - \omega t)\hat{\jmath}$

(b) $(c\varepsilon_0/2)E_0^2 \cos^2(kz - \omega t)\hat{k}$

(c) $c\varepsilon_0 E_0^2 \cos^2(kz - \omega t)\hat{\jmath}$

(d) $c\varepsilon_0 E_0^2 \cos^2(kz - \omega t)\hat{k}$

10. An infinitely long straight wire is carrying a steady current I. The ratio of magnetic energy density at distance r_1 to that at $r_2(= 2r_1)$ from the wire is.

[GATE 2018]

11. A light beam of intensity I_0 is falling normally on a surface. The surface absorbs 20% of the intensity and the rest is reflected. The radiation pressure on the surface is given by XI_0/c, where X is (up to one decimal place). Here c is the speed of light.

[GATE 2018]

12. A long straight wire, having radius a and resistance per unit length r, carries a current I. The magnitude and direction of the Poynting vector on the surface of the wire is

[GATE 2018]

(a) $I^2 r/2\pi a$, perpendicular to axis of the wire and pointing inwards

(b) $I^2 r/2\pi a$, perpendicular to axis of the wire and pointing outwards

(c) $I^2 r/\pi a$, perpendicular to axis of the wire and pointing inwards

(d) $I^2 r/\pi a$, perpendicular to axis of the wire and pointing outwards

13. The electric field of an electromagnetic wave in vacuum is given by

$$\vec{E} = E_0 \cos(3y + 4z - 1.5 \times 10^9 t)\hat{x}.$$

The wave is reflected from the $z = 0$ surface. If the pressure exerted on the surface is $\alpha\epsilon_0 E_0^2$, the value of α (rounded off to one decimal place) is

[GATE 2019]

14. Consider a tiny current loop driven by a sinusoidal alternating current. If the surface integral of its time-averaged Poynting vector is constant, then the magnitude of the time averaged magnetic field intensity, at any arbitrary position, $\vec{r}$, is proportional to

[GATE 2021]

(a) $\frac{1}{r^3}$ (b) $\frac{1}{r^2}$

(c) $\frac{1}{r}$ (d) r

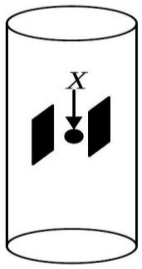
15. A point charge q is performing simple harmonic oscillations of amplitude A at angular frequency ω Using Lamor's formula, the power radiated by the change is proportional to **[GATE 2022]**

(a) $q\omega^2 A^2$ (b) $q\omega^4 A^2$

(c) $q^2\omega^2 A^2$ (d) $q^2\omega^4 A^2$

16. A current of $1A$ is flowing through a very long solenoid made of winding density 3000 turns $/m$. As shown in the figure, a parallel plate capacitor, with plates oriented parallel to the solenoid axis and carrying surface charge density $6\ \epsilon_0\ \mathrm{Cm}^{-2}$, is placed at the middle of the solenoid. The momentum density of the electromagnetic field at the

[GATE 2022]



midpoint X of the capacitor is $n \times 10^{-13}\mathrm{Nsm^{-3}}$. The value of n is
(Round off to the nearest integer)
(speed of light $c = 3 \times 10^{8}\ \mathrm{ms^{-1}}$)

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

[GATE 2023]

18. An oscillating electric dipole of moment $\vec{d}(t) = d_0 \cos(\omega t)\hat{z}$ is placed at origin as shown in figure.
Consider a point P(r, θ, ϕ) at a very large distance from the dipole. Here r, θ and ϕ are spherical polar coordinates. Which of the following statement is/are true for intensity of radiation?

[GATE 2024]

(a) Intensity at P $\left(r = R, \theta = \frac{\pi}{2}, \phi = \frac{\pi}{4}\right)$ is equal to that at P $\left(r = R, \theta = \frac{\pi}{4}, \phi = \frac{\pi}{4}\right)$
(b) Intensity at P $\left(r = R, \theta = \frac{\pi}{2}, \phi = \frac{\pi}{4}\right)$ is greater than that at P $\left(r = R, \theta = \frac{\pi}{4}, \phi = \frac{\pi}{4}\right)$
(c) Intensity is zero at P $\left(r = R, \theta = \frac{\pi}{2}, \phi = \frac{\pi}{4}\right)$
(d) Intensity is zero if P is on the z axis

❖ JEST PYQ

1. The electric and magnetic fields caused by an accelerated charged particle are found to scale as $E \propto r^{-n}$ and B $\propto r^{-m}$ at large distances. What are the values of n and m ?

[JEST 2013]

(a) n = 1, m = 2 (b) n = 2, m = 1
(c) n = 1, m = 1 (d) n = 2, m = 2

2. An electron is executing simple harmonic motion along the y-axis in right handed coordinate system. Which of the following statements is true for emitted radiation?

[JEST 2014]

(a) The radiation will be most intense in xz plane
(b) The radiation will be most intense in xy plane
(c) The radiation will violate causality
(d) The electron's rest mass energy will reduce due to radiation loss

3. The approximate force exerted on a perfectly reflecting mirror by an incident laser beam of power 10 mW at normal incidence is

[JEST 2015]

(a) 10^{-13} N (b) 10^{-11} N
(c) 10^{-9} N (d) 10^{-15} N

4. A laser has output power of 150 mW with beam diameter of 2 mm at a wavelength 630 nm. What is the value of the electric field in units of V/m is? Use Coulomb's constant, $1/4\pi\epsilon_0 = 9 \times 10^{9}\ \mathrm{N\,m^2C^{-2}}$. **[JEST 2020]**

❖ TIFR PYQ

1. The instantaneous electric and magnetic fields created at a distance r by a point source at the origin are given by

$$\vec{E} = \frac{A\cos\,\omega t}{2\pi\varepsilon_0 r}\hat{\theta}\ \vec{H} = \frac{B\cos\,\omega t}{\mu_0 r}\hat{\varphi}$$

where ω, A, B are constants, and the unit vectors $(\hat{r}, \hat{\theta}, \hat{\varphi})$ form an orthonormal set. The time-averaged power radiated by the source is **[TIFR 2014]**

(a) $\frac{\omega\varepsilon_0}{\mu_0}AB$ (b) $\frac{c^3}{2\pi}AB$

(c) c^2AB (d) $\frac{2\pi\omega}{c}AB$

2. A light source has a small filament at the centre of a spherical glass bulb of radius 5 cm and negligible thickness. If this source emits 100 Watts of power in the form of spherical electromagnetic waves, the r.m.s. electric field E at the surface of the bulb (in units of Volt/m) will be approximately **[TIFR 2015]**

(a) 1547 (b) 1094

(c) 109.4 (d) 15.47

3. An electromagnetic wave in free space is described by

$$\vec{E}(x, y, z, t) = \hat{z}E_0\cos\frac{1}{2}(kx - \sqrt{3}ky - 2\omega t)$$

The Poynting vector associated with this wave is along the direction **[TIFR 2017]**

(a) $\hat{x} + \sqrt{3}\hat{y}$ (b) $\sqrt{3}\hat{x} + \hat{y}$

(c) $-\sqrt{3}\hat{x} + \hat{y}$ (d) $\hat{x} - \sqrt{3}\hat{y}$

4. A plane electromagnetic wave, which has an electric field $\vec{E}(\vec{x}, t) = (P\hat{\imath} + Q\hat{\jmath})\exp\ i\omega\left(t - \frac{z}{c}\right)$ is passing through vacuum. Here P, Q and ω are all constants, while c is the speed of light in vacuum. What is the average energy flux per unit time (in SI units) crossing a unit area placed normal to the direction of propagation of this wave, in terms of the above constants?

[TIFR 2018]

5. Consider a dipole antenna with length ℓ, charge q and frequency ω. The power emitted by the antenna at a large distance r is P. Now suppose the length ℓ is increased to $\sqrt{2}\ell$, the charge is increased to $\sqrt{3}q$ and the frequency is increased to $\sqrt{5}\omega$. By what factor is the radiated power increased? **[TIFR 2018]**

6. A plane electromagnetic wave travelling through vacuum has electric field $\vec{E}$ and magnetic field $\vec{B}$ defined as

[TIFR 2019]

$$\vec{E} = (\hat{\imath} + \hat{\jmath})E_0\exp i\left(\omega t - \vec{k}\cdot\vec{x}\right)$$
$$\vec{B} = (\hat{\imath} - \hat{\jmath} - \hat{k})B_0\exp i\left(\omega t - \vec{k}\cdot\vec{x}\right)$$

where E_0 and B_0 are real constants. The time-averaged Poynting vector will be given by

(a) $\vec{S} = \sqrt{\frac{\varepsilon_0}{6\mu_0}}E_0^2\left(-\hat{\imath} + \hat{\jmath} - 2\hat{k}\right)$

(b) $\vec{S} = -\frac{1}{2}\sqrt{\frac{3\varepsilon_0}{\mu_0}}E_0^2\left(\hat{\imath} - \hat{\jmath} + 2\hat{k}\right)$

(c) $\vec{S} = -\frac{2}{\sqrt{\varepsilon_0\mu_0}}E_0B_0\left(\hat{\imath} - \hat{\jmath} + 2\hat{k}\right)$

(d) $\dot{S} = \frac{1}{2}\sqrt{\frac{\varepsilon_0}{\mu_0}}B_0^2\left(\hat{\imath} - \hat{\jmath} + 2\hat{k}\right)$

7. An oscillating point dipole of moment $\vec{p}(t) = \hat{z}p_0\cos\,\omega t$ generates time-dependent electric and magnetic fields. At distances r far away from the dipole, the vector potential due to this dipole, in SI units, is $\vec{A} = \hat{z}\frac{\mu_0 p_0\omega}{4\pi r}\sin\,\omega\left(t - \frac{r}{c}\right)$

The total power radiated from this dipole is **[TIFR 2021]**

(a) $\frac{\mu_0 p_0{}^2\omega^4}{12\pi c}$ (b) $\frac{\mu_0 p_0{}^2\omega^4}{8\pi c}$

(c) $\frac{\mu_0 p_0{}^2\omega^4}{16\pi^2 c}$ (d) $\frac{\mu_0 p_0{}^2\omega^4}{24\pi c}$

8. If an electron is set into oscillatory motion by the electric field of a laser of intensity $150\ W\ \mathrm{m}^{-2}$ and wavelength $554\ nm$, the amplitudes of its displacement and velocity, respectively, are expected to be

[TIFR 2022]

(a) $5.1 \times 10^{-18}\ m,$
$1.7 \times 10^{-2}\ m\,\mathrm{s}^{-1}$

(b) $3.4 \times 10^{-17}\ m$
$1.0 \times 10^{-1}\ \mathrm{m\,s^{-1}}$

(c) $3.4 \times 10^{-16}\ \mathrm{m}$
$1.7 \times 10^{-1}\ \mathrm{m\,s^{-1}}$

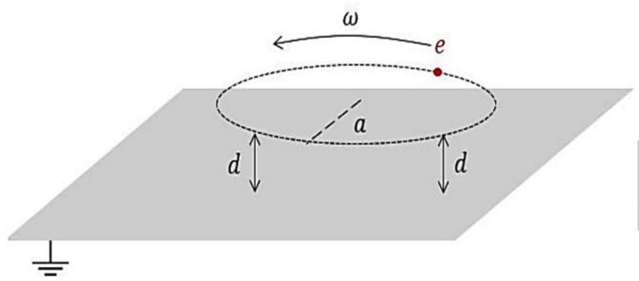
(d) $3.4 \times 10^{-18}\ \mathrm{m}$
$1.7 \times 10^{-2}\ \mathrm{m\,s^{-1}}$

9. The power radiated by a point charge q moving rapidly with a uniform speed v in a circle of radius R will be **[TIFR 2022]**

(a) $\frac{q^2c^3}{6\pi\varepsilon_0 R^3}\frac{v^2}{c^2-v^2}$ (b) $\frac{q^2c}{6\pi\varepsilon_0 R^2}\left(\frac{v^2}{c^2-v^2}\right)^2.$

(c) $\frac{q^4c^2}{6\pi\varepsilon_0 R^2}\left(\frac{v^2}{c^2-v^2}\right)^2$ (d) $\frac{q^2c}{6\pi\varepsilon_0 R^4}\frac{v^2}{c^2-v^2}$

10. A charge e is moving with an angular frequency ω along a circle of radius a always keeping a small distance $d(d \ll a)$ from a grounded infinite conducting plane.



The leading dependence of the radiated power $P(\omega)$ at a distance $r(r \gg a)$ will be **[TIFR 2023]**

(a) $P(\omega) \propto \omega^6$ (b) $P(\omega) \propto \omega^4$

(c) $P(\omega) \propto \omega^3$ (d) $P(\omega) \propto \omega^2$

11. A smartphone emits electromagnetic radiation with a power of 1 Watt. What is the approximate value of the r.m.s. magnetic field at a distance 25 cm from the phone? **[TIFR 2024]**

(a) 10^{-7} Tesla (b) 10^{-5} Tesla

(c) 10^{-9} Tesla (d) 10^{-11} Tesla

❖ Answer Key

CSIR PYQ				
1. c	2. b	3. c	4. b	
5. a	6. d	7. b	8. a	9. c
10. d	11. a	12. b	13. b	14. b
15. d	16. d	17. b	18. a	19. c
20. d	21. b			
GATE PYQ				
1. b	2. b	3. c	4. b	5. a
6. d	7. a	8. 10.6	9. d	10. 4
11. 1.8	12. a	13. 0.8	14. c	15. d
16. 2	17. 11.5-13.7	18. bd		
JEST PYQ				
1. c	2. a	3. b	4. 6000	
TIFR PYQ				
1. c	2. b	3. d	4.	5. 150
6. a	7. a	8. a	9. b	10. b
11. a				

❖ EMT 10 : Time Varying Potentials

❖ CSIR-NET PYQ's

1. For constant uniform electric and magnetic fields $\vec{E} = \vec{E}_0$ and $\vec{B} = \vec{B}_0$, it is possible to choose a gauge such that the scalar potential ϕ and vector potential $\vec{A}$ are given by **[NET June 2011]**

(a) $\phi = 0$ and $\vec{A} = \frac{1}{2}(\vec{B}_0 \times \vec{r})$

(b) $\phi = -\vec{E}_0 \cdot \vec{r}$ and $\vec{A} = \frac{1}{2}(\vec{B}_0 \times \vec{r})$

(c) $\phi = -\vec{E}_0 \cdot \vec{r}$ and $\vec{A} = 0$

(d) $\phi = 0$ and $\vec{A} = -\vec{E}_0 t$

2. A constant electric current I in an infinitely long straight wire is suddenly switched on at $t = 0$. The vector potential at a perpendicular distance r from the wire is given by $\vec{A} = \frac{\hat{k}\mu_0 I}{2\pi}\ell n\left[\frac{1}{r}\left(ct + \sqrt{c^2t^2 - r^2}\right)\right]$. The electric field at a distance $r(< ct)$ is: **[CSIR DEC 2011]**

(a) 0

(b) $\frac{\mu_0 I}{2\pi t}\frac{1}{\sqrt{2}}(\hat{\imath} - \hat{\jmath})$

(c) $\frac{c\mu_0 I}{2\pi\sqrt{c^2t^2-r^2}}\frac{1}{\sqrt{2}}(\hat{\imath} + \hat{\jmath})$

(d) $-\frac{c\mu_0 I}{2\pi\sqrt{c^2t^2-r^2}}\hat{k}$

3. Consider an infinite conducting sheet in the xy-plane with a time dependent current density $Kt\hat{\imath}$, where K is a constant. The vector potential at (x, y, z) is given by

$$\hat{A} = \frac{\mu_0 K}{4c}(ct - z)^2\hat{\imath}$$

The magnetic field $\vec{B}$ is; **[CSIR DEC 2012]**

(a) $\frac{\mu_0 Kt}{2}\hat{\jmath}$

(b) $-\frac{\mu_0 Kz}{2c}\hat{\jmath}$

(c) $-\frac{\mu_0 K}{2c}(ct - z)\hat{\imath}$

(d) $-\frac{\mu_0 K}{2c}(ct - z)\hat{\jmath}$

4. If the electric and magnetic fields are unchanged when the vector potential $\overline{A}$ changes (in suitable units) according to $\vec{A} \to \vec{A} + \hat{r}$, where $\vec{r} = r(t)\hat{r}$, then the scalar potential Φ must simultaneously change to **[CSIR JUNE 2013]**

