

PHYSICS - I

Solution

CBSE, NCERT



CLASS
XII



Stepwise Solution with Explanation



CLASS 12 PHYSICS

NCERT Part 1 — Complete Exercise Solutions

Chapters 1–8 | With Explanatory Notes for Easy Understanding



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Chapter 1: Electric Charges and Fields

Key Formula: Coulomb's Law: $F = k \cdot q_1 \cdot q_2 / r^2$ where $k = 9 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2$

💡 Note: The force between two charges follows an inverse-square law — double the distance, force becomes one-fourth.

1.1 What is the force between two small charged spheres having charges of $2 \times 10^{-7} \text{ C}$ and $3 \times 10^{-7} \text{ C}$ placed 30 cm apart in air?

Given: $q_1 = 2 \times 10^{-7} \text{ C}$, $q_2 = 3 \times 10^{-7} \text{ C}$, $r = 30 \text{ cm} = 0.30 \text{ m}$, $k = 9 \times 10^9 \text{ N} \cdot \text{m}^2 / \text{C}^2$

Using Coulomb's Law:

$$F = k \cdot q_1 \cdot q_2 / r^2$$

$$F = (9 \times 10^9) \times (2 \times 10^{-7}) \times (3 \times 10^{-7}) / (0.30)^2$$

$$F = (9 \times 10^9 \times 6 \times 10^{-14}) / 0.09$$

$$F = 54 \times 10^{-5} / 0.09 = 6 \times 10^{-3} \text{ N}$$

✓ Answer: $F = 6 \times 10^{-3} \text{ N}$ (repulsive, since both charges have same sign)

💡 Note: The force is repulsive because both charges are positive. If they were opposite signs, the force would be attractive.

1.2 The electrostatic force on a small sphere of charge $0.4 \mu\text{C}$ due to another of charge $-0.8 \mu\text{C}$ in air is 0.2 N . (a) Distance? (b) Force on second sphere due to first?

Given: $q_1 = 0.4 \times 10^{-6} \text{ C}$, $q_2 = 0.8 \times 10^{-6} \text{ C}$ (magnitudes), $F = 0.2 \text{ N}$

(a) Using Coulomb's Law: $F = k |q_1| |q_2| / r^2 \rightarrow r^2 = k |q_1| |q_2| / F$

$$r^2 = (9 \times 10^9 \times 0.4 \times 10^{-6} \times 0.8 \times 10^{-6}) / 0.2$$

$$r^2 = (9 \times 10^9 \times 3.2 \times 10^{-13}) / 0.2 = 2.88 \times 10^{-3} / 0.2 = 0.0144$$

$$r = 0.12 \text{ m} = 12 \text{ cm}$$

✓ Answer: (a) Distance = 12 cm

(b) By Newton's Third Law, the force on the second sphere due to the first is equal in magnitude but opposite in direction.

✓ Answer: (b) 0.2 N (attractive, towards the first sphere)

💡 Note: Newton's third law applies here — action and reaction forces are always equal and opposite.

1.3 Check that ke^2/Gm_{emp} is dimensionless. Find its value. What does it signify?

$$\text{Dimensions of } ke^2 : [\text{N} \cdot \text{m}^2 / \text{C}^2][\text{C}^2] = [\text{N} \cdot \text{m}^2] = [\text{M} \cdot \text{L}^3 \cdot \text{T}^{-2}]$$

$$\text{Dimensions of } Gm_{\text{emp}} : [\text{M}^{-1} \cdot \text{L}^3 \cdot \text{T}^{-2}][\text{M}][\text{M}] = [\text{M} \cdot \text{L}^3 \cdot \text{T}^{-2}]$$

Both have the same dimensions $\rightarrow$ the ratio is dimensionless. ✓

Values: $k = 9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$, $e = 1.6 \times 10^{-19} \text{ C}$, $G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$

$m_e = 9.11 \times 10^{-31} \text{ kg}$, $m_p = 1.67 \times 10^{-27} \text{ kg}$

$$\frac{k e^2}{G m_p m_e} = \frac{(9 \times 10^9 \times (1.6 \times 10^{-19})^2)}{(6.67 \times 10^{-11} \times 9.11 \times 10^{-31} \times 1.67 \times 10^{-27})}$$

$$\approx 2.3 \times 10^{-28} / (1.015 \times 10^{-67}) \approx 2.27 \times 10^{39}$$

✓ Answer: Ratio $\approx 2.4 \times 10^{39}$

💡 Note: This enormous number tells us that electrical force between an electron and a proton is about 10^{39} times stronger than gravitational force between them. This is why gravity is negligible at atomic scales.

