CLASS 12 · CBSE PHYSICS (042)

Physics Solved Board Papers

Chapter-wise and year-wise CBSE board questions with complete step-by-step solutions

10 years · 2016–2026

- ✓ Part A: every question from 124 CBSE papers (every set code of 2016 and 2018–2026), sorted chapter-wise, grouped by marks, with full solutions
- ✓ Part B: 17 complete board papers, each followed by its solutions
- ✓ Board weightage table and most-asked topics for every chapter
- ✓ Derivations, numericals and ray/circuit diagrams worked the way the board awards marks
- ✓ Questions on topics out of the board syllabus are flagged

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WHAT YOU GET

10 years of CBSE Physics papers. Every question solved. Sorted chapter-wise.

138	2262	10	14	598
board papers	solved questions	years · 2016–26	chapters	diagrams

✗ Questions scattered across years	→ ✓ All in one place, chapter-wise
✗ Don't know what to study first	→ ✓ Weightage + most-asked topics
✗ One-line answers online	→ ✓ Full solutions, board-style
✗ Old books carry deleted topics	→ ✓ Topics out of the syllabus clearly marked

A PART A
Chapter-wise
- ✓ Weightage table
- ✓ Most-asked topics
- ✓ Every question + solution

B PART B
Full papers
- ✓ Exactly as set by CBSE
- ✓ Solutions after each paper
- ✓ Timed 3-hour practice

2026 · 55/1/1	**2026** · 55/1/2	**2026** · 55/1/3	**2026** · 55/2/1	**2025** · 55/1/1
2025 · 55/2/1	**2024** · 55/1/1	**2024** · 55/2/1	**2023** · 55/1/1	**2023** · 55/2/1
2022 · 55/1/1 · T2	**2022** · 55/2/1 · T2	**2020** · 55/1/1	**2020** · 55/2/1	**2019** · 55/1/1
2019 · 55/2/1	**2018** · 55/1 · Set 1	**2017** · 55/1 · Set 1	**2016** · 55/1/N	

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CLASS 6–12 · ALL SUBJECTS

100% QUESTIONS SOLVED

Made for board toppers



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How to use this book

Part A puts every board question of a chapter together, from 1-mark MCQs to 5-mark long answers. Finish a chapter in your notes, then solve its Part A questions without looking at the solutions. Check your answer, mark the ones you got wrong, and repeat them a week later.

Each question shows where it was asked, for example **CBSE 2026 · 55/1/1 · Q13**. A question asked in many sets shows all of them. Use the weightage table and the most-asked topics chart at the start of each chapter to decide what to revise first.

Part B gives full papers. In the last month before the exam, sit with a clock and write one paper in 3 hours, then check it with the solutions that follow the paper.

Solutions are written the way the board awards marks: formula first, every step shown, units in the answer, and a labelled diagram wherever a derivation or ray diagram is asked. Write your answers the same way.

Contents

Part A · Chapter-wise questions with solutions

1. Electric Charges and Fields 126 Qs
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7. Alternating Current 145 Qs
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11. Dual Nature of Radiation and Matter 213 Qs
12. Atoms 151 Qs
13. Nuclei 99 Qs
14. Semiconductor Electronics 161 Qs

Part B · Full board papers, each followed by its solutions

1. CBSE 2026 · 55/1/1 solutions
2. CBSE 2026 · 55/1/2 solutions
3. CBSE 2026 · 55/1/3 solutions
4. CBSE 2026 · 55/2/1 solutions
5. CBSE 2025 · 55/1/1 solutions
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9. CBSE 2023 · 55/1/1 solutions
10. CBSE 2023 · 55/2/1 solutions
11. CBSE 2022 · 55/1/1 · Term 2 solutions
12. CBSE 2022 · 55/2/1 · Term 2 solutions
13. CBSE 2020 · 55/1/1 solutions
14. CBSE 2020 · 55/2/1 solutions
15. CBSE 2019 · 55/1/1 solutions
16. CBSE 2019 · 55/2/1 solutions
17. CBSE 2018 · 55/1 · Set 1 solutions
18. CBSE 2017 · 55/1 · Set 1 solutions
19. CBSE 2016 · 55/1/N solutions

2262 questions in all. Questions are taken from the CBSE Class 12 Physics board papers and the solutions are our own, checked against the official marking schemes where they are available. Questions on topics no longer in the current syllabus (communication systems, cyclotron, transistors and logic gates, zener diode, photodiode, solar cell, polarisation, resolving power, scattering of light, radioactivity, eddy currents and others) are left out of Part A for papers before 2022 and marked in Part B. Where a topic is named only in CBSE's practicals or objectives, or was asked in a recent paper, its questions stay in Part A so that nothing you may need is missing.

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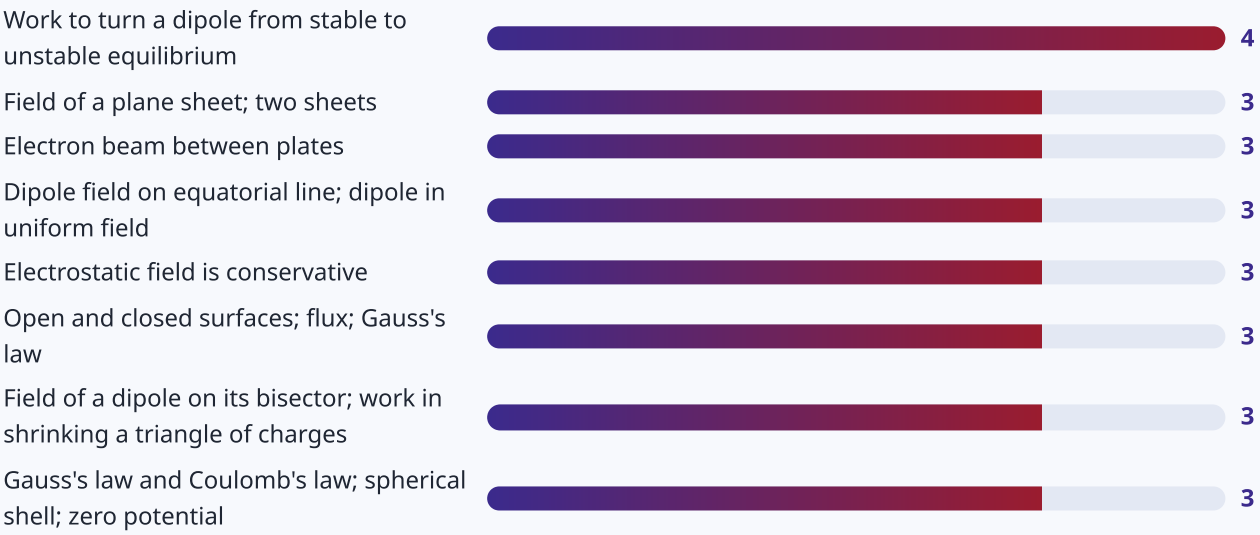
CHAPTER 1

Electric Charges and Fields

Board weightage 2016–2026

Year	2016	2017	2018	2019	2020	2022	2023	2024	2025	2026
Questions per paper	1.7	1.6	2	3.1	2.8	–	2.2	2.5	1.6	1.3
Marks per paper	5	5	10	7	8	–	6	7	5	3

Most asked topics



126 different questions from 116 papers. Repeated questions are shown once with every year they were asked.

1 mark: MCQ and Assertion–Reason

CBSE 2026 · 55/3/2 · Q4 — 1 mark

An electric dipole $\vec{P} = 2qa\,\hat{i}$ is placed in x-y plane, centred at the origin. Let E_1 and E_2 be the magnitudes of electric field at a point distant r (>> a) from its centre, along its axis and on its equatorial plane, respectively. Then the value of $\left(\frac{E_1}{E_2}\right)$ is :

(A) $\frac{1}{4}$ (B) $\frac{1}{2}$

(C) 2 (D) 4

Solution

Answer: (C) 2

For $r \gg a$: axial field $E_1 = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$, equatorial field $E_2 = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$, so $\frac{E_1}{E_2} = 2$.

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CBSE 2026 · 55/3/3 · Q5 — 1 mark

An electric dipole with dipole moment $\vec{P} = (2.54 \times 10^{-28}\ \text{C.m})(2.00\hat{i} + 3.00\hat{j})$ is placed in an electric field $\vec{E} = \left(1000\frac{\text{N}}{\text{C}}\right)\hat{i}$. An external agent turns the dipole until its electric dipole moment is $\vec{P} = (2.54 \times 10^{-28}\ \text{C.m})(-3.00\hat{i} + 2.00\hat{j})$. The work done by the agent is :

(A) 2.54×10^{-25} J
(B) 1.27×10^{-24} J
(C) 1.02×10^{-23} J
(D) 2.29×10^{-26} J

Solution

Answer: (B) 1.27×10^{-24} J

Potential energy $U = -\vec{p} \cdot \vec{E}$ (only the x-component of $\vec{p}$ matters, as $\vec{E}$ is along $\hat{i}$):

$U_i = -(2.54 \times 10^{-28} \times 2.00)(1000) = -5.08 \times 10^{-25}$ J

$U_f = -(2.54 \times 10^{-28} \times (-3.00))(1000) = +7.62 \times 10^{-25}$ J

$$W = U_f - U_i = 7.62 \times 10^{-25} + 5.08 \times 10^{-25} = 1.27 \times 10^{-24}\ \text{J}$$

CBSE 2026 · 55/5/1 · Q1 — 1 mark

Two small identical metallic balls having charges q and – 2q are kept far at a separation r. They are brought in contact and then separated at distance $\frac{r}{2}$. Compared to the initial force F, they will now :

(A) attract with a force $\frac{F}{2}$
(B) repel with a force $\frac{F}{2}$
(C) repel with a force F
(D) attract with a force F

Solution

Answer: (B) repel with a force $\frac{F}{2}$

Initially $F = \frac{k(q)(2q)}{r^2} = \frac{2kq^2}{r^2}$ (attraction).

On contact the total charge $q - 2q = -q$ is shared equally: each ball gets $-\frac{q}{2}$, so they now repel.

$$F' = \frac{k(q/2)^2}{(r/2)^2} = \frac{kq^2}{r^2} = \frac{F}{2}$$

CBSE 2026 · 55/5/2 · Q6 — 1 mark

Two point charges – Q and Q are located at points (d, 0) and (0, d) respectively, in x-y plane. The electric field $\vec{E}$ at the origin will be :

(A) $\frac{1}{4\pi\varepsilon_0}\frac{\sqrt{2}Q}{d^2}(\hat{i} - \hat{j})$
(B) $\frac{1}{4\pi\varepsilon_0}\frac{\sqrt{2}Q}{d^2}(-\hat{i} - \hat{j})$
(C) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{d^2}(\hat{i} - \hat{j})$
(D) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{d^2}(-\hat{i} - \hat{j})$

Solution

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Answer: (C) $\frac{1}{4\pi\varepsilon_0}\frac{Q}{d^2}(\hat{i}-\hat{j})$

The field of –Q at (d, 0) points towards it, i.e. along $+\hat{i}$; the field of +Q at (0, d) points away from it, i.e. along $-\hat{j}$. Each has magnitude $\frac{1}{4\pi\varepsilon_0}\frac{Q}{d^2}$, so $\vec{E}=\frac{1}{4\pi\varepsilon_0}\frac{Q}{d^2}(\hat{i}-\hat{j})$.

CBSE 2026 · 55/5/2 · Q7 — 1 mark

An electron is moving with velocity $v_0\hat{i}$. If a uniform electric field $\vec{E}=E_0\hat{j}$ is set up in the region, the electron will :

(A) describe a circular path
(B) describe a helical path
(C) describe a parabolic path
(D) continue moving without any deviation

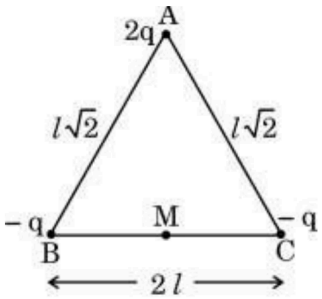
Solution

Answer: (C) describe a parabolic path

The force $-eE_0\hat{j}$ is constant and perpendicular to the initial velocity: uniform velocity along x and uniform acceleration along –y, like a projectile, give a parabola.

CBSE 2026 · 55/5/3 · Q9 — 1 mark

The figure shows three point charges kept at the vertices of triangle ABC. The net electric field, due to this system of charges, at the midpoint M of base BC will be :



(A) $\frac{q}{4\pi\varepsilon_0 l^2}$ pointing along MA
(B) $\frac{q}{\pi\varepsilon_0 l^2}$ pointing along AM
(C) $\frac{q}{2\pi\varepsilon_0 l^2}$ pointing along AM
(D) Zero

Solution

Answer: (C) $\frac{q}{2\pi\varepsilon_0 l^2}$ **pointing along AM**

The two –q charges at B and C are each at distance l from M; their fields at M are equal and opposite and cancel.

$AM=\sqrt{(l\sqrt{2})^2-l^2}=l$. The field of 2q at M points away from A, along AM:

$$E=\frac{1}{4\pi\varepsilon_0}\frac{2q}{l^2}=\frac{q}{2\pi\varepsilon_0 l^2}$$

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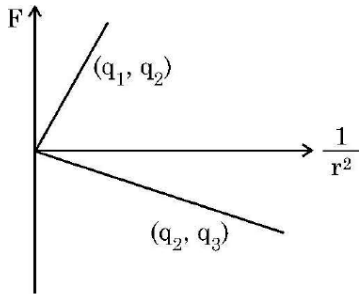
CBSE 2025 · 55/1/1 · Q1 — 1 mark

Figure shows variation of Coulomb force (F) acting between two point charges with $\frac{1}{r^2}$, r being the separation between the two charges (q_1, q_2) and (q_2, q_3). If q_2 is positive and least in magnitude, then the magnitudes of q_1, q_2 and q_3 are such that



(A) $q_2 < q_3 < q_1$

(B) $q_3 < q_1 < q_2$

(C) $q_1 < q_2 < q_3$

(D) $q_2 < q_1 < q_3$

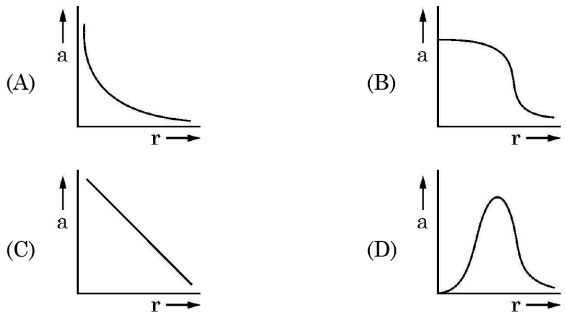
Solution

Answer: (A) $q_2 < q_3 < q_1$

$F = \frac{kq_aq_b}{r^2}$, so on an F–$\frac{1}{r^2}$ graph the slope is kq_aq_b. The (q_1, q_2) line is steeper (larger magnitude of slope) than the (q_2, q_3) line, so $|q_1q_2| > |q_2q_3|$, i.e. $|q_1| > |q_3|$. With q_2 the least: $q_2 < q_3 < q_1$. (The signs also tell us q_1 is positive, since F is repulsive, and q_3 is negative, since F is attractive.)

CBSE 2025 · 55/1/3 · Q1 — 1 mark

A charge Q is fixed in position. Another charge q is brought near charge Q and released from rest. Which of the following graphs is the correct representation of the acceleration of the charge q as a function of its distance r from charge Q?



Solution

Answer: (A)

$a = \frac{F}{m} = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{mr^2} \propto \frac{1}{r^2}$: the acceleration falls steeply and then more slowly as r increases, never reaching zero, as in graph (A).

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CBSE 2025 · 55/2/1 · Q1 — 1 mark

Two charges –q each are placed at the vertices A and B of an equilateral triangle ABC. If M is the mid-point of AB, the net electric field at C will point along

(A) CA
(B) CB
(C) MC
(D) CM

Solution

Answer: (D) CM

The field of a negative charge points towards it, so at C the fields point along CA and CB, with equal magnitudes. Their components parallel to AB cancel, and the components along the bisector add. The resultant points from C towards M, i.e. along CM.

CBSE 2025 · 55/2/1 · Q8 | CBSE 2025 · 55/2/2 · Q10 | CBSE 2025 · 55/2/3 · Q3 — asked 3 times — 1 mark

Which one of the following statements is correct? Electric field due to static charges is

(A) conservative and field lines do not form closed loops.
(B) conservative and field lines form closed loops.
(C) non-conservative and field lines do not form closed loops.
(D) non-conservative and field lines form closed loops.

Solution

Answer: (A)

The work done by an electrostatic field around any closed path is zero, so the field is conservative. Its lines start on positive charges and end on negative charges, so they never form closed loops.

CBSE 2025 · 55/2/2 · Q1 — 1 mark

Two identical point charges are placed at the two vertices A and B of an equilateral triangle of side l. The magnitude of the electric field at the third vertex P is E. If a hollow conducting sphere of radius (l/4) is placed at P, the magnitude of the electric field at point P now becomes

(A) >E
(B) E
(C) $\frac{E}{2}$
(D) zero

Solution

Answer: (D) zero

P is now inside the cavity of a conductor. Charges are induced on the outer surface of the hollow sphere so that the field inside the conductor and its cavity is zero (electrostatic shielding).

CBSE 2025 · 55/2/3 · Q1 — 1 mark

Consider two identical dipoles D_1 and D_2. Charges –q and q of dipole D_1 are located at (0, 0) and (a, 0) and that of dipole D_2 at (0, a) and (0, 2a) in x-y plane, respectively. The net dipole moment of the system is

(A) $qa(\hat{i}+\hat{j})$
(B) $-qa(\hat{i}+\hat{j})$
(C) $qa(\hat{i}-\hat{j})$
(D) $-qa(\hat{i}-\hat{j})$

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Solution

Answer: (A) $qa(\hat{i}+\hat{j})$

A dipole moment points from –q to +q. D_1: $\vec{p}_1 = qa\,\hat{i}$; D_2: $\vec{p}_2 = qa\,\hat{j}$. Net: $qa(\hat{i}+\hat{j})$.

CBSE 2025 · 55/4/1 · Q1 — 1 mark

A body acquires charge 8.0×10^{-12} C. The mass of the body :

(A) increases by 4.5×10^{-7} kg
(B) decreases by 1.0×10^{-6} kg
(C) decreases by 4.55×10^{-23} kg
(D) increases by 9.1×10^{-23} kg

Solution

Answer: (C) decreases by 4.55×10^{-23} kg

A positive charge means electrons were removed: $n = \dfrac{8.0 \times 10^{-12}}{1.6 \times 10^{-19}} = 5 \times 10^{7}$ electrons.

Mass lost $= 5 \times 10^{7} \times 9.1 \times 10^{-31} = 4.55 \times 10^{-23}$ kg.

CBSE 2025 · 55/4/2 · Q1 — 1 mark

An electric dipole of dipole moment 1.0×10^{-12} Cm lies along x-axis. An electric field of magnitude 2.0×10^{4} NC^{-1} is switched on at an instant in the region. The unit vector along the electric field is $\dfrac{\sqrt{3}}{2}\hat{i} + \dfrac{1}{2}\hat{j}$. The magnitude of the torque acting on the dipole at that instant is :

(A) 0.5×10^{-6} Nm
(B) 1.0×10^{-8} Nm
(C) 2.0×10^{-8} Nm
(D) 4.0×10^{-8} Nm

Solution

Answer: (B) 1.0×10^{-8} Nm

The field's unit vector makes angle θ with the x-axis where $\cos\theta = \dfrac{\sqrt{3}}{2}$, i.e. θ = 30°.

$\tau = pE\sin\theta = 1.0 \times 10^{-12} \times 2.0 \times 10^{4} \times \dfrac{1}{2} = 1.0 \times 10^{-8}$ N m.

CBSE 2025 · 55/4/3 · Q1 — 1 mark

Two point charges Q and – q are held 'r' distance apart in free space. A uniform electric field $\vec{E}$ is applied in the region perpendicular to the line joining the two charges. Which one of the following angles will the direction of the net force acting on charge – q make with the line joining Q and – q?

(A) $\tan^{-1}\dfrac{4\pi\varepsilon_0 E r^2}{Q}$
(B) $\cot^{-1}\dfrac{4\pi\varepsilon_0 E r^2}{Q}$
(C) $\tan^{-1}\dfrac{QE}{4\pi\varepsilon_0 r^2}$
(D) $\cot^{-1}\dfrac{QE}{4\pi\varepsilon_0 r^2}$

Solution

Answer: (A) $\tan^{-1}\dfrac{4\pi\varepsilon_0 E r^2}{Q}$

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On –q: the Coulomb attraction $F_1 = \dfrac{Qq}{4\pi\varepsilon_0 r^2}$ along the line (towards Q), and the field force $F_2 = qE$ perpendicular to it. The angle θ of the resultant with the line:

$$\tan\theta = \frac{F_2}{F_1} = \frac{qE}{Qq/(4\pi\varepsilon_0 r^2)} = \frac{4\pi\varepsilon_0 E r^2}{Q}$$

CBSE 2025 · 55/6/3 · Q3 — 1 mark

A particle of mass m and charge q moving with velocity $v\hat{i}$ is subjected to a uniform electric field $E\hat{j}$. The particle will initially have a tendency to move in a circle of radius :

(A) $\left(\dfrac{mv}{qE}\right)$ in x-y plane

(B) $\left(\dfrac{mv^2}{qE^2}\right)$ in x-z plane

(C) $\left(\dfrac{mv^2}{qE}\right)$ in x-y plane

(D) $\left(\dfrac{mv}{qE^2}\right)$ in y-z plane

Solution

Answer: (C) $\left(\dfrac{mv^2}{qE}\right)$ in x-y plane

At the start the force qE (along ĵ) is perpendicular to the velocity (along î), so it acts as a centripetal force: $\dfrac{mv^2}{r} = qE \Rightarrow r = \dfrac{mv^2}{qE}$. Both $\vec{v}$ and $\vec{F}$ lie in the x-y plane. (The path is actually a parabola; r is its initial radius of curvature.)

CBSE 2024 · 55/1/1 · Q1 | CBSE 2024 · 55/1/2 · Q1 | CBSE 2024 · 55/1/3 · Q1 asked 3 times — 1 mark

A thin plastic rod is bent into a circular ring of radius R. It is uniformly charged with charge density λ. The magnitude of the electric field at its centre is

(A) $\dfrac{\lambda}{2\varepsilon_0 R}$

(B) Zero

(C) $\dfrac{\lambda}{4\pi\varepsilon_0 R}$

(D) $\dfrac{\lambda}{4\varepsilon_0 R}$

Solution

Answer: (B) Zero

For every small element of the ring there is an identical element diametrically opposite. Their fields at the centre are equal and opposite, so the net field at the centre is zero.

CBSE 2024 · 55/1/2 · Q2 — 1 mark

A charged sphere of radius r has surface charge density σ. The electric field on its surface is E. If the radius of the sphere is doubled, keeping charge density the same, the ratio of the electric field on the old sphere to that on the new sphere will be :

(A) 1

(B) $\dfrac{1}{2}$

(C) $\dfrac{1}{4}$

(D) 4

Solution

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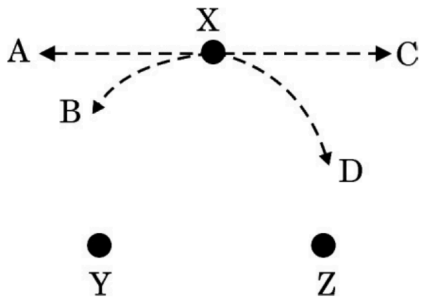
Answer: (A) 1

On the surface, $E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{\sigma \cdot 4\pi r^2}{r^2} = \frac{\sigma}{\varepsilon_0}$.

It depends only on σ, not on r. With σ unchanged the field stays the same, so the ratio is 1.

CBSE 2024 · 55/1/3 · Q2 — 1 mark

Three small charged spheres X, Y and Z carrying charges + q, – q and + q respectively are placed equidistant from each other, as shown in the figure. The spheres Y and Z are held in place. Initially X is also held in place, but is otherwise free to move. When X is released, the path followed by it will be :



(A) A
(B) B
(C) C
(D) D

Solution

Answer: (B) B

X, Y and Z form an equilateral triangle. X is attracted towards Y (–q) and repelled away from Z (+q) by forces of equal size F.

Attraction towards Y points down-left at 60° below the horizontal; repulsion from Z points up-left at 60° above it. The vertical parts cancel and the horizontal parts add: the initial force is F to the left, so X starts moving towards the left.

As X moves left it comes nearer to Y and farther from Z, so the attraction towards Y grows and pulls X downwards as well. The path bends down towards Y: path B.

CBSE 2024 · 55/2/1 · Q1 — 1 mark

Two charged particles P and Q, having the same charge but different masses m_P and m_Q, start from rest and travel equal distances in a uniform electric field $\vec{E}$ in time t_P and t_Q respectively. Neglecting the effect of gravity, the ratio $\left(\frac{t_P}{t_Q}\right)$ is

(A) $\frac{m_P}{m_Q}$
(B) $\frac{m_Q}{m_P}$
(C) $\sqrt{\frac{m_P}{m_Q}}$
(D) $\sqrt{\frac{m_Q}{m_P}}$

Solution

Answer: (C) $\sqrt{\frac{m_P}{m_Q}}$

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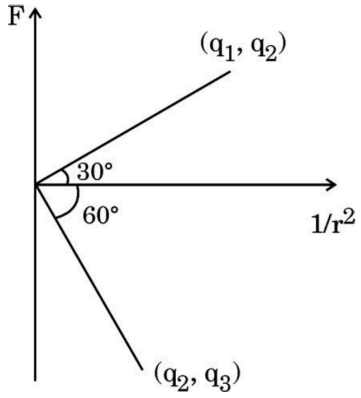
$a = \frac{qE}{m}$ and, from rest, $s = \frac{1}{2}at^2$, so $t = \sqrt{\frac{2s}{a}} = \sqrt{\frac{2sm}{qE}} \propto \sqrt{m}$ (same q, E and s).

CBSE 2024 · 55/2/3 · Q1 — 1 mark

Coulomb force F versus $\left(\frac{1}{r^2}\right)$ graphs for two pairs of point charges (q_1 and q_2) and (q_2 and q_3) are shown in the figure. The ratio of charges $\left(\frac{q_1}{q_3}\right)$ is :



(A) $\sqrt{3}$

(B) $\frac{1}{\sqrt{3}}$

(C) 3

(D) $\frac{1}{3}$

Solution

Answer: (D) $\frac{1}{3}$

$F = \frac{1}{4\pi\varepsilon_0} q_a q_b \cdot \frac{1}{r^2}$, so the slope of the F–(1/r²) graph is proportional to the product of the charges.

Slope for (q_1, q_2): $\tan 30^\circ = \frac{1}{\sqrt{3}}$ (positive: repulsion). Slope for (q_2, q_3): $-\tan 60^\circ = -\sqrt{3}$ (negative: attraction).

$$\frac{q_1 q_2}{q_2 q_3} = \frac{1/\sqrt{3}}{-\sqrt{3}} = -\frac{1}{3}$$

So q_1 and q_3 have opposite signs and $\left|\frac{q_1}{q_3}\right| = \frac{1}{3}$.

CBSE 2024 · 55/3/2 · Q1 — 1 mark

An isolated conductor, with a cavity, has a net charge +Q. A point charge +q is inside the cavity. The charges on the cavity wall and the outer surface are respectively :

(A) 0 and Q

(B) – q and Q – q

(C) – q and Q + q

(D) 0 and Q – q

Solution

Answer: (C) – q and Q + q

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The field inside the conducting material is zero, so a Gaussian surface drawn within the metal round the cavity must enclose zero net charge: the cavity wall carries –q.

The conductor's total charge is +Q, so the outer surface carries $Q - (-q) = Q + q$.

CBSE 2024 · 55/4/1 · Q2 — 1 mark

Two identical small conducting balls B_1 and B_2 are given –7 pC and + 4 pC charges respectively. They are brought in contact with a third identical ball B_3 and then separated. If the final charge on each ball is –2 pC, the initial charge on B_3 was

(A) –2 pC
(B) –3 pC
(C) –5 pC
(D) –15 pC

Solution

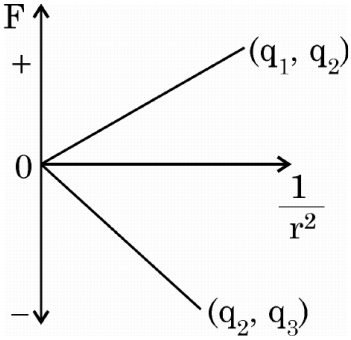
Answer: (B) –3 pC

Charge is conserved and shared equally among identical balls: total $= 3 \times (-2) = -6$ pC.

$-7 + 4 + q_3 = -6 \Rightarrow q_3 = -3$ pC.

CBSE 2024 · 55/4/2 · Q2 — 1 mark

The Coulomb force (F) versus ($1/r^2$) graphs for two pairs of point charges (q_1 and q_2) and (q_2 and q_3) are shown in figure. The charge q_2 is positive and has least magnitude. Then



(A) $q_1 > q_2 > q_3$
(B) $q_1 > q_3 > q_2$
(C) $q_3 > q_2 > q_1$
(D) $q_3 > q_1 > q_2$

Solution

Answer: (D) $q_3 > q_1 > q_2$ (in magnitude)

$F = \frac{q_a q_b}{4\pi\varepsilon_0} \cdot \frac{1}{r^2}$: the slope of each line is proportional to the product of the charges.