(a) $\Phi - r$

(b) $\Phi + r$

(c) $\Phi - \partial r/\partial t$

(d) $\Phi + \partial r/\partial t$

5. Let (V, A) and (V', A') denote two sets of scalar and vector potentials, and ψ a scalar function. Which of the following transformations leave the electric and magnetic fields (and hence Maxwell's equations) unchanged? **[CSIR DEC 2013]**

(a) $A' = A + \nabla\psi$ and $V = V - \frac{\partial\psi}{\partial t}$

(b) $A' = A - \nabla\psi$ and $V' = V + 2\frac{\partial\psi}{\partial t}$

(c) $A' = A + \nabla\psi$ and $V' = V + \frac{\partial\psi}{\partial t}$

(d) $A' = A - 2\nabla\psi$ and $V' = V - \frac{\partial\psi}{\partial t}$

6. A time-dependent current $\vec{I}(t) = Kt\hat{z}$ (where K is a constant) is switched on at $t = 0$ in an infinite current-carrying wire. The magnetic vector potential at a perpendicular distance ' a ' from the wire is given (for time $t > a/c$) by **[CSIR JUNE 2014]**

(a) $\hat{z}\frac{\mu_0 K}{4\pi c}\int_{-\sqrt{c^2t^2-a^2}}^{\sqrt{c^2t^2-a^2}} dz \frac{ct-\sqrt{a^2+z^2}}{(a^2+z^2)^{1/2}}$

(b) $\hat{z}\frac{\mu_0 K}{4\pi}\int_{-at}^{ct} dz \frac{t}{(a^2+z^2)^{1/2}}$

(c) $\hat{z}\frac{\mu_0 K}{4\pi c}\int_{-ct}^{ct} dz \frac{ct-\sqrt{a^2+z^2}}{(a^2+z^2)^{1/2}}$

(d) $\hat{z}\frac{\mu_0 K}{4\pi}\int_{-\sqrt{c^2t^2-a^2}}^{\sqrt{c^2a^2}} dz\frac{t}{(a^2+z^2)^{1/2}}$

7. The scalar and vector potentials $\varphi(\vec{x},t)$ and $\vec{A}(\vec{x},t)$ are determined up to a gauge transformation $\varphi \to \varphi' = \varphi - \frac{\partial\xi}{\partial t}$ and $\vec{A} \to \vec{A}' = \vec{A} + \vec{\nabla}\xi$ where ξ is an arbitrary continuous and differentiable function of $\vec{x}$ and t. If we further impose the Lorenz gauge condition $\vec{\nabla}\cdot\vec{A} + \frac{1}{c}\frac{\partial\varphi}{\partial t} = 0$ then a possible choice for the gauge function $\xi(\vec{x},t)$ is (where $\omega, \vec{k}$ are nonzero constants with $\omega = c|\vec{k}|$)

[CSIR DEC 2014]

(a) $\cos\,\omega t \cosh\,\vec{k}\cdot\vec{x}$ (b) $\sinh\,\omega t \cos\,\vec{k}\cdot\vec{x}$

(c) $\cosh\,\omega t \cos\,\vec{k}\cdot\vec{x}$ (d) $\cosh\omega t\,\cosh\vec{k}\cdot\vec{x}$

8. Which of the following transformations $(V,\vec{A}) \to (V',\vec{A}')$ of the electrostatic potential V and the vector potential $\vec{A}$ is a gauge transformation?

[CSIR JUNE 2015]

(a) $\left(V' = V + ax, \overrightarrow{A'} = \vec{A} + at\hat{k}\right)$

(b) $\left(V' = V + ax, \vec{A}' = \vec{A} - at\hat{k}\right)$

(c) $\left(V' = V + ax, \vec{A}' = \vec{A} + at\hat{\imath}\right)$

(d) $\left(V' = V + ax, \overrightarrow{A'} = \vec{A} - at\hat{\imath}\right)$

9. A dipole of moment $\vec{p}$, oscillating at frequency ω, radiates spherical waves. The vector potential at large distance is $\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi}i\omega\frac{e^{ikr}}{r}\vec{p}$. To order $(1/r)$ the magnetic field $\vec{B}$. at a point $\vec{r} = r\hat{n}$ is

[CSIR DEC 2015]

(a) $-\frac{\mu_0}{4\pi}\frac{\omega^2}{c}(\hat{n}\cdot\vec{p})\hat{n}\frac{e^{ikr}}{r}$

(b) $-\frac{\mu_0}{4\pi}\frac{\omega^2}{c}(\hat{n}\times\vec{p})\frac{e^{ikr}}{r}$

(c) $-\frac{\mu_0}{4\pi}\omega^2 k(\hat{n}\cdot\vec{p})\vec{p}\frac{e^{iks}}{r}$

(d) $-\frac{\pi_0}{4\pi}\frac{\omega}{c}\vec{p}\frac{e^{ikr}}{r}$

10. Consider the operator $\vec{\pi} = \vec{p} - q\vec{A}$, where $\vec{p}$ is the momentum operator, $\vec{A} = (A_x, A_y, A_z)$ is the vector potential and q denotes the electric charge. If $\vec{B} = (B_x, B_y, B_z)$ denotes the magnetic field, the $z-$ component of the vector operator $\vec{\pi}\times\vec{\pi}$ is

[CSIR DEC 2016]

(a) $iq\hbar B_z + q(A_x p_y - A_y p_x)$

(b) $-iq\hbar B_z - q(A_x p_y - A_y p_x)$

(c) $-iq\hbar B_z$

(d) $iq\hbar B_z$

11. The vector potential $\vec{A} = ke^{-at}r\hat{r}$, (where a and k are constants) correspond ing to an electromagnetic field is changed to $\vec{A}' = -ke^{-at}r\hat{r}$. This will be a gauge transformation if the corresponding change $\phi' - \phi$ in the scalar, potential is

[NET June 2017]

(a) akr^2e^{-at} (b) $2akr^2e^{-at}$

(c) $-akr^2e^{-at}$ (d) $-2akr^2e^{-at}$

12. The electric field $\vec{E}$ and the magnetic field $\vec{B}$ corresponding to the scalar and vector potentials, $V(x,y,z,t) = 0$ and $\vec{A}(x,y,z,t) = \frac{1}{2}\hat{k}\mu_0 A_0(ct - x)$, where A_0 is a constant, are

[CSIR JUNE 2018]

(a) $\vec{E} = 0$ and $\vec{B} = \frac{1}{2}\hat{\jmath}\mu_0 A_0$

(b) $\vec{E} = -\frac{1}{2}\hat{k}\mu_0 A_0 c$ and $\vec{B} = \frac{1}{2}\hat{\jmath}\mu_0 A_0$

(c) $\vec{E} = 0$ and $\vec{B} = -\frac{1}{2}\hat{\imath}\cdot\mu_0 A_0$

(d) $\vec{E} = \frac{1}{2}\hat{k}\mu_0 A_0 c$ and $\vec{B} = -\frac{1}{2}\hat{\imath}\mu_0 A_0$

❖ GATE PYQ's

1. For a vector potential $\vec{A}$, the divergence of $\vec{A}$ is $\vec{\nabla}\cdot\vec{A} = -\frac{\mu_0}{4\pi}\frac{Q}{r^2}$, where Q is a constant of appropriate dimension. The corresponding scalar potential $\varphi(\vec{r},t)$ that makes $\vec{A}$ and φ Lorentz gauge invariant is

[GATE 2005]

(a) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ (b) $\frac{1}{4\pi\varepsilon_0}\frac{Qt}{r}$

(c) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$ (d) $\frac{1}{4\pi\varepsilon_0}\frac{Qt}{r^2}$

2. Can the following scalar and vector potentials describe an electromagnetic field?

$\phi(\vec{x},t) = 3xyz - 4t$

$\vec{A}(\vec{x},t) = (2x-\omega t)\hat{\imath} + (y-2z)\hat{\jmath} + \left(z - 2xe^{iax}\right)\hat{k}$

where ω is a constant

[GATE 2007]

(a) Yes, in the Coulomb gauge

(b) Yes, in the Lorentz gauge

(c) Yes, provided $\omega = 0$

(d) No

3. The electric and the magnetic fields $E(z,t)$ and $B(z,t)$, respectively corresponding to the scalar potential $\phi(z,t) = 0$ and vector potential $\vec{A}(z,t) = \hat{\imath}z$ are

[GATE 2012]

(a) $\vec{E} = \hat{\imath}z$ and $\vec{B} = -jt$

(b) $\vec{E} = \hat{\imath}z$ and $\vec{B} = jt$

(c) $\vec{E} = -\hat{\imath}z$ and $\vec{B} = -jt$

(d) $\vec{E} = -\hat{\imath}z$ and $\vec{B} = jt$

4. If the vector potential

$$\vec{A} = \alpha x\hat{x} + 2y\hat{y} - 3z\hat{z}$$

satisfies the Coulomb gauge, the value of the constant α is……

[GATE 2014]

5. A constant and uniform magnetic field $\vec{B} = B_0\hat{k}$ pervades all space. Which one of the following is the correct choice for the vector potential in Coulomb gauge?

[GATE 2018]

(a) $-B_0(x+y)\hat{\imath}$ (b) $B_0(x+y)\hat{\jmath}$

(c) $B_0x\hat{\jmath}$ (d) $-\frac{1}{2}B_0(x\hat{\imath} - y\hat{\jmath})$

6. The vector potential inside a long solenoid, with n turns per unit length and carrying current I, written it cylindrical coordinates is $\vec{A}(s,\phi,z) = \frac{\mu_0 nI}{2}s\hat{\phi}$. If the term $\frac{\mu_0 nI}{2}s(\alpha\cos\phi\hat{\phi} + \beta\sin\phi\hat{s})$, where $\alpha \neq 0, \cdot\ \beta \neq 0$, is added to $\vec{A}(s:\phi,z)$, the magnetic field remains the same if

[GATE 2019]

(a) $\alpha = \beta$ (b) $\alpha = -\beta$

(c) $\alpha = 2\beta$ (d) $\alpha = \frac{\beta}{2}$

❖ JEST PYQ

1. Consider magnetic vector potential $\vec{A}$ and scalar potential Φ which define the magnetic field $\vec{B}$ and electric field $\vec{E}$ and electric field $\vec{E}$. If one adds $-\nabla\lambda$ to $\vec{A}$ for a well - defined λ, then what should be added to Φ so that $\vec{E}$ remains unchanged up to an arbitrary function of time, $f(t)$?

[JEST 2017]

(a) $\frac{\partial\lambda}{\partial t}$ (b) $-\frac{\partial\lambda}{\partial t}$

(c) $\frac{1}{2}\frac{\partial\lambda}{\partial t}$ (d) $-\frac{1}{2}\frac{\partial\lambda}{\partial t}$

2. Consider a sphere of radius R containing a charge with volume density $\rho(r) = 4\pi\in_0\alpha/r$. The charge is zero outside the sphere. The electromagnetic potentials (ϕ and $\vec{A}$) inside the sphre may be written in many ways. Which of the following values of ϕ and $\vec{A}$ inside the sphere describe the situation correctly?

[JEST 2021]

(a) $\phi = 0, \vec{A} = -2\pi\alpha t\hat{r}$ (b) $\phi = 2\pi\alpha r, \vec{A} = 0$

(c) $\phi = 0, \vec{A} = -\pi\alpha t\hat{r}$ (d) $\phi = \pi\alpha r, \vec{A} = 0$

❖ TIFR PYQ

1. The magnetic vector potential $\vec{A}(\vec{r})$ corresponding to a uniform magnetic field $\vec{B}$ is taken in the form $\vec{A} = \frac{1}{2}\vec{B} \times \vec{r}$

where $\vec{r}$ is the position vector. If the electric field has the timedependent form $\vec{E} = \vec{E}_0(\vec{r})e^{i\omega t}$, where ω is a constant, the gauge choice corresponding to this potential is a

[TIFR 2013]

(a) Lorenz gauge
(c) Coulomb gauge

(b) non-linear gauge
(d) time-varying gauge

2. The magnetic vector potential corresponding to a uniform magnetic field $\vec{B}$ is often taken as

$$\vec{A} = \frac{1}{2}\vec{B} \times \vec{x}$$

This choice is **[TIFR 2019]**

(a) valid in the Lorenz gauge.

(b) valid in the Coulomb gauge. ∇

(c) valid in the Weyl gauge.

(d) gauge invariant.

Answer Key				
CSIR PYQ				
1. b	2. d	3. d	4. c	5. a
6. a	7. d	8. d	9. b	10. d
11. c	12. b			
GATE PYQ				
1. d	2. d	3. d	4. 1	5. c
6. d				
JEST PYQ				
1. a	2. a			
TIFR PYQ				
1. c	2. b			

❖ EMT 11 : Relativistic Electrodynamics

❖ CSIR-NET PYQ's

1 In a given frame of reference, it is found that the electric field $\vec{E}(\vec{r},t)$ and the magnetic field $\vec{B}(\vec{r},t)$ are perpendicular to each other at all points, i.e., $\vec{E}(\vec{r},t)\cdot\vec{B}(\vec{r},t)=0$. If the fields observed in any other inertial frame are $\vec{E}'$ and $\vec{B}$, then

[NET 2008]

(a) $\vec{E}' || \vec{B}'$ at all points

(b) $\vec{E}'\cdot\vec{B}'<0$ at all points

(c) $\vec{E}'\cdot\vec{B}'>0$

(d) $\vec{E}'\cdot\vec{B}'=0$

2 Which of the following quantities is Lorentz invariant?

[NET June 2009]

(a) $|\mathrm{E}\times\mathrm{B}|^2$ (b) $|\mathrm{E}|^2-\mathrm{C}^2|\mathrm{B}|^2$

(c) $|\mathrm{E}|^2+|\mathrm{B}|^2$ (d) $|\mathrm{E}|^2|\,\mathrm{B}|^2$

3 Which of the following quantities is Lorentz invariant?

[CSIR JUNE 2012]

(a) $|E\times B|^2$ (b) $|E|^2-|B|^2$

(c) $|E|^2+|B|^2$ (d) $|E|^2|B|^2$

4 A rod of length L carrics a total charge Q distributed uniformly. If this is observed in a frame moving with a speed v along the rod, the charge per unit length (as measured by the moving observer) is

[NET June 2015]

(a) $\frac{Q}{L}\left(1-\frac{v^2}{c^2}\right)$ (b) $\frac{Q}{L}\sqrt{1-\frac{v^2}{c^2}}$

(c) $\frac{Q}{L\sqrt{1-\frac{v^2}{c^2}}}$ (d) $\frac{Q}{l\left(1-\frac{v^2}{c^2}\right)}$

5 The values of the electric and magnetic fields in a particular reference frame (in (Gaussian units) are $E=3x+4i$ and $B=3\mathrm{z}$, respectively. An inertial observer moving with respect to this frame measures the magnitude of the electric field to te $|\boldsymbol{E}'|=4$. The magnitude of the magnetic field $|\boldsymbol{B}|$ measured by him is

[NET June 2016]

(a) 5 (b) 9

(c) 0 (d) 1

6 In an inertial frame S, the magnetic vector potential in a region of space is given by $\vec{A}=az\hat{\imath}$ (where a is a constant) and the scalar potential is zero. The electric and magnetic fields seen by an inertial observer moving with a velocity $v\hat{\imath}$ with respect to S, are respectively. [In the following $\gamma=\frac{1}{\sqrt{1-v^2/c^2}}$].

[CSIR DEC 2017]

(a) 0 and $\gamma a\hat{\jmath}$ (b) $-va\hat{k}$ and $\gamma a\hat{\imath}$

(c) $r\gamma a\hat{k}$ and $r\gamma a\hat{\jmath}$ (d) $v\gamma a\hat{k}$ and $\gamma a\hat{\jmath}$

7 In the rest frame S_1 of a point particle with electric charge q_1, another point particle with electric charge q_2 moves with a speed v parallel to the x-axis at a perpendicular distance l. The magnitude of the electromagnetic force felt by q_1 due to q_2 when the distance between them is minimum, is [In the following $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$.