1.4 (a) What is charge quantisation? (b) Why can we ignore it for macroscopic charges?

(a) Charge Quantisation: Electric charge exists only in discrete multiples of the elementary charge $e = 1.6 \times 10^{-19} \text{ C}$. Any charge q must satisfy $q = ne$ where n is an integer.

💡 Note: This means charge cannot be $1.5e$ or $0.3e$ — it must be a whole number multiple of e .

(b) For macroscopic charges, even a tiny charge like $1 \mu\text{C} = 10^{-6} \text{ C}$ contains $\sim 6 \times 10^{12}$ elementary charges. At this scale, the discreteness is so fine that the charge appears continuous — like how water appears continuous even though it's made of discrete molecules.

✓ Answer: Quantisation is ignored because the quantum of charge (e) is negligibly small compared to macroscopic charges.

1.5 When glass is rubbed with silk, charges appear on both. Explain consistency with conservation of charge.

When glass rod is rubbed with silk, electrons transfer from glass to silk. Glass becomes positively charged, silk becomes negatively charged. The total charge of the (glass + silk) system remains zero — no charge is created or destroyed, only transferred.

✓ Answer: This observation perfectly illustrates the Law of Conservation of Charge: charge is neither created nor destroyed, only transferred from one body to another.

💡 Note: Every time charging occurs by friction, two bodies with equal and opposite charges are produced. Net charge of the universe remains constant.

1.6 Four charges $q_A = 2\mu\text{C}$, $q_B = -5\mu\text{C}$, $q_C = 2\mu\text{C}$, $q_D = -5\mu\text{C}$ at corners of square ABCD (side 10 cm). Force on $1\mu\text{C}$ at centre?

The centre O is equidistant from all four corners. Distance from corner to centre = $(10/2)\sqrt{2} = 5\sqrt{2} \text{ cm} = 0.0707 \text{ m}$

Analysis of symmetry:

→ $q_A = +2\mu\text{C}$ and $q_C = +2\mu\text{C}$ are at opposite corners → equal forces on q_0 , but in opposite directions → cancel

→ $q_B = -5\mu\text{C}$ and $q_D = -5\mu\text{C}$ are at opposite corners → equal forces on q_0 , but in opposite directions → cancel

✓ Answer: Net force on the charge at the centre = 0 (Zero)

💡 Note: Due to the symmetric arrangement, forces from diagonally opposite charges always cancel each other. This is a powerful application of symmetry!

1.7 (a) Why can't field lines have sudden breaks? (b) Why don't two field lines cross?

(a) A field line represents the path a positive test charge would follow. If a field line had a sudden break, it would mean there is a point where electric force on the test charge is zero — but the charge would not disappear. Field lines can only start at positive charges and end at negative charges (or at infinity). A break would violate this.

(b) At any point in space, there is only ONE electric field direction. If two field lines crossed at a point, it would mean the electric field has two different directions at that point — which is physically impossible.

✓ Answer: Field lines cannot break (charge doesn't disappear) and cannot cross (field has unique direction at each point).

1.8 $q_A = 3\mu\text{C}$ and $q_B = -3\mu\text{C}$ located 20 cm apart. (a) Electric field at midpoint O? (b) Force on -1.5×10^{-9} C at O?

Given: $q_A = +3 \times 10^{-6}$ C, $q_B = -3 \times 10^{-6}$ C, $AB = 20$ cm $\rightarrow AO = OB = 10$ cm = 0.1 m

(a) Electric field at O due to q_A (pointing away from +charge, i.e., towards B):

$$E_A = kq_A/r^2 = (9 \times 10^9 \times 3 \times 10^{-6}) / (0.1)^2 = 2.7 \times 10^6 \text{ N/C} \\ \text{(directed from A to B)}$$

Electric field at O due to q_B (pointing towards –charge, i.e., also towards B):

$$E_B = k|q_B|/r^2 = 2.7 \times 10^6 \text{ N/C (also directed from A to B)}$$

Both fields point in the SAME direction (from A to B, i.e., towards the negative charge).

$$E_{\text{total}} = E_A + E_B = 2.7 \times 10^6 + 2.7 \times 10^6 = 5.4 \times 10^6 \text{ N/C along AB (from A to B)}$$

✓ Answer: (a) $E = 5.4 \times 10^6$ N/C directed from q_A to q_B

(b) Force on test charge $q_0 = -1.5 \times 10^{-9}$ C:

$$F = q_0 E = (1.5 \times 10^{-9}) \times (5.4 \times 10^6) = 8.1 \times 10^{-3} \text{ N}$$

Since q_0 is negative, force is opposite to E , i.e., from B to A.