The (q_2, q_3) line is steeper than the (q_1, q_2) line, so $|q_2 q_3| > |q_1 q_2|$, i.e. $|q_3| > |q_1|$. q_2 has the least magnitude. Hence $|q_3| > |q_1| > |q_2|$.

(The signs: the (q_1, q_2) slope is positive, so q_1 is positive like q_2; the (q_2, q_3) slope is negative, so q_3 is negative. The CBSE answer compares magnitudes.)

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CBSE 2024 · 55/4/3 · Q1 — 1 mark

An electric dipole of dipole moment $\vec{p}$ is kept in a uniform electric field $\vec{E}$. The amount of work done to rotate it from the position of stable equilibrium to that of unstable equilibrium will be

(A) 2 pE
(B) –2 pE
(C) pE
(D) zero

Solution

Answer: (A) 2 pE

Stable equilibrium: θ = 0°; unstable: θ = 180°.

$W = pE(\cos 0^\circ - \cos 180^\circ) = pE(1+1) = 2pE.$

CBSE 2024 · 55/4/3 · Q2 — 1 mark

An infinite long straight wire having a charge density λ is kept along y'y axis in x-y plane. The Coulomb force on a point charge q at a point P (x, 0) will be

(A) attractive and $\frac{q\lambda}{2\pi\varepsilon_0 x}$
(B) repulsive and $\frac{q\lambda}{2\pi\varepsilon_0 x}$
(C) attractive and $\frac{q\lambda}{\pi\varepsilon_0 x}$
(D) repulsive and $\frac{q\lambda}{\pi\varepsilon_0 x}$

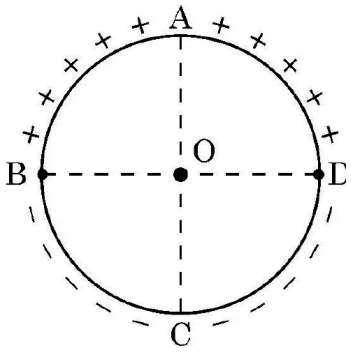
Solution

Answer: (B) repulsive and $\frac{q\lambda}{2\pi\varepsilon_0 x}$

Field of an infinite line charge at distance x: $E = \frac{\lambda}{2\pi\varepsilon_0 x}$, so $F = qE = \frac{q\lambda}{2\pi\varepsilon_0 x}$. Taking q and λ of the same sign (both positive), the force is repulsive.

CBSE 2024 · 55/5/1 · Q13 | CBSE 2024 · 55/5/2 · Q15 | CBSE 2024 · 55/5/3 · Q15 asked 3 times — 1 mark

Assertion (A) : Equal amount of positive and negative charges are distributed uniformly on two halves of a thin circular ring as shown in figure. The resultant electric field at the centre O of the ring is along OC.
Reason (R) : It is so because the net potential at O is not zero.



(A) If both Assertion (A) and Reason (R) are true and Reason (R) is correct explanation of Assertion (A).
(B) If both Assertion (A) and Reason (R) are true and Reason (R) is not the correct explanation of Assertion (A).
(C) If Assertion (A) is true but Reason (R) is false.
(D) If both Assertion (A) and Reason (R) are false.

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Solution

Answer: (C)

The positive upper half gives a field at O pointing away from it (towards C); the negative lower half gives a field pointing towards it (also towards C). The horizontal parts cancel by symmetry, so the net field is along OC: A is true.

The potential at O is $\frac{1}{4\pi\varepsilon_0}\frac{(+q)+(-q)}{R} = 0$, so R is false.

CBSE 2023 · 55/1/1 · Q1 | CBSE 2023 · 55/1/2 · Q15 | CBSE 2023 · 55/1/3 · Q9 **asked 3 times** — 1 mark

A point charge situated at a distance 'r' from a short electric dipole on its axis, experiences a force $\vec{F}$. If the distance of the charge is '2r', the force on the charge will be

(a) $\frac{\vec{F}}{16}$ (b) $\frac{\vec{F}}{8}$

(c) $\frac{\vec{F}}{4}$ (d) $\frac{\vec{F}}{2}$

Solution

Answer: (b) $\frac{\vec{F}}{8}$

On the axis of a short dipole $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2p}{r^3}$, so $F = qE \propto \frac{1}{r^3}$. Doubling r makes the force $\frac{1}{2^3} = \frac{1}{8}$ of its value.

CBSE 2023 · 55/2/1 · Q1 — 1 mark

The magnitude of the electric field due to a point charge object at a distance of 4.0 m is 9 N/C. From the same charged object the electric field of magnitude, 16 N/C will be at a distance of

(a) 1 m (b) 2 m

(c) 3 m (d) 6 m

Solution

Answer: (c) 3 m

$E \propto \frac{1}{r^2}$: $\frac{16}{9} = \frac{4^2}{r^2}$, so $r^2 = 9$ and r = 3 m.

CBSE 2023 · 55/2/2 · Q5 — 1 mark

An isolated point charge particle produces an electric field $\vec{E}$ at a point 3 m away from it. The distance of the point at which the field is $\frac{\vec{E}}{4}$ will be

(a) 2 m (b) 3 m

(c) 4 m (d) 6 m

Solution

Answer: (d) 6 m

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$E \propto \frac{1}{r^2}$. For the field to fall to a quarter, r must double: $r = 2 \times 3 = 6$ m.

CBSE 2023 · 55/2/3 · Q7 — 1 mark

An electric dipole of dipole moment 2×10^{-8} C-m in a uniform electric field experiences a maximum torque of 6×10^{-4} N-m. The magnitude of electric field is

(a) 2.2×10^{3} Vm^{-1} (b) 1.2×10^{4} Vm^{-1}
(c) 3.0×10^{4} Vm^{-1} (d) 4.2×10^{3} Vm^{-1}

Solution

Answer: (c) 3.0×10^{4} Vm^{-1}

$\tau_{max} = pE$ (at θ = 90°), so $E = \frac{6 \times 10^{-4}}{2 \times 10^{-8}} = 3.0 \times 10^{4}$ V m^{-1}.

CBSE 2023 · 55/3/1 · Q1 — 1 mark

An electron experiences a force $(1.6 \times 10^{-16}\ \mathrm{N})\,\hat{i}$ in an electric field $\vec{E}$. The electric field $\vec{E}$ is :

(a) $\left(1.0 \times 10^{3}\frac{N}{C}\right)\hat{i}$ (b) $-\left(1.0 \times 10^{3}\frac{N}{C}\right)\hat{i}$
(c) $\left(1.0 \times 10^{-3}\frac{N}{C}\right)\hat{i}$ (d) $-\left(1.0 \times 10^{-3}\frac{N}{C}\right)\hat{i}$

Solution

Answer: (b) $-\left(1.0 \times 10^{3}\frac{N}{C}\right)\hat{i}$

$\vec{E} = \frac{\vec{F}}{q} = \frac{1.6 \times 10^{-16}\hat{i}}{-1.6 \times 10^{-19}} = -1.0 \times 10^{3}\hat{i}$ N/C. The field is opposite to the force because the electron is negative.

CBSE 2023 · 55/3/1 · Q2 — 1 mark

Which one of the following is ***not*** a scalar quantity ?

(a) Electric field (b) Voltage
(c) Resistivity (d) Power

Solution

Answer: (a) Electric field

Electric field has both magnitude and direction (a vector). Voltage, resistivity and power have magnitude only.

CBSE 2023 · 55/3/2 · Q4 — 1 mark

An infinitely long uniformly charged wire produces an electric field of 18×10^{4} NC^{-1} at a distance of 1·0 cm. The linear charge density on the wire is :

(a) 1.12×10^{-14} Cm^{-1} (b) 3.08×10^{-15} Cm^{-1}
(c) 1.0×10^{-9} Cm^{-1} (d) 1.0×10^{-7} Cm^{-1}

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Solution

Answer: (d) 1.0×10^{-7} **Cm^{-1}**

$E = \dfrac{\lambda}{2\pi\varepsilon_0 r} = \dfrac{2k\lambda}{r}$, so $\lambda = \dfrac{Er}{2k} = \dfrac{18 \times 10^4 \times 0.01}{2 \times 9 \times 10^9} = 1.0 \times 10^{-7}$ C m^{-1}.

CBSE 2023 · 55/4/1 · Q1 — 1 mark

Two charges q_1 and q_2 are placed at the centres of two spherical conducting shells of radius r_1 and r_2 respectively. The shells are arranged such that their centres are d [> (r_1 + r_2)] distance apart. The force on q_2 due to q_1 is :

(a) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{d^2}$

(b) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{(d-r_1)^2}$

(c) Zero

(d) $\dfrac{1}{4\pi\varepsilon_0}\dfrac{q_1 q_2}{[d-(r_1+r_2)]^2}$

Solution

Answer: (c) Zero

q_2 sits inside a closed conducting shell. The shell shields its cavity from external fields (electrostatic shielding): the charges induced on its outer surface rearrange so that the field of q_1 (and its shell) is cancelled everywhere inside. So no net field from outside acts on q_2.

CBSE 2023 · 55/4/2 · Q6 — 1 mark

A point charge q is kept at a distance r from an infinitely long straight wire with charge density λ. The magnitude of the electrostatic force experienced by charge q is :

(a) Zero

(b) $\dfrac{q\lambda}{2\pi\varepsilon_0 r}$

(c) $\dfrac{q\lambda}{4\pi\varepsilon_0 r}$

(d) $\dfrac{q\lambda}{\pi\varepsilon_0 r}$

Solution

Answer: (b) $\dfrac{q\lambda}{2\pi\varepsilon_0 r}$

By Gauss's law the field of an infinite line charge is $E = \dfrac{\lambda}{2\pi\varepsilon_0 r}$, so $F = qE = \dfrac{q\lambda}{2\pi\varepsilon_0 r}$.

CBSE 2023 · 55/4/3 · Q4 — 1 mark

A particle of mass m and charge –q is moving with a uniform speed v in a circle of radius r, with another charge q at the centre of the circle. The value of r is :

(a) $\dfrac{1}{4\pi\varepsilon_0 m}\left(\dfrac{q}{v}\right)$

(b) $\dfrac{1}{4\pi\varepsilon_0 m}\left(\dfrac{q}{v}\right)^2$

(c) $\dfrac{m}{4\pi\varepsilon_0}\left(\dfrac{q}{v}\right)$

(d) $\dfrac{m}{4\pi\varepsilon_0}\left(\dfrac{q}{v}\right)^2$

Solution

Answer: (b) $\dfrac{1}{4\pi\varepsilon_0 m}\left(\dfrac{q}{v}\right)^2$

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The Coulomb attraction provides the centripetal force: $\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} = \frac{mv^2}{r}$, so $r = \frac{1}{4\pi\varepsilon_0 m}\frac{q^2}{v^2}$.

CBSE 2023 · 55/5/1 · Q1 | CBSE 2023 · 55/5/3 · Q1 **asked 2 times** **1 mark**

An electric dipole of length 2 cm is placed at an angle of 30° with an electric field 2×10^5 N/C. If the dipole experiences a torque of 8×10^{-3} Nm, the magnitude of either charge of the dipole, is

(A) 4 μC (B) 7 μC

(C) 8 mC (D) 2 mC

Solution

Answer: (A) 4 μC

$\tau = pE\sin\theta = q(2a)E\sin\theta$: $8 \times 10^{-3} = q \times 0.02 \times 2 \times 10^5 \times \frac{1}{2} = 2000q$, so $q = 4 \times 10^{-6}$ C = 4 μC.

CBSE 2023 · 55/5/2 · Q1 **1 mark**

A charge Q is placed at the centre of a cube. The electric flux through one of its face is

(A) $\frac{Q}{\varepsilon_0}$ (B) $\frac{Q}{6\varepsilon_0}$

(C) $\frac{Q}{8\varepsilon_0}$ (D) $\frac{Q}{3\varepsilon_0}$

Solution

Answer: (B) $\frac{Q}{6\varepsilon_0}$

Total flux through the cube $= \frac{Q}{\varepsilon_0}$ (Gauss's law). By symmetry the six faces share it equally: $\frac{Q}{6\varepsilon_0}$ each.

CBSE 2020 · 55/1/1 · Q1 | CBSE 2020 · 55/1/2 · Q9 | CBSE 2020 · 55/1/3 · Q9 **asked 3 times** **1 mark**

If the net electric flux through a closed surface is zero, then we can infer

(A) no net charge is enclosed by the surface. (B) uniform electric field exists within the surface.

(C) electric potential varies from point to point inside the surface. (D) charge is present inside the surface.

Solution

Answer: (A) no net charge is enclosed by the surface.

By Gauss's law $\Phi = \frac{q_{enc}}{\varepsilon_0}$; zero flux means the net enclosed charge is zero (there may be equal positive and negative charges inside).

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CBSE 2020 · 55/1/2 · Q8 — 1 mark

An electric dipole placed in a non-uniform electric field can experience

(A) a force but not a torque.
(B) a torque but not a force.
(C) always a force and a torque.
(D) neither a force nor a torque.

Solution

Answer: (C) always a force and a torque (as per the CBSE marking scheme).

In a non-uniform field the forces on +q and –q are unequal, so there is a net force; in general they also form a couple, giving a torque (the torque vanishes only when $\vec{p}$ is parallel or antiparallel to $\vec{E}$).

CBSE 2020 · 55/1/3 · Q8 — 1 mark

A point charge is situated at an axial point of a small electric dipole at a large distance from it. The charge experiences a force F. If the distance of the charge is doubled, the force acting on the charge will become

(A) 2F
(B) F/2
(C) F/4
(D) F/8

Solution

Answer: (D) F/8

On the axis, far away, the dipole field is $E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3} \propto \frac{1}{r^3}$, so F = qE ∝ 1/r³. Doubling r gives $\frac{F}{8}$.

CBSE 2020 · 55/2/1 · Q11 — 1 mark

Fill in the blank: If the electric flux entering and leaving a closed surface in air are ϕ_1 and ϕ_2 respectively, the net electric charge enclosed within the surface is _____.

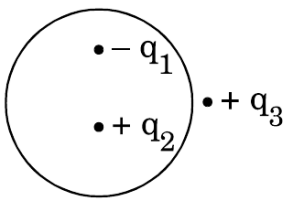
Solution

Answer: $(\phi_2 - \phi_1)\varepsilon_0$

Net outward flux $= \phi_2 - \phi_1 = \frac{q}{\varepsilon_0}$.

CBSE 2020 · 55/2/2 · Q11 — 1 mark

Fill in the blank: Electric flux through a spherical surface shown in the figure, is _____ .



Solution

Answer: $\frac{q_2 - q_1}{\varepsilon_0}$

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By Gauss's law only the charges inside count: $-q_1$ and $+q_2$. The charge $+q_3$ outside contributes zero net flux.

CBSE 2020 · 55/3/1 · Q2 | CBSE 2020 · 55/3/2 · Q10 | CBSE 2020 · 55/3/3 · Q9 **asked 3 times** **1 mark**

The electric flux emerging out from 1 C charge is

(A) $\frac{1}{\varepsilon_0}$

(B) 4π

(C) $\frac{4\pi}{\varepsilon_0}$

(D) ε_0

Solution

Answer: (A) $\frac{1}{\varepsilon_0}$

By Gauss's law, flux $= \frac{q}{\varepsilon_0} = \frac{1}{\varepsilon_0}$ (in N m^2 C^{-1}).

CBSE 2020 · 55/3/2 · Q3 **1 mark**

An electric dipole consisting of charges + q and – q separated by a distance r, is kept symmetrically at the centre of an imaginary sphere of radius R (> r). Another point charge Q is also kept at the centre of the sphere. The net electric flux coming out of the sphere will be

(A) $\frac{-(2q+Q)}{4\pi\varepsilon_0}$

(B) $\frac{Q}{\varepsilon_0}$

(C) $\frac{2q+Q}{\varepsilon_0}$

(D) $\frac{-Q}{\varepsilon_0}$

Solution

Answer: (B) $\frac{Q}{\varepsilon_0}$

Net charge enclosed = +q – q + Q = Q, so by Gauss's law the flux is Q/ε_0.

CBSE 2020 · 55/3/3 · Q3 **1 mark**

Two large conducting spheres carrying charges Q_1 and Q_2 are kept with their centres r distance apart. The magnitude of electrostatic force between them is not exactly $\frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}$ because

(A) these are not point charges.

(B) charge distribution on the spheres is not uniform.

(C) charges on spheres will shift towards the centres of their respective spheres.

(D) charges will shift towards the portions of the spheres which are closer and facing towards each other.

Solution

Answer: (B)

A uniformly charged sphere acts as a point charge at its centre. But when two large conductors are brought near each other, each induces a redistribution of charge on the other, so the charge

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distributions are no longer uniform and the effective centres of charge are not at the geometric centres.

CBSE 2020 · 55/4/1 · Q11 | CBSE 2020 · 55/4/2 · Q15 | CBSE 2020 · 55/4/3 · Q12 **asked 3 times** **1 mark**

Fill in the blank: Torque acting on an electric dipole placed in an electric field is maximum when the angle between the electric field and the dipole moment is _____.

Solution

Answer: 90° (π/2), since τ = pE sin θ.

CBSE 2020 · 55/5/1 · Q7 | CBSE 2020 · 55/5/2 · Q9 | CBSE 2020 · 55/5/3 · Q4 **asked 3 times** **1 mark**

The electric flux through a closed Gaussian surface depends upon

(a) Net charge enclosed and permittivity of the medium

(b) Net charge enclosed, permittivity of the medium and the size of the Gaussian surface

(c) Net charge enclosed only

(d) Permittivity of the medium only

Solution

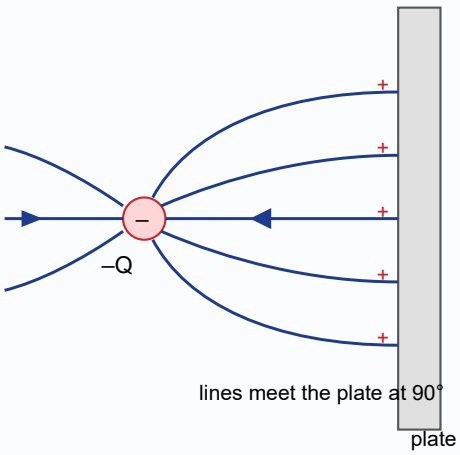
Answer: (a)

By Gauss's law $\phi = \frac{q_{enc}}{\varepsilon}$: it depends on the enclosed charge and the permittivity of the medium, not on the size or shape of the surface.

CBSE 2019 · 55/1/1 · Q1 **1 mark**

Draw the pattern of electric field lines, when a point charge – Q is kept near an uncharged conducting plate.

Solution



The field lines end on the charge –Q. They start on the induced positive charge on the near surface of the plate, and they meet the conducting surface at right angles (a conductor's surface is an equipotential).

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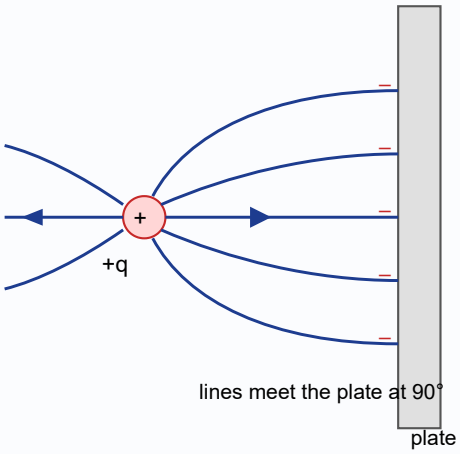
CBSE 2019 · 55/1/3 · Q5 — 1 mark

Draw the pattern of electric field lines when a point charge +q is kept near an uncharged conducting plate.

Solution

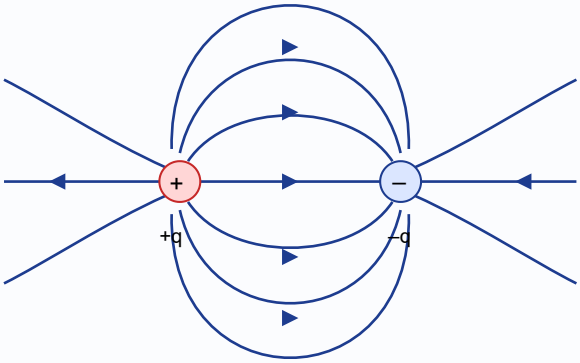


The field lines start on +q. Those towards the plate end on the negative charge induced on its near surface, and they meet the conducting surface at right angles (a conductor's surface is an equipotential).

CBSE 2019 · 55/2/2 · Q3 — 1 mark

Draw the pattern of electric field lines due to an electric dipole.

Solution



The lines start on +q and end on –q; they never cross, and between the charges they are crowded (strong field).

CBSE 2019 · 55/2/3 · Q2 — 1 mark

Draw a pattern of electric field lines due to two positive charges placed a distance d apart.

Solution

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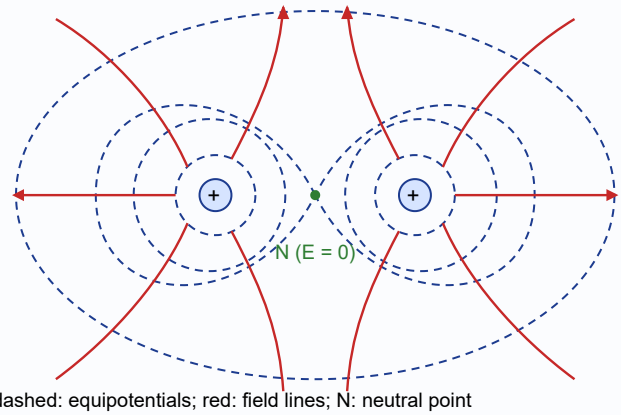
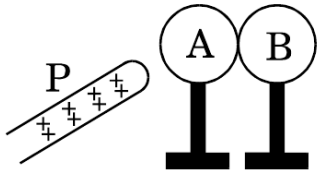


dashed: equipotentials; red: field lines; N: neutral point

The lines start on each positive charge and go out to infinity; lines from the two charges repel one another and never cross. Midway between the equal charges there is a neutral point N where E = 0.

CBSE 2019 · 55/3/1 · Q1(a) | CBSE 2019 · 55/3/2 · Q3(a) | CBSE 2019 · 55/3/3 · Q4(a) **asked 3 times** **1 mark**

Two metallic spheres A and B kept on insulating stands are in contact with each other. A positively charged rod P is brought near the sphere A as shown in the figure. The two spheres are separated from each other, and the rod P is removed. What will be the nature of charges on spheres A and B ?

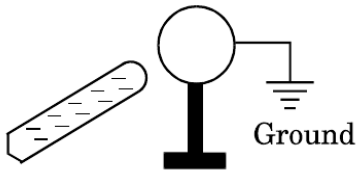


Solution

A becomes negatively charged and B positively charged. The positive rod attracts free electrons to the near sphere A and leaves a deficit of electrons (positive charge) on the far sphere B. Separating the spheres while the rod is still near traps these charges, and they remain after the rod is removed.

CBSE 2019 · 55/3/1 · Q1(b) | CBSE 2019 · 55/3/2 · Q3(b) | CBSE 2019 · 55/3/3 · Q4(b) **asked 3 times** **1 mark**

A metal sphere is kept on an insulating stand. A negatively charged rod is brought near it, then the sphere is earthed as shown. On removing the earthing, and taking the negatively charged rod away, what will be the nature of charge on the sphere ? Give reason for your answer.



Solution

Positive. The negative rod repels free electrons of the sphere to the far side; on earthing, these electrons flow to the earth. When the earth connection is removed first and then the rod, the sphere is left with a deficit of electrons, i.e. a positive charge (charging by induction).

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CBSE 2019 · 55/4/1 · Q1(a) | CBSE 2019 · 55/4/2 · Q3(a) | CBSE 2019 · 55/4/3 · Q4(a) **asked 3 times** **1 mark**

Two identical conducting balls A and B have charges –Q and +3Q respectively. They are brought in contact with each other and then separated by a distance d apart. Find the nature of the Coulomb force between them.

Solution

On contact the total charge –Q + 3Q = +2Q is shared equally (identical balls): each gets +Q. Two like charges: the force is **repulsive**, of magnitude $\frac{1}{4\pi\varepsilon_0}\cdot\frac{Q^2}{d^2}$.

CBSE 2019 · 55/4/1 · Q1(b) | CBSE 2019 · 55/4/2 · Q3(b) | CBSE 2019 · 55/4/3 · Q4(b) **asked 3 times** **1 mark**

A metallic spherical shell has an inner radius R_1 and outer radius R_2. A charge Q is placed at the centre of the shell. What will be the surface charge density on the (i) inner surface, and (ii) outer surface of the shell ?

Solution

The field inside the conducting material is zero, so a charge –Q is induced on the inner surface and +Q on the outer surface (the shell is uncharged).

(i) $\sigma_{inner} = -\frac{Q}{4\pi R_1^2}$ (ii) $\sigma_{outer} = +\frac{Q}{4\pi R_2^2}$

CBSE 2017 · 55/1/1 · Q1 | CBSE 2017 · 55/1/2 · Q3 | CBSE 2017 · 55/1/3 · Q5 **asked 3 times** **1 mark**

Does the charge given to a metallic sphere depend on whether it is hollow or solid ? Give reason for your answer.

Solution

No. Charge given to a conductor resides only on its outer surface, so it does not matter whether the inside is hollow or solid.

CBSE 2016 · 55/1/1 · Q2 | CBSE 2016 · 55/1/2 · Q5 | CBSE 2016 · 55/1/3 · Q3 **asked 3 times** **1 mark**

How does the electric flux due to a point charge enclosed by a spherical Gaussian surface get affected when its radius is increased ?

Solution

No change. By Gauss's law $\Phi = \frac{q}{\varepsilon_0}$, which depends only on the charge enclosed and not on the radius of the surface.

CBSE 2016 · 55/2/1 · Q5 | CBSE 2016 · 55/2/2 · Q3 | CBSE 2016 · 55/2/3 · Q2 **asked 3 times** **1 mark**

Define Electric Flux. Write its SI unit.

Solution

Electric flux through a surface is the surface integral of the electric field over it: $\Phi = \oint \vec{E}\cdot d\vec{S}$ (a measure of the number of field lines crossing the surface). SI unit: **N m² C⁻¹** (equivalently V m).

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2 marks: very short answer

CBSE 2026 · 55/4/1 · Q17 | CBSE 2026 · 55/4/2 · Q21 | CBSE 2026 · 55/4/3 · Q18 **asked 3 times** **2 marks**

An electric dipole consists of two point charges +1 μC and –1 μC, held 10 cm apart. It is subjected to a uniform electric field of 100 N/C. Calculate the amount of work done in turning the dipole from its position of stable equilibrium to the position of unstable equilibrium, in the field.

Solution

$p = q(2a) = 1 \times 10^{-6} \times 0.10 = 1 \times 10^{-7}$ C m.

$W = pE(\cos\theta_1 - \cos\theta_2)$ with $\theta_1 = 0^\circ$ (stable) and $\theta_2 = 180^\circ$ (unstable):

$$W = pE(1 - (-1)) = 2pE = 2 \times 10^{-7} \times 100 = \mathbf{2 \times 10^{-5}\ J}$$

CBSE 2024 · 55/5/1 · Q17(a) | CBSE 2024 · 55/5/2 · Q17(a) | CBSE 2024 · 55/5/3 · Q18(a) **asked 3 times** **2 marks**

Four point charges of 1 μC, –2 μC, 1 μC and –2 μC are placed at the corners A, B, C and D respectively, of a square of side 30 cm. Find the net force acting on a charge of 4 μC placed at the centre of the square.

Solution

All four corners are at the same distance $r = \dfrac{30}{\sqrt{2}}$ cm from the centre O.

A and C (both +1 μC) are at opposite corners: their forces on the 4 μC charge are equal in size and opposite in direction, so they cancel.

B and D (both –2 μC) are also at opposite corners: their forces are equal and opposite, so they cancel too.

Net force on the 4 μC charge = **zero**.

CBSE 2024 · 55/5/1 · Q17(b) | CBSE 2024 · 55/5/2 · Q17(b) | CBSE 2024 · 55/5/3 · Q18(b) **asked 3 times** **2 marks**

Three point charges, 1 pC each, are kept at the vertices of an equilateral triangle of side 10 cm. Find the net electric field at the centroid of triangle.

Solution

The centroid is equidistant from the three vertices ($r = \dfrac{a}{\sqrt{3}}$), so the three fields have equal magnitude $E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{r^2}$ and point away from the respective vertices, at 120° to one another.

Three equal vectors at 120° add to zero. Net field at the centroid = **zero**.

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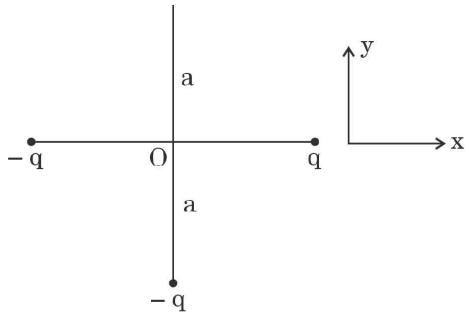
CBSE 2023 · 55/4/1 · Q19 — 2 marks

Two identical dipoles are arranged in x-y plane as shown in the figure. Find the magnitude and the direction of net electric field at the origin O.