[CSIR DEC 2017]

(a) $\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{\gamma l^2}$ (b) $\frac{1}{4\pi\varepsilon_0}\frac{\gamma q_1 q_2}{l^2}$

(c) $\frac{1}{4\pi\varepsilon_0}\frac{\gamma q_1 q_2}{l^2}\left(1+\frac{v^2}{c^2}\right)$ (d) $\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{\gamma l^2}\left(1+\frac{v^2}{c^2}\right)$

8 In an inertial frame, uniform electric and magnetic fields $\vec{E}$ and $\vec{B}$ are perpendicular to each other and satisfy $|\vec{E}|^2 - |\vec{B}|^2 = 29$ (in suitable units). In another inertial frame, which moves at a constant velocity with respect to the first frame, the magnetic field is $2\sqrt{5}\hat{k}$. In the second trame, an electric field consistent with the previous observations is

[CSIR DEC 2018]

(a) $\frac{7}{\sqrt{2}}(\hat{\imath}+\hat{\jmath})$ (b) $7(\hat{\imath}+\hat{k})$

(c) $\frac{7}{\sqrt{2}}(\hat{\imath}+\hat{k})$ (d) $7(\hat{\imath}+\hat{\jmath})$

9 An inertial observer A at rest measures the electric and magnetic field $E = (\alpha, 0, 0)$ and $B = (\alpha, 0, 2\alpha)$ in 2 region, where α is a constant. Another inertial observer B, moving with a constant velocity with respect to A measures the field as $\mathrm{E}' = (E_1', \alpha, 0)$ and $\mathrm{B}' = (\alpha, B', \alpha)$. Then, in units $c = 1$, E, and B', are given, respectively, by

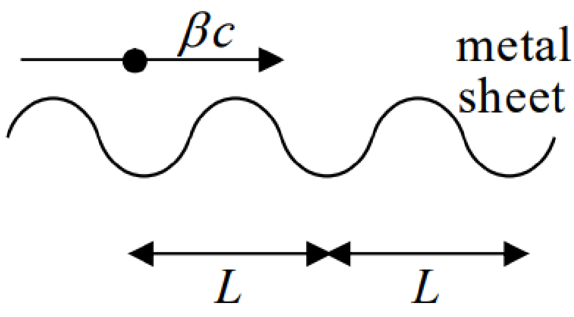
[NET June 2019]

(a) -2α and α (b) 2α and $-\alpha$

(c) α and -2α (d) $-a$ and 2α

10 A point charge is moving with a uniform velocity βc along the positive x-direction, parallel to and very *close to* a corrugated metal sheet (see the figure below).

[NET June 2019]



The wavelength electromagnetic radiation received by an observer along the direction of motion is

(a) $\frac{L}{\beta}\sqrt{1-\beta^2}$ (b) $L\cdot\sqrt{1-\beta^2}$

(c) $L\beta\sqrt{1-\beta^2}$ (d) L

11 The electric field due to a uniformly charged infinite line along the z-axis, as observed in the rest frame S of the line charge, is $\vec{E}(\vec{r}) = \frac{\lambda}{2\pi\epsilon_0}\frac{x\hat{\imath}+y\hat{\jmath}}{(x^2+y^2)}$. In a frame M moving with a constant speed v with respect to S along the z - direction, the electric field $\vec{E}'$ is (in the following $\beta = v/c$ and $\gamma = 1/\sqrt{1-\beta^2}$)

[CSIR JUNE 2020]

(a) $E_x' = E_x$ and $E_y' = E_y$

(b) $E_x' = \beta\gamma E_x$ and $E_y' = \beta\gamma E_y$

(c) $E_x' = E_x/\gamma$ and $E_y' = E_y/\gamma$

(d) $E_x' = \gamma E_x$ and $E_y' = \gamma E_y$

12 The charge density and current of an infinitely long perfectly conducting wire of radius a, which lies along the z-axis, as measured by a static observer are zero and a constant I, respectively. The charge density measured by an observer, who moves at a speed $v = \beta c$ parallel to the wire along the direction of the current, is

[CSIR JUNE 2023]

(a) $-\frac{I\beta}{\pi a^2 c\sqrt{1-\beta^2}}$ (b) $-\frac{I\beta\sqrt{1-\beta^2}}{\pi a^2 c}$

(c) $\frac{I\beta}{\pi a^2 c\sqrt{1-\beta^2}}$ (d) $\frac{I\beta\sqrt{1-\beta^2}}{\pi a^2 c}$

❖ GATE PYQ's

1. Which one of the following remains invariant under Lorentz transformations?

[GATE 2004]

(a) $\frac{\partial}{\partial x}+\frac{\partial}{\partial y}+\frac{\partial}{\partial z}-\frac{1}{c^2}\frac{\partial}{\partial t}$

(b) $\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}+\frac{1}{c^2}\frac{\partial^2}{\partial t^2}$

(c) $\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}-\frac{1}{c^2}\frac{\partial^2}{\partial t^2}$

(d) $\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}$

2. In an electromagnetic field, which one of the following remains invariant under Lorentz transformation?

[GATE 2006]

(a) $\vec{E}\times\vec{B}$ (b) $E^2-c^2B^2$

(c) B^2 (d) E^2

3. Which one of the following quantities is invariant under Lorentz transformation?

[GATE 2014]

(a) Charge density (b) Charge

(c) Current (d) Electric field A

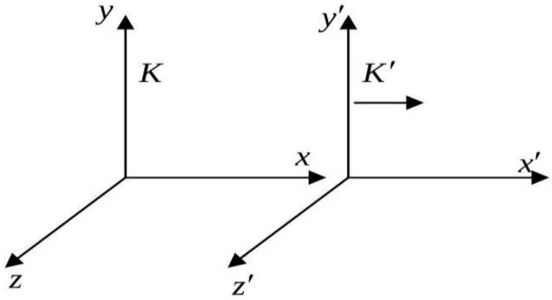
4. uniform magnetic field $\vec{B}=B_0\hat{y}$ exists in an internal frame K. A perfect conducting sphere moves with a constant velocity $\vec{v}=v_0\hat{x}$ with respect to this inertial frame. The rest frame of the sphere is K' (see figure). The electric and magnetic fields in K and K' are related as

$$\left.\begin{aligned}\vec{E}'_{\parallel}=\vec{E}_{\parallel}\quad \vec{E}'_{\perp}=\gamma(\vec{E}_{\perp}+\vec{v}\times\vec{B})\\ \vec{B}'_{\parallel}=\vec{B}_{\parallel}\quad \vec{B}'_{\perp}=\gamma\left(\vec{B}_{\perp}-\frac{\vec{v}}{c^2}\times\vec{E}\right)\end{aligned}\right\},$$

$$\gamma=\frac{1}{\sqrt{1-(v/c)^2}}$$

The induced surface charge density on the sphere (to the lowest order in v/c) in the frame K' is

[GATE 2020]



(a) maximum along z'

(b) maximum along y'

(c) maximum along x'

(d) uniform over the sphere

❖ JEST PYQ's

1. An observer in an inertial frame finds that at a point P the electric field vanishes but the magnetic field does not. This implies that in any other inertial frame the electric field $\vec{E}$ and the magnetic field $\vec{B}$ satisfy.

[JEST 2012]

(a) $|\vec{E}|^2=|\vec{B}|^2$ (b) $\vec{E}\times\vec{B}=0$

(c) $\vec{E}\cdot\vec{B}=0$ (d) $\vec{E}=0$

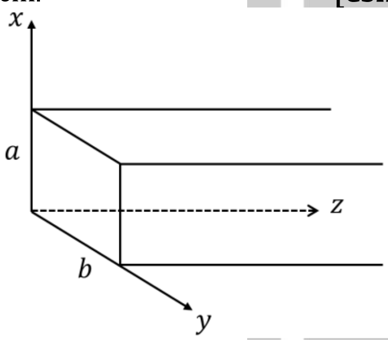
Answer Key				
CSIR PYQ				
1. d	2. b	3. b	4. c	5. c
6. d	7. b	8. a	9. d	10. *
11. d	12. a			
GATE PYQ				
1. c	2. b	3. b	4. a	
JEST PYQ				
1. c				

* No Answer matches

❖ EMT 12 : Waveguide , Transmission line

❖ CSIR-NET PYQ's

1. The magnetic field of the TE_{11} mode of a rectangular waveguide of dimensions a × b as shown in the figure is given by $H_z = H_0 \cos(0.3\pi x)\cos(0.4\pi y)$, where x and y are in cm. **[CSIR JUNE 2011]**



(A) The dimensions of the waveguide are

(a) $a = 3.33$ cm, $b = 2.50$ cm

(b) $a = 0.40$ cm, $b = 0.30$ cm

(c) $a = 0.80$ cm, $b = 0.60$ cm

(d) $a = 1.66$ cm, $b = 1.25$ cm

(B) The entire range of frequencies f for which the TE mode will propagate is: **[CSIR JUNE 2011]**

(a) $6.0\text{GHz} < f < 7.5\text{GHz}$

(b) $7.5\text{GHz} < f < 9.0\text{GHz}$

(c) $7.5\text{GHz} < f < 12.0\text{GHz}$

(d) $7.5\text{GHz} < f$

2. Consider a rectangular wave guide with transverse dimensions 2 m × 1 m driven with an angular frequency $\omega = 10^9$ rad/s. Which transverse electric (TE) modes will propagate in this wave guide? **[CSIR JUNE 2015]**

(a) TE_{10}, TE_{01} and TE_{20}

(b) TE_{10}, TE_{11} and TE_{20}

(c) TE_{01}, TE_{10} and TE_{11}^{20}

(d) TE_{01}, TE_{10} and TE_{2}

3. A wavelength has a square cross-section of side $2a$. For the TM modes of wavevector k, the transverse electromagnetic modes are obtained in terms of a function $\psi(x, y)$ which obeys the equation

$$\left[\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \left(\frac{\omega^2}{c^2} - k^2\right)\right]\psi(x, y) = 0$$

with the boundary condition $\psi(\pm a, y) = \psi(x, \pm a) = 0$. The frequency ω of the lowest mode is given by **[CSIR JUNE 2016]**

(a) $\omega^2 = c^2\left(k^2 + \frac{4\pi^2}{a^2}\right)$

(b) $\omega^2 = c^2\left(k^2 + \frac{\pi^2}{a^2}\right)$

(c) $\omega^2 = c^2\left(k^2 + \frac{\pi^2}{2a^2}\right)$

(d) $\omega^2 = c^2\left(k^2 + \frac{\pi^2}{4a^2}\right)$

4. A hollow waveguide supports transverse electric (TE) modes with the dispersion relation $k = \frac{1}{c}\sqrt{\omega^2 - \omega_{mn}^2}$, where ω_{mn} is the mode frequency. The speed of flow of electromagnetic energy at the mode frequency is **[CSIR JUNE 2018]**

(a) c (b) ω_{mn}/k

(c) 0 (d) ∞

5. A metallic wave guide of square cross-section of side L is excited by an electromagnetic wave of wave number k. The group velocity of the TE_{11} mode is

[CSIR DEC 2019]

(a) $\frac{ckL}{\sqrt{k^2L^2+\pi^2}}$ (b) $\frac{c}{kL}\sqrt{k^2L^2-2\pi^2}$

(c) $\frac{c}{kL}\sqrt{k^2L^2-\pi^2}$ (d) $\frac{ckL}{\sqrt{k^2L^2+2\pi^2}}$

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

[CSIR DEC 2023]

(a) $\frac{5}{7}$ (b) $\frac{1}{2}$

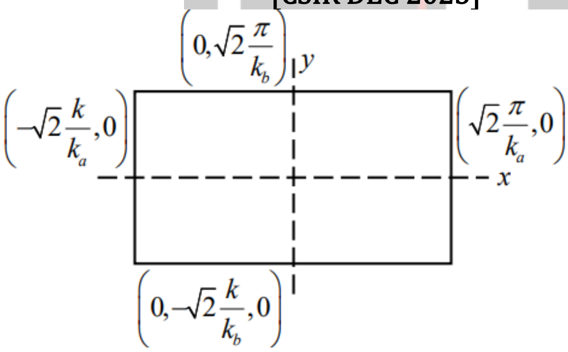
(c) $\frac{1}{6}$ (d) $\frac{1}{7}$

7. A 2-dimensional resonant cavity supports a TM mode built from a function

$$\psi(x,y,t)=\sin\left(\vec{k}_a\cdot\vec{r}-\omega t\right)+\sin\left(\vec{k}_b\cdot\vec{r}-\omega t\right)+\sin\left(\vec{k}_a\cdot\vec{r}+\omega t\right)+\sin\left(\vec{k}_b\cdot\vec{r}+\omega t\right)$$

where $\vec{k}_a$ and $\vec{k}_b$ lie in the xy-plane and make angles $\frac{\pi}{4}$ and $\frac{3\pi}{4}$ with the x-axis, respectively. If $0<|\vec{k}_a|<|\vec{k}_b|$, then which of the following closely describes the outline of the cavity?

[CSIR DEC 2023]

1.


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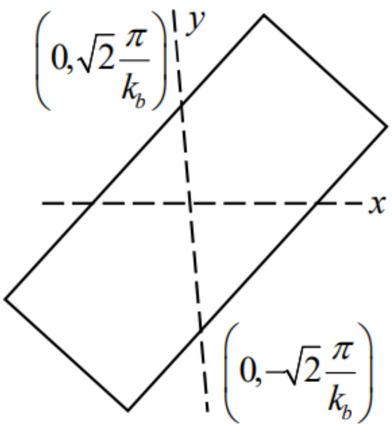

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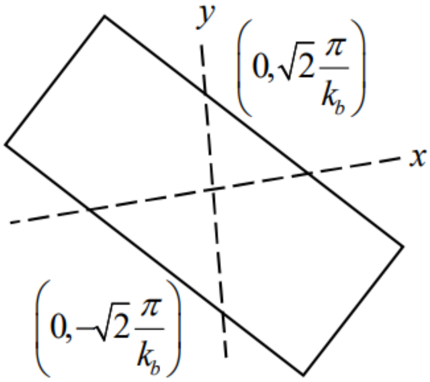
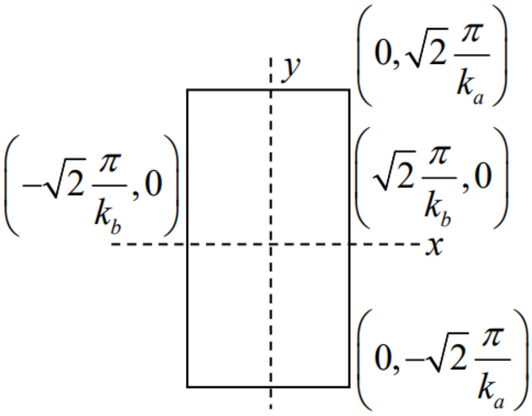


4.


❖ TIFR PYQ

1. For an electromagnetic wave propagating through a rectangular waveguide, the electric and magnetic fields **[TIFR 2023]**

(a) are never perpendicular to each other
(b) are always perpendicular to each other
(c) are perpendicular to each other only in the TE mode
(d) are perpendicular to each other only in the TM mode

Answer Key

CSIR PYQ				
1. a/d	2. a	3. c	4. c	5. d
6. c	7. d			
TIFR PYQ				
1. a				

❖ EMT 13 : Miscellaneous Topics

❖ CSIR-NET PYQ's

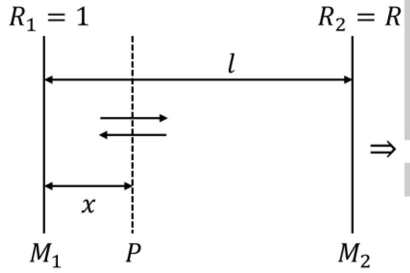
1. The components of a vector potential $A_\mu = (A_0, A_1, A_2, A_3)$ are given by $A_\mu = k(-xyz, yzt, zxt, xyt)$ where k is a constant. The three components of the electric field are

[CSIR JUNE 2013]

(a) k(yz, zx, xy)
(b) $k(x, y, z)$
(c) (0,0,0)
(d) k(xt, yt, zt)

2. Consider the laser resonator cavity shown in the figure. If I_1 is the intensity of the radiation at mirror M_1 and α is the gain coefficient of the medium between the mirrors, then the energy density of photons in the plane P at a distance x from M_1 is

[CSIR JUNE 2013]



(a) $(I_1/c)e^{-\alpha x}$
(b) $(I_1/c)e^{\alpha x}$
(c) $(I_1/c)(e^{\alpha x} + e^{-\alpha x})$
(d) $(I_1/c)e^{2\alpha x}$

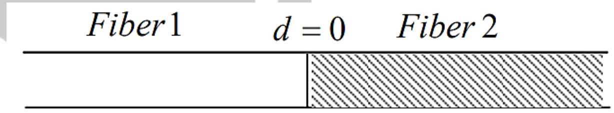
3. Two monochromatic sources, L_1, and L_2, emit light at 600 and 700 nm, respectively. If their frequency bandwidths are 10^{-1} and 10^{-3}GHz, respectively, then the ratio of linewidth of L_1 and L_2 is approximately

[CSIR DEC 2013]

(a) 100: 1
(b) 1: 85
(c) 75: 1
(d) 1: 75

4. A laser beam propagates from fiber 1 to fiber 2 in a cavity made up of two optical fibers (as shown in the figure). The loss factor of fiber 2 is $\frac{10\text{ dB}}{\text{km}}$.