✓ Answer: (b) $F = 8.1 \times 10^{-3}$ N directed from B to A (i.e., from q_B to q_A)

1.9 $q_A = 2.5 \times 10^{-7}$ C at A(0,0,–15cm), $q_B = -2.5 \times 10^{-7}$ C at B(0,0,+15cm). Total charge and dipole moment?

$$\text{Total charge} = q_A + q_B = 2.5 \times 10^{-7} - 2.5 \times 10^{-7} = 0$$

Dipole moment: $p = q \times 2a$ (from –q to +q)

Here $q = 2.5 \times 10^{-7}$ C, $2a =$ distance from A to B = 30 cm = 0.30 m

$$p = 2.5 \times 10^{-7} \times 0.30 = 7.5 \times 10^{-8} \text{ C} \cdot \text{m}$$

Direction: from q_B (negative) at B to q_A (positive) at A $\rightarrow$ from B(0,0,+15) to A(0,0,–15) = along –z direction

✓ Answer: Total charge = 0; Dipole moment = 7.5×10^{-8} C·m along –z axis

1.10 Electric dipole ($p = 4 \times 10^{-9} \text{ C}\cdot\text{m}$) at 30° to field $E = 5 \times 10^4 \text{ N/C}$. Find torque.

$$\text{Torque } \tau = pE \sin\theta$$

$$\tau = (4 \times 10^{-9}) \times (5 \times 10^4) \times \sin 30^\circ$$

$$\tau = 4 \times 10^{-9} \times 5 \times 10^4 \times 0.5 = 10^{-4} \text{ N}\cdot\text{m}$$

✓ Answer: $\tau = 10^{-4} \text{ N}\cdot\text{m}$

💡 Note: The torque tends to align the dipole with the electric field. When $\theta = 0$ (aligned), torque = 0. When $\theta = 90^\circ$, torque is maximum.

1.11 Polythene rubbed with wool has charge $-3 \times 10^{-7} \text{ C}$. (a) Electrons transferred? (b) Mass transfer?

(a) Charge = $n \times e \rightarrow n = Q/e$

$$n = 3 \times 10^{-7} / 1.6 \times 10^{-19} = 1.875 \times 10^{12} \approx 2 \times 10^{12} \text{ electrons}$$

Electrons transfer FROM wool TO polythene (polythene gained electrons, becoming negative).

✓ Answer: (a) $\sim 2 \times 10^{12}$ electrons transferred from wool to polythene

(b) Mass of transferred electrons:

$$m = n \times m_e = 2 \times 10^{12} \times 9.11 \times 10^{-31} \approx 1.82 \times 10^{-18} \text{ kg}$$

✓ Answer: (b) Yes, but negligibly small mass ($\sim 2 \times 10^{-18} \text{ kg}$) is transferred from wool to polythene.

1.12 Spheres A and B with charge $6.5 \times 10^{-7} \text{ C}$ each, 50 cm apart. (a) Repulsion force? (b) Force when charge doubled, distance halved?

(a): $q = 6.5 \times 10^{-7} \text{ C}$, $r = 0.50 \text{ m}$

$$F_1 = kq^2/r^2 = (9 \times 10^9 \times (6.5 \times 10^{-7})^2) / (0.5)^2$$

$$F_1 = (9 \times 10^9 \times 4.225 \times 10^{-13}) / 0.25 = 1.52 \times 10^{-2} \text{ N} \approx 1.5 \times 10^{-2} \text{ N}$$

✓ Answer: (a) $F_1 \approx 1.5 \times 10^{-2} \text{ N}$

(b): New charge = $2q = 1.3 \times 10^{-6} \text{ C}$, new distance = $r/2 = 0.25 \text{ m}$

$$F_2 = k(2q)^2 / (r/2)^2 = k \cdot 4q^2 / (r^2/4) = 16 \cdot kq^2/r^2 = 16 \times F_1$$

$$F_2 = 16 \times 1.5 \times 10^{-2} = 0.24 \text{ N}$$

✓ Answer: (b) $F_2 = 0.24 \text{ N}$

💡 Note: Doubling charge multiplies force by 4 (charge squared), halving distance multiplies force by 4. Combined effect: force $\times 16$!