Solution

Let $k = \dfrac{1}{4\pi\varepsilon_0}$. Each charge is at distance a from O.

Dipole on the x-axis (–q at (–a, 0), +q at (a, 0)): +q pushes a test charge at O away from it, towards –x; –q pulls it towards itself, also towards –x. $E_1 = \dfrac{2kq}{a^2}$ along –x.

Dipole on the y-axis (+q at (0, a), –q at (0, –a)): similarly $E_2 = \dfrac{2kq}{a^2}$ along –y.

$$E = \sqrt{E_1^2 + E_2^2} = \frac{2\sqrt{2}\,kq}{a^2} = \frac{\sqrt{2}\,q}{2\pi\varepsilon_0 a^2}$$

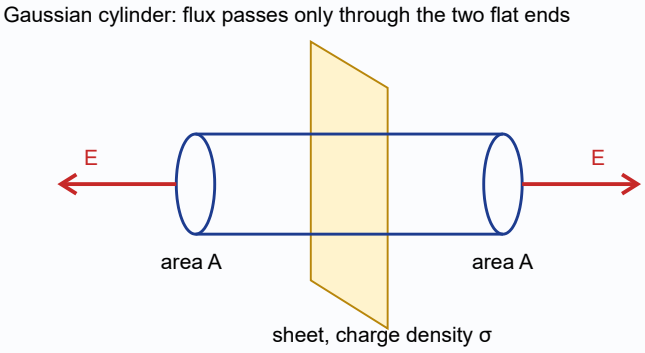
It points along the bisector of the –x and –y axes, i.e. at 45° below the –x axis (225° from +x).

CBSE 2023 · 55/4/2 · Q24 — 2 marks

Use Gauss's law to obtain the expression for electric field due to a uniformly charged infinite plane thin sheet.

Solution

Let the sheet have surface charge density σ. Take a cylindrical Gaussian surface of cross-section A, cutting the sheet perpendicularly, with its flat ends on either side.



By symmetry $\vec{E}$ is perpendicular to the sheet, pointing away on both sides (σ > 0), with the same magnitude at equal distances. No flux passes through the curved surface; each flat end has flux EA. Total flux = 2EA; charge enclosed = σA.

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}, \qquad \vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$$

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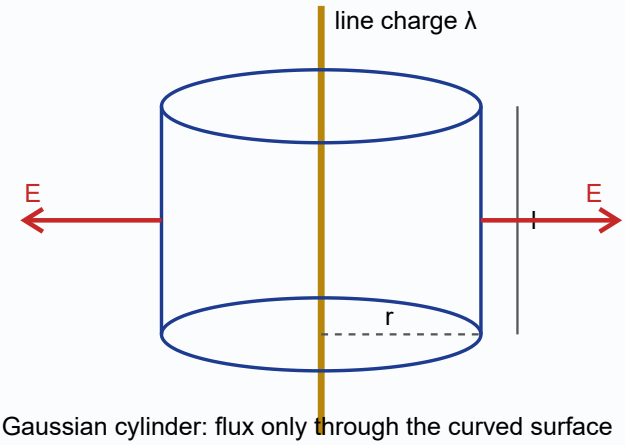
The field is uniform: it does not depend on the distance from the sheet.

CBSE 2023 · 55/4/3 · Q21 — 2 marks

Use Gauss's law to obtain an expression for the electric field due to an infinitely long straight uniformly charged wire.

Solution

Let the wire have linear charge density λ. By symmetry the field is radial (perpendicular to the wire) and has the same magnitude at all points at distance r. Choose a coaxial cylindrical Gaussian surface of radius r and length l.



Gaussian cylinder: flux only through the curved surface

There is no flux through the flat ends ($\vec{E}$ is parallel to them); through the curved surface the flux is $E \cdot 2\pi rl$. Charge enclosed = λl. Gauss's law:

$$E \cdot 2\pi rl = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

directed radially outward for λ > 0; E ∝ 1/r.

CBSE 2020 · 55/5/1 · Q21(a) | CBSE 2020 · 55/5/2 · Q27(a) | CBSE 2020 · 55/5/3 · Q26(a) — asked 3 times — 2 marks

Derive the expression for the torque acting on an electric dipole, when it is held in a uniform electric field. Identify the orientation of the dipole in the electric field, in which it attains a stable equilibrium.

Solution

A dipole of charges ±q, separation 2a, makes angle θ with a uniform field $\vec{E}$. The forces qE and –qE are equal and opposite (no net force) but have different lines of action: they form a couple. The perpendicular distance between them is $2a\sin\theta$:

$$\tau = qE(2a\sin\theta) = pE\sin\theta, \qquad \vec{\tau} = \vec{p} \times \vec{E}$$

Stable equilibrium: when $\vec{p}$ is parallel to $\vec{E}$ (θ = 0°); then τ = 0 and the potential energy –pE is minimum, so a small rotation produces a restoring torque.

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CBSE 2019 · 55/3/1 · Q6(a) | CBSE 2019 · 55/3/2 · Q9(a) | CBSE 2019 · 55/3/3 · Q12(a) asked 3 times 2 marks

Five point charges, each of charge + q are placed on five vertices of a regular hexagon of side 'l'. Find the magnitude of the resultant force on a charge – q placed at the centre of the hexagon.

Solution

Each vertex of a regular hexagon is at distance l from the centre. If all six vertices carried +q, the six forces on –q would cancel in pairs (equal and opposite) and the net force would be zero.

With the charge missing at one vertex V, the net force equals minus the force that the missing charge would have exerted. That force (attraction towards V) has magnitude $\frac{1}{4\pi\varepsilon_0}\cdot\frac{q^2}{l^2}$, so

$$F=\frac{1}{4\pi\varepsilon_0}\cdot\frac{q^2}{l^2}$$

directed from the centre towards the vertex opposite to the empty one (i.e. away from the empty vertex).

CBSE 2019 · 55/3/1 · Q6(b) | CBSE 2019 · 55/3/2 · Q9(b) | CBSE 2019 · 55/3/3 · Q12(b) asked 3 times 2 marks

A simple pendulum consists of a small sphere of mass m suspended by a thread of length l. The sphere carries a positive charge q. The pendulum is placed in a uniform electric field of strength E directed vertically downwards. Find the period of oscillation of the pendulum due to the electrostatic force acting on the sphere, neglecting the effect of the gravitational force.

Solution

The electric force qE acts vertically downwards, like weight. For a small displacement x, the restoring force is $F=-qE\sin\theta\approx -qE\frac{x}{l}$:

$$m\frac{d^2x}{dt^2}=-\frac{qE}{l}x\Rightarrow\omega^2=\frac{qE}{ml}$$

This is SHM with

$$T=\frac{2\pi}{\omega}=2\pi\sqrt{\frac{ml}{qE}}$$

CBSE 2019 · 55/4/1 · Q6(a) | CBSE 2019 · 55/4/2 · Q9(a) | CBSE 2019 · 55/4/3 · Q8(a) asked 3 times 2 marks

Apply Gauss's law to show that for a charged spherical shell, the electric field outside the shell is, as if the entire charge were concentrated at the centre.

Solution

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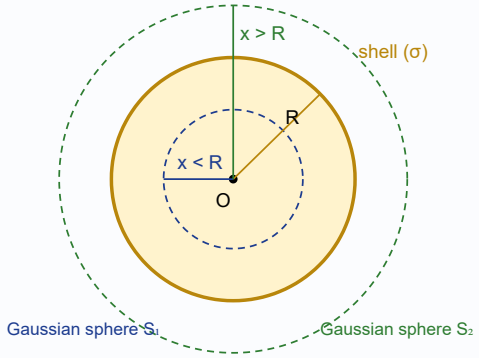


Let the shell of radius R carry charge q. For a point P at distance r > R, take a concentric spherical Gaussian surface of radius r through P. By symmetry $\vec{E}$ is radial and has the same magnitude at every point of this surface, so

$$\oint \vec{E} \cdot d\vec{S} = E \cdot 4\pi r^2$$

The charge enclosed is q, so by Gauss's law $E \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$:

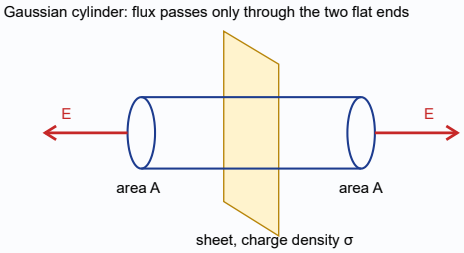
$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$$

This is the field of a point charge q placed at the centre.

CBSE 2019 · 55/4/1 · Q6(b) | CBSE 2019 · 55/4/2 · Q9(b) | CBSE 2019 · 55/4/3 · Q8(b) **asked 3 times** **2 marks**

Two large parallel plane sheets have uniform charge densities +σ and –σ. Determine the electric field (i) between the sheets, and (ii) outside the sheets.

Solution



A single large sheet of charge density σ produces $E = \frac{\sigma}{2\varepsilon_0}$ on either side, directed away from it if positive (towards it if negative).

(i) **Between the sheets** both fields point from the +σ sheet to the –σ sheet and add:

$$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}$$

(ii) **Outside** (on either side) the two fields are equal and opposite: E = 0.

CBSE 2019 · 55/5/1 · Q6(a) | CBSE 2019 · 55/5/2 · Q8(a) | CBSE 2019 · 55/5/3 · Q10(a) **asked 3 times** **2 marks**

Derive an expression for the torque acting on an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. Write the direction along which the torque acts.

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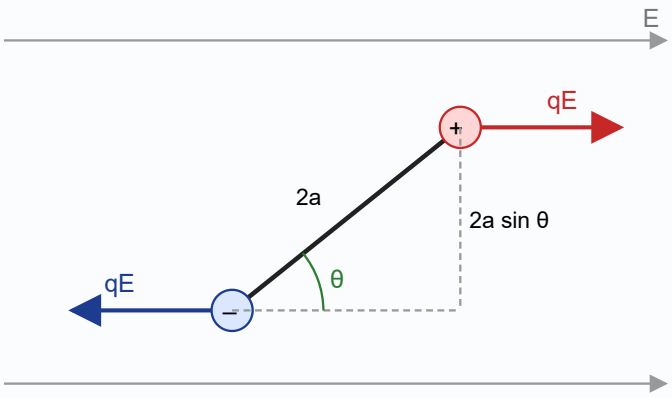
Solution



couple: τ = qE · 2a sin θ = pE sin θ; τ = p × E

Let the dipole (charges ±q, separation 2a) make angle θ with $\vec{E}$. The forces +q$\vec{E}$ and –q$\vec{E}$ are equal and opposite, so the net force is zero, but they act along different lines and form a couple. The perpendicular distance between their lines of action is 2a sin θ:

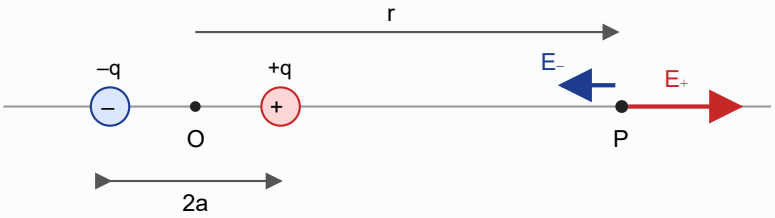
$$\tau = qE \times 2a\sin\theta = pE\sin\theta, \qquad \vec{\tau} = \vec{p} \times \vec{E}$$

Direction: perpendicular to the plane containing $\vec{p}$ and $\vec{E}$ (by the right-hand rule for $\vec{p} \times \vec{E}$); it tends to rotate the dipole into alignment with $\vec{E}$.

CBSE 2019 · 55/5/1 · Q6(b) | CBSE 2019 · 55/5/2 · Q8(b) | CBSE 2019 · 55/5/3 · Q10(b) **asked 3 times** **2 marks**

Derive an expression for the electric field at a point on the axis of an electric dipole of dipole moment $\vec{p}$. Also write its expression when the distance r >> the length 'a' of the dipole.

Solution



Let P be on the axis at distance r from the centre O, on the side of +q. Distance from +q is (r – a) and from –q is (r + a).

$$E_+ = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r-a)^2}\ (\text{away from } +\text{q}), \qquad E_- = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r+a)^2}\ (\text{towards } -\text{q})$$

$$E = E_+ - E_- = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right] = \frac{1}{4\pi\varepsilon_0}\cdot\frac{4qar}{(r^2-a^2)^2} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2pr}{(r^2-a^2)^2}$$

directed along $\vec{p}$ (p = 2qa).

For r ≫ a: $\vec{E} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2\vec{p}}{r^3}$.

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CBSE 2016 · 55/1/E · Q6 | CBSE 2016 · 55/2/E · Q8 | CBSE 2016 · 55/3/E · Q7 **asked 3 times** **2 marks**

Derive an expression for the work done in rotating a dipole from the angle θ_0 to θ_1 in a uniform electric field E.

Solution

At angle θ the field exerts a torque τ = pE sin θ on the dipole. To rotate it slowly through a further angle dθ against this torque, the work needed is dW = pE sin θ dθ. So

$$W = \int_{\theta_0}^{\theta_1} pE \sin\theta \, d\theta = pE(\cos\theta_0 - \cos\theta_1)$$

This work is stored as the potential energy of the dipole.

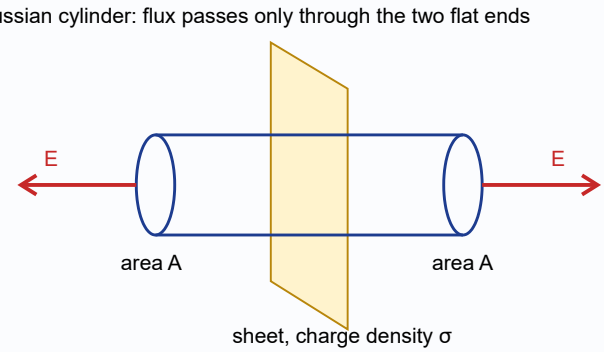
3 marks: short answer

CBSE 2026 · 55/1/1 · Q22(a) | CBSE 2026 · 55/1/2 · Q24(a) | CBSE 2026 · 55/1/3 · Q25(a) **asked 3 times** **3 marks**

(a) Using Gauss's law, deduce an expression for electric field at a point due to a uniformly charged infinite plane thin sheet.
(b) Two large thin plane sheets, each having surface charge density σ, are held close and parallel to each other in air. What is the net electric field at a point (i) inside and (ii) outside, the sheets?

Solution

(a) Take a cylindrical Gaussian surface of end-area A, cutting the sheet perpendicularly.



By symmetry $\vec{E}$ is normal to the sheet. There is no flux through the curved surface; through each flat end the flux is EA.
Total flux $= 2EA$; charge enclosed $= \sigma A$. Gauss's law:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

directed away from the sheet if $\sigma > 0$; it does not depend on distance.
(b) Each sheet gives $\frac{\sigma}{2\varepsilon_0}$.
(i) Inside: the two fields are opposite, so $E = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$.
(ii) Outside: the fields add, so $E = \frac{\sigma}{\varepsilon_0}$, directed away from the sheets.

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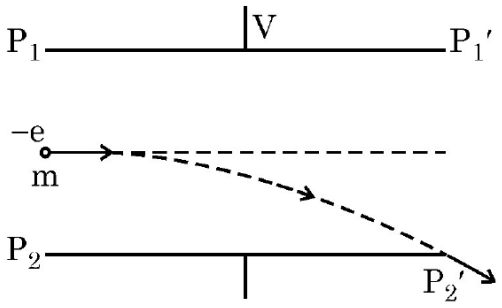
CBSE 2026 · 55/1/1 · Q24 | CBSE 2026 · 55/1/2 · Q22 | CBSE 2026 · 55/1/3 · Q23 **asked 3 times** **3 marks**

Figure shows a narrow beam of electrons entering with a velocity of 3×10^7 m/s, symmetrically through the space between two parallel horizontal plates P_1P_1' and P_2P_2' kept 2 cm apart. If each plate is 3 cm long, calculate the potential difference V applied between the plates so that the beam just strikes the end P_2'.



Solution

Field between plates $E = \dfrac{V}{d}$; acceleration of the electron $a = \dfrac{eE}{m} = \dfrac{eV}{md}$ (towards the positive plate).

Time to cross the plates: $t = \dfrac{L}{u}$.

To just strike the end, the deflection must be $y = \dfrac{d}{2} = 1$ cm:

$$y = \frac{1}{2}at^2 = \frac{1}{2} \cdot \frac{eV}{md} \cdot \frac{L^2}{u^2} \Rightarrow V = \frac{2ymdu^2}{eL^2}$$

$$V = \frac{2 \times 0.01 \times 9.1 \times 10^{-31} \times 0.02 \times (3 \times 10^7)^2}{1.6 \times 10^{-19} \times (0.03)^2} = \frac{3.276 \times 10^{-19}}{1.44 \times 10^{-22}} \approx \mathbf{2275\ V}$$

CBSE 2026 · 55/5/3 · Q25 **3 marks**

Two point charges $q_1 = 2.5 \times 10^{-7}$ C and $q_2 = -2.5 \times 10^{-7}$ C are located at points (0, 0, – 15 cm) and (0, 0, 15 cm) respectively. Find :
(a) the electric dipole moment of the system, and
(b) the magnitude and direction of electric field at the origin (0, 0, 0).

Solution

(a) $p = q \times 2a = 2.5 \times 10^{-7} \times 0.30 = \mathbf{7.5 \times 10^{-8}\ C\ m}$, directed from the negative to the positive charge, i.e. along **–z**.

(b) Each charge is 0.15 m from the origin:

$$E_1 = E_2 = \frac{9 \times 10^9 \times 2.5 \times 10^{-7}}{(0.15)^2} = \frac{2250}{0.0225} = 1.0 \times 10^5\ \text{N/C}$$

The field of q_1 (positive, below the origin) points away from it, along +z; the field of q_2 (negative, above) points towards it, also along +z. So

$$E = 2.0 \times 10^5\ \text{N/C along } +z$$

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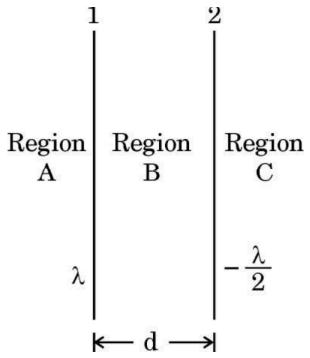
CBSE 2025 · 55/5/1 · Q28(b) | CBSE 2025 · 55/5/2 · Q22(b) | CBSE 2025 · 55/5/3 · Q26(b) **asked 3 times** **3 marks**

Two infinitely long straight wires '1' and '2' are placed d distance apart, parallel to each other, as shown in the figure. They are uniformly charged having charge densities λ and $-\frac{\lambda}{2}$ respectively. Locate the position of the point from wire '1' at which the net electric field is zero and identify the region in which it lies.



Solution

Field of a line charge: $E = \dfrac{\lambda}{2\pi\varepsilon_0 r}$, away from a positive and towards a negative line.

Region B (between the wires): both fields point from 1 towards 2, so they cannot cancel.

Region A: wire 1 is nearer and has the larger charge, so its field always wins.

Region C, at distance x from wire 1 (x > d): the field of wire 1 points away from it, that of wire 2 points towards wire 2, i.e. opposite. For E = 0:

$$\frac{\lambda}{2\pi\varepsilon_0 x} = \frac{\lambda/2}{2\pi\varepsilon_0 (x-d)} \Rightarrow 2(x-d) = x \Rightarrow x = \mathbf{2d}$$

The point lies in **region C**, at distance 2d from wire 1 (d beyond wire 2).

CBSE 2025 · 55/7/3 · Q23 **3 marks**

An electric field $\vec{E}$ given by : $\vec{E} = 100\hat{i}$ N/C for x > 0, $= -100\hat{i}$ N/C for x < 0, exists in a region. A right circular cylinder of length 10 cm and radius 2 cm, is placed in the region such that its axis coincides with x-axis and its two faces are at x = – 5 cm and x = 5 cm. Calculate :
(a) the net outward flux through the cylinder, and
(b) the net charge inside the cylinder.

Solution

(a) On the curved surface $\vec{E}$ is parallel to the surface, so the flux there is zero. On both flat faces the field points outward (along +x at x = +5 cm and along –x at x = –5 cm), each with flux

$$EA = 100 \times \pi(0.02)^2 = 100 \times 1.257 \times 10^{-3} = 0.1257\ \mathrm{N\,m^2/C}$$

Net outward flux $= 2 \times 0.1257 \approx \mathbf{0.251\ N\,m^2/C}$.

(b) Gauss's law: $q = \varepsilon_0 \Phi = 8.85 \times 10^{-12} \times 0.251 \approx \mathbf{2.2 \times 10^{-12}\ C}$.

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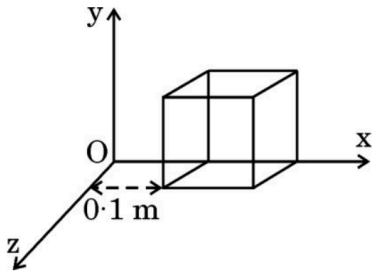
CBSE 2024 · 55/1/1 · Q22 — 3 marks

A cube of side 0.1 m is placed, as shown in the figure, in a region where electric field $\vec{E} = 500\,x\,\hat{i}$ exists. Here x is in meters and E in N C^{-1}. Calculate: (a) the flux passing through the cube, and (b) the charge within the cube.



Solution

(a) $\vec{E}$ is along x, so only the two faces perpendicular to x carry flux. Area of each face $= (0.1)^2 = 0.01$ m^2. The cube lies from x = 0.1 m to x = 0.2 m.

Left face (x = 0.1 m, area vector along –x): $\phi_L = -(500 \times 0.1)(0.01) = -0.5$ N m^2 C^{-1}.

Right face (x = 0.2 m, area vector along +x): $\phi_R = (500 \times 0.2)(0.01) = +1.0$ N m^2 C^{-1}.

$$\phi = \phi_L + \phi_R = \mathbf{0.5\ N\,m^2\,C^{-1}}$$

(b) Gauss's law: $q = \varepsilon_0 \phi = 8.854 \times 10^{-12} \times 0.5 \approx \mathbf{4.4 \times 10^{-12}\ C}$.

CBSE 2024 · 55/5/1 · Q23 — 3 marks

(a) Define the term 'electric flux' and write its dimensions.

(b) A plane surface, in shape of a square of side 1 cm is placed in an electric field $\vec{E} = \left(100\frac{N}{C}\right)\hat{i}$ such that the unit vector normal to the surface is given by $\hat{n} = 0.8\hat{i} + 0.6\hat{k}$. Find the electric flux through the surface.

Solution

(a) Electric flux through a surface is the number of field lines crossing it normally: $\phi = \oint \vec{E} \cdot d\vec{S}$ (for a flat surface in a uniform field, $\phi = EA\cos\theta$). Unit N m^2 C^{-1} (V m).

Dimensions: $[E][A] = [\mathrm{MLT^{-3}A^{-1}}][\mathrm{L^2}] = [\mathrm{ML^3T^{-3}A^{-1}}]$.

(b) $\vec{S} = A\hat{n} = 10^{-4}(0.8\hat{i} + 0.6\hat{k})$ m^2.

$\phi = \vec{E} \cdot \vec{S} = 100 \times 0.8 \times 10^{-4} = 8 \times 10^{-3}$ N m^2 C^{-1}.

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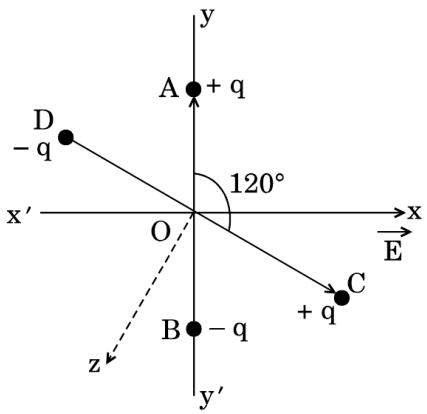
CBSE 2020 · 55/2/1 · Q28(a) — 3 marks

Two small identical electric dipoles AB and CD, each of dipole moment $\vec{p}$ are kept at an angle of 120° to each other in an external electric field $\vec{E}$ pointing along the x-axis as shown in the figure. Find the (a) dipole moment of the arrangement, and (b) magnitude and direction of the net torque acting on it.



Solution

(a) $\vec{p}_1$ (B → A) points along +y; $\vec{p}_2$ (D → C) points at 120° from it, i.e. 30° below the x-axis. The resultant of two equal vectors at 120° has magnitude

$$p_{net} = \sqrt{p^2 + p^2 + 2p^2\cos 120^\circ} = p$$

along the bisector, i.e. at 60° to each, which is **30° above the x-axis**.

(b) $\tau = p_{net} E \sin 30^\circ = \dfrac{pE}{2}$.

$\vec{\tau} = \vec{p}_{net} \times \vec{E}$: with $\vec{p}_{net}$ at 30° above +x and $\vec{E}$ along +x, the torque points along the **–z direction**; it tends to rotate the arrangement clockwise (towards $\vec{E}$).

CBSE 2020 · 55/2/2 · Q28(a) — 3 marks

(a) Two electric field lines cannot cross each other. Also, they cannot form closed loops. Give reasons.

(b) A particle of charge 2 μC and mass 1·6 g is moving with a velocity $4\hat{i}$ ms^{-1}. At t = 0 the particle enters in a region having an electric field $\vec{E}$ (in NC^{-1}) = $80\hat{i} + 60\hat{j}$. Find the velocity of the particle at t = 5 s.

Solution

(a) If two field lines crossed, there would be two tangents, i.e. two directions of the electric field, at the crossing point, which is impossible. Electrostatic field lines start on positive charges and end on negative charges (the field is conservative), so they cannot form closed loops.

(b) $\vec{a} = \dfrac{q\vec{E}}{m} = \dfrac{2\times10^{-6}(80\hat{i}+60\hat{j})}{1.6\times10^{-3}} = (0.1\hat{i} + 0.075\hat{j})$ m s^{-2}.

$$\vec{v} = \vec{u} + \vec{a}t = 4\hat{i} + (0.1\hat{i} + 0.075\hat{j}) \times 5 = (4.5\hat{i} + 0.375\hat{j})\ \text{m s}^{-1}$$

(speed ≈ 4.52 m/s).

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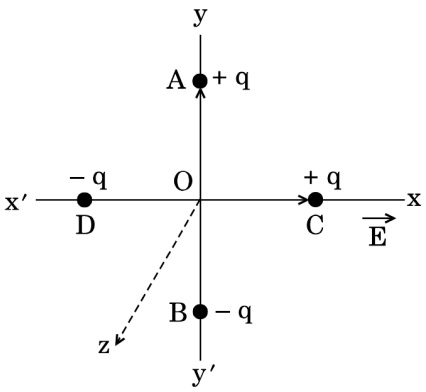
CBSE 2020 · 55/2/3 · Q28(b) — 3 marks

Two small identical electric dipoles AB and CD, each of dipole moment $\vec{p}$ are kept at an angle of 90° to each other in an external electric field $\vec{E}$ pointing along the x-axis as shown in the figure. Find the

(a) dipole moment of the arrangement, and

(b) magnitude and direction of the net torque acting on it.



Solution

Dipole moment points from –q to +q: AB (B at –y, A at +y) gives $\vec{p}_1 = p\hat{j}$; CD (D at –x, C at +x) gives $\vec{p}_2 = p\hat{i}$.

(a) $\vec{p}_{net} = p\hat{i} + p\hat{j}$, magnitude $\sqrt{2}\,p$, directed at 45° to the x-axis (between OC and OA).

(b) $\vec{\tau} = \vec{p}_{net} \times \vec{E} = (p\hat{i} + p\hat{j}) \times E\hat{i} = pE(\hat{j} \times \hat{i}) = -pE\hat{k}$.

Magnitude $\tau = \sqrt{2}\,pE \sin 45^\circ = pE$, directed along the **–z** axis (it tends to turn the arrangement so that $\vec{p}_{net}$ aligns with $\vec{E}$).

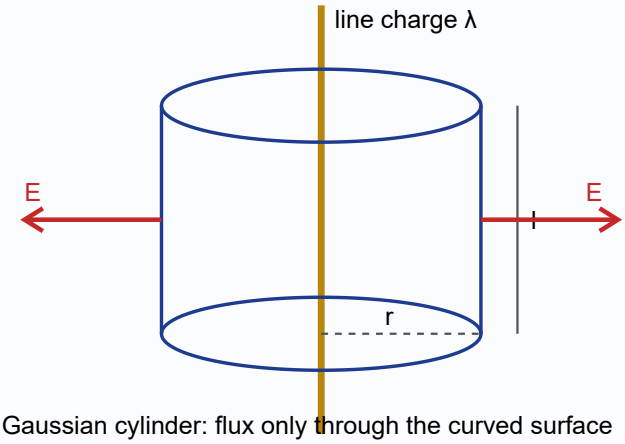
CBSE 2020 · 55/4/1 · Q28(b) | CBSE 2020 · 55/4/2 · Q34(b) | CBSE 2020 · 55/4/3 · Q33(b) — asked 3 times — 3 marks

(a) An infinitely long thin straight wire has a uniform linear charge density λ. Obtain the expression for the electric field (E) at a point lying at a distance x from the wire, using Gauss' law.

(b) Show graphically the variation of this electric field E as a function of distance x from the wire.