[NET June 2021]



If $E_2(d)$ denotes the magnitude of the electric field in fiber 2 at a distance d from the interface, the ratio $\frac{E_2(0)}{E_2(d)}$ for $d = 10$ km, is

(a) 10^2
(b) 10^3
(c) 10^5
(d) 10^7

5. The components of the electric field, in a region of space devoid of any charge or current sources, are given to be $E_i = a_i + \sum_{j=1,2,3} b_{ij} x_j$, where a_i and b_{ij} are constants independent of the coordinates. The number of independent components of the matrix b_{ij} is

[CSIR JUNE 2021]

(a) 5
(b) 6
(c) 3
(d) 4

6. Electrons polarized along the x-direction are in a magnetic field

$$B_1\hat{\imath} + B_2(\cos\,\omega t\hat{\jmath} + \sin\,\omega t\hat{k})$$

where $B_1 > B_2$ and ω are positive constants. The value of $\hbar\omega$ for which the polarization-flip process is a resonant one, is

[CSIR JUNE 2023]

(a) $2\mu_B|B_2|$
(b) $\mu_B|B_1|$
(c) $\mu_B|B_2|$
(d) $2\mu_B|B_1|$

❖ GATE PYQ's

1. A circular conducting loop C_1 of radius 2 m is located in the XOY plane such that its centre is at (0,0,0). Another circular conducting loop C_2 of radius 2 m is located at (0,0,4) such that the plane of C_2 is parallel to the XOY plane. A current of 5 A is flowing in each of these loops such that the positive Z-axis lies to the left of the directions of the currents. Find the magnetic induction $\vec{B}$ produced at (0,0,0), neglecting the mutual induction of the loops in μT.

[GATE 2001]

2. An electron propagating along the x-axis passes through a slit of width $\Delta y = 1$ nm. The uncertainty in the y-component of its velocity after passing through the slit is

[GATE 2002]

(a) 7.322×10^5 m/s (b) 1.166×10^5 m/s

(c) 3.436×10^5 m/s (d) 2.326×10^4 m/s

3. A charged capacitor (C) is connected in series with an inductor (L). When the displacement current reduces to zero, the energy of the LC circuit is

[GATE 2007]

(a) stored entirely in its magnetic field

(b) stored entirely in its electric field

(c) distributed equally among its electric and magnetic fields

(d) radiated out of the circuit

4. Match the following

P. rest mass	1. time like vector
Q. charge	2. Lorentz invariant
R. four-momentum	3. tensor of rank 2
S. electromagnetic field	4. conserved and Lorentz invariant

[GATE 2007]

(a)	(b)	(c)	(d)
P-2	P-4	P-2	P-4
Q-4	Q-2	Q-4	Q-2
R-3	R-1	R-1	R-3
S-1	S-3	S-3	S-1

5. Consider the operations $P: \vec{r} \to \vec{r}$ (parity) and $T: t \to -t$ (time-reversal). For the electric and magnetic fields $\bar{E}$ and $\bar{B}$, which of the following set of transformations is correct?

[GATE 2010]

(a) $P: \vec{E} \to -\vec{E}, \vec{B} \to \vec{B}$
$T: \vec{E} \to \vec{E}, \vec{B} \to -\vec{B}$

(b) $P: \vec{E} \to -\vec{E}, \vec{B} \to \vec{B}$
$P: \vec{E} \to \vec{E}, \vec{B} \to -\vec{B}$

(c) $P: \vec{E} \to -\vec{E}, \vec{B} \to \vec{B};$
$T: \vec{E} \to -\vec{E}, \vec{B} \to -\vec{B}$

(d) $P: \vec{E} \to \vec{E}, \vec{B} \to -\vec{B}$
$T: \vec{E} \to -\vec{E}, \vec{B} \to \vec{B}$

6. Among electric field ($\vec{E}$), magnetic field ($\vec{B}$), angular momentum ($\vec{L}$) and vector potential ($\vec{A}$), which is/are odd under parity (space inversion) operation?

[GATE 2018]

(a) $\vec{E}$ only (b) $\vec{E}$ and $\vec{A}$ only

(c) $\vec{E}$ and $\vec{B}$ only (d) $\vec{B}$ and $\vec{L}$ only

7. The number of independent components of a general electromagnetic field tensor is

[GATE 2018]

8. If $\vec{E}$ and $\vec{B}$ are the electric and magnetic fields respectively, then $\vec{E} \cdot \vec{B}$ is **[GATE 2020]**

(a) odd under parity and even under time reversal

(b) even under parity and odd under time reversal

(c) odd under parity and odd under time reversal

(d) even under parity and even under time reversal

9. An electromagnetic pulse has a pulse width of 10^{-3} s. The uncertainty in the momentum of the corresponding photon is of the order of 10^{-N} kg m s^{-1}, where N is an integer. The value of N is [Speed of light $= 3 \times 10^{8}$ m s^{-1}, $h = 6.6 \times 10^{-34}$ J s] **[GATE 2022]**

10. A spectrometer is used to detect plasma oscillations in a simple. The spectrometer can work in the range of 3×10^{12}rads^{-1} to 30×10^{12}rads^{-1}. The minimum carrier concentration that can be detected by using this spectrometer is $n \times 10^{21}$ m^{-3}. The value of n is . (Round off to two decimal places) **[GATE 2022]**

[Charge of an electron $= -1.6 \times 10^{-1}$C, massof an electron $= 9.1 \times 10^{-31}$ kg and $\varepsilon_0 = 8.85 \times 10^{-12}$C^2 N^{-1} m^{-2}]

11. Under parity and time reversal transformations, which of the following statements is (are) TRUE about the electric dipole moment $\vec{p}$ and the magnetic dipole moment $\vec{\mu}$? **[GATE 2023]**

(a) $\vec{p}$ is odd under parity and $\vec{\mu}$ is odd under time reversal

(b) $\vec{p}$ is odd under parity and $\vec{\mu}$ is even under time reversal

(c) $\vec{p}$ is even under parity and $\vec{\mu}$ is odd under time reversal

(d) $\vec{p}$ is even under parity and $\vec{\mu}$ is even under time reversal

❖ JEST PYQ

1. The equation describing the shape of a curved mirror with the property that the light from a point source at the origin will be reflected in a beam of rays parallel to the x-axis is (with a as some constant) **[JEST 2013]**

(a) $y^2 = ax + a^2$ (b) $2y = x^2 + a^2$

(c) $y^2 = 2ax + a^2$ (d) $y^2 = ax^3 + 2a^2$

2. Assume the earth to be an uniform sphere of radius 6400 km and having a uniform electric permittivity of 8.85×10^{-12}Farad/m. What would be the self capacitance (in micro-Farads) of the earth? Round off your answer to the nearest integer. **[JEST 2021]**

Answer Key				
CSIR-NET PYQ				
1. c	2. c	3. c	4. c	5. a
6. d				
GATE PYQ				
1. 1.7	2. b	3. b	4. c	5. a
6. b	7. 6	8. c	9. 39 to 40	10. 2.70 to 2.96
11. a				
JEST PYQ				
1. c	2. 0712			

❖ EMT 14 : Optics

INTEREREFERENCE & DIFRACTION

❖ CSIR-NET PYQ's

1. In a Young's double slit interference experiment, the slits are at a distance 2 L from each other and the screen is at a distance D from the slits. If a glass slab of refractive index μ and thickness d is placed in the path of one of the beams, the minimum value of d for the central fringe to be dark is

[CSIR DEC 2011]

(a) $\frac{\lambda D}{(\mu-1)\sqrt{D^2+L^2}}$ (b) $\frac{\lambda D}{(\mu-1)L}$

(c) $\frac{\lambda}{(\mu-1)}$ (d) $\frac{\lambda}{2(\mu-1)}$

2. Consider the interference of two coherent electromagnetic waves whose electric field vectors are given by $\vec{E}_1 = \hat{\imath}E_0\cos\,\omega t$ and $\vec{E}_2 = \hat{\jmath}E_0\cos\,(\omega t+\varphi)$ where φ is the phase difference. The intensity of the resulting wave is given by $\frac{\varepsilon_0}{2}\langle E^2\rangle$, where $\langle E^2\rangle$ is the time average of E^2. The total intensity is

[CSIR DEC 2012]

(a) 0 (b) $\varepsilon_0 E_0^2$

(c) $\varepsilon_0 E_0^2\sin^2\,\varphi$ (d) $\varepsilon_0 E_0^2\cos^2\,\varphi$

3. A double slit interference experiment uses a laser emitting light of two adjacent frequencies v_1 and v_2 $(v_1 < v_2)$. The minimum path difference between the interfering beams for which the interference pattern disappears is

[CSIR JUNE 2014]

(a) $\frac{c}{v_2+v_1}$ (b) $\frac{c}{v_2-v_1}$

(c) $\frac{c}{2(v_2-v_1)}$ (d) $\frac{c}{2(v_2+v_1)}$

4. A parallel beam of light of wavelength λ is incident normally on a thin polymer film with air on both sides. If the film has a refractive index $n > 1$, then second-order bright fringes can be observed in reflection when the thickness of the film is

[CSIR DEC 2014]

(a) $\lambda/4n$ (b) $\lambda/2n$

(c) $3\lambda/4n$ (d) λ/n

5. A plane electromagnetic wave incident normally on the surface of a material is partially reflected. Measurements on the standing wave in the region in front of the interface show that the ratio of the electric field amplitude at the maxima and the minima is 5. The ratio of the reflected intensity to the incident intensity is

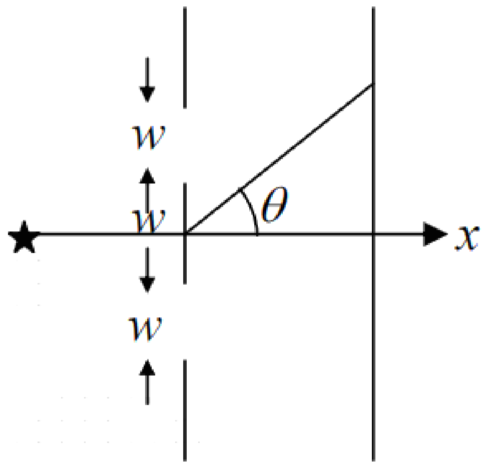
[CSIR DEC 2014]

(a) 4/9 (b) 2/3

(c) 2/5 (d) 1/5

6. A screen has two slits, each of width w, with their centres at a distance $2w$ apart. It is illuminated by a monochromatic plane wave travelling along the x-axis. The intensity of the interference pattern, measured on a distant screen, at an angle $\theta = n\lambda/w$ to the x axis is

[CSIR DEC 2016]



(a) zero for $n = 1,2,3 \ldots$

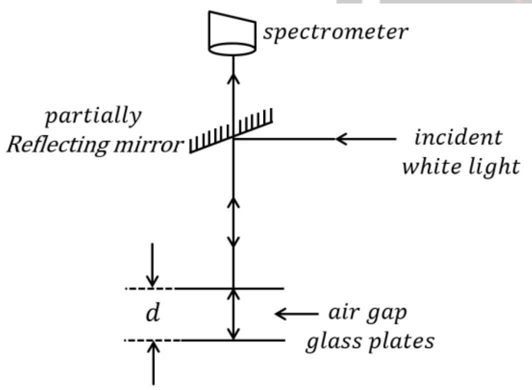
(b) maximum for $n = 1,2,3 \ldots$

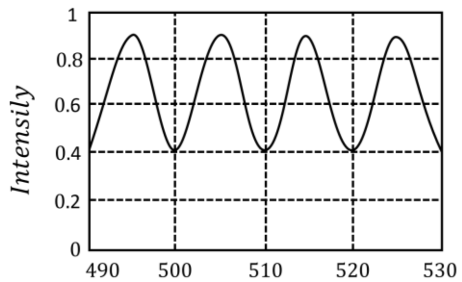
(c) maximum for $n = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$

(d) zero for $n = 0$ only

7. A pair of parallel glass plates separated by a distance d is illuminated by white light as shown in the figure below. Also shown is the graph of the intensity of the reflected light light I as a function of the wavelength λ recorded by a spectrometer.

[CSIR DEC 2016]





Assuming that the interference takes place only between light reflected by the bottom surface of the top plate and the top surface of bottom plate, the distance d is closest to

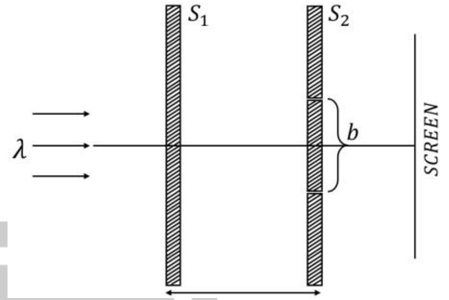
[CSIR DEC 2016]

(a) $12\mu m$ (b) $24\mu m$

(c) $60\mu m$ (d) $120\mu m$

8. The figure below describes the arrangement of slits and screens in a Young's double slit experiment. The width of the slit in S_1 is a and the slits in S_2 are of negligible width.