1.13 Figure 1.30: Signs of three charges, and which has highest charge-to-mass ratio?

Looking at the curvature of particle tracks in a uniform electric field:

→ Positive charges deflect in the direction of the field

→ Negative charges deflect opposite to the field

✓ Answer: Charges 1 and 2 are negative; Charge 3 is positive. Particle 3 has the highest charge-to-mass ratio (most curved path for its deflection).

1.14 $E = 3 \times 10^3 \hat{i}$ N/C. (a) Flux through $10\text{cm} \times 10\text{cm}$ square parallel to yz -plane? (b) Normal at 60° to x -axis?

Given: $E = 3 \times 10^3$ N/C along x -axis, $A = (0.10)^2 = 0.01 \text{ m}^2$

(a) When plane is parallel to yz -plane, its normal is along x -axis. Angle between E and normal $= 0^\circ$

$$\Phi = E \cdot A \cdot \cos\theta = 3 \times 10^3 \times 0.01 \times \cos 0^\circ = 30 \text{ N} \cdot \text{m}^2/\text{C}$$

✓ Answer: (a) $\Phi = 30 \text{ N} \cdot \text{m}^2/\text{C}$

(b) Normal makes 60° with x -axis (which is E 's direction):

$$\Phi = E \cdot A \cdot \cos 60^\circ = 3 \times 10^3 \times 0.01 \times 0.5 = 15 \text{ N} \cdot \text{m}^2/\text{C}$$

✓ Answer: (b) $\Phi = 15 \text{ N} \cdot \text{m}^2/\text{C}$

1.15 Net flux of the uniform field in Ex. 1.14 through a cube of side 20 cm?

In a uniform field, the number of field lines entering any closed surface equals the number leaving. The net flux through any closed surface in a uniform field is zero.

✓ Answer: Net flux $= 0$

💡 Note: By Gauss's Law: $\Phi = q_{\text{enclosed}}/\epsilon_0$. Zero flux means zero enclosed charge. A uniform field has no charge enclosed.

1.16 Outward flux $= 8 \times 10^3 \text{ N} \cdot \text{m}^2/\text{C}$ from a black box. (a) Net charge inside? (b) If flux $= 0$, are there no charges?

(a) By Gauss's Law: $\Phi = q/\epsilon_0$

$$q = \Phi \times \epsilon_0 = 8 \times 10^3 \times 8.85 \times 10^{-12} = 7.08 \times 10^{-8} \text{ C} \approx 0.07 \text{ } \mu\text{C}$$

✓ Answer: (a) Net charge inside $= 0.07 \text{ } \mu\text{C}$

(b) Zero flux means zero NET charge inside. There could still be equal amounts of positive and negative charges cancelling each other.

✓ Answer: (b) No, we cannot conclude there are no charges — only that the net charge is zero.

1.17 $+10 \mu\text{C}$ charge 5 cm above centre of $10\text{cm} \times 10\text{cm}$ square. Flux through square?

Trick (Hint given): Think of the square as one face of a cube with edge 10 cm. The point charge is at the centre of this cube (5 cm above the centre of each face).

By Gauss's Law, total flux from the charge through the complete cube $= q/\epsilon_0$

$$\text{Total flux} = 10 \times 10^{-6} / 8.85 \times 10^{-12} = 1.13 \times 10^6 \text{ N} \cdot \text{m}^2/\text{C}$$

By symmetry, flux through each of the 6 faces is equal $\rightarrow$ flux through one face $= \text{total}/6$

$$\Phi_{\text{through square}} = 1.13 \times 10^6 / 6 \approx 1.88 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C} \approx 2.2 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}$$

✓ Answer: $\Phi \approx 1.88 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}$

💡 Note: This is a brilliant use of Gauss's Law + symmetry. Without this trick, the calculation would involve complex integration!