Solution

(a) By symmetry the field is radial, with equal magnitude at equal distances. Take a coaxial cylindrical Gaussian surface of radius x and length l.



Gaussian cylinder: flux only through the curved surface

Flux through the flat ends is zero; through the curved surface it is E·2πxl. Charge enclosed = λl:

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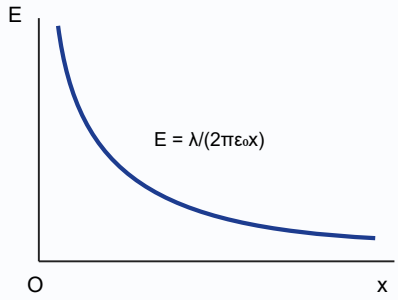
$$E \cdot 2\pi x l = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{\lambda}{2\pi\varepsilon_0 x}$$

(b) E ∝ 1/x: a rectangular hyperbola.

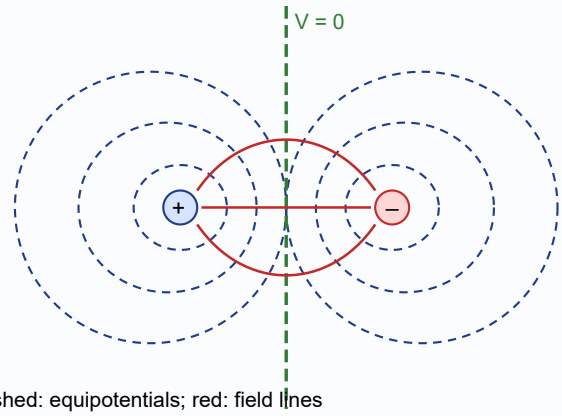


CBSE 2019 · 55/1/3 · Q16 — 3 marks

(a) Draw the equipotential surfaces due to an electric dipole.
(b) Derive an expression for the electric field due to a dipole of dipole moment $\vec{p}$ at a point on its perpendicular bisector.

Solution

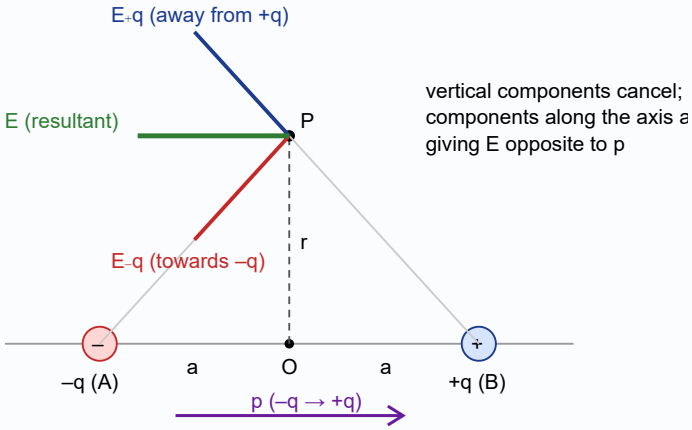
(a)



dashed: equipotentials; red: field lines

Equipotentials are closed surfaces around each charge (positive potentials round +q, negative round –q), perpendicular to the field lines everywhere; the perpendicular bisector plane is the zero-potential surface.

(b)



Let the charges –q and +q be at distance a on either side of the centre O, and P a point on the bisector at distance r from O. Each charge is at distance $\sqrt{r^2+a^2}$ from P:

$$|\vec{E}_{+q}| = |\vec{E}_{-q}| = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}$$

Their components perpendicular to the dipole axis cancel; the components parallel to the axis add, both pointing from +q towards –q. With $\cos\theta = \dfrac{a}{\sqrt{r^2+a^2}}$:

$$E = 2\cdot\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}\cdot\frac{a}{\sqrt{r^2+a^2}} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2qa}{(r^2+a^2)^{3/2}}$$

In vector form, with p = 2qa: $\vec{E} = -\dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{\vec{p}}{(r^2+a^2)^{3/2}}$ (opposite to $\vec{p}$). For r ≫ a: $\vec{E} = -\dfrac{\vec{p}}{4\pi\varepsilon_0 r^3}$.

CBSE 2019 · 55/2/1 · Q17(a) | CBSE 2019 · 55/2/2 · Q19(a) | CBSE 2019 · 55/2/3 · Q18(a) **asked 3 times** **3 marks**

Two large charged plane sheets of charge densities σ and –2σ C/m² are arranged vertically with a separation of d between them. Deduce expressions for the electric field at points (i) to the left of the first sheet, (ii) to the right of the second sheet, and (iii) between the two sheets.

Solution

Each sheet gives a field $\dfrac{|\sigma|}{2\varepsilon_0}$: away from the positive sheet (σ), towards the negative sheet (–2σ), i.e. $\dfrac{\sigma}{2\varepsilon_0}$ and $\dfrac{\sigma}{\varepsilon_0}$. Take the σ sheet on the left.

(i) Left of the first sheet: σ-sheet field points left ($\frac{\sigma}{2\varepsilon_0}$), –2σ-sheet field points right ($\frac{\sigma}{\varepsilon_0}$):

$$E = \frac{\sigma}{\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = \frac{\sigma}{2\varepsilon_0}\ \text{towards the right}$$

(ii) Right of the second sheet: σ-sheet field points right, –2σ-sheet field points left:

$$E = \frac{\sigma}{2\varepsilon_0}\ \text{towards the left}$$

(iii) Between the sheets: both point right:

$$E = \frac{\sigma}{2\varepsilon_0} + \frac{\sigma}{\varepsilon_0} = \frac{3\sigma}{2\varepsilon_0}\ \text{towards the right (from σ to –2σ)}$$

CBSE 2019 · 55/2/1 · Q17(b) | CBSE 2019 · 55/2/2 · Q19(b) | CBSE 2019 · 55/2/3 · Q18(b) **asked 3 times** **3 marks**

A spherical conducting shell of inner radius r_1 and outer radius r_2 has a charge Q. (a) A charge q is placed at the centre of the shell. Find out the surface charge density on the inner and outer surfaces of the shell. (b) Is the electric field inside a cavity (with no charge) zero; independent of the fact whether the shell is spherical or not? Explain.

Solution

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(a) The field inside the conducting material is zero, so a Gaussian surface within it encloses zero charge: the inner surface carries –q. The outer surface then carries Q + q.

$$\sigma_{in} = \frac{-q}{4\pi r_1^2}, \qquad \sigma_{out} = \frac{Q+q}{4\pi r_2^2}$$

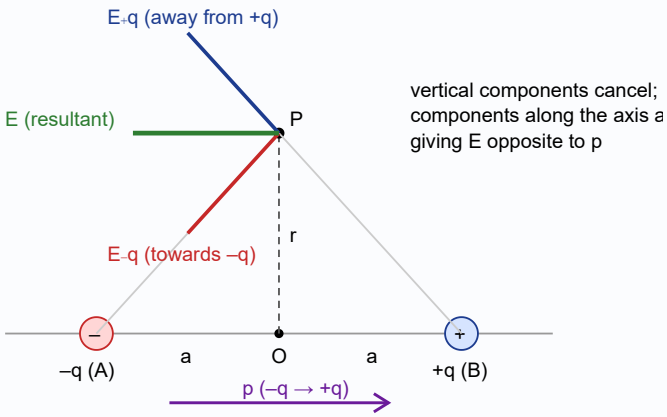
(b) **Yes.** For a cavity with no charge inside a conductor, the field in the cavity is zero whatever the shape of the conductor (electrostatic shielding). A Gaussian surface around the cavity inside the conductor encloses no charge, and any field lines inside would have to start and end on the cavity wall, which is an equipotential, giving zero work around a closed path, which is impossible unless E = 0.

CBSE 2017 · 55/1/1 · Q18 — 3 marks

(i) Derive the expression for electric field at a point on the equatorial line of an electric dipole.
(ii) Depict the orientation of the dipole in (i) stable, (ii) unstable equilibrium in a uniform electric field.

Solution

(i)



Let P be at a distance r from the mid-point of the dipole (charges ±q, separation 2a). The fields due to +q and –q are equal in magnitude:

$$E_{+q} = E_{-q} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}$$

Their components normal to the axis cancel; the components along the axis add:

$$E = 2E_{+q}\cos\theta = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2qa}{(r^2+a^2)^{3/2}}$$

With p = 2qa, $\vec{E} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{\vec{p}}{(r^2+a^2)^{3/2}}$, opposite to $\vec{p}$. For $r \gg a$: $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^3}$.

(ii) Stable: $\vec{p}$ parallel to $\vec{E}$ (θ = 0). Unstable: $\vec{p}$ antiparallel to $\vec{E}$ (θ = 180°).

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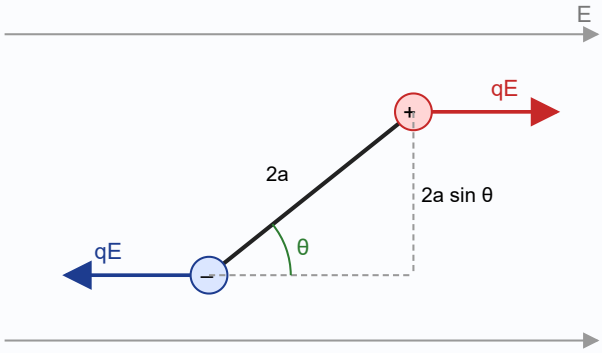
(a) stable: p ∥ E, U = –pE (b) unstable: p opposite to E, U = +pE

CBSE 2017 · 55/1/3 · Q16 — **3 marks**

(i) Obtain the expression for the torque $\vec{\tau}$ experienced by an electric dipole of dipole moment $\vec{p}$ in a uniform electric field, $\vec{E}$.
(ii) What will happen if the field were not uniform ?

Solution

(i)



couple: τ = qE · 2a sin θ = pE sin θ; τ = p × E

Let the dipole make an angle θ with $\vec{E}$. Force on +q: $q\vec{E}$; force on –q: $-q\vec{E}$. The net force is zero, but the two forces form a couple.

Magnitude of the torque = force × perpendicular distance between the forces:

$$\tau = qE \times 2a \sin\theta = pE \sin\theta$$

In vector form, $\vec{\tau} = \vec{p} \times \vec{E}$.

(ii) If the field is not uniform, the dipole experiences a net (translatory) force as well as a torque.

CBSE 2017 · 55/2/1 · Q15 — **3 marks**

A long charged cylinder of linear charge density + λ_1 is surrounded by a hollow coaxial conducting cylinder of linear charge density – λ_2. Use Gauss's law to obtain expressions for the electric field at a point (i) in the space between the cylinders, and (ii) outside the larger cylinder.

Solution

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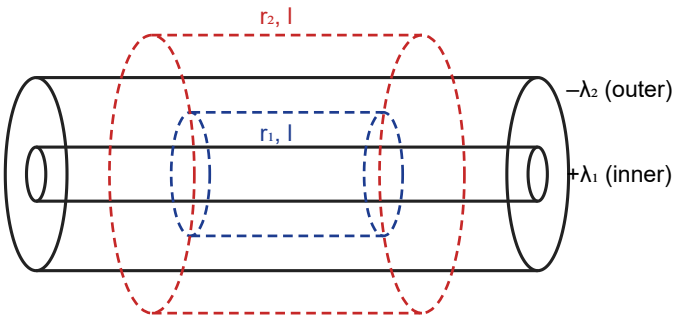


Gauss's law: $\oint \vec{E} \cdot d\vec{s} = \frac{q}{\varepsilon_0}$. Take a coaxial cylindrical Gaussian surface of length l. By symmetry E is radial, so there is flux only through the curved surface, $E(2\pi rl)$.

(i) Between the cylinders (radius r_1), the charge enclosed is $\lambda_1 l$:

$$E_1(2\pi r_1 l) = \frac{\lambda_1 l}{\varepsilon_0} \Rightarrow E_1 = \frac{\lambda_1}{2\pi\varepsilon_0 r_1} \text{ (radially outward)}$$

(ii) Outside the larger cylinder (radius r_2), the charge enclosed is $(\lambda_1 - \lambda_2)l$:

$$E_2(2\pi r_2 l) = \frac{(\lambda_1 - \lambda_2)l}{\varepsilon_0} \Rightarrow E_2 = \frac{\lambda_1 - \lambda_2}{2\pi\varepsilon_0 r_2}$$

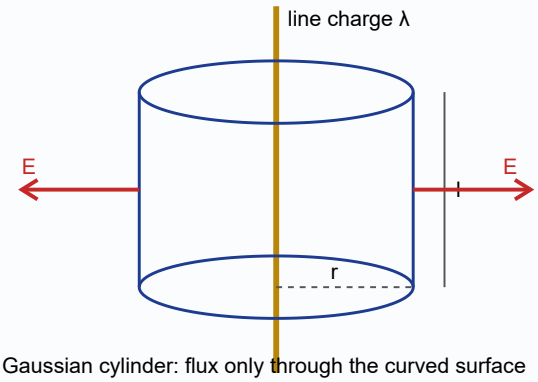
It is radially outward if $\lambda_1 > \lambda_2$ and radially inward if $\lambda_1 < \lambda_2$.

CBSE 2017 · 55/2/2 · Q12 — **3 marks**

Define electric flux. Write its SI unit.
Using Gauss's law, deduce an expression for electric field intensity due to an infinitely long straight uniformly charged wire.

Solution

Electric flux through a surface: $\phi_E = \vec{E} \cdot \vec{A} = EA\cos\theta$. SI unit: **N m² C⁻¹**.



Gaussian cylinder: flux only through the curved surface

Take a cylindrical Gaussian surface of radius r and length l around the wire. The field is radial. On the curved part, $\vec{E}$ is normal to the surface at every point and its magnitude is constant; there is no flux through the ends.

By Gauss's theorem, $\oint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$:

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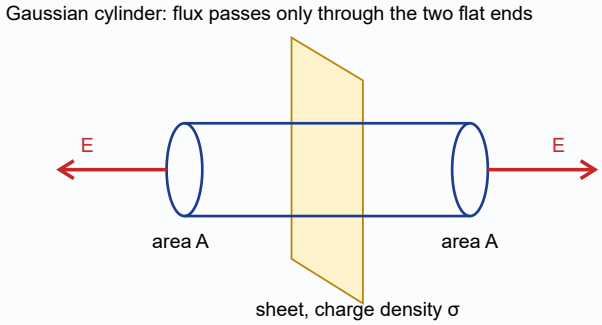
$$E(2\pi rl) = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

CBSE 2017 · 55/2/3 · Q13 — **3 marks**

Using Gauss's law in electrostatics, deduce an expression for electric field intensity due to a uniformly charged infinite plane sheet. If another identical sheet is placed parallel to it, show that there is no electric field in the region between the two sheets.

Solution



Take a cylindrical Gaussian surface crossing the sheet, with end faces of area A. By Gauss's law, $\oint \vec{E} \cdot d\vec{s} = \frac{q}{\varepsilon_0}$. Flux passes only through the two ends, and the charge enclosed is σA:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

Two identical sheets: both have the same charge density, so their fields have the same magnitude $\frac{\sigma}{2\varepsilon_0}$. In the region between the sheets the two fields are opposite in direction:

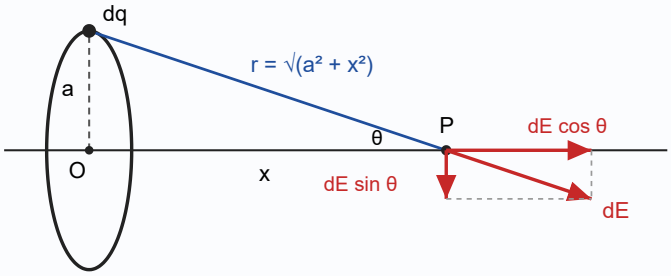
$$E = \frac{\sigma}{2\varepsilon_0} - \frac{\sigma}{2\varepsilon_0} = 0$$

Hence the net field between the sheets is zero.

CBSE 2016 · 55/1/1 · Q11 | CBSE 2016 · 55/1/2 · Q14 | CBSE 2016 · 55/1/3 · Q12 **asked 3 times** — **3 marks**

A charge is distributed uniformly over a ring of radius 'a'. Obtain an expression for the electric intensity E at a point on the axis of the ring. Hence show that for points at large distances from the ring, it behaves like a point charge.

Solution



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Let the ring carry total charge q, and P lie on the axis at distance x from the centre O. An element dq of the ring is at distance $r = \sqrt{a^2 + x^2}$ from P and gives

$$dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2}$$

Resolve dE: the components $dE\sin\theta$ perpendicular to the axis cancel in pairs (from elements on opposite ends of a diameter). The components $dE\cos\theta$ along the axis add up, with $\cos\theta = \frac{x}{r}$:

$$E = \int dE\cos\theta = \frac{1}{4\pi\varepsilon_0}\frac{x}{r^3}\int dq = \frac{1}{4\pi\varepsilon_0}\frac{qx}{(a^2+x^2)^{3/2}}$$

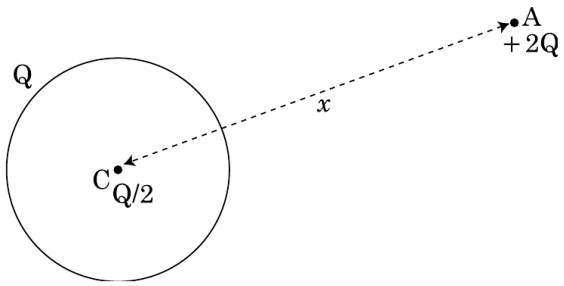
directed along the axis, away from the ring for positive q.
At large distances, $x \gg a$, so $(a^2 + x^2)^{3/2} \approx x^3$ and

$$E \approx \frac{1}{4\pi\varepsilon_0}\frac{q}{x^2}$$

This is the field of a point charge q placed at O, so the ring behaves like a point charge.

CBSE 2016 · 55/1/E · Q11 | CBSE 2016 · 55/2/E · Q15 | CBSE 2016 · 55/3/E · Q12 **asked 3 times** 3 marks

A thin metallic spherical shell of radius R carries a charge Q on its surface. A point charge Q/2 is placed at the centre C and another charge +2Q is placed outside the shell at A at a distance x from the centre as shown in the figure.
(i) Find the electric flux through the shell.
(ii) State the law used.
(iii) Find the force on the charges at the centre C of the shell and at the point A.



Solution

(i) The charge enclosed by the shell is the charge Q/2 at its centre (charges outside, like 2Q, contribute no net flux). So the flux through the shell is

$$\Phi = \frac{Q/2}{\varepsilon_0} = \frac{Q}{2\varepsilon_0}$$

(For a Gaussian surface drawn just outside the shell, which also encloses the charge Q on the shell, the flux would be $\frac{3Q}{2\varepsilon_0}$.)

(ii) **Gauss's law:** the total electric flux through a closed surface is $\frac{1}{\varepsilon_0}$ times the net charge enclosed by it: $\oint \vec{E}\cdot d\vec{S} = \frac{q_{enc}}{\varepsilon_0}$.

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(iii) **At C:** the field inside the conducting shell due to the shell's own charge and to the outside charge 2Q is zero (electrostatic shielding), so the force on Q/2 is **zero**.

At A: outside the shell, the shell (charge Q) and the central charge (Q/2) act like a total charge 3Q/2 at the centre:

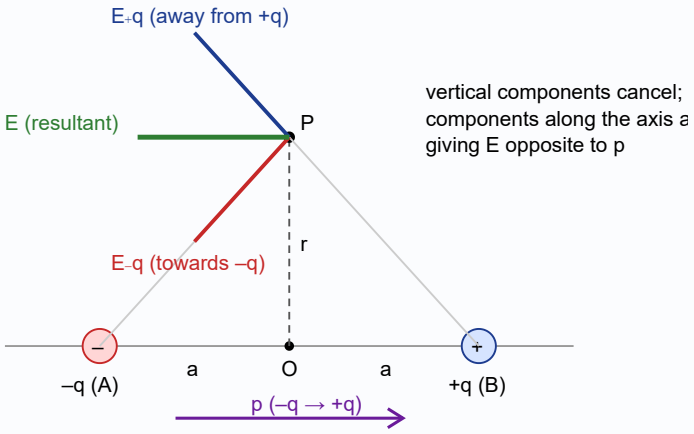
$$F = \frac{1}{4\pi\varepsilon_0}\cdot\frac{(3Q/2)(2Q)}{x^2} = \frac{3Q^2}{4\pi\varepsilon_0 x^2}$$

directed away from the centre (repulsive), along CA.

CBSE 2016 · 55/1/S · Q11 | CBSE 2016 · 55/2/S · Q20 | CBSE 2016 · 55/3/S · Q22 **asked 3 times** **3 marks**

Derive an expression for the electric field intensity at a point on the equatorial line of an electric dipole of dipole moment $\vec{p}$ and length 2a. What is the direction of this field ?

Solution



Let P be on the equatorial line at distance r from the centre. Each charge is at distance $\sqrt{r^2+a^2}$ from P:

$$E_{+q} = E_{-q} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}$$

The components perpendicular to the dipole axis cancel; the components parallel to the axis add (both directed from +q towards –q), each being E cos θ with $\cos\theta = \frac{a}{\sqrt{r^2+a^2}}$:

$$E = 2\cdot\frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}\cdot\frac{a}{\sqrt{r^2+a^2}} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{(r^2+a^2)^{3/2}} \quad (p = 2qa)$$

For r ≫ a: $E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{p}{r^3}$.

Direction: parallel to the dipole axis, opposite to $\vec{p}$ (from +q to –q): $\vec{E} = -\frac{\vec{p}}{4\pi\varepsilon_0(r^2+a^2)^{3/2}}$.

CBSE 2016 · 55/1/N · Q11 | CBSE 2016 · 55/2/N · Q17 | CBSE 2016 · 55/3/N · Q22 **asked 3 times** **3 marks**

Find the electric field intensity due to a uniformly charged spherical shell at a point (i) outside the shell and (ii) inside the shell. Plot the graph of electric field with distance from the centre of the shell.

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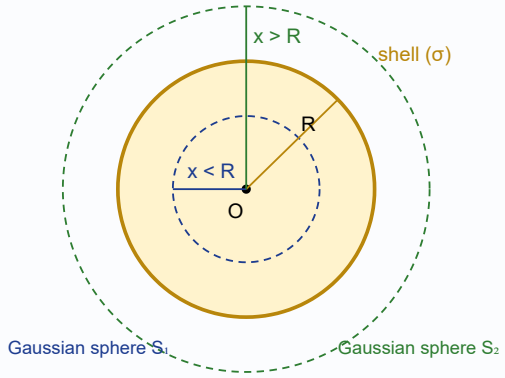
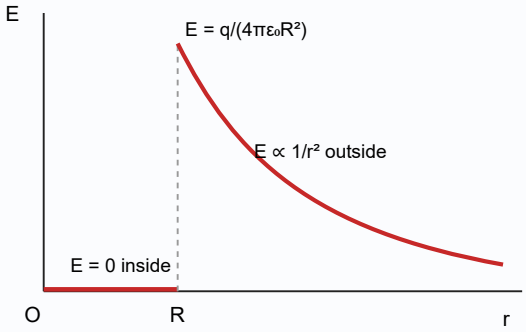
Solution



(i) Outside (r > R): Gaussian sphere of radius r encloses q: $E \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$, so $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$ (radial).

(ii) Inside (r < R): the Gaussian sphere encloses no charge, so E = 0.



CBSE 2016 · 55/2/1 · Q11 | CBSE 2016 · 55/2/2 · Q19 | CBSE 2016 · 55/2/3 · Q16 **asked 3 times** **3 marks**

(a) Define torque acting on a dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. Express it in the vector form and point out the direction along which it acts.
(b) What happens if the field is non-uniform ?
(c) What would happen if the external field $\vec{E}$ is increasing (i) parallel to $\vec{p}$ and (ii) anti-parallel to $\vec{p}$?

Solution

(a) The two equal and opposite forces on the charges ±q form a couple. The torque is the product of either force and the perpendicular distance between them: $\tau = pE\sin\theta$. In vector form:

$$\vec{\tau} = \vec{p} \times \vec{E}$$

It acts perpendicular to the plane containing $\vec{p}$ and $\vec{E}$, in the direction given by the right-hand screw rule, and tends to align $\vec{p}$ along $\vec{E}$.

(b) In a non-uniform field the forces on the two charges are unequal, so the dipole experiences a **net force** as well as a torque (the torque is zero only when $\vec{p}$ is parallel or anti-parallel to the field).

(c) In both cases the torque is zero, because $\vec{p}$ lies along $\vec{E}$.

(i) $\vec{p}$ parallel to $\vec{E}$: the net force is in the direction of increasing field.

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(ii) $\vec{p}$ anti-parallel to $\vec{E}$: the net force is opposite to the direction of increasing field (towards the weaker field).

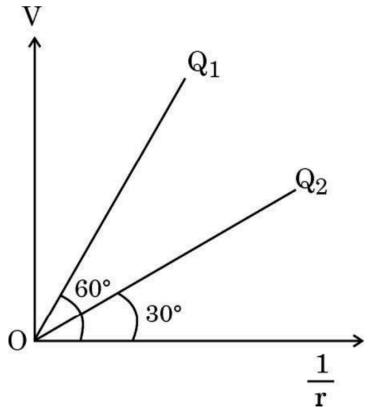
4 marks: case-based / source-based

CBSE 2023 · 55/4/1 · Q34 | CBSE 2023 · 55/4/2 · Q35 | CBSE 2023 · 55/4/3 · Q34 **asked 3 times** **4 marks**

Electrostatics deals with the study of forces, fields and potentials arising from static charges. Force and electric field, due to a point charge is basically determined by Coulomb's law. For symmetric charge configurations, Gauss's law, which is also based on Coulomb's law, helps us to find the electric field. A charge/a system of charges like a dipole experience a force/torque in an electric field. Work is required to be done to provide a specific orientation to a dipole with respect to an electric field.

(a) Consider a uniformly charged thin conducting shell of radius R. Plot a graph showing the variation of $|\vec{E}|$ with distance r from the centre, for points 0 ≤ r ≤ 3R.

(b) The figure shows the variation of potential V with $\frac{1}{r}$ for two point charges Q_1 and Q_2, where V is the potential at a distance r due to a point charge. Find $\frac{Q_1}{Q_2}$.



(c) An electric dipole of dipole moment of 6×10^{-7} C-m is kept in a uniform electric field of 10^4 N/C such that the dipole moment and the electric field are parallel. Calculate the potential energy of the dipole.

OR

(c) An electric dipole of dipole moment $\vec{p}$ is initially kept in a uniform electric field $\vec{E}$ such that $\vec{p}$ is perpendicular to $\vec{E}$. Find the amount of work done in rotating the dipole to a position at which $\vec{p}$ becomes antiparallel to $\vec{E}$.

Solution

(a)

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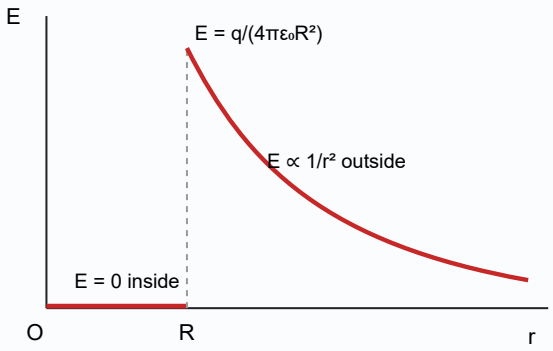


E = 0 for r < R; at r = R it jumps to $\frac{1}{4\pi\varepsilon_0}\frac{Q}{R^2}$ and then falls as $\frac{1}{r^2}$ up to 3R (to one-ninth of the surface value).

(b) $V = \frac{Q}{4\pi\varepsilon_0}\cdot\frac{1}{r}$: the slope is proportional to Q.

$$\frac{Q_1}{Q_2} = \frac{\tan 60^\circ}{\tan 30^\circ} = \frac{\sqrt{3}}{1/\sqrt{3}} = 3.$$

(c) $U = -pE\cos 0^\circ = -6\times10^{-7}\times10^{4} = -6\times10^{-3}$ J.

OR **(c)** $W = pE(\cos\theta_1 - \cos\theta_2) = pE(\cos 90^\circ - \cos 180^\circ) = pE(0+1) = pE.$

5 marks: long answer

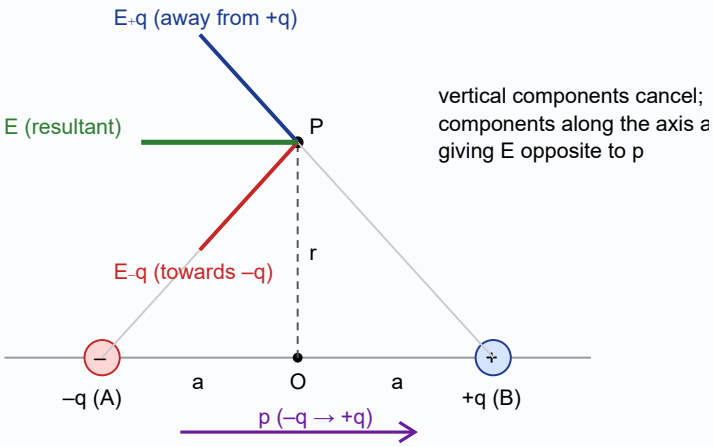
CBSE 2026 · 55/1/1 · Q31(a) | CBSE 2026 · 55/1/2 · Q32(a) | CBSE 2026 · 55/1/3 · Q33(a) **asked 3 times** **5 marks**

(a) An electric dipole consists of two point charges q and –q separated by a distance 2a. Derive an expression for the electric field $\vec{E}$ due to this dipole at a point distant r from the centre of the dipole on the equatorial plane. Write the expression for the electric field at a far off point, i.e. $r \gg a$.