[CSIR JUNE 2017]



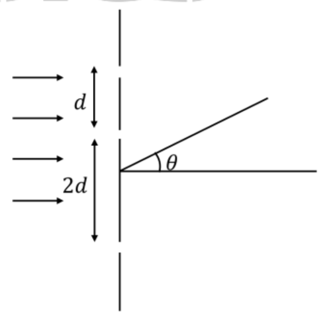
If the wavelength of the light is λ, the value of d for which the screen would be dark is

(a) $b\sqrt{\left(\frac{a}{\lambda}\right)^2 - 1}$ (b) $\frac{b}{2}\sqrt{\left(\frac{a}{\lambda}\right)^2 - 1}$

(c) $\frac{a}{2}\left(\frac{b}{\lambda}\right)^2$ (d) $\frac{ab}{\lambda}$

9. The following configuration of three identical narrow slits are illuminated by monochromatic light of wavelength λ (as shown in the figure below). The intensity is measured at angle θ (where θ is the angle with the incident beam) at a large distance from the slits. If $\delta = \frac{2\pi d}{2} \sin\theta$, the intensity is proportional to

[CSIR JUNE 2018]



(a) $2\cos\delta + 2\cos 2\delta$

(b) $3 + \frac{1}{8^2}\sin^2 3\delta$

(c) $3 + 2\cos\delta + 2\cos 2\delta + 2\cos 3\delta$

(d) $2 + \frac{1}{\delta^2}\sin^2 3\delta$

10. A monochromatic and linearly polarized light is used in a Young's double slit experiment. A linear polarizer, whose pass axis is at an angle 45° to the polarization of the incident wave, is placed in front of one of the slits. If $I_{\max}$ and $I_{\min}$, respectively, denote the maximum and minimum intensities of the interference pattern on the screen, the visibility, defined as the ratio $\frac{I_{\max}-I_{\min}}{I_{\max}+I_{\min}}$, is

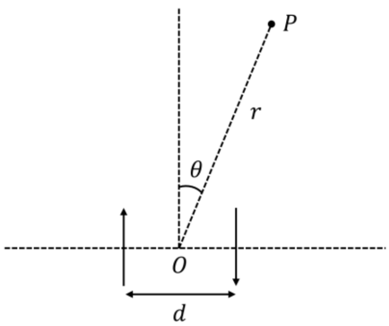
[CSIR DEC 2018]

(a) $\frac{\sqrt{2}}{3}$ (b) $\frac{2}{3}$

(c) $\frac{2\sqrt{2}}{3}$ (d) $\sqrt{\frac{2}{3}}$

11. The phase difference between two small oscillating electric dipoles, separated by a distance d, is π. If the wavelength of the radiation is λ, the condition for constructive interference between the two dipolar radiations at a point P when $r \gg d$ (symbols are as shown in the figure, and n is an integer) is

[CSIR DEC 2019]



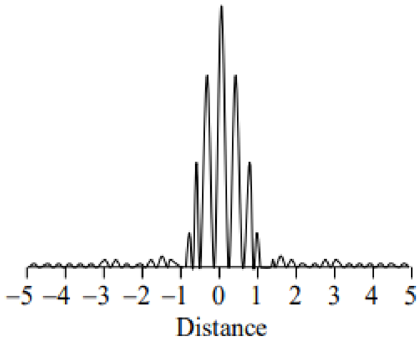
(a) $d\sin\,\theta = \left(n+\frac{1}{2}\right)\lambda$ (b) $d\sin\,\theta = n\lambda$

(c) $d\cos\,\theta = n\lambda$ (d) $d\cos\,\theta = \left(n+\frac{1}{2}\right)\lambda$

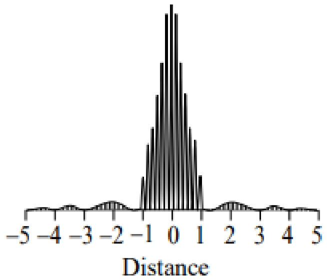
12. The following figure shows the intensity of the interference pattern in the Young's double-slit experiment with two slits of equal width is observed on a distant screen

If the separation between the slits is doubled and the width of each of the slits is halved, then the new interference pattern is best represented be

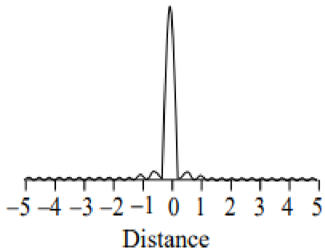
[CSIR JUNE 2020]



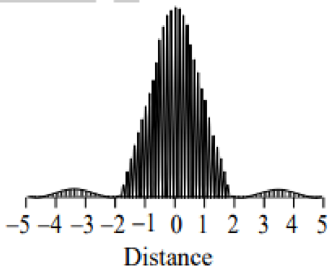
(a)



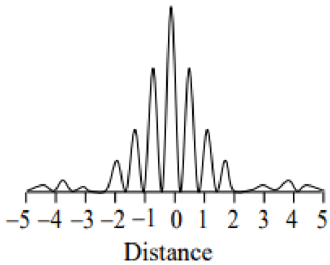
(c)



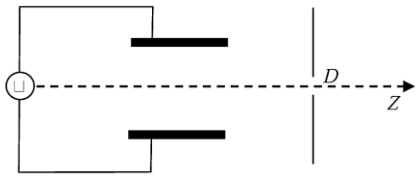
(b)



(d)

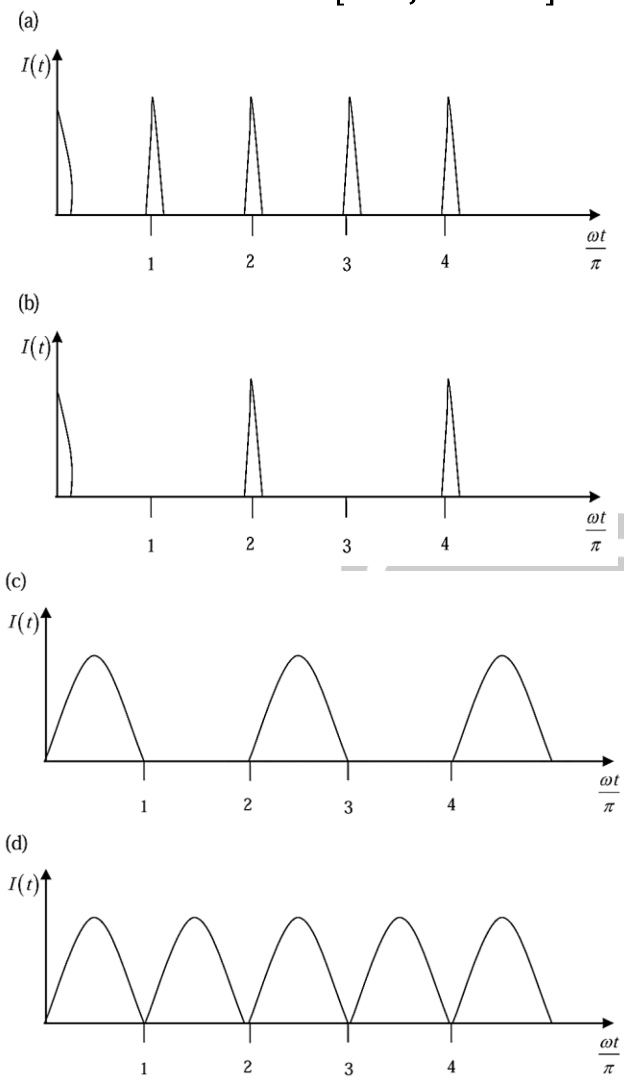


13. A high frequency voltage signal $V_i = V_m \sin\,\omega t$ is applied to a parallel plate deflector as shown in the figure



An electron beam is passing through the deflector along the central line. The best qualitative representation of the intensity I(t) of the beam after it goes through the narrow circular aperture D, is

[CSIR JUNE 2022]



14. A charged particle moves uniformly on the xy-plane along a circle of radius a centred at the origin. A detector is put at a distance d on the x-axis to detect the electromagnetic wave radiated by the particle along the x-direction. If $d >> a$, the wave received by the detector is

[CSIR JUNE 2023]

(a)Unpolarized

(b)Circularly polarized with the plane of polarization being the yz-plane

(c)Linearly polarized along the y-direction

(d)Linearly polarized along the z-direction

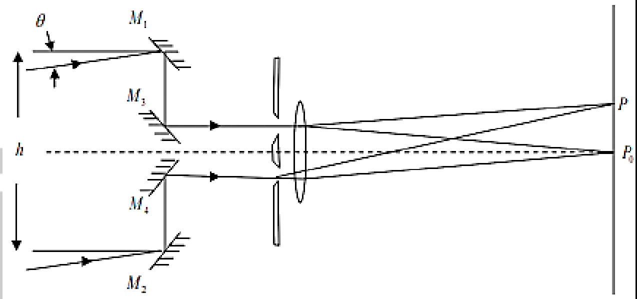
15. The angular width θ of a distant star can be measured by the Michelson radiofrequency stellar interferometer (as shown in the figure below).

The distance h between the reflectors M_1 and M_2 (assumed to be much larger than the aperture of the lens), is increased till the interference fringes (at P_0, P on the plane as shown) vanish for the first time. This happens for $h = 3$ m for a star which emits radiowaves of wavelength 2.7 cm. The measured value of θ (in degrees) is closest to

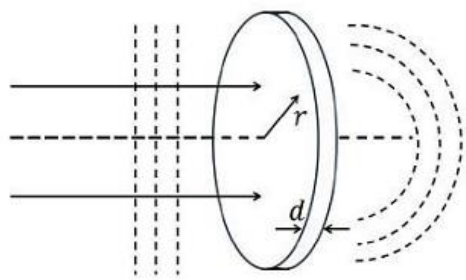
[CSIR JUNE 2023]

(a)0.63 (b)0.32

(c)0.52 (d)0.26



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



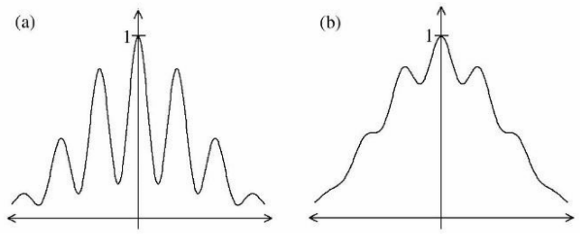
If the emergent wavefront is spherical and centered on the axis of the plate, the $n(r) - n(0)$ should be proportional to

[CSIR DEC 2023]

(a)$r^{1/2}$ (b)r

(c)r^2 (d)$r^{3/2}$

17. A finite sized light source is used in a double slit experiment. The observed intensity pattern changes from figure (a) to figure (b), as shown below. **[CSIR JUNE 2024]**



The observed change can occur due to
(a)narrowing of the slits.

(b)a reduction in the distance between the slits.

(c)a decrease in the coherence length of the light source.

(d)a reduction in the size of the light source.

❖ GATE PYQ's

1. In a two beam interference pattern, the maximum and minimum intensity values are found to be $25I_0$ and $9I_0$ respectively, where I_0 is a constant. The intensities of the two interfering beams are

[GATE 2002]

(a) $16I_0$ and I_0 (b) $5I_0$ and $3I_0$

(c) $17I_0$ and $8I_0$ (d) $8I_0$ and $2I_0$

2. A parallel beam of infrared radiation of wavelength of 1.01×10^{-6} m is incident normally on a screen with two slits 5×10^{-6} m apart and the resulting interference pattern is observed on a distant screen. What is the largest number of maxima that can be observed on the screen?

[GATE 2003]

(a) 4 (b) 9

(c) 13 (d) infinitely many

3. A parallel beam of electrons of a given momentum pass through a screen S_1 containing a slit and then produces a diffraction pattern on a screen S_2 placed behind it. The width of the central maximum observed on the screen S_2 can be increased by

[GATE 2003]

(a) decreasing the distance between the screens S_1 and S_2

(b) increasing the width of the slit in screen S_1

(c) decreasing the momentum of the electrons

(d) increasing the momentum of the electrons

4. A Michelson interferometer is illuminated with monochromatic light. When one of the mirrors is moved through a distance of 25.3μm, 92 fringes pass through the cross-wire. The wavelength of the monochromatic light is

[GATE 2004]

(a) 500 nm (b) 550 nm

(c) 600 nm (d) 650 nm

5. A monochromatic plane wave at oblique incidence undergoes reflection at a dielectric interface. If $\hat{k}_i$, $\hat{k}_r$ and $\hat{n}$ are the unit vectors in the directions of incident wave, reflected wave and the normal to the surface respectively, which one of the following expressions is correct?

[GATE 2013]

(a) $(\hat{k}_i - \hat{k}_r) \times \hat{n} \neq 0$ (b) $(\hat{k}_i - \hat{k}_r) \cdot \hat{n} = 0$

(c) $(\hat{k}_i \times \hat{n}) \cdot \hat{k}_r = 0$ (d) $(\hat{k}_i \times \hat{n}) \cdot \hat{k}_r \neq 0$

6. In a Young's double slit experiment using light; the apparatus has two slits of unequal widths. When only slit-1 is open, the maximum observed intensity on the screen is $4I_0$. When only slit-2 is open, the maximum observed intensity is I_0. When both the slits are open, an interference pattern appears on the screen. The ratio of the intensity of the principal maximum to that of the nearest minimum is______________.

[GATE 2016]

7. A student sets up Young's double slit experiment with electrons of momentum p incident normally on the slits of width w separated by distance d. In order to observe interference fringes on a screen at a distance D from the slits, which of the following conditions should be satisfied?

[GATE 2022]

(a) $\frac{\hbar}{p} > \frac{Dw}{d}$ (b) $\frac{\hbar}{p} > \frac{dw}{D}$

(c) $\frac{\hbar}{p} > \frac{d^2}{D}$ (d) $\frac{\hbar}{p} > \frac{d^2}{\sqrt{Dw}}$

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

[GATE 2023]

(a) 5 (b) 6

(c) 7 (d) 8

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

[GATE 2023]

(a) $\frac{n^2-4}{4n^2}$ (b) $\frac{n^2+4}{4n^2}$

(c) $\frac{4n^2}{n^2-4}$ (d) $\frac{4n^2}{n^2+4}$

10. An unpolarized plane electromagnetic wave in a dielectric medium 1 is incident on a plane interface that separates medium 1 from another dielectric medium 2. Medium 1 and medium 2 have refractive indices n_1 and n_2, respectively, with $n_2 > n_1$. If the angle of incidence is $\tan^{-1}\left(\frac{n_2}{n_1}\right)$, which one of the following statements is true?

[GATE 2024]

(a) There is no transmitted wave

(b)The reflected wave is polarized perpendicular to the plane of incidence

(c)The reflected wave is polarized parallel to the plane of incidence

(d) The reflected wave is unpolarized

❖ JEST PYQ's

1. For an optical fiber with core and cladding index of $n_1 = 1.45$ and $n_2 = 1.44$, respectively, what is the approximate cut-off angle of incidence? Cut-off angle of incidence is defined as the incidence angle below which light will be guided.

[JEST 2014]

(a) 7° (b) 22°

(c) 5° (d) 0°

2. The resolving power of a grating spectrograph can be improved by **[JEST 2014]**

(a) recording the spectrum in the lowest order

(b) using a grating with longer grating period

(c) masking a part of the grating surface.

(d) illuminating the grating to the maximum possible extent.

3. Three sinusoidal waves have the same frequency with amplitude $A, A/2$ and $A/3$ while their phase angles are $0, \pi/2$ and π respectively. The amplitude of the resultant wave is

[JEST 2014]

(a) 11 A/6 (b) 2 A/3

(c) 5 A/6 (d) 7 A/6

4. A thin air film of thickness d is formed in a glass medium. For normal incidence, the condition for constructive interference in the reflected beam is (in terms of wavelength λ and integer $m = 0,1,2, \ldots$)

[JEST 2017]

(a) $2d = (m - 1/2)\lambda$ (b) $2d = m\lambda$

(c) $2d = (m - 1)\lambda$ (d) $2\lambda = (m - 1/2)d$

5. A collimated white light source illuminates the slits of a double slit interference setup and forms the interference pattern on a screen. If one slit is covered with a blue filter, which one of the following statements is correct?

[JEST 2019]

(a) No interference pattern is observed after the slit is covered with the blue filter

(b) Interference pattern remains unchanged with and without the blue filter

(c) A blue interference pattern is observed

(d) The central maximum is blue with colored higher order maxima

6. The refractive index (n) of the entire environment around a double slit interference setup is changed from $n = 1$ to $n = 2$. Which one of the following statements is correct about the change in the interference pattern?

[JEST 2019]

(a) The fringe pattern disappears

(b) The central bright maximum turns dark, i.e. becomes a minimum

(c) Fringe width of the pattern increases by a factor 2

(d) Fringe width of the pattern decreases by a factor 2

7. In the Young's double slit experiment (screen distance $D = 50$ cm and $d = 0.1$ cm), a thin mica sheet of refractive index $n = 1.5$ is introduced in the path of one of the beams. If the central fringe gets shifted by 0.2 , what is the thickness (in micrometer) of the mica sheet?

[JEST 2019]

8. A thin film of water having refractive index $n = 1.333$ floats on the surface of a beaker of silicone oil having refractive index $n_s = 1.40$. The arrangement is illuminated by 600 nm light incident normally from top and a large region of the film appears bright red. What is the minimum possible thickness of the film (in nm)?

[JEST 2020]

9. A glass of radius R and refractive index n acts like a lens with focal length

[JEST 2021]

(a) $-\frac{nR}{2(n-1)}$ (b) $+\frac{nR}{2(n-1)^2}$

(c) $-\frac{nR}{2(n-1)^2}$ (d) $+\frac{nR}{2(n-1)^2}$

10. A flat soap film has a uniform thickness of 510 nm. White light (having wavelengths in the range of about $390 - 700$ nm) is incident normally on the film. If the refractive index of the soap is 1.33, what will be the dominant colour of the reflected light?

[JEST 2021]

(a) Violet (b) Green

(c) Red (d) White

11. A thin film surrounded by air has an index of refraction of 1.4. A region of the film appears bright blue ($\lambda = 400$ nm) when white light is incident perpendicular to the surface. What might be the minimum thickness of the film?