1.18 2.0 μC charge at centre of cubic Gaussian surface, 9 cm edge. Net electric flux?

$$\Phi = q/\epsilon_0 = 2 \times 10^{-6} / 8.85 \times 10^{-12} = 2.26 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C} \approx 1.9 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}$$

✓ Answer: $\Phi \approx 2.26 \times 10^5 \text{ N} \cdot \text{m}^2/\text{C}$

💡 Note: For Gauss's Law, only the enclosed charge matters — not the shape or size of the Gaussian surface!

1.19 Point charge causes flux $-1 \times 10^3 \text{ N} \cdot \text{m}^2/\text{C}$ through spherical surface of 10 cm radius. (a) Flux if radius doubled? (b) Value of charge?

(a) Gauss's Law: $\Phi = q/\epsilon_0$. Flux depends only on the enclosed charge, NOT on the size of the surface.

✓ Answer: (a) Flux remains $-1 \times 10^3 \text{ N} \cdot \text{m}^2/\text{C}$ (unchanged)

(b) $q = \Phi \times \epsilon_0 = -1 \times 10^3 \times 8.85 \times 10^{-12} = -8.85 \times 10^{-9} \text{ C} \approx -8.8 \text{ nC}$

✓ Answer: (b) Charge = -8.85 nC (negative, since flux is negative — field lines pointing inward)

1.20 Conducting sphere (radius 10 cm). $E = 1.5 \times 10^3 \text{ N/C}$ radially inward at 20 cm from centre. Net charge?

Since E points radially inward, the charge is negative.

Using Gauss's Law with spherical surface of radius $r = 0.20 \text{ m}$:

$$E \times 4\pi r^2 = |q|/\epsilon_0 \rightarrow q = -E \times 4\pi r^2 \times \epsilon_0$$

$$q = -1.5 \times 10^3 \times 4\pi \times (0.20)^2 \times 8.85 \times 10^{-12}$$

$$q = -1.5 \times 10^3 \times 4\pi \times 0.04 \times 8.85 \times 10^{-12} \approx -6.67 \times 10^{-9} \text{ C}$$

✓ Answer: Net charge = -6.67 nC

1.21 Uniformly charged sphere (diameter 2.4 m, surface charge density $80 \mu\text{C}/\text{m}^2$). (a) Charge? (b) Total electric flux?

Given: Radius $R = 1.2 \text{ m}$, $\sigma = 80 \times 10^{-6} \text{ C}/\text{m}^2$

(a) Surface area $= 4\pi R^2 = 4\pi \times (1.2)^2 = 18.09 \text{ m}^2$

$$q = \sigma \times A = 80 \times 10^{-6} \times 18.09 = 1.45 \times 10^{-3} \text{ C}$$

✓ Answer: (a) Charge = $1.45 \times 10^{-3} \text{ C} \approx 1.45 \text{ mC}$

$$(b) \Phi = q/\epsilon_0 = 1.45 \times 10^{-3} / 8.85 \times 10^{-12} \approx 1.64 \times 10^8 \text{ N} \cdot \text{m}^2/\text{C}$$

✓ Answer: (b) $\Phi \approx 1.64 \times 10^8 \text{ N} \cdot \text{m}^2/\text{C}$

1.22 Infinite line charge produces $E = 9 \times 10^4 \text{ N/C}$ at 2 cm. Find linear charge density.

For an infinite line charge: $E = \lambda/(2\pi\epsilon_0 r)$

$$\lambda = E \times 2\pi\epsilon_0 \times r = 9 \times 10^4 \times 2\pi \times 8.85 \times 10^{-12} \times 0.02$$

$$\lambda = 9 \times 10^4 \times 1.113 \times 10^{-12} / 0.02 \dots = 10^{-7} \text{ C/m} = 0.1 \text{ } \mu\text{C/m}$$

✓ Answer: Linear charge density $\lambda = 10^{-7} \text{ C/m} = 0.1 \text{ } \mu\text{C/m}$

1.23 Two parallel plates with surface charge densities $\pm 17 \times 10^{-22} \text{ C/m}^2$. Find E in: (a) outer region of plate 1, (b) outer region of plate 2, (c) between plates.