(b) A dipole is placed in x-y plane such that charges q and –q are located at $x = a$ and $x = b$ respectively. There exists an electric field $\vec{E} = 2\hat{i}$ N/C in the region. Calculate the force $\vec{F}$ and torque $\vec{\tau}$ experienced by the dipole.

Solution

(a)



P is on the perpendicular bisector at distance r from the centre O. Distance of P from each charge $= \sqrt{r^2 + a^2}$, so

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$$|\vec{E}_{+q}| = |\vec{E}_{-q}| = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{r^2+a^2}$$

Their components perpendicular to the axis cancel. The components parallel to the axis add, both pointing from +q towards –q (opposite to $\vec{p}$). If θ is the angle each field makes with the axis, $\cos\theta = \dfrac{a}{\sqrt{r^2+a^2}}$:

$$E = 2E_{+q}\cos\theta = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2qa}{(r^2+a^2)^{3/2}}$$

With $\vec{p} = q(2a)\hat{p}$:

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{\vec{p}}{(r^2+a^2)^{3/2}}$$

For a far-off point $(r \gg a)$:

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{\vec{p}}{r^3}$$

(b) The field is uniform, so the forces on +q and –q are $q\vec{E}$ and $-q\vec{E}$: net force $\vec{F} = q\vec{E} - q\vec{E} = \mathbf{0}$.

Dipole moment (from –q to +q): $\vec{p} = q(a-b)\hat{i}$. Torque:

$$\vec{\tau} = \vec{p}\times\vec{E} = q(a-b)\hat{i}\times 2\hat{i} = \mathbf{0}$$

(the dipole lies along the field, so it is in equilibrium).

CBSE 2025 · 55/2/1 · Q31(b) | CBSE 2025 · 55/2/2 · Q32(b) | CBSE 2025 · 55/2/3 · Q33(b) **asked 3 times** **5 marks**

(i) What is difference between an open surface and a closed surface? Draw elementary surface vector $d\vec{S}$ for a spherical surface S.
(ii) Define electric flux through a surface. Give the significance of a Gaussian surface. A charge outside a Gaussian surface does not contribute to total electric flux through the surface. Why?
(iii) A small spherical shell S_1 has point charges $q_1 = -3$ μC, $q_2 = -2$ μC and $q_3 = 9$ μC inside it. This shell is enclosed by another big spherical shell S_2. A point charge Q is placed in between the two surfaces S_1 and S_2. If the electric flux through the surface S_2 is four times the flux through surface S_1, find charge Q.

Solution

(i) An open surface (like a disc or a hemisphere) has a boundary and does not enclose a volume; a closed surface (like a sphere) encloses a volume and has no boundary. For a closed surface, the area vector $d\vec{S}$ of every small element points along the outward normal: on a sphere, radially outward from the centre.

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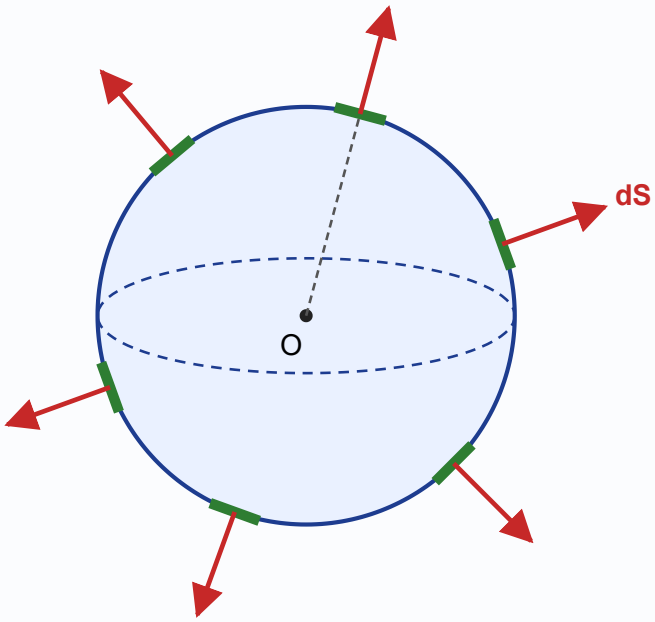

small element (green) of the closed surface S; its area vector dS points along the outward normal, i.e. radially outward from O

(ii) Electric flux through a surface is $\Phi_E = \oint \vec{E} \cdot d\vec{S}$ (for a uniform field $EA\cos\theta$): a measure of the number of field lines crossing the surface. Its SI unit is N m^2 C^{-1}.

A Gaussian surface is a closed surface, chosen to fit the symmetry, through which the flux is $\frac{q_{enc}}{\varepsilon_0}$; it makes the field easy to calculate.

A charge outside the surface contributes nothing because every field line from it that enters the surface also leaves it, so its inward and outward flux cancel.

(iii) Charge inside S_1: $-3 - 2 + 9 = 4$ μC, so $\Phi_1 = \frac{4\ \mu\text{C}}{\varepsilon_0}$.

Charge inside S_2: $(Q + 4)$ μC, so $\Phi_2 = \frac{Q + 4\ \mu\text{C}}{\varepsilon_0}$.

$$\Phi_2 = 4\Phi_1 \Rightarrow Q + 4 = 16 \Rightarrow Q = \mathbf{12\ \mu C}$$

CBSE 2025 · 55/4/1 · Q31(a) | CBSE 2025 · 55/4/2 · Q33(a) | CBSE 2025 · 55/4/3 · Q32(a) **asked 3 times** **5 marks**

(i) Two point charges + q and – q are held at (a, 0) and (– a, 0) in x-y plane. Obtain an expression for the net electric field due to the charges at a point (0, y). Hence, find electric field at a far off point (y >> a).

(ii) Three point charges of – 2 nC, – 1 nC, and + 5 nC are kept at the vertices A, B and C of an equilateral triangle of side 0.2 m. Find the total amount of work done in shifting the charges from A to A_1, B to B_1 and C to C_1. Here A_1, B_1 and C_1 are the midpoints of sides AB, BC and CA, respectively.

Solution

(i)

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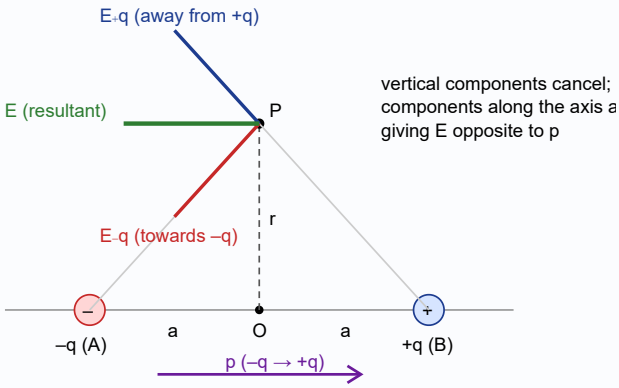

Each charge is at distance $\sqrt{y^2 + a^2}$ from P(0, y), giving fields of equal magnitude

$$E_{+q} = E_{-q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{y^2 + a^2}$$

E_{+q} points away from (a, 0) and E_{-q} towards (–a, 0). Their y-components cancel; their x-components add, both along –x, i.e. opposite to the dipole moment $\vec{p} = q(2a)\hat{i}$. With $\cos\theta = \frac{a}{\sqrt{y^2 + a^2}}$:

$$\vec{E} = -2E_{+q}\cos\theta\,\hat{i} = -\frac{1}{4\pi\varepsilon_0}\frac{2qa}{(y^2 + a^2)^{3/2}}\hat{i} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{(y^2 + a^2)^{3/2}}$$

For $y \gg a$:

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{y^3}$$

(ii) $U = \frac{1}{4\pi\varepsilon_0}\sum\frac{q_i q_j}{r}$; for an equilateral arrangement all separations are equal.

$\sum q_i q_j = (-2)(-1) + (-1)(5) + (5)(-2) = 2 - 5 - 10 = -13$ (in nC²).

Initially (side 0.2 m):

$$U_1 = \frac{9\times10^9 \times (-13\times10^{-18})}{0.2} = -5.85\times10^{-7}\ \text{J}$$

The midpoints form an equilateral triangle of side 0.1 m:

$$U_2 = \frac{9\times10^9 \times (-13\times10^{-18})}{0.1} = -11.7\times10^{-7}\ \text{J}$$

Work done $W = U_2 - U_1 = \mathbf{-5.85\times10^{-7}\ J}$ (the field does positive work; the external agent's work is negative).

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CBSE 2025 · 55/4/1 · Q31(b) | CBSE 2025 · 55/4/2 · Q33(b) | CBSE 2025 · 55/4/3 · Q32(b) asked 3 times 5 marks

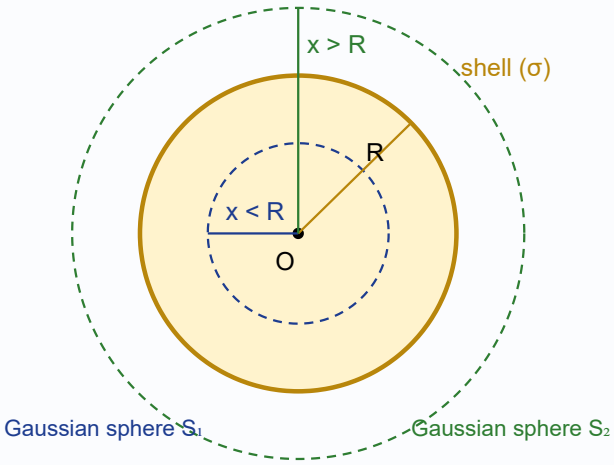
(i) Show that Gauss's theorem is consistent with Coulomb's law. Using it, derive an expression for the electric field due to a uniformly charged thin spherical shell of radius r at a point at a distance y from the centre of the shell such that (I) y > r, and (II) y < r.
(ii) A point charge of + 2 nC is kept at the origin of a three-dimensional coordinate system. Find the type and magnitude of the charge which should be kept at (0, 0, – 6m) so that the potential due to the system becomes zero at (0, 0, 2m).

Solution

(i) Take a point charge q and a spherical Gaussian surface of radius r centred on it. By symmetry E is radial and the same everywhere on the sphere, so

$$\oint \vec{E}\cdot d\vec{S} = E(4\pi r^2) = \frac{q}{\varepsilon_0} \Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

The force on a charge q_0 placed there is $F = q_0 E = \dfrac{1}{4\pi\varepsilon_0}\dfrac{qq_0}{r^2}$, which is Coulomb's law. So Gauss's theorem is consistent with Coulomb's law.



Let the shell carry charge q (surface density $\sigma = \dfrac{q}{4\pi r^2}$). Take a concentric spherical Gaussian surface of radius y.

(I) y > r: it encloses q, so $E(4\pi y^2) = \dfrac{q}{\varepsilon_0} \Rightarrow \vec{E} = \dfrac{1}{4\pi\varepsilon_0}\dfrac{q}{y^2}\hat{r}$, as if all the charge were at the centre.

(II) y < r: it encloses no charge, so $E(4\pi y^2) = 0 \Rightarrow E = 0$ inside the shell.

(ii) The point (0, 0, 2 m) is 2 m from the origin and 8 m from (0, 0, –6 m). For zero potential:

$$\frac{1}{4\pi\varepsilon_0}\left(\frac{2\times10^{-9}}{2} + \frac{q}{8}\right) = 0 \Rightarrow q = -8\times10^{-9}\ \text{C}$$

A **negative** charge of **8 nC**.

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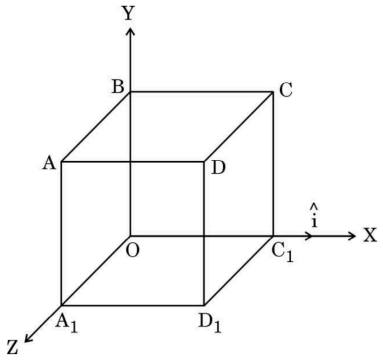
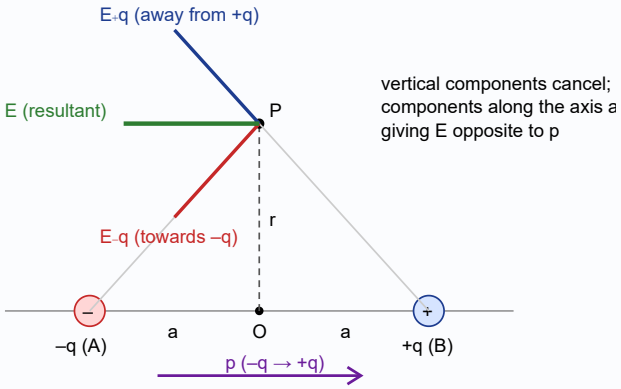
CBSE 2025 · 55/6/1 · Q33(b) | CBSE 2025 · 55/6/2 · Q32(b) | CBSE 2025 · 55/6/3 · Q31(b) asked 3 times 5 marks

(i) Obtain an expression for the electric field $\vec{E}$ due to a dipole of dipole moment $\vec{p}$ at a point on its equatorial plane and specify its direction. Hence, find the value of electric field :
(I) at the centre of the dipole (r = 0), and
(II) at a point r >> a,
where 2a is the length of the dipole.
(ii) An electric field $\vec{E} = (10x + 5)\hat{i}$ N/C exists in a region in which a cube of side L is kept as shown in the figure. Here x and L are in metres. Calculate the net flux through the cube.



Solution

(i)



The charges –q and +q are 2a apart; P is at distance r from the centre on the equatorial line, $\sqrt{r^2 + a^2}$ from each charge:

$$E_{+q} = E_{-q} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2 + a^2}$$

The components perpendicular to the axis cancel; those parallel to the axis add, both pointing from +q towards –q. With $\cos\theta = \dfrac{a}{\sqrt{r^2 + a^2}}$:

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0}\frac{2qa}{(r^2 + a^2)^{3/2}}\hat{p} = -\frac{1}{4\pi\varepsilon_0}\frac{\vec{p}}{(r^2 + a^2)^{3/2}}$$

The field is antiparallel to $\vec{p}$.

(I) At the centre (r = 0): $\vec{E} = -\dfrac{1}{4\pi\varepsilon_0}\dfrac{\vec{p}}{a^3}$, i.e. magnitude $\dfrac{1}{4\pi\varepsilon_0}\dfrac{2q}{a^2}$, directed from +q to –q.

(II) For $r \gg a$: $\vec{E} = -\dfrac{1}{4\pi\varepsilon_0}\dfrac{\vec{p}}{r^3}$.

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(ii) $\vec{E}$ is along x, so flux passes only through the two faces perpendicular to x: the face through O (x = 0) and the opposite face (x = L), each of area L^2.

At x = 0: E = 5 N/C, flux $= -5L^2$ (field entering). At x = L: E = 10L + 5, flux $= +(10L+5)L^2$.

$$\Phi_{net} = (10L+5)L^2 - 5L^2 = \mathbf{10L^3\ N\ m^2/C}$$

CBSE 2024 · 55/1/1 · Q31(a) | CBSE 2024 · 55/1/2 · Q32(a) | CBSE 2024 · 55/1/3 · Q32(a) **asked 3 times** **5 marks**

(i) Derive an expression for potential energy of an electric dipole $\vec{p}$ in an external uniform electric field $\vec{E}$. When is the potential energy of the dipole (1) maximum, and (2) minimum?

(ii) An electric dipole consists of point charges –1.0 pC and +1.0 pC located at (0, 0) and (3 mm, 4 mm) respectively in x – y plane. An electric field $\vec{E} = \left(\frac{1000\ \text{V}}{\text{m}}\right)\hat{i}$ is switched on in the region. Find the torque $\vec{\tau}$ acting on the dipole.

Solution

(i) A dipole at angle θ with $\vec{E}$ experiences a torque $\tau = pE\sin\theta$ that tends to align it with the field. Work done in rotating it slowly from θ_0 to θ against this torque:

$$W = \int_{\theta_0}^{\theta} pE\sin\theta\, d\theta = pE(\cos\theta_0 - \cos\theta)$$

This work is stored as potential energy. Taking $U = 0$ at $\theta_0 = 90^\circ$:

$$U(\theta) = -pE\cos\theta = -\vec{p}\cdot\vec{E}$$

(1) Maximum, $U = +pE$, when θ = 180° ($\vec{p}$ antiparallel to $\vec{E}$, unstable equilibrium).

(2) Minimum, $U = -pE$, when θ = 0° ($\vec{p}$ parallel to $\vec{E}$, stable equilibrium).

(ii) $\vec{p}$ points from –q to +q: $\vec{p} = q\vec{r} = 1.0\times10^{-12}\times(3\hat{i}+4\hat{j})\times10^{-3}$ C m $= (3\hat{i}+4\hat{j})\times10^{-15}$ C m.

$$\vec{\tau} = \vec{p}\times\vec{E} = (3\hat{i}+4\hat{j})\times10^{-15}\times1000\,\hat{i} = 4\times10^{-12}(\hat{j}\times\hat{i}) = \mathbf{-4\times10^{-12}\,\hat{k}\ N\,m}$$

(magnitude 4×10^{-12} N m, along –z).

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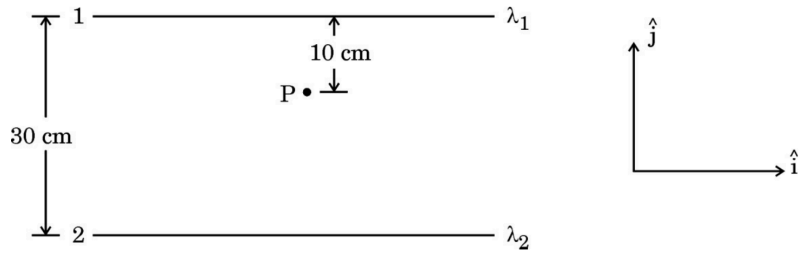
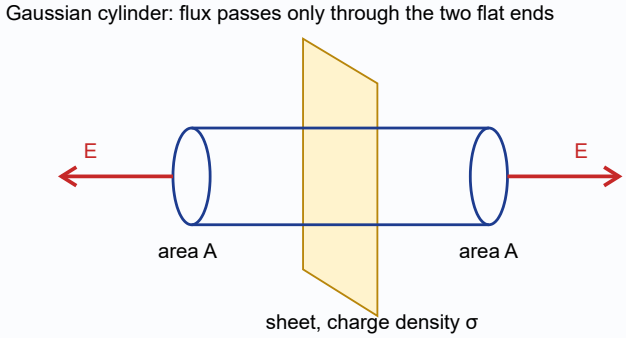
CBSE 2024 · 55/2/1 · Q31(b) | CBSE 2024 · 55/2/2 · Q32(b) | CBSE 2024 · 55/2/3 · Q32(b) asked 3 times 5 marks

(i) State Gauss's Law in electrostatics. Apply this to obtain the electric field $\vec{E}$ at a point near a uniformly charged infinite plane sheet.
(ii) Two long straight wires 1 and 2 are kept as shown in the figure. The linear charge density of the two wires are λ_1 = 10 μC/m and λ_2 = –20 μC/m. Find the net force $\vec{F}$ experienced by an electron held at point P.



Solution

(i) Gauss's law: the total electric flux through any closed surface equals $\frac{1}{\varepsilon_0}$ times the net charge enclosed by it: $\oint \vec{E} \cdot d\vec{S} = \frac{q_{enc}}{\varepsilon_0}$.



Take a cylinder of end-area A crossing the sheet (surface charge density σ). By symmetry $\vec{E}$ is normal to the sheet: no flux through the curved surface, flux EA through each end. Total flux $2EA$; charge enclosed σA:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

directed away from the sheet (for σ > 0), independent of distance.

(ii) Field of a long line charge: $E = \frac{\lambda}{2\pi\varepsilon_0 r} = \frac{2k\lambda}{r}$.

P is 10 cm below wire 1 and 20 cm above wire 2.

Wire 1 (positive): $E_1 = \frac{2 \times 9 \times 10^9 \times 10 \times 10^{-6}}{0.10} = 1.8 \times 10^6$ N/C, away from wire 1, i.e. along $-\hat{j}$.

Wire 2 (negative): $E_2 = \frac{2 \times 9 \times 10^9 \times 20 \times 10^{-6}}{0.20} = 1.8 \times 10^6$ N/C, towards wire 2, i.e. along $-\hat{j}$.

Net field: $\vec{E} = -3.6 \times 10^6\, \hat{j}$ N/C.

Force on the electron (charge –e):

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$$\vec{F} = -e\vec{E} = 1.6 \times 10^{-19} \times 3.6 \times 10^{6}\,\hat{j} = \mathbf{5.76 \times 10^{-13}\,\hat{j}\ N}$$

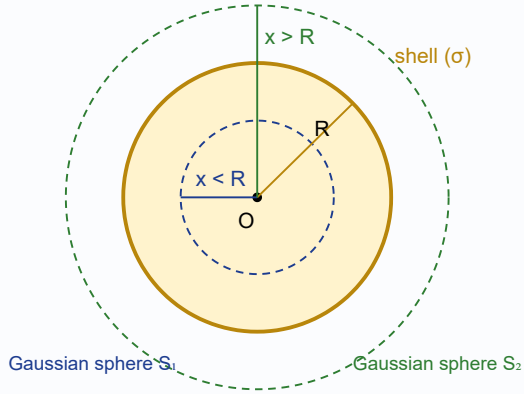
(towards wire 1).

CBSE 2024 · 55/3/1 · Q31(b) | CBSE 2024 · 55/3/2 · Q31(b) | CBSE 2024 · 55/3/3 · Q31(b) **asked 3 times** **5 marks**

(i) A charge + Q is placed on a thin conducting spherical shell of radius R. Use Gauss's theorem to derive an expression for the electric field at a point lying (i) inside and (ii) outside the shell.
(ii) Show that the electric field for same charge density (σ) is twice in case of a conducting plate or surface than in a nonconducting sheet.

Solution

(i) By symmetry the field is radial and has the same magnitude at all points at the same distance r from the centre. Choose a concentric spherical Gaussian surface of radius r.



(1) Inside (r < R): the Gaussian surface encloses no charge. $E \cdot 4\pi r^2 = 0$, so **E = 0**.

(2) Outside (r > R): it encloses +Q. $E \cdot 4\pi r^2 = \dfrac{Q}{\varepsilon_0}$, so

$$E = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

directed radially outward, as if the whole charge were at the centre.

(ii) Thin non-conducting sheet (charge density σ): a cylindrical Gaussian surface of end-area A pierces the sheet; flux leaves through both ends: $2EA = \dfrac{\sigma A}{\varepsilon_0}$, so $E = \dfrac{\sigma}{2\varepsilon_0}$.

Conducting plate (surface charge density σ on the surface): the field inside the conductor is zero, so flux leaves only through the outer end of the cylinder: $EA = \dfrac{\sigma A}{\varepsilon_0}$, so $E = \dfrac{\sigma}{\varepsilon_0}$.

Hence for the same σ, $E_{conductor} = 2E_{sheet}$.

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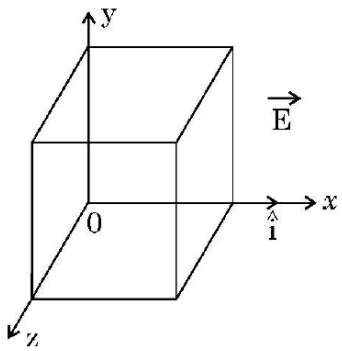
CBSE 2024 · 55/4/1 · Q32(b) | CBSE 2024 · 55/4/2 · Q32(b) | CBSE 2024 · 55/4/3 · Q31(b) asked 3 times 5 marks

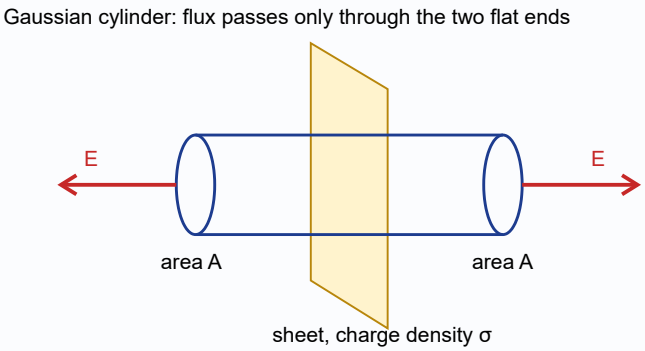
(i) Using Gauss's law, show that the electric field $\vec{E}$ at a point due to a uniformly charged infinite plane sheet is given by $\vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$ where symbols have their usual meanings.

(ii) Electric field $\vec{E}$ in a region is given by $\vec{E} = (5x^2 + 2)\hat{i}$ where E is in N/C and x is in meters. A cube of side 10 cm is placed in the region as shown in figure. Calculate (1) the electric flux through the cube, and (2) the net charge enclosed by the cube.



Solution

(i) Take a cylindrical Gaussian surface of end-area A piercing the sheet perpendicularly, with equal lengths on each side.



By symmetry $\vec{E}$ is perpendicular to the sheet, so there is no flux through the curved surface, and each flat end has flux EA. Total flux = 2EA; charge enclosed = σA. By Gauss's law:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow \vec{E} = \frac{\sigma}{2\varepsilon_0}\hat{n}$$

where $\hat{n}$ is the unit vector normal to the sheet, pointing away from it (for σ > 0).

(ii) The field is along x, so only the two faces perpendicular to x have flux: the left face at x = 0 and the right face at x = 0.1 m, each of area $A = (0.1)^2 = 10^{-2}$ m^2.

At x = 0: E = 2 N/C, flux $= -2 \times 10^{-2}$ (field enters). At x = 0.1 m: $E = 5(0.01) + 2 = 2.05$ N/C, flux $= +2.05 \times 10^{-2}$.

(1) Net flux $\Phi = (2.05 - 2) \times 10^{-2} = 5 \times 10^{-4}$ N m^2 C^{-1}.

(2) $q = \varepsilon_0\Phi = 8.85 \times 10^{-12} \times 5 \times 10^{-4} = 4.4 \times 10^{-15}$ C.

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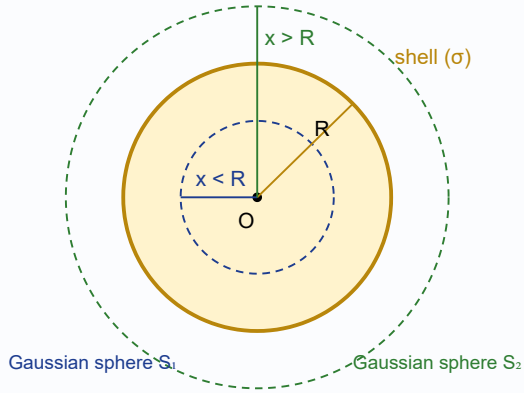
CBSE 2024 · 55/5/1 · Q31(b) | CBSE 2024 · 55/5/2 · Q32(b) | CBSE 2024 · 55/5/3 · Q33(b) **asked 3 times** **5 marks**

(i) A thin spherical shell of radius R has a uniform surface charge density σ. Using Gauss' law, deduce an expression for electric field (i) outside and (ii) inside the shell.
(ii) Two long straight thin wires AB and CD have linear charge densities 10 μC/m and –20 μC/m, respectively. They are kept parallel to each other at a distance 1 m. Find magnitude and direction of the net electric field at a point midway between them.

Solution

(i) Take concentric spherical Gaussian surfaces; by symmetry $\vec{E}$ is radial with the same magnitude everywhere on each surface.



(1) Outside (r > R): charge enclosed $q = \sigma \cdot 4\pi R^2$. $E \cdot 4\pi r^2 = \dfrac{\sigma 4\pi R^2}{\varepsilon_0}$, so

$$E = \frac{\sigma R^2}{\varepsilon_0 r^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}$$

radially outward (for σ > 0).
(2) Inside (r < R): no charge is enclosed, so $E \cdot 4\pi r^2 = 0$ and **E = 0**.

(ii) Field of a line charge: $E = \dfrac{\lambda}{2\pi\varepsilon_0 r}$, with r = 0.5 m.

$E_1 = \dfrac{2 \times 9 \times 10^9 \times 10 \times 10^{-6}}{0.5} = 3.6 \times 10^5$ N/C, away from AB (positive), i.e. towards CD.

$E_2 = \dfrac{2 \times 9 \times 10^9 \times 20 \times 10^{-6}}{0.5} = 7.2 \times 10^5$ N/C, towards CD (negative).

Both point towards CD: $E = 1.08 \times 10^6$ N/C, directed from AB towards CD.

CBSE 2023 · 55/1/1 · Q31(a) | CBSE 2023 · 55/1/2 · Q33(a) | CBSE 2023 · 55/1/3 · Q32(a) **asked 3 times** **5 marks**

(i) State Coulomb's law in electrostatics and write it in vector form, for two charges.
(ii) 'Gauss's law is based on the inverse-square dependence on distance contained in the Coulomb's law.' Explain.
(iii) Two charges A (charge q) and B (charge 2q) are located at points (0, 0) and (a, a) respectively. Let $\hat{i}$ and $\hat{j}$ be the unit vectors along x-axis and y-axis respectively. Find the force exerted by A on B, in terms of $\hat{i}$ and $\hat{j}$.