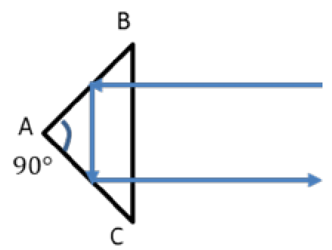
[JEST 2022]

(a) 70 nm (b) 280 nm

(c) 420 nm (d) 140 nm

12. A right-angled prism is placed in air (the refractive index of air is 1) and a light beam is incident perpendicular to the base of the prism as shown in the figure. In order to get the light beam totally reflected, the minimum value of the refractive index of the prism should be

[JEST 2023]

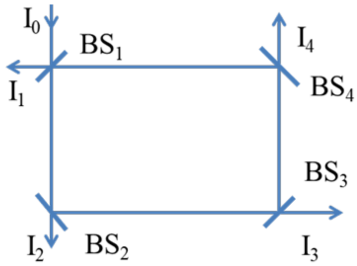


(a) 1 (b) $\frac{\sqrt{3}}{2}$

(c) $\frac{\pi}{2}$ (d) $\sqrt{2}$

13. A beam of light of intensity $I_0 = 120\ \mathrm{W/m^2}$ is incident on the optical system shown in the figure. BS_1, BS_2, BS_3, and BS_4 are ideal, 50/50 beamsplitters (reflects 50% and transmits 50% of incident light intensity). I_1, I_2, I_3, and I_4 are the total intensities measured by detectors. What will be the intensity I_3 ?

[JEST 2023]

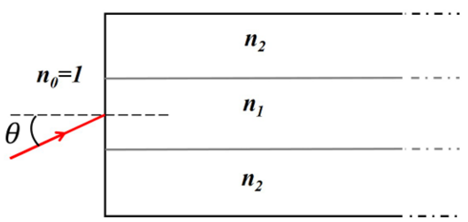


(a) $32\ \mathrm{W/m^2}$ (b) $20\ \mathrm{W/m^2}$

(c) $16\ \mathrm{W/m^2}$ (d) $12\ \mathrm{W/m^2}$

14. A step index optical fiber has refractive indices $n_1 = 1.474$ for core region and $n_2 = 1.470$ for the cladding region. A ray of light is incident from air into the core through the cross section of the fiber at an angle θ with the normal. What is the limiting value of θ below which the light ray will be totally internally reflected? Refractive index of air is taken as 1 .

[JEST 2024]



(a) 6.229° (b) 58.194°

(c) 2.862° (d) 4.222°

15. An object of height 10 mm is located 150 mm to the left of a thin lens of focal length +50 mm. A second thin lens of focal length −100 mm is to be placed to the right of the first lens such that the real image of the object is located 100 mm to the right of the second lens. What should be the separation in mm between the two lenses?

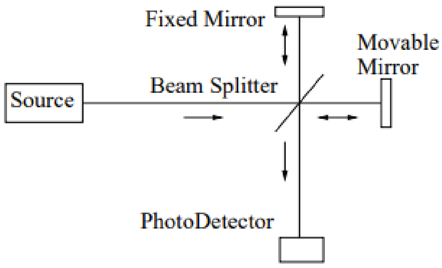
❖ **TIFR PYQ**

1. A narrow beam of light of wavelength 589.3 nm from a sodium lamp is incident normally on a diffraction grating of transmission type. If the grating constant is $1000000\ \mathrm{m^{-1}}$, the number of principal maxima observed in the transmitted light will be **[TIFR 2011]**

(a) 7 (b) 5

(c) 3 (d) 1

2. The Michelson interferometer in the figure below can be used to study properties of light emitted by distant sources.



A Source S_1, when at rest, is known to emit light of wavelength 632.8 nm. In this case, if the Movable Mirror is translated through a distance d, it is seen that 99,565 interference fringes pass across the Photo-Detector. For another Source S_2, moving at an uniform speed of $1.5 \times 10^7\ \mathrm{m\,s^{-1}}$ towards the interferometer along the straight line joining it to the Beam Splitter, one sees 100,068 interference fringes pass across the Photo-Detector for the same displacement d of the Movable Mirror. It follows that S_2, in its own rest frame, must be emitting light of wavelength

[TIFR 2011]

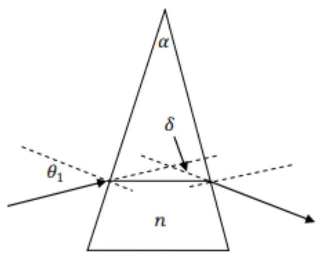
(a) 661.9 nm (b) 662.8 nm

(c) 598.9 nm (d) 631.2 nm

(e) 599.6 nm (f) 628.0 nm

3. A ray of light is incident on the surface of a thin prism at a small angle θ_1 with the normal, as shown in the figure on the right. The material of the prism has refractive index n and you may assume the outside refractive index to be unity. If the (small) apex angle of the prism is α, the deviation angle δ (angle between the incident and exited ray; see figure) is given by

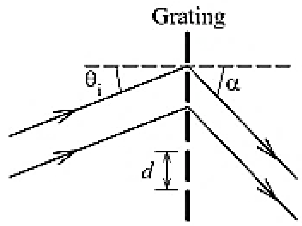
[TIFR 2013]



(a) α (b) αn

(c) $\alpha(n+1)$ (d) $\alpha(n-1)$

4. A parallel beam of light of wavelength λ is incident on a transmission grating with



groove spacing d, at an angle θ_i, as shown in the figure on the left. The plane of incidence is normal to the grooves. After diffraction, the transmitted beam is seen to be at an angle α relative to the normal. Which of the following conditions must be satisfied for this to happen?

[TIFR 2013]

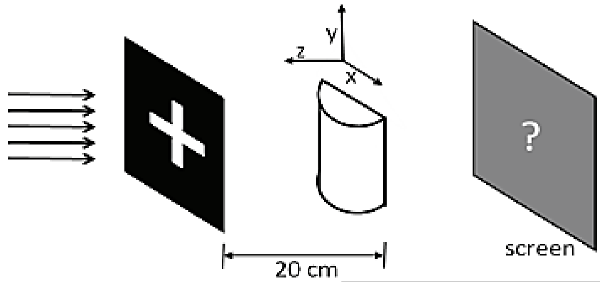
(a) $d(\sin\ \theta_i - \sin\ \alpha) = n\lambda$

(b) $d(\sin\ \theta_i + \sin\ \alpha) = n\lambda$

(c) $2d\sin\ (\theta_i - \alpha) = n\lambda$

(d) $2d\sin\ (\alpha + \theta_i) = n\lambda$

5. A cross-shaped opening is illuminated by a parallel beam of white light. A thin plano-convex cylindrical glass lens is placed 20 cm in front of it, as shown in the figure below.



The radius of curvature of the curved surface of the lens is 5 cm and 1.5 is the refractive index of glass. On a screen placed as shown at the plane where a real image forms on the other side of the lens, the image of the opening will appear as

[TIFR 2013]

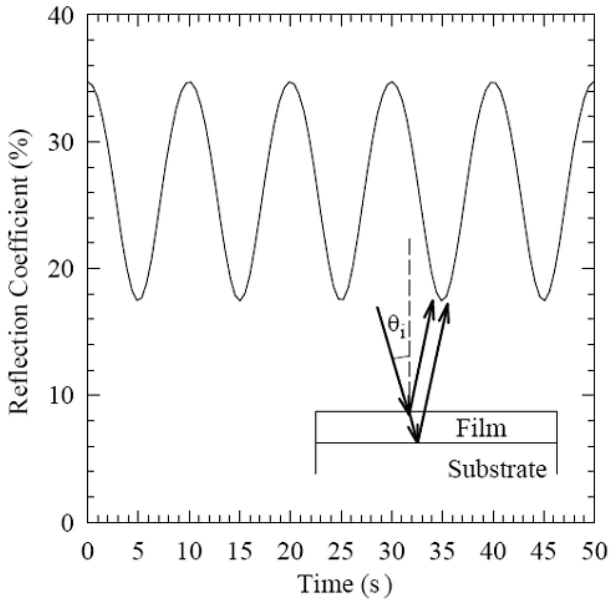
(a) 

(c) 

(b) 

(d) 

6. The rate of deposition of a dielectric thin film on a thick dielectric substrate was monitored by the following experiment: a laser beam of wavelength $\lambda = 633$ nm, at nearnormal incidence θ_i, was reflected from the thin film (see inset figure on the right), and the reflection coefficient R was measured. As the film thickness increased R varied with time as shown on the



right. The refractive index of the film is 3.07 and is less than that of the substrate. Using the graph, the approximate thickness of the film at the end of 25 seconds can be estimated to be

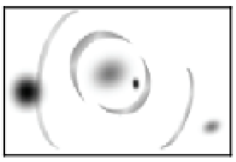
[TIFR 2013]

(a) 0.017μm (b) 0.26μm

(c) 0.51μm (d) 2.2μm

7. The negative image on the right represents a very small portion of the night sky at a very high resolution. Notice the broken ring(s) around the central bright object in the middle of the picture. These are most likely to be due to

[TIFR 2013]



(a) debris from a smaller object torn apart by tidal forces

(b) gas clouds forming the remnant of a supernova explosion

(c) ice collected on the lens used for taking the picture

(d) gravitational lensing of a distant object by the central massive object

8. Two telescopes X and Y have identical objective lenses, but the single-lens eyepiece of X is converging whereas the single-lens eyepiece of Y is diverging. If the magnification M of these two telescopes for objects at infinity is the same, the lengths L_X and L_Y of the two telescopes (length of a telescope is defined as the distance between the objective lens and the eyepiece) must be in the ratio $L_X/L_Y =$

[TIFR 2014]

(a) $\frac{2M+1}{2M-1}$ (a) $\frac{2M-1}{M+1}$

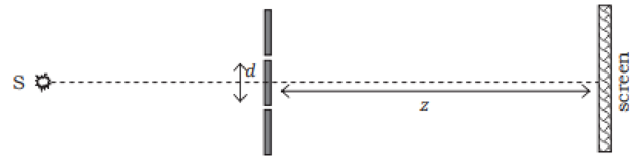
(c) $\frac{M+1}{M-1}$ (d) $\frac{M-1}{M+1}$

9. A lens can be constructed using a flat circular glass plate whose refractive index n varies radially, i.e. $n = n(r)$, where r is the radial distance from the centre of the plate. In order to make a convex lens by this method $n(r)$ should vary (in terms of positive constants $n(0)$ and α) as **[TIFR 2014]**

(a) $n(0) - \alpha/r^2$ (b) $n(0) - \alpha/r$

(c) $n(0) - \alpha r$ (d) $n(0) - \alpha r^2$

10. In a laboratory, the double-slit experiment is performed with free nonrelativistic electrons, each having energy E, emitted from a source S (see figure below). The screen consists of a uniform sheet of charge-sensitive pixels of size r. If the slit-screen distance is z and the spacing between slits is d, which of the following restrictions on the electron energy E should be satisfied so that the fringes can be distinctly observed? **[TIFR 2014]**



(a) $E \leq \frac{1}{2m_e}\left(\frac{hz}{rd}\right)^2$ (b) $E \geq \frac{1}{2m_e}\left(\frac{hz}{rd}\right)^2$

(c) $E \leq c\left(\frac{hz}{rd}\right)$ (d) $E \geq c\left(\frac{hz}{rd}\right)$

11. A glass plate P (refractive index $n_p = 1.54$) is coated with a dielectric material C with the refractive index $n_C = 1.6$. In order to have enhanced reflection from this coated glass for near-normal incident light of wavelength λ, the thickness of the coating material C must be

[TIFR 2014]

(a) even multiples of $\lambda/2n_C$

(b) even multiples of $\lambda/4n_C$

(c) odd multiples of $\lambda/4n_C$

(d) integral multiples of $\lambda/4n_C$

12. The focal length in air of a thin lens made of glass of refractive index 1.5 is ℓ. When immersed in water (refractive index = 4/3), its focal length becomes

[TIFR 2015]

(a) 4ℓ (b) $\ell/4$

(c) $3\ell/4$ (d) $4\ell/3$

13. A light beam of intensity I_0 passes at normal incidence through a flat plate of plastic kept in air. If reflection at the interface reduces the intensity by 20% and absorption on passing through the plate reduces the intensity by 2%, the intensity of the emergent beam will be about

[TIFR 2015]

(a) $0.60I_0$ (b) $0.63I_0$

(c) $0.65I_0$ (d) $0.78I_0$

14. In a transmission diffraction grating, there are 10^4 lines /mm. Which of the following ranges of wavelength (in nm) will produce at least one principal maximum? **[TIFR 2015]**

(a) $1 - 200$ (b) $201 - 500$

(c) $501 - 1000$ (d) $1001 - 5000$

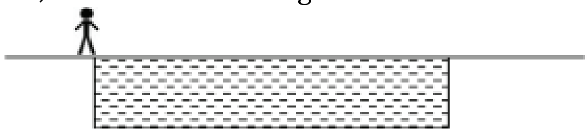
15. In a glass fibre, light propagates by total internal reflection from the inner surface. A very short pulse of light enters a perfectly uniform glass fibre at $t = 0$ and emerges from the other end of the fibre with negligible losses. If the refractive index of the glass used in the fibre is 1.5 and its length is exactly 1.0 km, the time t at which the output pulse will have completely exited the fibre will be

[TIFR 2016]

(a) $5.0\mu s$ (b) $7.5\mu s$

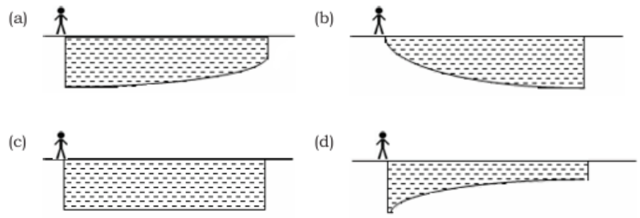
(c) $25n$ s (d) 750 ns

16. An observer stands at the edge of a swimming pool, as sketched in the figure below.

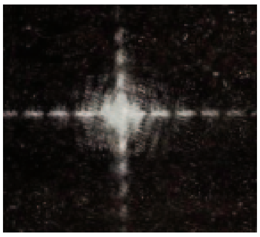


This observer will perceive the pool as

[TIFR 2016]



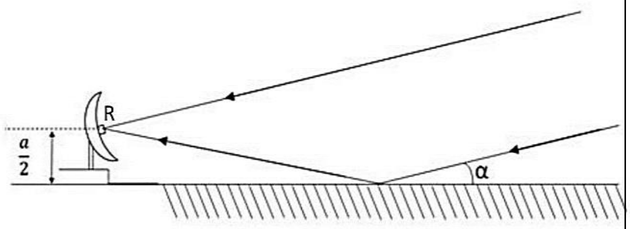
17. Light passes through a narrow slit and gives the Fraunhofer diffraction pattern shown in the adjacent figure.



Which of the following could be the shape of the slit?

[TIFR 2017]

18. The sketch below shows a radio antenna located at the edge of a calm lake, which has a receiver R at the centre of the dish at a height $a/2$ above the ground. This is picking up a signal from a distant radio-emitting star which is just rising above the horizon. However, the receiver also picks up a reflected signal from the surface of the lake, which, at the relevant radio-wavelength, may be taken to be a plane.