For infinite parallel plates with equal and opposite charge densities:

→ Outside either plate: fields from both plates cancel → $E = 0$

→ Between the plates: fields add → $E = \sigma/\epsilon_0$

$$\underline{E_{\text{between}}} = \sigma/\epsilon_0 = 17 \times 10^{-22} / 8.85 \times 10^{-12} = 1.92 \times 10^{-10} \text{ N/C} \approx 1.9 \times 10^{-10} \text{ N/C}$$

✓ Answer: (a) $E = 0$ (b) $E = 0$ (c) $E \approx 1.9 \times 10^{-10} \text{ N/C}$

💡 Note: The extremely small charge density makes the field between the plates tiny. Real capacitors have much larger charge densities.

Chapter 2: Electrostatic Potential & Capacitance

Key Formulas: $V = kq/r$ | $C = Q/V = \epsilon_0 A/d$ | $U = \frac{1}{2} CV^2$

💡 Note: Electric potential is a scalar quantity — much easier to add than vector electric fields!

2.1 Two charges 5×10^{-8} C and -3×10^{-8} C are 16 cm apart. Where is electric potential zero on the line joining them?

Given: $q_1 = +5 \times 10^{-8}$ C at point A, $q_2 = -3 \times 10^{-8}$ C at point B, AB = 16 cm

Let potential be zero at point P. $V = kq/r$ (scalar, can be positive or negative).

CASE 1: P between A and B, at distance x from A (so distance from B = $16 - x$ cm):

$$kq_1/x + kq_2/(16-x) = 0$$

$$5 \times 10^{-8}/x = 3 \times 10^{-8}/(16-x)$$

$$5(16-x) = 3x \rightarrow 80 = 8x \rightarrow x = 10 \text{ cm}$$

CASE 2: P outside (beyond the negative charge), at distance y from B (on far side):

$$5 \times 10^{-8}/(16+y) = 3 \times 10^{-8}/y$$

$$5y = 3(16+y) \rightarrow 5y = 48 + 3y \rightarrow 2y = 48 \rightarrow y = 24 \text{ cm}$$

✓ Answer: $V = 0$ at two points: (1) 10 cm from positive charge (between them), and (2) 40 cm from positive charge (beyond the negative charge)

💡 Note: Since potential is a scalar, we can set up algebraic (not vector) equations. This is much simpler than force problems!

2.2 Regular hexagon of side 10 cm, charge $5 \mu\text{C}$ at each vertex. Potential at centre?

All six vertices are equidistant from the centre. Distance from each vertex to centre = side length = 10 cm = 0.1 m.

$$V = 6 \times kq/r = 6 \times (9 \times 10^9 \times 5 \times 10^{-6}) / 0.1$$

$$V = 6 \times 4.5 \times 10^5 = 2.7 \times 10^6 \text{ V}$$

✓ Answer: $V = 2.7 \times 10^6 \text{ V}$

💡 Note: In a regular hexagon, all vertices are at the same distance from the centre as the side length. The potentials simply add (scalar addition).

2.3 Charges $+2 \mu\text{C}$ and $-2 \mu\text{C}$ at A and B, 6 cm apart. (a) Identify equipotential surface. (b) Direction of E on this surface?

(a) For an electric dipole ($+q$ at A, $-q$ at B), the locus of all points where $V = 0$ is the perpendicular bisector plane of AB (the plane normal to AB passing through its midpoint).

At any point on this perpendicular bisector, the distance from $+q$ equals the distance from $-q$, so $V = k(+q)/r + k(-q)/r = 0$.

✓ Answer: (a) The equipotential surface is the plane perpendicular to line AB and passing through its midpoint M.

(b) Electric field is always perpendicular to equipotential surfaces, pointing from high to low potential.

✓ Answer: (b) The electric field at every point on this surface is directed from A (positive) to B (negative), i.e., along the direction AB.

2.4 Spherical conductor (radius 12 cm, charge 1.6×10^{-7} C). E at: (a) inside, (b) just outside, (c) 18 cm from centre?

Given: $R = 0.12$ m, $q = 1.6 \times 10^{-7}$ C

(a) Inside a conductor, $E = 0$ always (charge resides on surface).