Solution

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(i) The force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, and acts along the line joining them:

$$\vec{F}_{21} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1 q_2}{r_{21}^2} \hat{r}_{21}$$

where $\vec{F}_{21}$ is the force on q_2 due to q_1 and $\hat{r}_{21}$ is the unit vector from q_1 to q_2.

(ii) For a point charge q at the centre of a sphere of radius r, $E = \frac{q}{4\pi\varepsilon_0 r^2}$ and the area is $4\pi r^2$, so the flux $\Phi = E \cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$ does not depend on r. This is so only because E falls as $\frac{1}{r^2}$ while the area grows as r^2. If the force law were any other power of r, the flux through a closed surface would depend on its size, and Gauss's law $\oint \vec{E} \cdot d\vec{S} = \frac{q}{\varepsilon_0}$ would not hold.

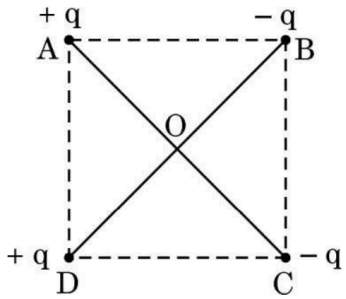
(iii) $\vec{r}_{BA} = (a\hat{i} + a\hat{j}),\ r = a\sqrt{2},\ \hat{r} = \frac{\hat{i}+\hat{j}}{\sqrt{2}}$.

$$\vec{F} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q(2q)}{2a^2} \cdot \frac{\hat{i}+\hat{j}}{\sqrt{2}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q^2}{\sqrt{2}\,a^2}(\hat{i}+\hat{j})$$

(repulsive, along AB produced).

CBSE 2023 · 55/1/1 · Q31(b) | CBSE 2023 · 55/1/2 · Q33(b) | CBSE 2023 · 55/1/3 · Q32(b) **asked 3 times** **5 marks**

(i) Derive an expression for the electric field at a point on the equatorial plane of an electric dipole consisting of charges q and – q separated by a distance 2a.
(ii) The distance of a far off point on the equatorial plane of an electric dipole is halved. How will the electric field be affected for the dipole?
(iii) Two identical electric dipoles are placed along the diagonals of a square ABCD of side $\sqrt{2}$ m as shown in the figure. Obtain the magnitude and direction of the net electric field at the centre (O) of the square.



Solution

(i)

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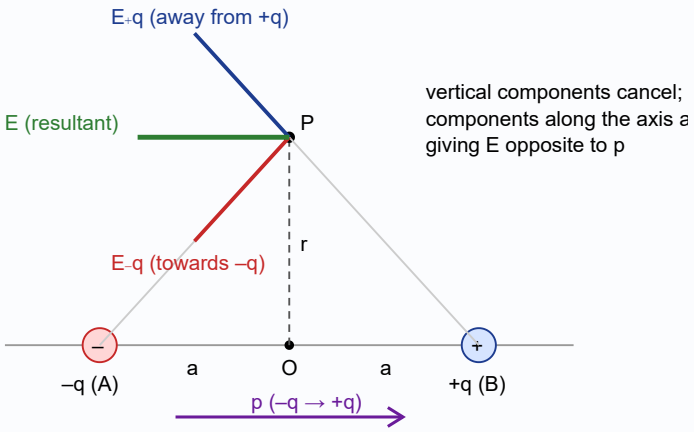

The point P is at distance r from the centre on the perpendicular bisector; each charge is at distance $\sqrt{r^2 + a^2}$:

$$E_{+q} = E_{-q} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2 + a^2}$$

The components perpendicular to the axis cancel; the components along the axis add, pointing from +q towards –q:

$$E = 2E_{+q}\cos\theta = 2 \cdot \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2 + a^2} \cdot \frac{a}{\sqrt{r^2 + a^2}} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{p}{(r^2 + a^2)^{3/2}}$$

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{\vec{p}}{(r^2 + a^2)^{3/2}} \approx -\frac{1}{4\pi\varepsilon_0} \cdot \frac{\vec{p}}{r^3} \; (r \gg a)$$

(ii) For a far point $E \propto \frac{1}{r^3}$; halving r makes the field **8 times**.

(iii) The diagonal of the square is $\sqrt{2} \times \sqrt{2} = 2$ m, so each charge is 1 m from O. Each charge produces a field of magnitude kq at O.

Dipole A(+q)–C(–q): both fields point from A towards C, total $2kq$ along AC.

Dipole D(+q)–B(–q): both fields point from D towards B, total $2kq$ along DB.

AC and DB are perpendicular, and their bisector is parallel to DC (AB). Each makes 45° with it, so the components perpendicular to DC cancel:

$$E = 2 \times 2kq\cos 45^\circ = 2\sqrt{2}\,kq = \frac{2\sqrt{2}\,q}{4\pi\varepsilon_0}\ \mathrm{N/C}$$

directed parallel to DC (from the AD side towards the BC side).

CBSE 2023 · 55/2/1 · Q31(a) | CBSE 2023 · 55/2/2 · Q32(a) | CBSE 2023 · 55/2/3 · Q33(a) **asked 3 times** **5 marks**

(i) Use Gauss' law to obtain an expression for the electric field due to an infinitely long thin straight wire with uniform linear charge density λ.
(ii) An infinitely long positively charged straight wire has a linear charge density λ. An electron is revolving in a circle with a constant speed v such that the wire passes through the centre, and is perpendicular to the plane, of the circle. Find the kinetic energy of the electron in terms of magnitudes of its charge and linear charge density λ on the wire.
(iii) Draw a graph of kinetic energy as a function of linear charge density λ.

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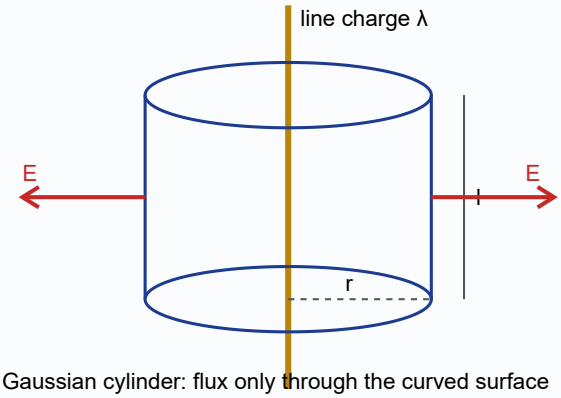
Solution

(i)



Gaussian cylinder: flux only through the curved surface

Take a coaxial cylinder of radius r and length l as the Gaussian surface. By symmetry $\vec{E}$ is radial and has the same magnitude on the curved surface. The flux through the flat ends is zero ($\vec{E} \perp d\vec{S}$ there).

Flux $= E(2\pi rl)$; charge enclosed $= \lambda l$:

$$E \cdot 2\pi rl = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

directed radially outward for λ > 0.

(ii) The electrostatic attraction provides the centripetal force:

$$\frac{mv^2}{r} = eE = \frac{e\lambda}{2\pi\varepsilon_0 r} \Rightarrow mv^2 = \frac{e\lambda}{2\pi\varepsilon_0}$$

$$K = \tfrac{1}{2}mv^2 = \frac{e\lambda}{4\pi\varepsilon_0}$$

(independent of the radius of the orbit).

(iii) K ∝ λ: a straight line through the origin (slope $\dfrac{e}{4\pi\varepsilon_0}$).

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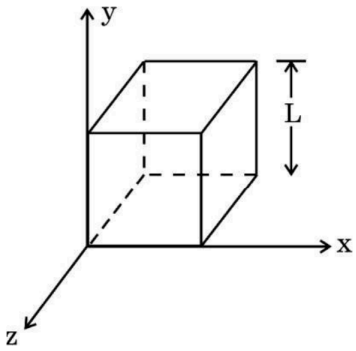
CBSE 2023 · 55/3/1 · Q31(a) | CBSE 2023 · 55/3/2 · Q33(a) | CBSE 2023 · 55/3/3 · Q32(a) asked 3 times 5 marks

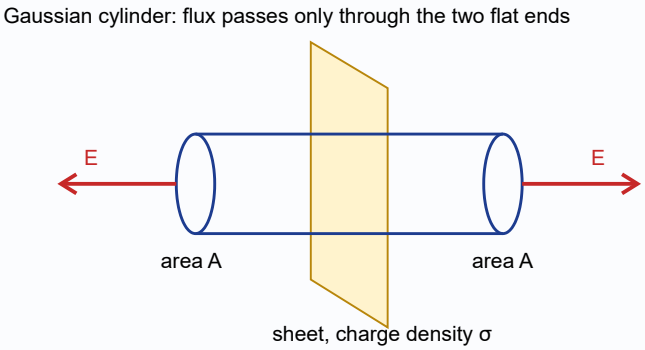
(i) Define electric flux and write its SI unit.
(ii) Use Gauss' law to obtain the expression for the electric field due to a uniformly charged infinite plane sheet.
(iii) A cube of side L is kept in space, as shown in the figure. An electric field $\vec{E} = (Ax + B)\hat{i}\ \frac{N}{C}$ exists in the region. Find the net charge enclosed by the cube.



Solution

(i) Electric flux through a surface is the number of electric field lines passing through it normally: $\phi = \int \vec{E} \cdot d\vec{S}$. SI unit: N m^2 C^{-1} (or V m).

(ii) Take a cylindrical Gaussian surface of end-area A crossing the sheet perpendicularly.



By symmetry $\vec{E}$ is normal to the sheet; the curved surface has no flux and each end has EA. Total flux 2EA, charge enclosed σA:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

directed away from the sheet (σ > 0), independent of distance.

(iii) The field is along x, so only the faces at x = 0 and x = L have flux, each of area L^2.
At x = 0: E = B, flux $= -BL^2$ (entering). At x = L: E = AL + B, flux $= +(AL + B)L^2$.
Net flux $\phi = AL \cdot L^2 = AL^3$. By Gauss's law:

$$q = \varepsilon_0 \phi = \varepsilon_0 AL^3$$

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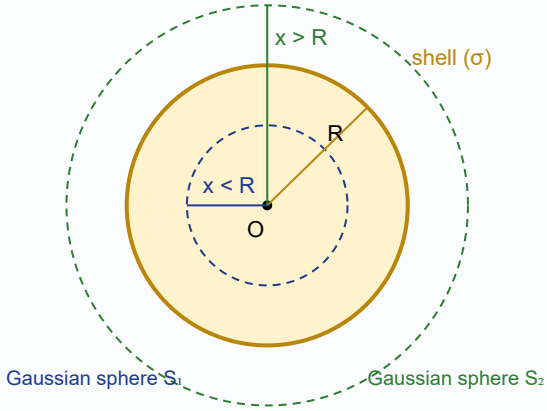
CBSE 2020 · 55/1/1 · Q35(a) | CBSE 2020 · 55/1/2 · Q37(a) | CBSE 2020 · 55/1/3 · Q36(a) asked 3 times 5 marks

(a) Using Gauss law, derive expression for electric field due to a spherical shell of uniform charge distribution σ and radius R at a point lying at a distance x from the centre of shell, such that (i) 0 < x < R, and (ii) x > R.
(b) An electric field is uniform and acts along + x direction in the region of positive x. It is also uniform with the same magnitude but acts in – x direction in the region of negative x. The value of the field is E = 200 N/C for x > 0 and E = – 200 N/C for x < 0. A right circular cylinder of length 20 cm and radius 5 cm has its centre at the origin and its axis along the x-axis so that one flat face is at x = + 10 cm and the other is at x = – 10 cm. Find: (i) The net outward flux through the cylinder. (ii) The net charge present inside the cylinder.

Solution

(a)



By symmetry $\vec{E}$ is radial and has the same magnitude at all points at distance x.
(i) Inside (x < R): a Gaussian sphere of radius x encloses no charge, so $E \cdot 4\pi x^2 = 0$ and $\mathbf{E = 0}$.
(ii) Outside (x > R): the sphere encloses $q = \sigma \cdot 4\pi R^2$:

$$E \cdot 4\pi x^2 = \frac{\sigma 4\pi R^2}{\varepsilon_0} \Rightarrow E = \frac{\sigma R^2}{\varepsilon_0 x^2} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{x^2}$$

directed radially outward (for σ > 0).

(b) (i) On both flat faces the field points outward (along +x at x = +10 cm, along –x at x = –10 cm); there is no flux through the curved surface. Area of each face $A = \pi(0.05)^2 = 7.85 \times 10^{-3}$ m².

$$\phi = EA + EA = 2 \times 200 \times 7.85 \times 10^{-3} \approx \mathbf{3.14\ N\,m^2\,C^{-1}}$$

(ii) $q = \varepsilon_0\phi = 8.854 \times 10^{-12} \times 3.14 \approx \mathbf{2.78 \times 10^{-11}\ C}$.

CBSE 2020 · 55/2/1 · Q35(a) | CBSE 2020 · 55/2/2 · Q37(a) | CBSE 2020 · 55/2/3 · Q36(a) asked 3 times 5 marks

(a) Use Gauss's law to show that due to a uniformly charged spherical shell of radius R, the electric field at any point situated outside the shell at a distance r from its centre is equal to the electric field at the same point, when the entire charge on the shell were concentrated at its centre. Also plot the graph showing the variation of electric field with r, for r ≤ R and r ≥ R.
(b) Two point charges of + 1 μC and + 4 μC are kept 30 cm apart. How far from the + 1 μC charge on the line joining the two charges, will the net electric field be zero?

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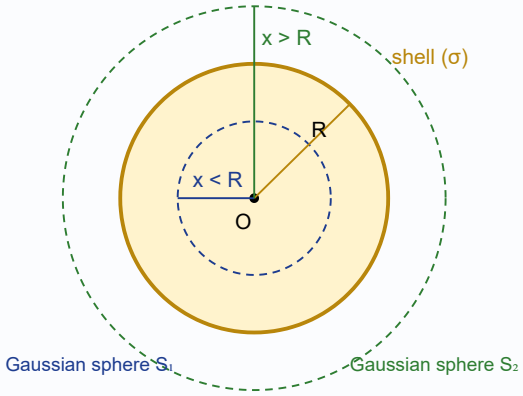
Solution

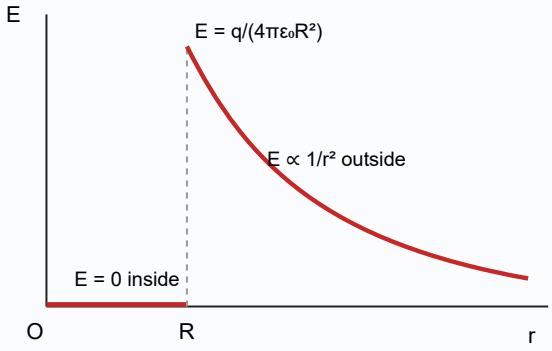
(a)



Take a concentric Gaussian sphere of radius r > R. By symmetry $\vec{E}$ is radial with the same magnitude everywhere on it:

$$E \cdot 4\pi r^2 = \frac{q}{\varepsilon_0} \Rightarrow E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2}$$

This is exactly the field of a point charge q at the centre. Inside (r < R) the Gaussian sphere encloses no charge, so E = 0.



(b) Let the point be x from +1 μC (between the charges, since both are positive):

$$\frac{k(1)}{x^2} = \frac{k(4)}{(0.3-x)^2} \Rightarrow 0.3 - x = 2x \Rightarrow x = \mathbf{0.1\ m = 10\ cm}$$

from the +1 μC charge.

CBSE 2020 · 55/3/1 · Q35(a) | CBSE 2020 · 55/3/2 · Q37(a) | CBSE 2020 · 55/3/3 · Q36(a) **asked 3 times** **5 marks**

(a) An electric dipole of dipole moment $\vec{p}$ is placed in a uniform electric field $\vec{E}$ at an angle θ with it. Derive the expression for torque ($\vec{\tau}$) acting on it. Find the orientation of the dipole relative to the electric field for which torque on it is (i) maximum, and (ii) half of maximum.
(b) Two point charges q_1 = + 1 μC and q_2 = + 4 μC are placed 2 m apart in air. At what distance from q_1 along the line joining the two charges, will the net electric field be zero ?

Solution

(a) A dipole of charges ±q, separation 2a, makes angle θ with $\vec{E}$. The forces $+q\vec{E}$ and $-q\vec{E}$ are equal and opposite (net force zero) but act along different lines, forming a couple. The

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perpendicular distance between their lines of action is $2a\sin\theta$:

$$\tau = qE \times 2a\sin\theta = pE\sin\theta, \qquad \vec{\tau} = \vec{p} \times \vec{E}$$

(i) Maximum (= pE) when θ = 90°: $\vec{p}$ perpendicular to $\vec{E}$.

(ii) Half the maximum: $\sin\theta = \frac{1}{2}$, θ = 30° (or 150°).

(b) Both charges are positive, so the zero-field point lies between them. Let it be x from q_1:

$$\frac{k(1\ \mu\text{C})}{x^2} = \frac{k(4\ \mu\text{C})}{(2-x)^2} \Rightarrow \frac{2-x}{x} = 2 \Rightarrow x = \frac{2}{3}\ \text{m} \approx 0.67\ \text{m}$$

CBSE 2020 · 55/5/1 · Q37(a) | CBSE 2020 · 55/5/2 · Q35(a) | CBSE 2020 · 55/5/3 · Q36(a) **asked 3 times** **5 marks**

(a) Write two important characteristics of equipotential surfaces.
(b) A thin circular ring of radius r is charged uniformly so that its linear charge density becomes λ. Derive an expression for the electric field at a point P at a distance x from it along the axis of the ring. Hence, prove that at large distances (x >> r), the ring behaves as a point charge.

Solution

(a) Any two: (1) no work is done in moving a charge along an equipotential surface; (2) the electric field is always perpendicular to the equipotential surface at every point; (3) two equipotential surfaces never intersect; (4) equipotentials are closer together where the field is stronger.

(b) Total charge Q = 2πrλ. An element dq of the ring is at distance $\sqrt{r^2+x^2}$ from P and gives $dE = \frac{1}{4\pi\varepsilon_0}\frac{dq}{r^2+x^2}$. By symmetry the components perpendicular to the axis cancel; the axial components ($dE\cos\theta$, with $\cos\theta = \frac{x}{\sqrt{r^2+x^2}}$) add:

$$E = \frac{1}{4\pi\varepsilon_0}\frac{x}{(r^2+x^2)^{3/2}}\int dq = \frac{1}{4\pi\varepsilon_0}\frac{(2\pi r\lambda)x}{(r^2+x^2)^{3/2}}$$

along the axis (away from the ring for λ > 0).

For x ≫ r: $(r^2+x^2)^{3/2} \approx x^3$, so $E \approx \frac{1}{4\pi\varepsilon_0}\frac{Q}{x^2}$: the field of a point charge Q at the centre.

CBSE 2020 · 55/5/1 · Q37(b) | CBSE 2020 · 55/5/2 · Q35(b) | CBSE 2020 · 55/5/3 · Q36(b) **asked 3 times** **5 marks**

(a) State Gauss's law on electrostatics and derive an expression for the electric field due to a long straight thin uniformly charged wire (linear charge density λ) at a point lying at a distance r from the wire.
(b) The magnitude of electric field (in NC^{-1}) in a region varies with the distance r(in m) as E = 10 r + 5. By how much does the electric potential increase in moving from point at r = 1 m to a point at r = 10 m.

Solution

(a) Gauss's law: the total electric flux through any closed surface equals $\frac{1}{\varepsilon_0}$ times the net charge enclosed: $\oint \vec{E}\cdot d\vec{S} = \frac{q_{enc}}{\varepsilon_0}$.

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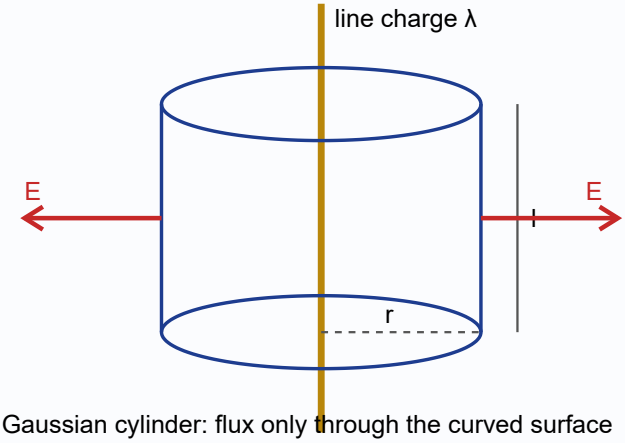


Gaussian cylinder: flux only through the curved surface

Take a coaxial cylinder of radius r and length l. By symmetry E is radial and constant on the curved surface; the end faces have no flux:

$$E \cdot 2\pi r l = \frac{\lambda l}{\varepsilon_0} \Rightarrow E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

(b) $\Delta V = V_{10} - V_1 = -\int_1^{10} E\,dr = -\int_1^{10} (10r + 5)\,dr = -\left[5r^2 + 5r\right]_1^{10} = -(550 - 10) = -540$ V.

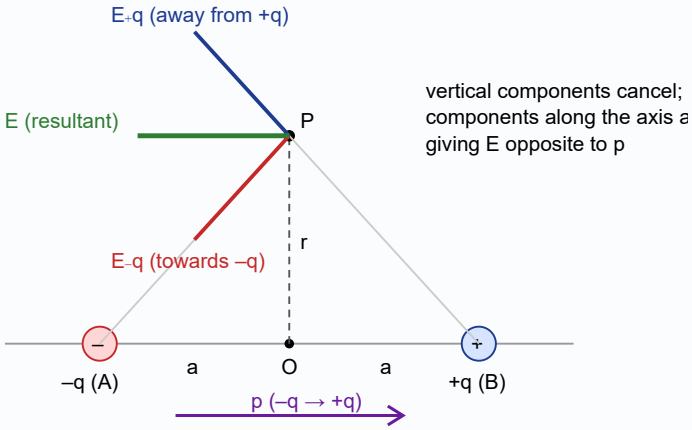
So the potential **decreases by 540 V** (it "increases" by –540 V) in moving from r = 1 m to r = 10 m, if E points along increasing r.

CBSE 2019 · 55/1/1 · Q27(b) | CBSE 2019 · 55/1/2 · Q26(b) | CBSE 2019 · 55/1/3 · Q25(b) **asked 3 times** **5 marks**

(a) Derive an expression for the electric field at any point on the equatorial line of an electric dipole. (b) Two identical point charges, q each, are kept 2m apart in air. A third point charge Q of unknown magnitude and sign is placed on the line joining the charges such that the system remains in equilibrium. Find the position and nature of Q.

Solution

(a)



At P on the perpendicular bisector (distance r from the centre), each charge is at distance $\sqrt{r^2 + a^2}$ and produces $\frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2 + a^2}$. Components perpendicular to the axis cancel; those along the axis add (from +q towards –q):

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$$E = \frac{1}{4\pi\varepsilon_0}\cdot\frac{2qa}{(r^2+a^2)^{3/2}}, \qquad \vec{E} = -\frac{1}{4\pi\varepsilon_0}\cdot\frac{\vec{p}}{(r^2+a^2)^{3/2}}$$

For $r \gg a$: $E = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{p}{r^3}$.

(b) For Q to be in equilibrium between two equal charges, it must be at the **midpoint**, 1 m from each (the two forces on it balance there).

For each q to be in equilibrium, the attraction by Q must balance the repulsion of the other q:

$$\frac{kq|Q|}{1^2} = \frac{kq^2}{2^2} \Rightarrow |Q| = \frac{q}{4}$$

Q must attract q, so it is **negative**: $Q = -\dfrac{q}{4}$, placed at the midpoint.

CBSE 2019 · 55/4/1 · Q25(b) | CBSE 2019 · 55/4/2 · Q26(b) | CBSE 2019 · 55/4/3 · Q27(b) **asked 3 times** **5 marks**

(a) Derive an expression for the potential energy of an electric dipole in a uniform electric field. Explain conditions for stable and unstable equilibrium.
(b) Is the electrostatic potential necessarily zero at a point where the electric field is zero ? Give an example to support your answer.

Solution

(a) A dipole of moment p in a field E at angle θ experiences a torque τ = pE sin θ. The work done in rotating it slowly from θ_0 to θ against this torque is

$$W = \int_{\theta_0}^{\theta} pE\sin\theta\, d\theta = pE(\cos\theta_0 - \cos\theta)$$

This is stored as potential energy. Taking U = 0 at θ_0 = 90°:

$$U(\theta) = -pE\cos\theta = -\vec{p}\cdot\vec{E}$$

Stable equilibrium: θ = 0° ($\vec{p}$ along $\vec{E}$), U = –pE is minimum; a small displacement produces a restoring torque.

Unstable equilibrium: θ = 180° ($\vec{p}$ opposite to $\vec{E}$), U = +pE is maximum; a small displacement makes the dipole turn further away.

(b) No. E = –dV/dr is zero where the potential is constant (has zero slope), not where it is zero. Example: at the midpoint between two equal positive charges q separated by 2a, the fields cancel (E = 0) but $V = \dfrac{2q}{4\pi\varepsilon_0 a} \neq 0$. (Also, inside a charged conducting sphere E = 0 but V = kQ/R.)

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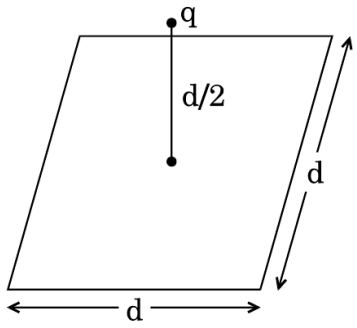
CBSE 2018 · 55/1 · Set 1 · Q24(a) | CBSE 2018 · 55/2 · Q25(a) | CBSE 2018 · 55/3 · Q26(a) **asked 3 times** **5 marks**

(a) Define electric flux. Is it a scalar or a vector quantity? A point charge q is at a distance of d/2 directly above the centre of a square of side d, as shown in the figure. Use Gauss' law to obtain the expression for the electric flux through the square. (b) If the point charge is now moved to a distance 'd' from the centre of the square and the side of the square is doubled, explain how the electric flux will be affected.



Solution

(a) Electric flux through a surface is $\phi = \int \vec{E} \cdot d\vec{S}$, the number of field lines crossing it. It is a **scalar**.

Imagine a cube of side d with the charge at its centre: the square is one face of this cube (the charge is d/2 from it). By Gauss's law the total flux through the cube is $\frac{q}{\varepsilon_0}$, shared equally by the six faces:

$$\phi = \frac{q}{6\varepsilon_0}$$

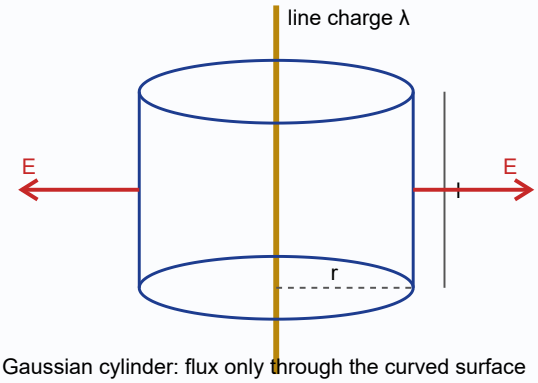
(b) Now the charge is at distance d from a square of side 2d: it is again at the centre of a cube (side 2d) of which the square is a face. So the flux remains $\frac{q}{6\varepsilon_0}$: **unchanged**.

CBSE 2018 · 55/1 · Set 1 · Q24(b) | CBSE 2018 · 55/2 · Q25(b) | CBSE 2018 · 55/3 · Q26(b) **asked 3 times** **5 marks**

(a) Use Gauss' law to derive the expression for the electric field $(\vec{E})$ due to a straight uniformly charged infinite line of charge density λ C/m. (b) Draw a graph to show the variation of E with perpendicular distance r from the line of charge. (c) Find the work done in bringing a charge q from perpendicular distance r_1 to r_2 $(r_2 > r_1)$.

Solution

(a)



Gaussian cylinder: flux only through the curved surface

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Take a coaxial cylinder of radius r and length l. E is radial, so flux passes only through the curved surface: $E(2\pi rl) = \dfrac{\lambda l}{\varepsilon_0}$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r},\ \text{radially outward } (\lambda > 0)$$

(b) $E \propto \dfrac{1}{r}$: a rectangular hyperbola, decreasing with r.

(c) Work done by the field as q moves from r_1 to r_2:

$$W = \int_{r_1}^{r_2} qE\,dr = \frac{q\lambda}{2\pi\varepsilon_0}\ln\frac{r_2}{r_1}$$

(The work done by an external agent is the negative of this.)

CBSE 2017 · 55/1 · Set 1 · Q24(a) | CBSE 2017 · 55/2 · Q25(a) | CBSE 2017 · 55/3 · Q26(a) **asked 3 times** **5 marks**

(a) Derive an expression for the electric field E due to a dipole of length '2a' at a point distant r from the centre of the dipole on the axial line.
(b) Draw a graph of E versus r for r >> a.
(c) If this dipole were kept in a uniform external electric field E_0, diagrammatically represent the position of the dipole in stable and unstable equilibrium and write the expressions for the torque acting on the dipole in both the cases.