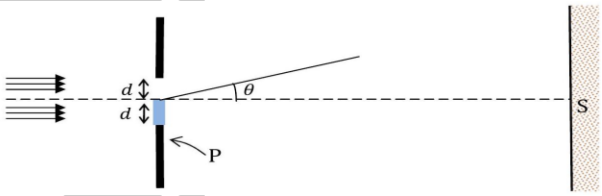
If the instantaneous angle of the star above the horizon is denoted α, the receiver R will detect the first interference maximum when $\alpha =$

[TIFR 2018]

(a) $\arcsin\left(\frac{\lambda}{a}\right)^{1/3}$ (b) $\arcsin\left(\frac{\lambda}{2a}\right)^{1/3}$

(c) $\arcsin\frac{\lambda}{a}$ (d) $\arcsin\frac{\lambda}{2a}$

19. The lower half of a single slit of width d is covered with a half-wave plate P as shown in the figure below.



As a result, a beam of coherent monochromatic light of wave vector $k = 2\pi/\lambda$ incident on the single slit, transmits with an amplitude

$$T(x) = \begin{cases} 1 \text{ for } 0 < x \le d/2 \\ -1 \text{ for } -d/2 < x \le 0 \\ 0 \text{ otherwise} \end{cases}$$

and a Fraunhofer diffraction pattern is formed on a screen S placed parallel to the slit. The intensity at a point on the screen at an angle θ measured from the centre of the slit (see figure), is proportional to

[TIFR 2021]

(a) $\frac{1}{\Phi^2}\sin^2\Phi$ where $\Phi = \frac{1}{2}kd\sin\theta$

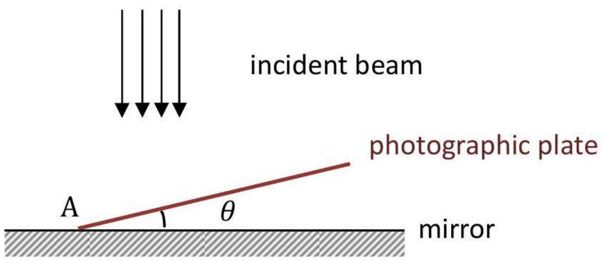
(b) $\frac{1}{\Phi^2}\sin^4\Phi$ where $\Phi = kd\tan\theta$

(c) $\frac{1}{\Phi}\sin\Phi$ where $\Phi = kd\cos\theta$

(d) $\frac{1}{\Phi^2}\cos^2\Phi$ where $\Phi = \frac{1}{2}kd\sin\theta$

20. A collimated coherent light beam of wavelength λ is incident normally on an assembly of a mirror and a photographic plate as shown below. The photographic plate is placed at the position A with a small angle θ with respect to the mirror surface as shown in the figure below. Assume that the photographic plate is almost transparent to the incident light and has a negligible thickness. After sufficient exposure, the plate is developed.

[TIFR 2021]



Which of the following statements is true for the above experimental setup?

(a) The plate will show dark strips separated by distances $\frac{\lambda}{\sin\theta}$ with the first strip at the point of contact.

(b) The plate will show dark strips separated by distances $\frac{\lambda}{2\sin\theta}$ with the first strip at a distance $\frac{\lambda}{4\sin\theta}$ from the point of contact

(c) The plate will show dark strips separated by distances $\frac{\lambda}{\sin\theta}$ with the first strip at a distance $\frac{\lambda}{2\sin\theta}$ from the point of contact

(d) The plate will show dark strips separated by distances $\frac{\lambda}{2\sin\theta}$ with the first strip at the point of contact.

21. Since the refractive index of water is 4/3, the angular velocity (in degrees per hour) of the Sun at noon is perceived by a fish in the ocean deep below the surface as around

[TIFR 2022]

(a) 20.0 (b) 15.0

(c) 13.2 (d) 11.3

22. On a wet monsoon day at 12 noon, a thin film of oil of thickness 0.3μm is formed on a wet road. If the refractive index of oil and water are 1.475 and 1.333, respectively, which of the following wavelengths of light will be reflected with maximum intensity? **[TIFR 2022]**

(a) 407 nm (b) 590 nm

(c) 443 nm (d) 640 nm

23. According to a standard table, the refractive index of water at 4°C is 1.33 at a wavelength of 590 nm. However, a carefully performed experiment in the lab yielded a refractive index of 1.41 . Which one of the following statements could be the explanation of this discrepancy?

[TIFR 2022]

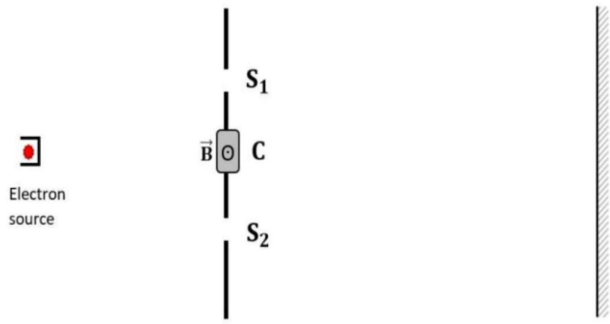
(a) The experiment was performed at a wavelength lower than 590 nm.

(b) The experiment was performed at a wavelength higher than 590 nm.

(c) The water sample was at a temperature lower than 4°C.

(d) The water sample was at a temperature much higher than 4°C.

24. Consider an electron double slit experiment as shown in the figure below, with slits S_1 and S_2.



If now, within the shaded region marked C, a constant uniform magnetic field pointing outside the page is turned on, the fringe pattern

[TIFR 2023]

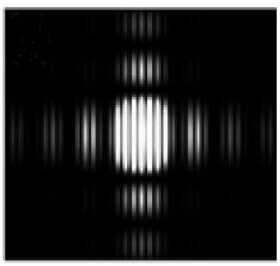
(a) will become dimmer.

(b) will disappear.

(c) will remain unchanged.

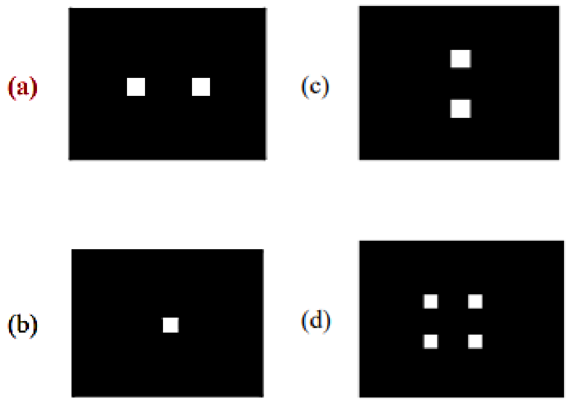
(d) will get shifted.

25. The following Fraunhofer diffraction pattern was observed in an experiment.



The aperture arrangement that would yield such a fringe pattern is

[TIFR 2023]



26. A diffraction grating spectrograph is used to resolve the two sodium D lines (589 and 589.6 nm) in the first order of diffraction. If the width of the grating is 2 cm and the focal length of the spectrograph camera is 20 cm, what the linear separation at the focal plane of the two D lines will be about **[TIFR 2023]**

(a) 6 mm (b) $6\mu m$

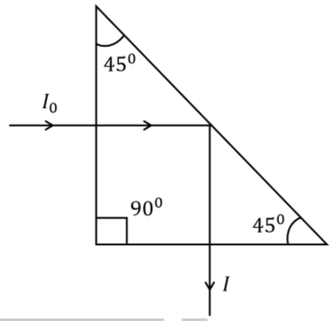
(c) $60\mu m$ (d) 60 nm

Answer Key				
CSIR PYQ				
1. d	2. a	3. d	4. c	5. a
6. b	7. a	8. b	9. c	10. b
11. a	12. b	13. a	14. c	15. a
16. c	17. c			
GATE PYQ				
1. a	2. a	3. c	4. a	5. C
6. 9.1	7. b	8. d	9. c	10. b
JEST PYQ				
1. a	2. d	3. c	4. a	5. c
6. d	7. 8	8. 0225	9. b	10. b
11. d	12. d	13. c	14. a	15. 25
TIFR PYQ				
1. **d**	2. b	3. D		
4. b	5. a	6. b	7. d	8. c
9. d	10. a	11. c	12. a	13. c
14. a	15. b	16. a	17. a	18. d
19. a	20. b	21. d	22. b	23. a
24. d	25. a	26. b		

❖ POLARISATION

❖ CSIR-NET PYQ's

1. Circularly polarized light with intensity I_0 is incident normally on a glass prism as shown in the figure. The index of refraction of glass is 1.5. The intensity I of light emerging from the prism is: **[CSIR JUNE 2011]**



(a) I_0 (b) 0.96I

(c) 0.92I (d) $0.88I_0$.

2. A beam of light of frequency $\vec{\omega}$ is reflected from a dielectric-metal interface at normal incience. The refractive index of the dielectric medium is n and that of the metal is $n_2 = n(1 + i\rho)$. If the beam is polarised parallel to the interface, then the phase change experienced by the light upon reflection is

[CSIR JUNE 2014]

(a) $\tan\left(\frac{2}{\rho}\right)$ (b) $\tan^{-1}\left(\frac{1}{\rho}\right)$

(c) $\tan^{-1}\left(\frac{2}{\rho}\right)$ (d) $\tan^{-1}(2\rho)$

3. A beam of unpolarized light in a medium with dielectric constant ϵ_1 is reflected from a plane interface formed with another medium of dielectric constant $\epsilon_2 = 3\epsilon_1$. The two media have identical magnetic permeability. If the angle of incidence is 60°, then the reflected light

[CSIR DEC 2015]

(a) is plane polarized perpendicular to the plane of incidence

(b) is plane polarized parallel to the plane of incidence

(c) is circularly polarized

(d) has the same polarization as the incident light

4. The electric field of an electromagnetic wave is $\vec{E}(z,t) = E_0 \cos(kz + \omega t)\hat{\imath} + 2E_0 \sin(kz + \omega t)\hat{\jmath}$, where ω and k are positive constants. This represents

[CSIR DEC 2016]

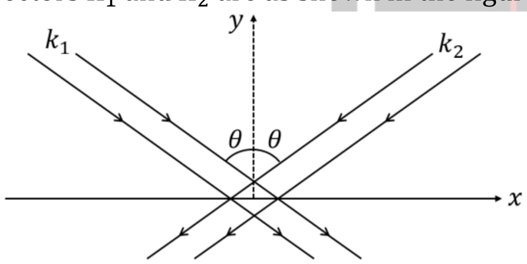
(a) a linearly polarized wave travelling in the positive z-direction

(b) a circularly polarised wave travelling in the negative z-direction

(c) an elliptically polarised wave travelling in the negative z-direction

(d) an unpolarised wave travelling in the positive z-direction

5. Two coherent plane electromagnetic waves of wavelength $0.5\mu m$ (both have the same amplitude and are linearly polarized along the z-direction) fall on the $y = 0$ plane. Their wave vectors $\mathbf{k}_1$ and $\mathbf{k}_2$ are as shown in the figure.



If the angle θ is $30°$, the fringe spacing of the interference pattern produced on the plane is

[CSIR JUNE 2019]

(a) $1.0\mu m$ (b) $0.29\mu m$

(c) $0.58\mu m$ (d) $0.5\mu m$

6. A charged particle moves uniformly on the xy-plane along a circle of radius a centered at the origin. A detector is put at a distance d on the x axis is to detect the electromagnetic wave radiated by the particle along the x direction. If $d >> a$, the wave received by detector is

[CSIR JUNE 2023]

(a) unpolarized

(b) circularly polarized with the plane of polarization being the yz-plane

(c) linearly polarized along the y-direction

(d) linearly polarized along the z-direction

❖ GATE PYQ's

1. A left circularly polarized light beam of wavelength 600 nm is incident on a crystal of thickness d and propagates perpendicular to its optic axis. The ordinary and extraordinary refractive indices of the crystal are $n_0 = 1.54$ and $n_e = 1.55$ respectively. The emergent light will be right circularly polarized if d is

[GATE 2002]

(a) $120\mu m$ (b) $60\mu m$

(c) $30\mu m$ (d) $15\mu m$

2. The state of polarization of light with the electric field vector $\vec{E} = \hat{\imath}E_0 \cos(kz - \omega t) - \hat{\jmath}E_0 \cos(kz - \omega t)$ is

[GATE 2004]

(a) linearly polarized along z-direction

(b) linearly polarized at $-45°$ to x-axis

(c) circularly polarized

(d) elliptically polarized with the major axis along x-axis

3. The electric field $\vec{E}(\vec{r},t)$ for a circularly polarized electromagnetic wave propagating along the position direction is

[GATE 2005]

(a) $E_0(\hat{x} + \hat{y})\exp[i(kz - \omega t)]$

(b) $E_0(\hat{x} + i\hat{y})\exp[i(kz - \omega t)]$

(c) $E_0(\hat{x} + i\hat{y})\exp[i(kz + \omega t)]$

(d) $E_0(\hat{x} + \hat{y})\exp[i(kz + \omega t)]$

4. A classical charged particle moving with frequency ω in a circular orbit of radius a, centred at the origin in the xy-plane, electromagnetic radiation. At points $(b, 0,0)$ and $(0,0, b)$, where $b \gg a$, the electromagnetic waves are

[GATE 2006]

(a) circularly polarized and elliptically polarized, respectively

(b) plane polarized and elliptically polarized, respectively

(c) plane polarized and circularly polarized, respectively

(d) circularly polarized and plane polarized, respectively

5. Unpolarized light falls from air to a planar air-glass interface (refractive index of glass is 1.5) and the reflected light is observed to be plane polarized. The polarization vector and the angle of incidence θ_i are

[GATE 2008]

(a) perpendicular to the plane of incidence and $\theta_i = 42''$

(b) parallel to the plane of incidence and $\theta_i = 56''$

(c) perpendicular to the plane of incidence and $\theta_i = 56''$

(d) parallel to the plane of incidence and $\theta_i = 42''$

6. A non-relativistic charged particles moves along the positive x-axis with a constant positive acceleration $a\hat{x}$. The particle is at the origin at $t = 0$ at a distant point $(0, d, 0)$ on the y-axis. Which one of the following statements is correct?

[GATE 2008]

(a) The radiation in unpolarized

(b) The radiation is plane polarized with polarization parallel to the x-axis

(c) The radiation is plane polarized with polarization parallel to the xy plane along a line inclined to the x axis

(d) The radiation is elliptically polarized

7. A circularly polarized monochromatic plane wave is incident on a dielectric interface at Brewster angle. Which one of the following statements is correct?

[GATE 2013]

(a) The reflected light is plane polarized in the plane of incidence and the transmitted light is circularly polarized

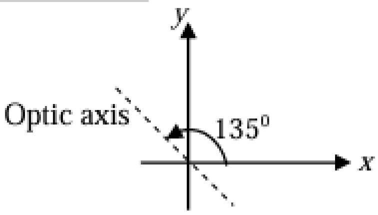
(b) The reflected light is plane polarized perpendicular to the plane of incidence and the transmitted light is plane polarized in the plane of incidence

(c) The reflected light is plane polarized perpendicular to the plane of incidence and the transmitted light is elliptically polarized

(d) there will be no reflected light and the transmitted light is circularly polarized

8. A quarter wave plate introduces a path difference of $\lambda/4$ between the two components of polarization parallel and perpendicular to the optic axis. An electromagnetic wave with $\vec{E} = (\hat{x} + \hat{y})E_0 e^{(nkz-nt)}$ is incident normally on a quarter wave plate which has its optic axis making an angle 135° with the x-axis as shown. The emergent electromagnetic wave would be

[GATE 2018]



(a) elliptically polarized

(b) circularly polarized

(c) linearly polarized with polarization as that of incident wave

(d) linearly polarized but with polarization at 90° to that of the incident wave

9. The electric field of an electromagnetic wave is given by $\vec{E} = 3\sin(kz - \omega t)\hat{x} + 4\cos(kz - \omega t)\hat{y}$. The wave is

[GATE 2019]

(a) linearly polarized at an angle $\tan^{-1}\left(\frac{4}{3}\right)$ from the x-axis

(b) linearly polarized at an angle $\tan^{-1}\left(\frac{3}{4}\right)$ from the x-axis

(c) elliptically polarized in clockwise direction when seen travelling towards the observer

(d) elliptically polarized in counter-clockwise direction when seen travelling towards the observer

10. In a set of N successive polarizers, the m^{th} polarizer makes an angle $\left(\frac{m\pi}{2N}\right)$ with the vertical. A vertically polarized light beam of intensity I_0 is incident on two such sets with $N = N_1$ and $N = N_2$, where $N_2 > N_1$. Let the intensity of light beams coming out be $I(N_1)$ and $I(N_2)$, respectively. Which of the following statements is correct about the two outgoing beams?

[GATE 2019]

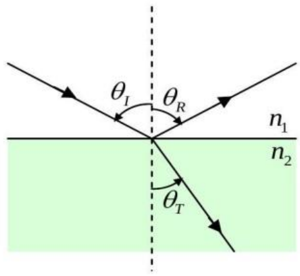
(a) $I(N_2) > I(N_1)$; the polarization in each case is vertical

(b) $I(N_2) < I(N_1)$; the polarization in each case is vertical

(c) $I(N_2) > I(N_1)$; the polarization in each case is horizontal

(d) $I(N_2) < I(N_1)$; the polarization in each case is horizontal

11. As shown in the figure, an electromagnetic wave with intensity I_I is incident at the interface of two media having refractive indices $n_1 = 1$ and $n_2 = \sqrt{3}$. The wave is reflected with intensity I_R and transmitted with intensity I_T. Permeability of each medium is the same. (Reflection coefficient $R = I_R/I_I$ and Transmission coefficient $T = I_T/I_I$).