Solution

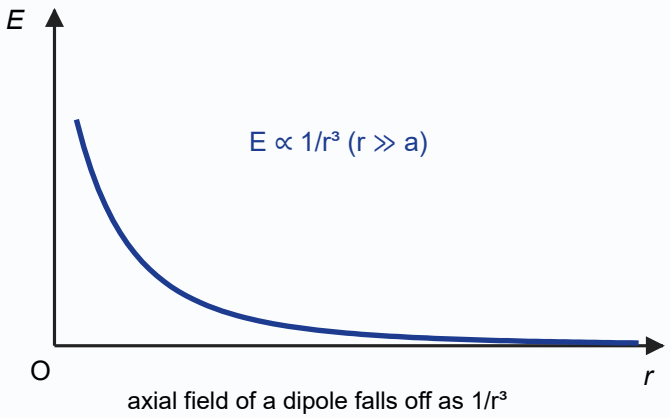
(a) Charges –q at A and +q at B, P on the axis at distance r from the centre, nearer to +q.

$$E_{+q} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r-a)^2},\quad E_{-q} = \frac{1}{4\pi\varepsilon_0}\cdot\frac{q}{(r+a)^2}\ (\text{opposite})$$

$$E = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2}\right] = \frac{1}{4\pi\varepsilon_0}\cdot\frac{4qar}{(r^2-a^2)^2}$$

along $\vec{p}$. For $r \gg a$: $E = \dfrac{1}{4\pi\varepsilon_0}\cdot\dfrac{2p}{r^3}$.

(b) For $r \gg a$, $E \propto \dfrac{1}{r^3}$: a curve falling steeply with r.



axial field of a dipole falls off as 1/r³

(c) Stable equilibrium: $\vec{p}$ parallel to $\vec{E}_0$ (θ = 0). Unstable equilibrium: $\vec{p}$ antiparallel (θ = 180°). In both, $\tau = pE_0\sin\theta = 0$.



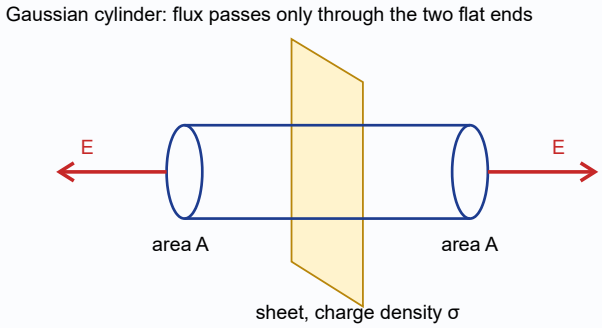
(a) stable: p ∥ E, U = –pE (b) unstable: p opposite to E, U = +pE

CBSE 2017 · 55/1 · Set 1 · Q24(b) | CBSE 2017 · 55/2 · Q25(b) | CBSE 2017 · 55/3 · Q26(b) **asked 3 times** **5 marks**

(a) Use Gauss's theorem to find the electric field due to a uniformly charged infinitely large plane thin sheet with surface charge density σ.
(b) An infinitely large thin plane sheet has a uniform surface charge density +σ. Obtain the expression for the amount of work done in bringing a point charge q from infinity to a point, distance r, in front of the charged plane sheet.

Solution

(a)



Cylindrical Gaussian surface crossing the sheet: flux $2EA$, charge enclosed σA: $E = \dfrac{\sigma}{2\varepsilon_0}$, normal to the sheet.

(b) The force on q is $F = \dfrac{q\sigma}{2\varepsilon_0}$, the same at every distance. The work done against it in bringing q from infinity to r is

$$W = -\int_{\infty}^{r} \vec{F} \cdot d\vec{r} = \frac{q\sigma}{2\varepsilon_0}(\infty - r) = \infty$$

So the work done is **infinite**, as in the CBSE marking scheme. (A finite answer needs a finite start: moving q from a distance r_1 to r takes $W = \dfrac{q\sigma}{2\varepsilon_0}(r_1 - r)$.)

CBSE 2016 · 55/1/C · Q26(a) | CBSE 2016 · 55/2/C · Q25(a) | CBSE 2016 · 55/3/C · Q24(a) **asked 3 times** **5 marks**

(i) Use Gauss's law to find the electric field due to a uniformly charged infinite plane sheet. What is the direction of field for positive and negative charge densities ?
(ii) Find the ratio of the potential differences that must be applied across the parallel and series combination of two capacitors C_1 and C_2 with their capacitances in the ratio 1 : 2 so that the energy stored in the two cases becomes the same.

Solution

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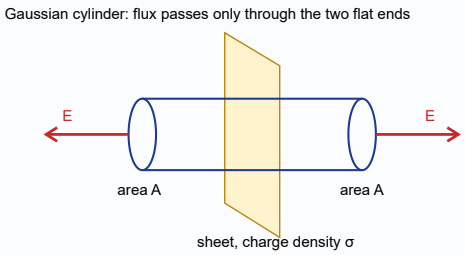
(i)



Take a cylindrical Gaussian surface of cross-section A, piercing the sheet (charge density σ) perpendicularly, with its ends on either side. By symmetry E is normal to the sheet and equal in magnitude at both ends; there is no flux through the curved surface. Flux = EA + EA = 2EA; charge enclosed = σA:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

independent of the distance from the sheet. For positive σ the field points **away from** the sheet on both sides; for negative σ it points **towards** the sheet.

(ii) Let C_1 = C, C_2 = 2C. Parallel: C_p = 3C. Series: $C_s = \dfrac{C \cdot 2C}{3C} = \dfrac{2C}{3}$.

Equal energies: $\frac{1}{2}C_pV_p^2 = \frac{1}{2}C_sV_s^2 \Rightarrow \dfrac{V_p^2}{V_s^2} = \dfrac{C_s}{C_p} = \dfrac{2/3}{3} = \dfrac{2}{9}$

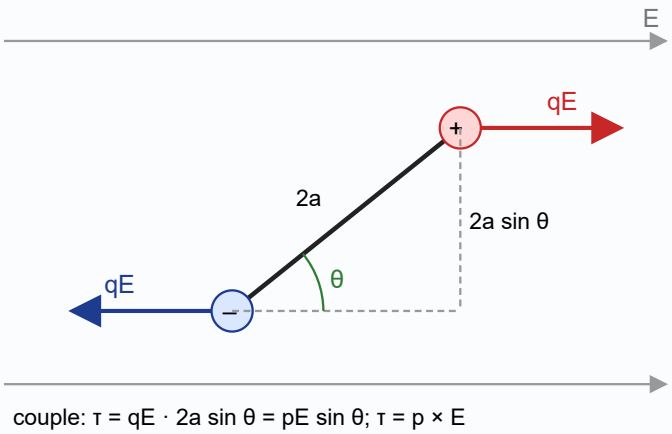
$$\frac{V_p}{V_s} = \frac{\sqrt{2}}{3} \quad (\approx 0.47)$$

CBSE 2016 · 55/1/E · Q26(b) | CBSE 2016 · 55/2/E · Q25(b) | CBSE 2016 · 55/3/E · Q24(b) **asked 3 times** **5 marks**

(a) Deduce the expression for the torque acting on a dipole of dipole moment $\vec{p}$ placed in a uniform electric field $\vec{E}$. Depict the direction of the torque. Express it in the vector form.
(b) Show that the potential energy of a dipole making angle θ with the direction of the field is given by $u(\theta) = -\vec{p} \cdot \vec{E}$. Hence find out the amount of work done in rotating it from the position of unstable equilibrium to the stable equilibrium.

Solution

(a)



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The forces +qE and –qE on the charges are equal and opposite (net force zero) but act along different lines, forming a couple. The arm of the couple is 2a sin θ:

$$\tau = qE \cdot 2a\sin\theta = pE\sin\theta, \qquad \vec{\tau} = \vec{p} \times \vec{E}$$

The torque is perpendicular to the plane containing $\vec{p}$ and $\vec{E}$ (into the page for the figure), and tends to align $\vec{p}$ with $\vec{E}$.

(b) Work done in rotating the dipole slowly from θ_0 to θ against the torque: $W = \int_{\theta_0}^{\theta} pE\sin\theta\, d\theta = pE(\cos\theta_0 - \cos\theta)$. Taking U = 0 at $\theta_0 = 90°$:

$$U(\theta) = -pE\cos\theta = -\vec{p}\cdot\vec{E}$$

Unstable equilibrium: θ = 180°, U = +pE. Stable equilibrium: θ = 0°, U = –pE. Work done (by the external agent) in rotating from unstable to stable equilibrium:

$$W = U_{final} - U_{initial} = -pE - pE = -2pE$$

i.e. the field itself does work +2pE (the dipole gives up energy 2pE).

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CBSE BOARD PAPER

2026 · Q.P. Code 55/1/1

Time: 3 hours
Maximum marks: 70

Section A · Multiple choice and Assertion–Reason (1 mark each)

1. In a region, the electric potential varies as $V = 10 - 50x$, where V is in volts and x in meters. The electric field in the region is 1

(A) 10 N/C along $+x$
(B) 10 N/C along $-x$
(C) 50 N/C along $+x$
(D) 50 N/C along $-x$

2. A conducting wire connects two charged metallic spheres A and B of radii r_1 and r_2 respectively. The distance between the spheres is very large compared to their radii. The ratio of electric fields (E_A/E_B) at the surfaces of spheres A and B will be 1

(A) $\frac{r_1}{r_2}$
(B) $\frac{r_2}{r_1}$
(C) $\frac{r_1^2}{r_2^2}$
(D) $\frac{r_2^2}{r_1^2}$

3. A long straight wire of circular cross-section (radius a) carries a steady current I. The current is uniformly distributed across this cross-section. The magnitude of the magnetic field produced at a point at a distance $(a/2)$ from the axis of the wire will be 1

(A) Zero
(B) $\frac{\mu_0 I}{2\pi a}$
(C) $\frac{\mu_0 I}{4\pi a}$
(D) $\frac{\mu_0 I}{6\pi a}$

4. The shape of the interference fringes in Young's double-slit experiment, when the distance between the slit and the screen is very large as compared to the slit-separation, is nearly 1

(A) straight
(B) parabolic
(C) circular
(D) hyperbolic

5. An electromagnetic wave passes from vacuum into a dielectric medium with relative electrical permittivity $(3/2)$ and relative magnetic permeability $(8/3)$. Then, its 1

(A) wavelength is doubled and frequency remains unchanged.
(B) wavelength is doubled and frequency is halved.
(C) wavelength is halved and frequency remains unchanged.
(D) wavelength and frequency both will remain unchanged.

6. In a series LCR circuit, the voltage across the resistor, capacitor and inductor is 10 V each. If the capacitor is short circuited, the voltage across the inductor will be 1

(A) 10 V
(B) $5\sqrt{2}$ V
(C) $\frac{5}{\sqrt{2}}$ V
(D) $10\sqrt{2}$ V

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7. Electromagnetic waves used in a diagnostic tool in medicine have a wavelength range 1

(A) 1 nm to 10^{-3} nm
(B) 400 nm to 1 nm
(C) 1 mm to 700 nm
(D) 0.1 m to 1 mm

8. The 'distance of closest approach' of an alpha-particle is 'd' when it moves with a velocity v head-on towards the target nucleus. If the velocity of alpha particle is halved, the new 'distance of closest approach' will be 1

(A) $\frac{d}{2}$
(B) $2d$
(C) $\frac{d}{4}$
(D) $4d$

9. A concave lens of focal length 10 cm is cut into two identical plano-concave lenses. The focal length of each lens will be 1

(A) 20 cm
(B) 30 cm
(C) 40 cm
(D) 5 cm

10. Four independent waves are expressed as (i) $y_1 = A_1 \sin \omega t$ (ii) $y_2 = A_2 \sin 2\omega t$ (iii) $y_3 = A_3 \cos \omega t$ (iv) $y_4 = A_4 \sin(\omega t + \pi/3)$. The interference between two of these waves is possible in 1

(A) (i) and (iii) only
(B) (iii) and (iv) only
(C) (i), (iii) and (iv) only
(D) All of them

11. Two heaters rated as (P_1, V) and (P_2, V) are connected in series across a dc source of $\frac{V}{2}$ volt. The power consumed by the combination will be 1

(A) $(P_1 + P_2)$
(B) $\frac{P_1 + P_2}{2}$
(C) $\frac{P_1 P_2}{2(P_1 + P_2)}$
(D) $\frac{P_1 P_2}{4(P_1 + P_2)}$

12. In an unbiased p-n junction, at equilibrium, which of the following statements is true? 1

(A) Diffusion current is zero but drift current exists.
(B) Diffusion current exists but drift current is zero.
(C) Diffusion and drift currents are equal and opposite.
(D) Both the diffusion and drift currents exist but are unequal.

13. Assertion (A): All atoms have a net magnetic moment. 1
Reason (R): A current loop does not always behave as a magnetic dipole.

(A) Both A and R are true and R is the correct explanation of A. (B) Both A and R are true but R is not the correct explanation of A. (C) A is true but R is false. (D) A is false but R is true.

14. Assertion (A): If accelerated electrons are passed through a narrow slit, a diffraction pattern is observed. 1
Reason (R): Electrons behave as both particles and waves.

(A) Both A and R are true and R is the correct explanation of A. (B) Both A and R are true but R is not the correct explanation of A. (C) A is true but R is false. (D) A is false but R is true.

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15. Assertion (A): The mass of a nucleus is less than the sum of the masses of the constituent nucleons. 1
Reason (R): Energy is absorbed when the nucleons are bound together to form a nucleus.

(A) Both A and R are true and R is the correct explanation of A. (B) Both A and R are true but R is not the correct explanation of A. (C) A is true but R is false. (D) A is false but R is true.

16. Assertion (A): In Bohr model of hydrogen atom, the energy levels are discrete and quantised. 1
Reason (R): In a hydrogen atom, the electrostatic force on the electron provides the necessary centripetal force to it to revolve around the nucleus.

(A) Both A and R are true and R is the correct explanation of A. (B) Both A and R are true but R is not the correct explanation of A. (C) A is true but R is false. (D) A is false but R is true.

Section B · Very short answer (2 marks each)

17. In a photoelectric experiment, the emitter plate is irradiated with radiation of 200 nm. The photocurrent becomes zero when the collector plate potential is -0.80 V. Calculate the work function (in eV) of the emitter. 2

18. **(a)** A beam of light consisting of two wavelengths 400 nm and 600 nm is used to illuminate a single slit of width 1 mm. Find the least distance of the point from the central maximum where the dark fringes due to both wavelengths coincide on the screen placed 1.5 m from the slit. 2

OR

(b) In a Young's double-slit experimental set-up with slit separation 0.6 mm a beam of light consisting of two wavelengths 440 nm and 660 nm is used to obtain interference pattern on a screen kept 1.5 m in front of the slits. Find the least distance of the point from the central maximum where the bright fringes due to both the wavelengths coincide. 2

19. A wire of length L is bent round into (i) a square coil having N turns and (ii) a circular coil having N turns. The coil in both cases is free to turn about a vertical axis coinciding with the plane of the coil, in a uniform, horizontal magnetic field and carry the same currents. Find the ratio of the maximum value of the torque acting on the square coil to that on the circular coil. 2

20. What is the order of magnitude of drift velocity of electrons in a conductor? Deduce the relation between the current flowing through a conductor and drift velocity of electrons in it. 2

21. Draw the plot of potential energy of a pair of nucleons as a function of their separation. Write two important conclusions that can be drawn from this plot. 2

Section C · Short answer (3 marks each)

22. **(a)** Using Gauss's law, deduce an expression for electric field at a point due to a uniformly charged infinite plane thin sheet. 3
(b) Two large thin plane sheets, each having surface charge density σ, are held close and parallel to each other in air. What is the net electric field at a point (i) inside and (ii) outside, the sheets?

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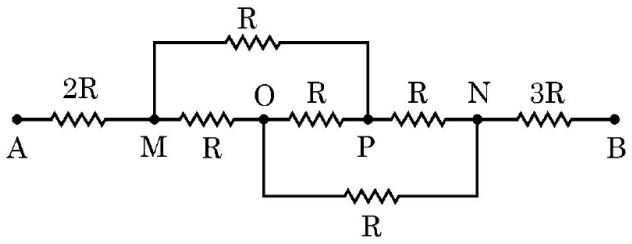
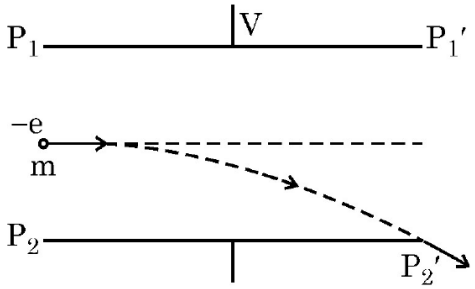
OR

(b) (a) Obtain the condition of balance of a Wheatstone bridge. 3
(b) Find net resistance of the network of resistors connected between A and B, as shown in figure.



23. A parallel plate capacitor of capacitance C has a dielectric slab between its plates. It is charged to a potential difference V by connecting it across a battery. The battery is then disconnected. If the dielectric slab is now withdrawn from the capacitor, how will the following be affected? (a) Capacitance of the capacitor, (b) Energy stored in the capacitor, and (c) The potential difference between the plates of the capacitor. Justify your answer in each case. 3

24. Figure shows a narrow beam of electrons entering with a velocity of 3×10^7 m/s, symmetrically through the space between two parallel horizontal plates P_1P_1' and P_2P_2' kept 2 cm apart. If each plate is 3 cm long, calculate the potential difference V applied between the plates so that the beam just strikes the end P_2'. 3



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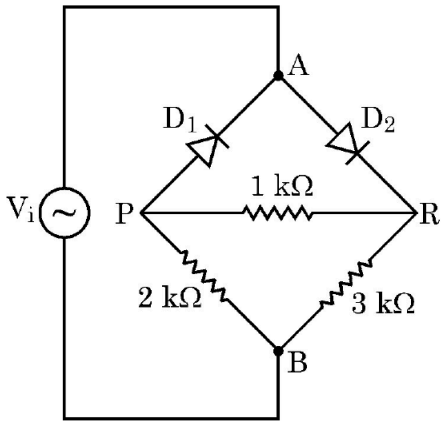
25. An ac voltage $V_i = 12\sin(100\pi t)$ V is applied between points A and B in a network of two ideal diodes and three resistors as shown in figure. During the positive half-cycle of the input voltage V_i supplied to the network, (a) Identify which of the two diodes will conduct and why? 3

(b) Redraw an equivalent circuit diagram to show the flow of current.

(c) Calculate the output voltage drops V_0 across the three resistors when the input voltage attains its peak value.



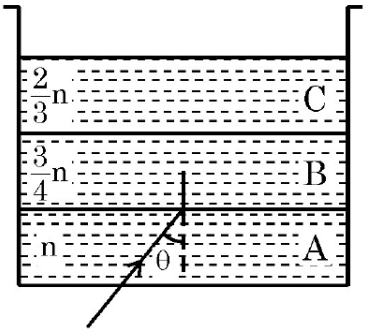
26. Briefly explain the two important processes that occur during the formation of a p-n junction. 3

27. (a) Draw the ray diagram to show the image formation by a refracting telescope and write the expression for angular magnification for the telescope in normal adjustment. 3

(b) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope.

28. (a) State the two conditions under which total internal reflection occurs. 3

(b) A transparent container contains layers of three immiscible transparent liquids A, B and C of refractive indices n, $\frac{3}{4}$n and $\frac{2}{3}$n, respectively. A laser beam is incident at the interface between A and B at an angle θ as shown in figure. Prove that the beam does not enter region C at all for $\sin\theta \geq \frac{2}{3}$.



Section D · Case-based (4 marks each)

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29. *A galvanometer is used to detect or/and measure small currents in an electrical circuit. It essentially works on the fact that a current-carrying coil experiences a deflecting torque when placed in a magnetic field. This deflection in the coil can be measured and it is related to the current flowing in the coil, the number of turns in the coil, area of the coil and the magnetic field. A hair spring attached to the coil provides a counter torque and helps in measuring the deflection. A galvanometer can be converted to an ammeter or a voltmeter of desired range by using suitable resistances.* 4

(I) The torque on the coil remains constant irrespective of the coil's orientation during rotation due to

(A) use of soft iron core which increases the magnetic field

(B) radial magnetic field

(C) hair spring which provides the counter torque

(D) eddy current in the iron core which causes damping

(II) The best way to increase current sensitivity of a galvanometer is by

(A) increasing number of turns of the coil

(B) increasing area of coil and magnetic field strength

(C) decreasing area of coil and magnetic field strength

(D) increasing torsional constant of the hair spring

(III) A moving coil galvanometer has a coil with area of cross-section 4.0×10^{-3} m² and number of turns 50. The coil is rotating in a magnetic field of 0.25 T. The torque acting on the coil when a current of 5 A passes through it is

(A) 1.0 N m

(B) 2.0 N m

(C) 0.50 N m

(D) 0.25 N m

OR

A galvanometer coil has a resistance of 15 Ω and the meter shows full scale deflection for a current of 3 mA. The value of resistance required to convert it into a voltmeter of range (0 – 12 V) is

(A) 4015 Ω

(B) 3985 Ω

(C) 415 Ω

(D) 385 Ω

(IV) A galvanometer with coil of resistance 20 Ω shows full scale deflection for a current of 5 mA. To convert it into an ammeter of range (0 – 10 A), a resistance of

(A) 0.05 Ω should be connected in series with it

(B) 0.05 Ω should be connected in parallel with it

(C) 0.01 Ω should be connected in parallel with it

(D) 0.01 Ω should be connected in series with it

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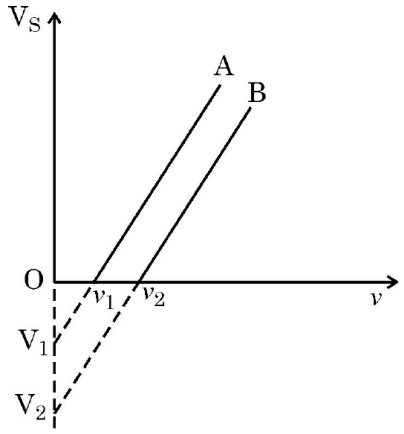
30. *A researcher performs an experiment on photo-electric effect using two metals A and B with unknown work functions. She illuminates the surfaces of A and B with monochromatic radiation of various frequencies and records the value of corresponding stopping potentials (V_s). The graph shows the variation of stopping potential (V_s) with the frequency of incident radiation (ν) for metals A and B.* 4



(I) From the graph, the work functions of A and B are (h is Planck's constant and e value of charge on an electron)

(A) ν_1 and ν_2

(B) V_1 and V_2

(C) $h\nu_1$ and $h\nu_2$

(D) $\frac{h\nu_1}{e}$ and $\frac{h\nu_2}{e}$

(II) For radiation of frequency $\nu > \nu_2$ incident on the surfaces of A and B, the maximum kinetic energy of ejected electron is

(A) greater for metal A because it has a smaller work function

(B) greater for metal B because it has a larger work function

(C) greater for metal B because it has higher threshold frequency

(D) the same for both metal A and metal B because it is independent of work functions of metals

(III) If the intensity of the incident radiation for both metals A and B, is doubled keeping its frequency constant, then

(A) the slope of the parallel lines will increase

(B) the slope of the parallel lines will decrease

(C) the threshold frequencies for both A and B will decrease

(D) the slope of the parallel lines will not change but more electrons will be emitted per second

(IV) The threshold frequency for a metal surface is ν_0. If the radiation of frequency $3\nu_0$ illuminates the surface, the maximum kinetic energy (KE) of photoelectrons is E_1. If the frequency were increased to $6\nu_0$, the maximum KE of the photoelectrons becomes E_2. Then $\left(\frac{E_1}{E_2}\right)$ equals

(A) 1/3

(B) 1/2

(C) 2/5

(D) 3/4

OR

Let m be the slope of the graph line for metal B. If e is the value of electron charge, then Planck's constant 'h' is given by

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(A) me

(B) $\frac{1}{me}$

(C) $\frac{m}{e}$

(D) $\frac{e}{m}$

Section E · Long answer (5 marks each)

31. **(a)** An electric dipole consists of two point charges q and –q separated by a distance 2a. Derive an expression for the electric field $\vec{E}$ due to this dipole at a point distant r from the centre of the dipole on the equatorial plane. Write the expression for the electric field at a far off point, i.e. $r \gg a$. 5

(b) A dipole is placed in x-y plane such that charges q and –q are located at $x = a$ and $x = b$ respectively. There exists an electric field $\vec{E} = 2\hat{i}$ N/C in the region. Calculate the force $\vec{F}$ and torque $\vec{\tau}$ experienced by the dipole.

OR

(b) (a) Two cells of emf E_1 and E_2 with internal resistances r_1 and r_2 respectively, are connected in parallel by connecting their positive terminals together and negative terminals together. Deduce an expression for equivalent emf and equivalent internal resistance of the combination. 5

(b) A parallel combination, as stated in (a) above, of two cells of emfs E and 3E and internal resistances R each is connected across a resistance 2R. Find the current that flows through resistance 2R.

32. **(a)** Using the relation for refraction at a curved spherical surface, derive the expression for lens maker's formula. 5

(b) Three lenses L_1, L_2 and L_3, each of focal length 40 cm, are placed coaxially. The distance between L_1 and L_2 and between L_2 and L_3 are 120 cm and 20 cm respectively. An object is kept at a distance of 80 cm to the left of lens L_1. Find the distance of the final image formed from the object.

OR

(b) (a) Draw a ray diagram to show the image formation by a concave mirror when the object is kept between its focus and the centre of curvature. Using this diagram, derive the mirror formula. 5

(b) A concave mirror produces a two times magnified virtual image of an object kept 10 cm in front of it. Calculate the focal length of the mirror.

33. **(a)** State Faraday's law of electromagnetic induction. 5

(b) Derive an expression for the self-inductance of an air-filled long solenoid of length l and cross-sectional area A having N turns.

(c) A conducting rod of length 50 cm, with one end pivoted, is rotated with angular speed of 60 rpm in a uniform magnetic field of 4.0 mT directed perpendicular to the plane of rotation of rod. Find the emf induced in the rod.

OR

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(b) (a) Draw a labelled diagram of a step-up transformer. State the principle on which it works and obtain the ratio of secondary voltage to primary voltage in terms of number of turns and currents in the two coils. 5

(b) The ratio of the number of turns in the primary to the secondary of an ideal transformer is 1 : 5. If 5 kW power at 200 V is supplied to the primary, find (i) current in the primary, and (ii) output voltage.

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Q1 **Answer: (C) 50 N/C along $+x$**

$$E_x = -\frac{dV}{dx} = -\frac{d}{dx}(10 - 50x) = +50 \text{ V/m} = 50 \text{ N/C}$$

The positive sign means the field points along $+x$ (the direction in which V decreases).

Q2 **Answer: (B) $\frac{r_2}{r_1}$**

Connected spheres are at the same potential: $\frac{kq_1}{r_1} = \frac{kq_2}{r_2}$, so $\frac{q_1}{q_2} = \frac{r_1}{r_2}$.

$$\frac{E_A}{E_B} = \frac{kq_1/r_1^2}{kq_2/r_2^2} = \frac{q_1}{q_2}\cdot\frac{r_2^2}{r_1^2} = \frac{r_1}{r_2}\cdot\frac{r_2^2}{r_1^2} = \frac{r_2}{r_1}$$

Q3 **Answer: (C) $\frac{\mu_0 I}{4\pi a}$**

Inside the wire $(r < a)$, Ampere's law with the enclosed current $I\frac{r^2}{a^2}$ gives $B = \frac{\mu_0 I r}{2\pi a^2}$. At $r = a/2$:

$$B = \frac{\mu_0 I(a/2)}{2\pi a^2} = \frac{\mu_0 I}{4\pi a}$$

Q4 **Answer: (A) straight**

The fringes are strictly hyperbolic, but when $D \gg d$ the part of each hyperbola on the screen is practically a straight line, so the fringes appear as straight bright and dark bands.

Q5 **Answer: (C) wavelength is halved and frequency remains unchanged.**

$v = \frac{c}{\sqrt{\varepsilon_r \mu_r}} = \frac{c}{\sqrt{\frac{3}{2}\times\frac{8}{3}}} = \frac{c}{\sqrt{4}} = \frac{c}{2}$.

Frequency is set by the source and does not change; $\lambda = v/\nu$, so the wavelength becomes half.

Q6 **Answer: (B) $5\sqrt{2}$ V**

$V_L = V_C$, so the circuit is at resonance and the supply voltage is $V = V_R = 10$ V. Also $IR = IX_L$, so $X_L = R$.

With C shorted: $Z = \sqrt{R^2 + X_L^2} = \sqrt{2}\,R$, $I' = \frac{10}{\sqrt{2}R}$, and

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$$V_L = I' X_L = \frac{10}{\sqrt{2}R} \times R = \frac{10}{\sqrt{2}} = 5\sqrt{2}\ \text{V}$$

Q7 **Answer: (A) 1 nm to 10^{-3} nm**

X-rays are used as a diagnostic tool in medicine; their wavelengths lie roughly between 10 nm and 10^{-4} nm, so the range 1 nm to 10^{-3} nm fits.

Q8 **Answer: (D) 4d**

At closest approach all kinetic energy becomes potential energy: $\frac{1}{2}mv^2 = \frac{k(2e)(Ze)}{d}$, so $d \propto \frac{1}{v^2}$.

Halving v makes v^2 one-fourth, so $d' = 4d$.

Q9 **Answer: (A) 20 cm**

For the equi-concave lens, $\frac{1}{f} = (n-1)\left(-\frac{2}{R}\right)$, so $|f| = \frac{R}{2(n-1)} = 10$ cm.

Each plano-concave half has one curved surface: $\frac{1}{f'} = (n-1)\left(-\frac{1}{R}\right)$, so $|f'| = \frac{R}{n-1} = 2 \times 10 = 20$ cm.

Q10 **Answer: (C) (i), (iii) and (iv) only**

Sustained interference needs the same frequency and a constant phase difference. Waves (i), (iii) and (iv) all have angular frequency ω with fixed phase differences ($\pi/2$ and $\pi/3$). Wave (ii) has frequency 2ω, so it cannot interfere steadily with the others.

Q11 **Answer: (D) $\frac{P_1 P_2}{4(P_1+P_2)}$**

$R_1 = \frac{V^2}{P_1}$, $R_2 = \frac{V^2}{P_2}$, so in series $R = V^2\left(\frac{1}{P_1} + \frac{1}{P_2}\right) = \frac{V^2(P_1+P_2)}{P_1 P_2}$.

$$P = \frac{(V/2)^2}{R} = \frac{V^2}{4} \cdot \frac{P_1 P_2}{V^2(P_1+P_2)} = \frac{P_1 P_2}{4(P_1+P_2)}$$

Q12 **Answer: (C) Diffusion and drift currents are equal and opposite.**

At equilibrium both currents flow, but they balance exactly, so the net current through an unbiased junction is zero.

Q13 **Answer: (D) Both Assertion (A) and Reason (R) are false.**

Atoms of diamagnetic substances have zero net magnetic moment (the moments of their electrons cancel), so A is false. A current loop always behaves as a magnetic dipole of moment $\vec{m} = I\vec{A}$, so R is also false.

Q14 **Answer: (A) Both A and R are true and R is the correct explanation of A.**

Moving electrons have a de Broglie wavelength $\lambda = h/p$. This wave nature makes them diffract at a narrow slit (as in the Davisson–Germer experiment), so R explains A.

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Q15 **Answer: (C) Assertion (A) is true, but Reason (R) is false.**

The nucleus has a mass defect Δm, so A is true. When nucleons combine, energy $\Delta m\, c^2$ (the binding energy) is **released**, not absorbed, so R is false.

Q16 **Answer: (B) Both A and R are true, but R is not the correct explanation of A.**

The energy levels are discrete because of Bohr's quantum condition $mvr = \dfrac{nh}{2\pi}$. The electrostatic force acting as centripetal force is true, but on its own it allows any orbit; it does not explain quantisation.

Q17 Einstein's equation: $h\nu = \phi_0 + eV_0$, so $\phi_0 = \dfrac{hc}{\lambda} - eV_0$.

$$\frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{200 \times 10^{-9}}\ \text{J} = \frac{9.945 \times 10^{-19}}{1.6 \times 10^{-19}}\ \text{eV} \approx 6.2\ \text{eV}$$

Stopping potential $V_0 = 0.80$ V, so $eV_0 = 0.80$ eV.

$$\phi_0 = 6.2 - 0.8 = \mathbf{5.4\ eV}$$

Q18(a) Minima of a single slit: $a \sin\theta = n\lambda$, at $y = \dfrac{n\lambda D}{a}$.

For coincidence $n_1\lambda_1 = n_2\lambda_2$: $n_1 \times 400 = n_2 \times 600$. The smallest whole numbers are $n_1 = 3$, $n_2 = 2$.

$$y = \frac{n_2\lambda_2 D}{a} = \frac{2 \times 600 \times 10^{-9} \times 1.5}{1 \times 10^{-3}} = 1.8 \times 10^{-3}\ \text{m} = \mathbf{1.8\ mm}$$

(Check: $3 \times 400 \times 10^{-9} \times 1.5 / 10^{-3} = 1.8$ mm.)

Q18(b) Bright fringes: $y = \dfrac{n\lambda D}{d}$. For coincidence $n_1\lambda_1 = n_2\lambda_2$: $n_1 \times 440 = n_2 \times 660$, so $n_1 = 3$, $n_2 = 2$.

$$y = \frac{2 \times 660 \times 10^{-9} \times 1.5}{0.6 \times 10^{-3}} = 3.3 \times 10^{-3}\ \text{m} = \mathbf{3.3\ mm}$$

Q19 Maximum torque $\tau_{max} = NIAB$, so $\dfrac{\tau_s}{\tau_c} = \dfrac{A_s}{A_c}$.

Square: perimeter of one turn $= \dfrac{L}{N} = 4a$, so $a = \dfrac{L}{4N}$ and $A_s = \dfrac{L^2}{16N^2}$.

Circle: $2\pi r = \dfrac{L}{N}$, so $r = \dfrac{L}{2\pi N}$ and $A_c = \pi r^2 = \dfrac{L^2}{4\pi N^2}$.

$$\frac{\tau_s}{\tau_c} = \frac{L^2/16N^2}{L^2/4\pi N^2} = \frac{4\pi}{16} = \frac{\pi}{4}$$

Ratio $= \pi : \mathbf{4}$.

Q20 Order of drift velocity: about 10^{-4} m/s (a fraction of a mm per second).

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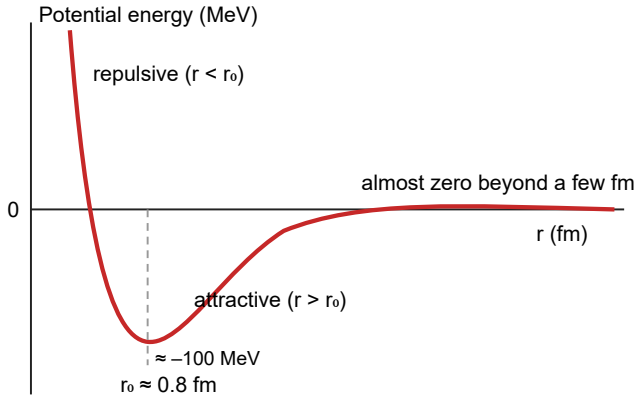
Relation: Take a conductor of cross-section A with n free electrons per unit volume, drifting with speed v_d.

In time Δt each electron moves $v_d \Delta t$, so all electrons in a length $v_d \Delta t$ cross a section: their number is $nAv_d \Delta t$.

Charge crossing: $\Delta Q = e\, nAv_d \Delta t$.

$$I = \frac{\Delta Q}{\Delta t} = neAv_d$$

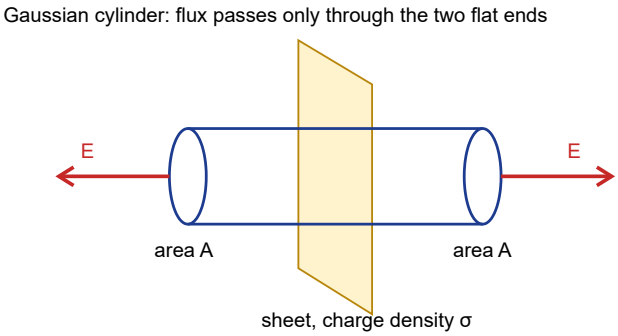
Q21



Conclusions (any two):

1. The potential energy is minimum at a separation $r_0 \approx 0.8$ fm.
2. For $r > r_0$ the nuclear force is attractive; for $r < r_0$ it is strongly repulsive.
3. The nuclear force is short range: it becomes negligible beyond a few femtometres.

Q22(a) **(a)** Take a cylindrical Gaussian surface of end-area A, cutting the sheet perpendicularly.



By symmetry $\vec{E}$ is normal to the sheet. There is no flux through the curved surface; through each flat end the flux is EA.

Total flux $= 2EA$; charge enclosed $= \sigma A$. Gauss's law:

$$2EA = \frac{\sigma A}{\varepsilon_0} \Rightarrow E = \frac{\sigma}{2\varepsilon_0}$$

directed away from the sheet if $\sigma > 0$; it does not depend on distance.

(b) Each sheet gives $\dfrac{\sigma}{2\varepsilon_0}$.

(i) Inside: the two fields are opposite, so $E = \dfrac{\sigma}{2\varepsilon_0} - \dfrac{\sigma}{2\varepsilon_0} = 0$.

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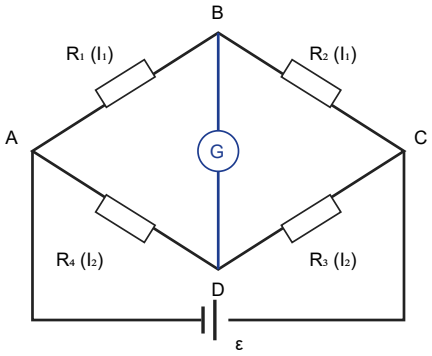
(ii) Outside: the fields add, so $E = \dfrac{\sigma}{\varepsilon_0}$, directed away from the sheets.

Q22(b) **(a)**



At balance no current flows through the galvanometer, so B and D are at the same potential. Then R_1 and R_2 carry the same current I_1; R_4 and R_3 carry I_2.

Kirchhoff's loop rule:

Loop ABDA: $I_1R_1 + 0 - I_2R_4 = 0 \Rightarrow I_1R_1 = I_2R_4$ ...(1)

Loop BCDB: $I_1R_2 - I_2R_3 - 0 = 0 \Rightarrow I_1R_2 = I_2R_3$ ...(2)

Dividing (1) by (2):

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

(b) Between M and N, the resistors M–O (R), M–P (R, top), O–N (R, bottom), P–N (R) and O–P (R) form a Wheatstone bridge. Since $\dfrac{R}{R} = \dfrac{R}{R}$, it is balanced and O–P carries no current.

R_{MN} = two paths of $2R$ in parallel $= R$.

$$R_{AB} = 2R + R + 3R = \mathbf{6R}$$

Q23 With the battery disconnected, the charge $Q = CV$ stays constant. Let K be the dielectric constant.

(a) $C = \dfrac{K\varepsilon_0 A}{d}$; without the slab $C' = \dfrac{\varepsilon_0 A}{d} = \dfrac{C}{K}$. Capacitance **decreases** K times.

(b) $U = \dfrac{Q^2}{2C}$; $U' = \dfrac{Q^2}{2C'} = KU$. Energy **increases** K times (work is done in pulling the slab out).

(c) $V' = \dfrac{Q}{C'} = KV$. Potential difference **increases** K times.

Q24 Field between plates $E = \dfrac{V}{d}$; acceleration of the electron $a = \dfrac{eE}{m} = \dfrac{eV}{md}$ (towards the positive plate).

Time to cross the plates: $t = \dfrac{L}{u}$.

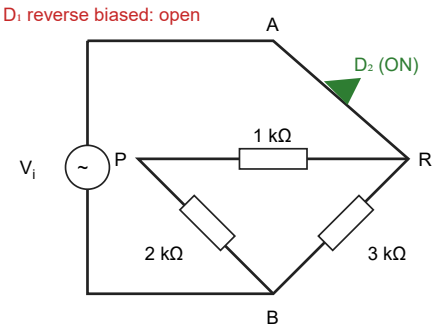
To just strike the end, the deflection must be $y = \dfrac{d}{2} = 1$ cm:

$$y = \frac{1}{2}at^2 = \frac{1}{2}\cdot\frac{eV}{md}\cdot\frac{L^2}{u^2} \Rightarrow V = \frac{2ymdu^2}{eL^2}$$

$$V = \frac{2\times 0.01\times 9.1\times 10^{-31}\times 0.02\times (3\times 10^7)^2}{1.6\times 10^{-19}\times (0.03)^2} = \frac{3.276\times 10^{-19}}{1.44\times 10^{-22}} \approx \mathbf{2275\ V}$$

Q25 (a) In the positive half-cycle A is at the higher potential. D_2 (pointing from A towards R) is forward biased and conducts; D_1 (pointing from P towards A) is reverse biased and does not conduct.

(b) Equivalent circuit (D_2 a closed switch, D_1 open):

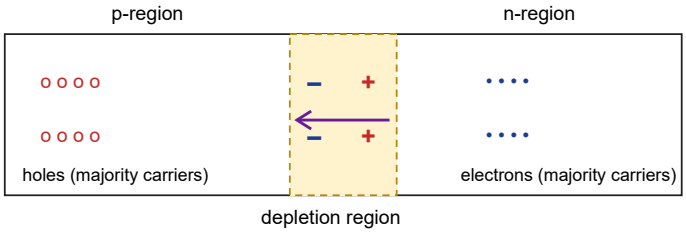


From R the current divides: through 3 kΩ directly to B, and through 1 kΩ and 2 kΩ (via P) to B.

(c) The two branches are 3 kΩ and $(1+2) = 3$ kΩ, in parallel: $R = 1.5$ kΩ. At peak $V = 12$ V: $I = \dfrac{12}{1.5\times 10^3} = 8$ mA, which splits equally, 4 mA in each branch.

Drops: across 3 kΩ: $4\ \text{mA}\times 3\ \text{k}\Omega = \mathbf{12\ V}$; across 1 kΩ: $\mathbf{4\ V}$; across 2 kΩ: $\mathbf{8\ V}$.

Q26 The two processes are **diffusion** and **drift**.



Diffusion: holes p → n, electrons n → p (concentration gradient)

Drift: barrier field (n → p) pushes minority carriers back

1. **Diffusion:** the n-side has more electrons and the p-side more holes. Due to this concentration gradient, electrons diffuse from n to p and holes from p to n. This gives the diffusion current (p → n). Electrons leaving the n-side leave behind positive donor ions, and holes leaving the p-side leave negative acceptor ions near the junction. This layer of immobile ions, free of charge carriers, is the **depletion region**.

2. **Drift:** the ions in the depletion region set up an electric field from n to p (the barrier potential). This field pushes minority carriers across the junction (electrons p → n, holes n → p), giving a drift current opposite to the diffusion current.

At first the diffusion current is large; as the depletion layer widens the drift current grows. Equilibrium is reached when the two currents are equal, and no net current flows.

Q27 **(a)**

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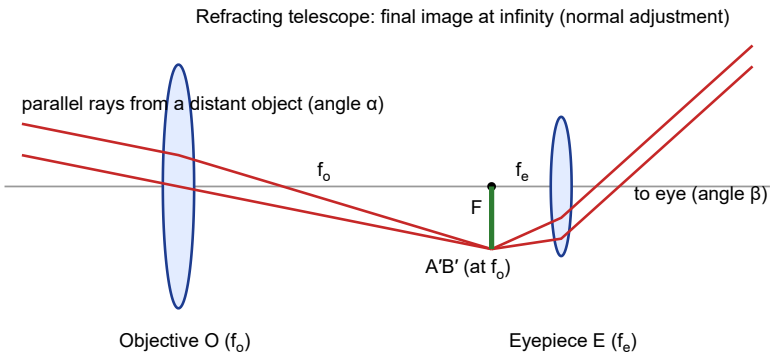

In normal adjustment (final image at infinity):

$$m = \frac{\beta}{\alpha} = \frac{f_o}{f_e}$$

(the length of the tube is $f_o + f_e$).

(b) Any two:

1. A mirror has no chromatic aberration (no dispersion), and a parabolic mirror removes spherical aberration.
2. A large mirror is easier and cheaper to make and support (it can be supported over its whole back), whereas a large lens is heavy and sags.
3. The image is brighter, since a large aperture gathers more light.

Q28

(a) 1. Light must travel from an optically denser medium to a rarer medium.

2. The angle of incidence must be greater than the critical angle for the pair of media.

(b) At the A–B interface (Snell's law), with refraction angle θ_1:

$$n \sin\theta = \tfrac{3}{4} n \sin\theta_1 \quad \Rightarrow \quad \sin\theta_1 = \tfrac{4}{3}\sin\theta \quad \ldots(1)$$

At the B–C interface, with refraction angle r:

$$\tfrac{3}{4} n \sin\theta_1 = \tfrac{2}{3} n \sin r \quad \ldots(2)$$

From (1) and (2): $n \sin\theta = \tfrac{2}{3} n \sin r$, so $\sin r = \tfrac{3}{2}\sin\theta$.

For $\sin\theta = \tfrac{2}{3}$: $\sin r = 1$, $r = 90^\circ$, and the ray grazes the B–C surface. For $\sin\theta > \tfrac{2}{3}$, $\sin r$ would exceed 1, which is impossible: the ray is totally internally reflected at the B–C interface. Hence for $\sin\theta \geq \tfrac{2}{3}$ the beam does not enter region C at all.

Q29

(I) **(B) radial magnetic field.** In a radial field the plane of the coil is always parallel to $\vec{B}$, so $\sin\theta = 1$ and $\tau = NIAB$ at every position.

(II) **(A) increasing number of turns of the coil** (answer as per the CBSE marking scheme). Current sensitivity $\dfrac{\phi}{I} = \dfrac{NAB}{k}$ increases with N.

(III) **(D) 0.25 N m.** $\tau = NIAB = 50 \times 5 \times 4.0 \times 10^{-3} \times 0.25 = 0.25$ N m.

OR **(B) 3985 Ω.** $R = \dfrac{V}{I_g} - G = \dfrac{12}{3 \times 10^{-3}} - 15 = 4000 - 15 = 3985\ \Omega$, in series.

(IV) **(C) 0.01 Ω in parallel.** Shunt $S = \dfrac{I_g G}{I - I_g} = \dfrac{5 \times 10^{-3} \times 20}{10 - 0.005} \approx 0.01\ \Omega$, connected in parallel.

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Q30 (I) **(C) $h\nu_1$ and $h\nu_2$.** The intercepts on the ν-axis are the threshold frequencies, and $\phi_0 = h\nu_0$.

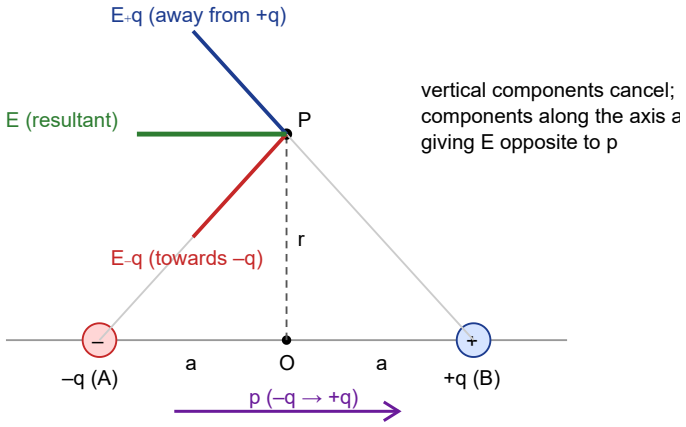
(II) **(A) greater for metal A because it has a smaller work function.** $K_{max} = h\nu - \phi_0$; for the same ν, the smaller ϕ_0 (metal A) gives the larger K_{max}.

(III) **(D)** The slope h/e does not depend on intensity, and the threshold frequency does not change; higher intensity means more photons, so more electrons are emitted per second.

(IV) **(C) 2/5.** $E_1 = h(3\nu_0) - h\nu_0 = 2h\nu_0$; $E_2 = h(6\nu_0) - h\nu_0 = 5h\nu_0$; $\dfrac{E_1}{E_2} = \dfrac{2}{5}$.

OR **(A) me.** $V_s = \dfrac{h}{e}\nu - \dfrac{\phi_0}{e}$, so the slope $m = \dfrac{h}{e}$ and $h = me$.

Q31(a) **(a)**



P is on the perpendicular bisector at distance r from the centre O. Distance of P from each charge $= \sqrt{r^2 + a^2}$, so

$$|\vec{E}_{+q}| = |\vec{E}_{-q}| = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q}{r^2 + a^2}$$

Their components perpendicular to the axis cancel. The components parallel to the axis add, both pointing from +q towards –q (opposite to $\vec{p}$). If θ is the angle each field makes with the axis, $\cos\theta = \dfrac{a}{\sqrt{r^2 + a^2}}$:

$$E = 2E_{+q}\cos\theta = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2qa}{(r^2 + a^2)^{3/2}}$$

With $\vec{p} = q(2a)\hat{p}$:

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{\vec{p}}{(r^2 + a^2)^{3/2}}$$

For a far-off point $(r \gg a)$:

$$\vec{E} = -\frac{1}{4\pi\varepsilon_0} \cdot \frac{\vec{p}}{r^3}$$

(b) The field is uniform, so the forces on +q and –q are $q\vec{E}$ and $-q\vec{E}$: net force $\vec{F} = q\vec{E} - q\vec{E} = \mathbf{0}$.

Dipole moment (from –q to +q): $\vec{p} = q(a - b)\hat{i}$. Torque:

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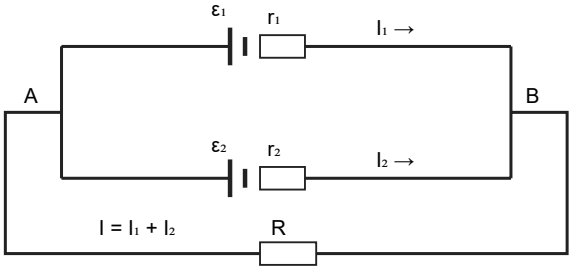
$$\vec{\tau} = \vec{p} \times \vec{E} = q(a-b)\hat{i} \times 2\hat{i} = \mathbf{0}$$

(the dipole lies along the field, so it is in equilibrium).

Q31(b) **(a)**



Let I_1 and I_2 leave the positive terminals; the external current is $I = I_1 + I_2$. The terminal voltage V is common:

$$V = E_1 - I_1 r_1 \Rightarrow I_1 = \frac{E_1 - V}{r_1}; V = E_2 - I_2 r_2 \Rightarrow I_2 = \frac{E_2 - V}{r_2}$$

$$I = \frac{E_1}{r_1} + \frac{E_2}{r_2} - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$V = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} - I\,\frac{r_1 r_2}{r_1 + r_2}$$

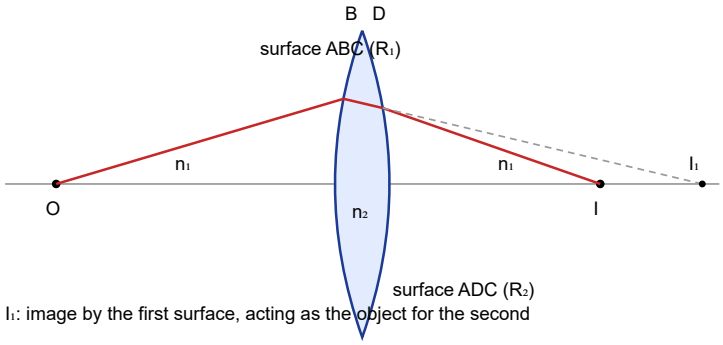
Comparing with $V = E_{eq} - I r_{eq}$:

$$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}, \qquad r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

(b) $E_{eq} = \dfrac{E \cdot R + 3E \cdot R}{R + R} = 2E; r_{eq} = \dfrac{R \cdot R}{2R} = \dfrac{R}{2}.$

$$I = \frac{E_{eq}}{2R + r_{eq}} = \frac{2E}{2R + R/2} = \mathbf{\frac{4E}{5R}}$$

Q32(a) **(a)**



A thin lens of refractive index n_2 in a medium n_1 has surfaces of radii R_1 and R_2. Object O on the axis.

Refraction at the first surface ABC forms image I_1:

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$$\frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \quad \ldots(1)$$

I_1 acts as the object for the second surface ADC, which forms the final image I (light goes from n_2 to n_1):

$$\frac{n_1}{v} - \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \quad \ldots(2)$$

Adding (1) and (2) (the lens is thin, so distances are from the optical centre):

$$\frac{n_1}{v} - \frac{n_1}{u} = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

For an object at infinity, $v = f$:

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

This is the lens maker's formula (in air, $\frac{n_2}{n_1} = n$).

(b) Taking each lens as converging, $f = +40$ cm.

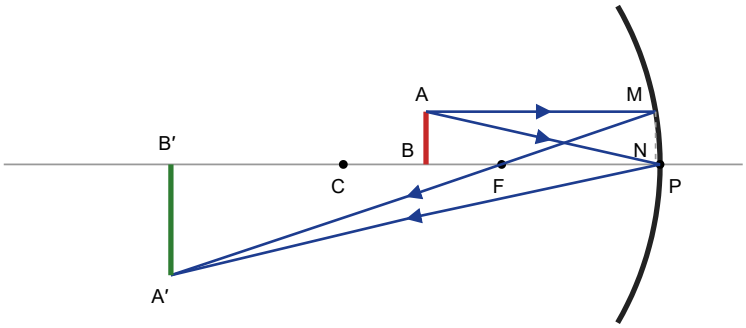
L_1: $u = -80$ cm: $\frac{1}{v} = \frac{1}{40} - \frac{1}{80} = \frac{1}{80}$, so $v = 80$ cm (to the right of L_1).

L_2 is 120 cm from L_1, so this image is 40 cm to the left of L_2: $u = -40$ cm $= -f$, so the image is at infinity (rays leave L_2 parallel).

L_3: parallel rays focus at $v = f = 40$ cm to the right of L_3.

Distance of the final image from the object $= 80 + 120 + 20 + 40 = \mathbf{260\ cm}$.

Q32(b) **(a)**



Object between F and C: real, inverted, magnified image beyond C

Object AB between F and C; the ray parallel to the axis reflects through F, and the ray to the pole P reflects symmetrically. They meet at A′, giving a real, inverted image A′B′ beyond C. MN is the normal from M to the axis; for a small aperture, $MN \approx AB$ and N ≈ P.

$\triangle A'B'F \sim \triangle MNF$ (approximately $\triangle MPF$):

$$\frac{A'B'}{AB} = \frac{B'F}{FP} \quad \ldots(1)$$

$\triangle A'B'P \sim \triangle ABP$ (equal angles of incidence and reflection at P):

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$$\frac{A'B'}{AB} = \frac{B'P}{BP} \quad \ldots(2)$$

So $\frac{B'F}{FP} = \frac{B'P}{BP}$, i.e. $\frac{B'P - FP}{FP} = \frac{B'P}{BP}$.

Using the sign convention $B'P = -v$, $FP = -f$, $BP = -u$:

$$\frac{-v + f}{-f} = \frac{-v}{-u} \Rightarrow \frac{v - f}{f} = \frac{v}{u} \Rightarrow \frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

(b) Virtual image, $m = +2$; $u = -10$ cm.

$m = -\frac{v}{u} \Rightarrow v = -mu = +20$ cm (behind the mirror).

$$\frac{1}{f} = \frac{1}{v} + \frac{1}{u} = \frac{1}{20} - \frac{1}{10} = -\frac{1}{20}$$

$f = -20$ cm: the focal length is **20 cm** (concave).

Q33(a) **(a)** The magnitude of the emf induced in a circuit equals the time rate of change of magnetic flux through it: $\varepsilon = -\frac{d\Phi_B}{dt}$ (for N turns, $\varepsilon = -N\frac{d\Phi_B}{dt}$). The negative sign shows the induced emf opposes the change (Lenz's law).

(b) Turns per unit length $n = \frac{N}{l}$. A current I gives a field inside the solenoid

$$B = \mu_0 n I = \frac{\mu_0 N I}{l}$$

Total flux linkage: $N\Phi = N \cdot BA = \frac{\mu_0 N^2 A I}{l}$.

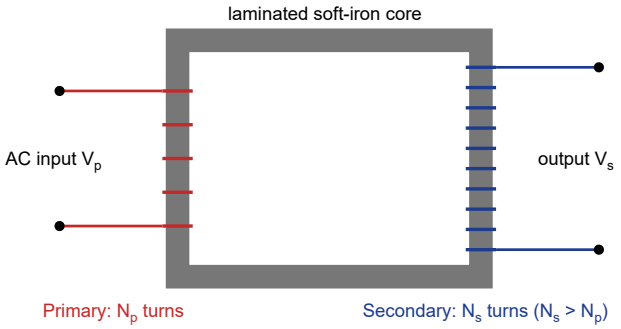
Since $N\Phi = LI$:

$$L = \frac{\mu_0 N^2 A}{l}$$

(c) $\omega = 60$ rpm $= 1$ rev/s $= 2\pi$ rad/s; $l = 0.5$ m; $B = 4.0 \times 10^{-3}$ T.

$$\varepsilon = \tfrac{1}{2} B\omega l^2 = \tfrac{1}{2} \times 4.0 \times 10^{-3} \times 2\pi \times (0.5)^2 = \pi \times 10^{-3}\ \text{V} \approx \mathbf{3.14\ mV}$$

Q33(b) **(a)**



Principle: mutual induction. An alternating current in the primary produces a changing flux in the core, which links the secondary and induces an emf in it.

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If the flux in each turn is ϕ, and there is no flux leakage:

$\varepsilon_s = -N_s \dfrac{d\phi}{dt}$ and $\varepsilon_p = -N_p \dfrac{d\phi}{dt}$.

Taking $V_s \approx \varepsilon_s$ and $V_p \approx \varepsilon_p$ (negligible resistance):

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

For an ideal transformer (no losses), input power = output power: $V_p I_p = V_s I_s$, so

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

For a step-up transformer $N_s > N_p$, so $V_s > V_p$ and $I_s < I_p$.

(b) (i) $I_p = \dfrac{P}{V_p} = \dfrac{5000}{200} = \mathbf{25\ A}$.

(ii) $V_s = V_p \dfrac{N_s}{N_p} = 200 \times 5 = \mathbf{1000\ V}$.

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