Choose the correct statement(s)

[GATE 2021]

(a) $R = 0$ if $\theta_I = 0^0$ and polarization of incident light is parallel to the plane of incidence.

(b) $T = 1$ if $\theta_I = 60°$ and polarization of incident light is parallel to the plane of incidence

(c) $R = 0$ if $\theta_I = 60°$ and polarization of incident light is perpendicular to the plane of incidence

(d) $T = 1$ if $\theta_I = 60°$ and polarization of incident light is perpendicular to the plane of incidence

12. A plane polarized electromagnetic wave propagating in $y - z$ plane is incident at the interface of two media at Brewster's angle. Taking $z = 0$ as the boundary between the two media, the electric field of the reflected wave is given by

$$\vec{E}_R = A_R \cos\left[k_0\left\{\frac{\sqrt{3}}{2}y - \frac{1}{2}z\right\} - \omega t\right]\hat{x}$$

then which among the following statements are correct?

(a) The angle of refraction is $\frac{\pi}{6}$

(b) Ratio of permittivity of the medium of refraction (ϵ_2) with respect to the medium on incidence (ϵ_1), $\frac{\epsilon_2}{\epsilon_1} = 3$

(c) The incident wave can have components of its electric field in $y - z$ plane

(d) The angle of reflection is $\frac{\pi}{6}$

13. An unpolarized plane electromagnetic wave in a dielectric medium 1 is incident on a plane interface that separates medium 1 from another dielectric medium 2. Medium 1 and medium 2 have refractive indices n_1 and n_2, respectively, with $n_2 > n_1$. If the angle of incidence is

$\tan^{-1}\left(\frac{n_2}{n_1}\right)$, which one of the following statements is true?

[GATE 2024]

(a) The reflected wave is unpolarized

(b) The reflected wave is polarized parallel to the plane of incidence

(c) The reflected wave is polarized perpendicular to the plane of incidence

(d) There is no transmitted wave

❖ JEST PYQ

1. When unpolarized light is incident on a glass plate at a particular angle, it is observed that the reflected beam is linearly polarized. What is the angle of the refracted beam with respect to the surface normal? Refractive index of glass is 1.52

[JEST 2012]

(a) 56.7°
(b) 33.4°
(c) 23.3°
(d) The light is completely reflected and there is no refracted beam.

2. The electric field $\vec{E} = E_0 \sin(\omega t - kz)x + 2E_0 \sin\left(\omega t - kz + \frac{\pi}{2}\right) y$ represents:

[JEST 2016]

(a) a linearly polarized wave

(b) a right hand circularly polarized wave

(c) a left hand circularly polarized wave

(d) an elliptically polarized wave

3. Three polarizers are stacked, normal to a central axis, along which is incident a beam of unpolarized light of intensity I_0. The first and the third polarizers are perpendicular to each other and the middle polarizer is rotated at an angular frequency ω about the central axis (light beam). The time dependent intensity of light emerging after the third polarizer will be given by

[JEST 2020]

(a) $I(t) = \left(\frac{I_0}{16}\right)\{1 - \cos(4\omega t)\}$

(b) $I(t) = \left(\frac{I_0}{8}\right)\{1 - \cos(2\omega t)\}$

(c) $I(t) = \left(\frac{I_0}{4}\right)\{1 - 2\cos \omega t\}$

(d) $I(t) = \left(\frac{I_0}{2}\right)\cos^2 \omega t$

4. A monochromatic linearly polarized light with electromagnetic field $\vec{E} = E_0 \sin(\omega t - kz)(\hat{x} + \hat{y})$ is incident normally on a birefringent calcite crystal. The wavelength of the wave is 590 nm and the refractive indices of the crystal along the x-directions and y-directions ar e 1.66 and 1.49, respectively. If the thickness of the crystal is 434 nm, what will be the polarization of the light that emerges from the crystal?

[JEST 2021]

(a) Linearly polarized along the same axis as the incident light

(b) Linearly polarized but along a different axis than the incident light

(c) Circularly polarized

(d) Neither linearly nor circularly polarized but elliptically polarized

5. A pair of crossed ideal linear polarizers allow no light to pass through. To produce some output one can insert optical elements between the crossed polarizers. For given light beam of input intensity I_0, Nirmalya inserts a quarter-wave plate between the mercury crossed polarizers and records an output intensity $\alpha I_\circ$. On the other hand, Ayan inserts two linear polarizers having orientations 30° and 60° w.r.t. the first polarizer of the crossed pair, and records an output intensity of $\beta I_\circ$. What is the ratio $\frac{\alpha}{\beta}$? **[JEST 2022]**

6. If linearly polarized light is sent through two polarizers, the first at 45° to the original axis of polarization and the second at 90° to the original axis of polarization, what fraction of the original intensity passes through the last polarizer?

[JEST 2023]

(a) $\frac{1}{2}$ (b) $\frac{1}{4}$

(c) 0 (d) $\frac{1}{8}$

7. Two linear polarizers are placed coaxially with the transmission axis of the first polarizer in the vertical orientation and the second polarizer in the horizontal orientation. A half wave plate placed coaxially between these crossed polarizers is rotating about its axis at an angular frequency ω. At $t = 0$, the fast axis of the half waveplate was oriented vertically. A beam of unpolarized light of intensity I_0 is incident along the axis of this optical system. The output intensity measured by a detector after the beam passes through this optical system is

[JEST 2023]

(a) $\frac{I_0}{4}[1 + \cos(\omega t)]$ (b) $\frac{I_0}{4}[1 - \cos(2\omega t)]$

(c) $\frac{I_0}{4}[1 - \cos(4\omega t)]$ (d) $\frac{I_0}{2}[1 - \cos(\omega t)]$

8. What is the right sequence of optical components to convert unpolarized light into circularly polarized light?

[JEST 2024]

(a) Light source → quarter wave plate → half wave plate

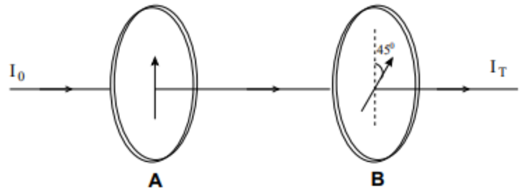
(b) Light source → linear polarizer → quarter wave plate

(c) Light source → linear polarizer → half wave plate

(d) Light source → half wave plate → quarter wave plate

❖ TIFR PYQ

1. Unpolarized light of intensity I_0 passes successively through two identical linear polarisers A and B, placed such that their polarisation axes are at angle of 45° (see figure) with respect to one another.



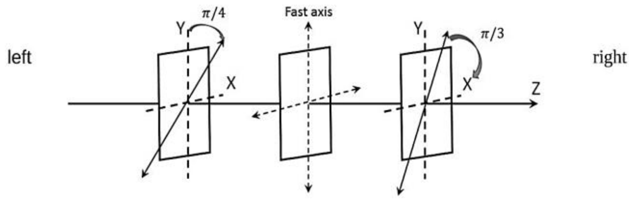
Assuming A and B to be perfect polarizers (i.e. no absorption losses), the intensity of the transmitted light will be I_T =

[TIFR 2012]

(a) $I_0/4$ (b) $I_0/2\sqrt{2}$

(c) $I_0/2$ (d) $I_0/\sqrt{2}$

2. A plane polarized light wave with electric field expressed as $\vec{\boldsymbol{E}}(z,t) = E_0\hat{\boldsymbol{J}}\cos(kz - \omega t)$ is incident from the left on the apparatus as sketched below.



The apparatus consists of (from left to right) a polarizer with transmission axis at $\pi/4$ w.r.t. the y-axis, followed by a quarter-wave plate with fast axis along the y-axis, and finally, a polariser with transmission axis at $\pi/3$ about the x-axis. If the incident intensity of the wave is I_0, What will be the intensity of the light emerging out of the apparatus (on the right)?

[TIFR 2020]

(a) $I_0/4$ (b) $I_0/8$

(c) $3I_0/8$ (d) $I_0/16$

3. An electromagnetic wave is described by the following expression

$$\vec{E}(z,t) = E_0 \sin kz \left\{\hat{\imath}\cos \omega t + \hat{\jmath}\cos\left(\omega t - \frac{\pi}{2}\right)\right\}$$

Which of the following correctly describes this waveform?

[TIFR 2023]

(a) A right circular-polarized travelling wave along the positive z-axis.

(b) A right circular-polarized standing wave along the positive z-axis.

(c) A left circular-polarized travelling wave along the positive z-axis.

(d) A left circular-polarised standing wave along the positive z-axis.

4. Unpolarized light of intensity 200 W/m^2 is incident on a set of two perfect polarisers arranged one behind the other. The first polariser has its transmission axis at $+55^0$ with respect to the vertical and the second polariser has its transmission axis at $+100°$ with respect to the vertical. What is the intensity of the transmitted light?

[TIFR 2024]

(a) 3.01 W/m^2 (b) 100 W/m^2

(c) 1.98 W/m^2 (d) 50 W/m^2

Answer Key				
CSIR PYQ				
1. c	2. c	3. a	4. a	5. d
6. c				
GATE PYQ				
1. c	2. b	3. b	4. c	5. c
6. b	7. c	8. c	9. d	10. c
11. b	12. abc	13. c		
JEST PYQ				
1. b	2. d	3. a	4. d	5. 1.19
6. b	7. c	8. b		
TIFR PYQ				
1. a	2. a	3. d	4. d	

❖ FRESNEL EQAUTIONS:

❖ CSIR-NET PYQ

1. An electromagnetic wave is incident on a water-air interface. The phase of the perpendicular component of the electric field, $E_{\perp}$, of the reflected wave into the water is found to remain the same
for all angles of incidence. The phase of the magnetic field H.

[CSIR JUNE 2012]

(a) does not change (b) changes by $3\pi/2$

(c) changes by $\pi/2$ (d) changes by π

2. A plane electromagnetic wave from within a dielectric medium (with $\varepsilon = 4\varepsilon_0$ and $\mu = \mu_0$) is incident on its boundary with air, at $z = 0$. The magnetic field in the medium is $\ddot{H} = \hat{j}H_0 \cos(\omega t - kx - k\sqrt{3}z)$, where ω and k are positive constants. The angles of reflection and refraction are, respectively,

[CSIR DEC 2017]

(a) 45° and 60° (b) 30° and 90°

(c) 30° and 60° (d) 60° and 90°

3. An electromagnetic wave is incident from vacuum normally on a planar surface of a non-magnetic medium. If the amplitude of the electric field of the incident wave is E_0 and that of the transmitted wave is $\frac{2E_0}{3}$, then neglecting any loss, the refractive index of the medium is

[NET June 2022]

(a) 1.5 (b) 2.0

(c) 2.4 (d) 2.7

❖ GATE PYQ

1. A plane electromagnetic wave of frequency ω is incident on an air-dielectric interface. The dielectric is linear, isotropic, non-magnetic and its refractive index is n. The reflectance (R) and transmittance (T) from the interface are

[GATE 2004]

(a) $R=\left(\frac{n-1}{n+1}\right)^2, T=\frac{4n}{(n+1)^2}$

(b) $R=-\left(\frac{n-1}{n+1}\right), T=\frac{2}{(n+1)^2}$

(c) $R=-\left(\frac{n-1}{n+1}\right)^3, T=\frac{4n^3}{(n+1)^3}$

(d) $R=-\left(\frac{n-1^2}{n+1}\right), T=\frac{4n^2}{(n+1)^2}$

2. A plane electromagnetic wave travelling in vacuum is incident normally on a non-magnetic, non-absorbing medium of refractive index n. The incident (E_i), reflected (E_r) and transmitted (E_t) electric fields are given as, $E_i = E\exp[i(kz-\omega t)], E_r = E_{0r}\exp[i(k_r z-\omega t)], E_t = E_{0t}\exp[i(k_t z-\omega t)]$. If $E = 2$ V/m and $n = 1.5$, then the application of appropriate boundary conditions leads to

[GATE 2005]

(a) $E_{0r} = -\frac{3}{5}$ V/m, $E_{0t} = \frac{7}{5}$ V/m

(b) $E_{0r} = -\frac{1}{5}$ V/m, $E_{0t} = \frac{8}{5}$ V/m

(c) $E_{0r} = -\frac{2}{5}$ V/m, $E_{0t} = \frac{8}{5}$ V/m

(d) $E_{0r} = \frac{4}{5}$ V/m, $E_{0t} = \frac{6}{5}$ V/m

3. For normal incidence at an air-glass interface with $\mu = 1.5$ the fraction of energy reflected is given by

[GATE 2007]

(a) 0.40 (b) 0.20

(c) 0.16 (d) 0.04

Common Data for Questions 4 , 5:
The Fresnel relations between the amplitudes of incident and reflected electromagnetic waves at an interface between air and a dielectric of refractive index μ, are

$$E_{\parallel}^{\text{reflected}} = \frac{\cos r-\mu\cos i}{\cos r+\mu\cos i}E_{\parallel}^{\text{incident}} \text{ and } E_{\perp}^{\text{reflected}} = \frac{\mu\cos r-\cos i}{\mu\cos r+\cos i}E_{\perp}^{\text{incident}}$$

The subscripts | and ⊥ refer to polarization, parallel and normal to the plane of incidence respectively. Here, i and r are the angles of incidence and refraction respectively

4. The coordination for the reflected ray to be completely polarized is

[GATE 2007]

(a) $\mu\cos i = \cos r$ (b) $\cos i = \mu\cos r$

(c) $\mu\cos i = -\cos r$ (d) $\cos i = -\mu\cos r$

5. For an normal Incidence at an air – glass interface, the fraction of energy reflected is given by **[GATE 2007]**

(a)0.40 (b)0.20

(c)0.16 (d)0.04

6. An electromagnetic wave having electric field $E = 8\cos(kz-\omega t)\hat{y}V\ \text{cm}^{-1}$ is incident at 90° (normal incidence) on a square slab from vacuum (with refractive index $n_0 = 1.0$) as shown in the figure. The slab is composed of two different materials with refractive indices n_1 and n_2. Assume that the permeability of each medium is the same. After passing through the slab for the first time, the electric field amplitude, in $V\ \text{cm}^{-1}$, of the electromagnetic wave, which emerges from the slab in region 2, is closest to

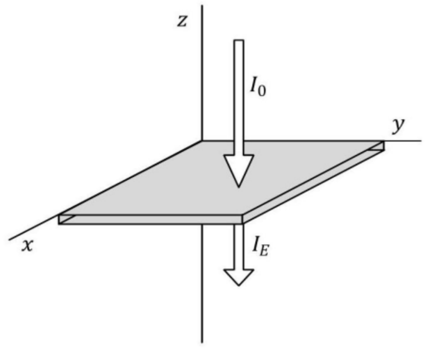
[GATE 2021]

(a) $\frac{11}{1.6}$ (b) $\frac{11}{3.2}$

(c) $\frac{11}{25.6}$ (d) $\frac{11}{13.8}$

❖ **TIFR PYQ**

1. Consider the following situation.
An infinite plane metallic plate of thickness 1.8 cm is placed along the $x-y$ plane, with the z axis normal to the sheet (see figure).
A plane radio wave of intensity I_0 and frequency 29.5MHz propagates in vacuum along the negative z-axis and strikes the metal foil at normal incidence.



If the metal of the foil has conductivity $9\Omega^{-1}\ \mathrm{m}^{-1}$ and magnetic permeability $\mu \simeq 1$, the intensity I_E of the emergent wave will be approximately **[TIFR 2020]**

(a) $0.26 I_0$ (b) $0.51 I_0$

(c) $0.29 \times 10^{-7} I_0$ (d) $2.08 \times 10^{-4} I_0$

Answer Key				
CSIR PYQ				
1. d	2. b	3. b		
GATE PYQ				
1. a	2. c	3. d	4. a	5. d
6. a				
TIFR PYQ				
1. a				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