✓ Answer: (a) $E = 0$ inside the sphere

$$(b) \ E_{\text{surface}} = kq/R^2 = (9 \times 10^9 \times 1.6 \times 10^{-7}) / (0.12)^2 = 1440/0.0144 = 10^5 \text{ N/C}$$

✓ Answer: (b) $E = 10^5$ N/C (radially outward just outside)

$$(c) \ E = kq/r^2 = (9 \times 10^9 \times 1.6 \times 10^{-7}) / (0.18)^2 = 1440/0.0324 \approx 4.4 \times 10^4 \text{ N/C}$$

✓ Answer: (c) $E \approx 4.4 \times 10^4$ N/C

💡 Note: Outside a conducting sphere, the field behaves exactly as if all charge were concentrated at the centre — a key result of Gauss's Law.

2.5 Parallel plate capacitor with air, $C = 8$ pF. Capacitance if distance halved and dielectric ($k = 6$) inserted?

Original: $C_0 = \epsilon_0 A/d = 8$ pF

New: distance $d' = d/2$, dielectric constant $K = 6$

$$C_{\text{new}} = K\epsilon_0 A/d' = K \times \epsilon_0 A/(d/2) = 2K \times \epsilon_0 A/d = 2 \times 6 \times C_0 = 12 \times 8 \text{ pF}$$

✓ Answer: $C_{\text{new}} = 96$ pF

💡 Note: Two separate effects: halving distance doubles C , inserting dielectric multiplies C by $K=6$. Total increase = $2 \times 6 = 12$ times.

2.6 Three capacitors each 9 pF in series. (a) Total capacitance? (b) Potential across each at 120 V?

$$(a) \ 1/C = 1/9 + 1/9 + 1/9 = 3/9 = 1/3 \rightarrow C = 3 \text{ pF}$$

✓ Answer: (a) Total capacitance = 3 pF

(b) Since all three are identical and in series, voltage divides equally:

$$V_{\text{each}} = 120/3 = 40 \text{ V}$$

✓ Answer: (b) Potential difference across each capacitor = 40 V

💡 Note: For identical capacitors in series, voltage divides equally. For capacitors in parallel, charge divides equally.

2.7 Three capacitors 2 pF, 3 pF, 4 pF in parallel at 100 V. (a) Total capacitance?
(b) Charge on each?

$$(a) C_{\text{total}} = 2 + 3 + 4 = 9 \text{ pF}$$

✓ Answer: (a) Total capacitance = 9 pF

(b) Each capacitor has the same voltage $V = 100 \text{ V}$:

$$Q_1 = C_1 V = 2 \times 10^{-12} \times 100 = 2 \times 10^{-10} \text{ C}$$

$$Q_2 = C_2 V = 3 \times 10^{-12} \times 100 = 3 \times 10^{-10} \text{ C}$$

$$Q_3 = C_3 V = 4 \times 10^{-12} \times 100 = 4 \times 10^{-10} \text{ C}$$

✓ Answer: (b) $Q_1 = 200 \text{ pC}$, $Q_2 = 300 \text{ pC}$, $Q_3 = 400 \text{ pC}$

2.8 Parallel plate capacitor: area $6 \times 10^{-3} \text{ m}^2$, distance 3 mm, connected to 100 V. Find C and charge Q.

$$C = \epsilon_0 A / d = (8.85 \times 10^{-12} \times 6 \times 10^{-3}) / (3 \times 10^{-3})$$

$$C = 53.1 \times 10^{-15} / 3 \times 10^{-3} = 17.7 \times 10^{-12} \text{ F} \approx 18 \text{ pF}$$

✓ Answer: Capacitance $C \approx 18 \text{ pF}$

$$Q = CV = 18 \times 10^{-12} \times 100 = 1.8 \times 10^{-9} \text{ C} = 1.8 \text{ nC}$$

✓ Answer: Charge on each plate $Q = 1.8 \text{ nC}$

2.9 For capacitor in Ex. 2.8, a 3mm mica sheet ($K=6$) inserted: (a) with supply connected, (b) after disconnecting supply.

Original values: $C_0 = 18 \text{ pF}$, $V_0 = 100 \text{ V}$, $Q_0 = 1.8 \text{ nC}$

New capacitance with mica: $C_{\text{new}} = K \times C_0 = 6 \times 18 = 108 \text{ pF}$

(a) Supply REMAINS CONNECTED (voltage stays at 100 V):

→ Voltage $V = 100 \text{ V}$ (fixed by supply)

→ New charge $Q = C_{\text{new}} \times V = 108 \text{ pF} \times 100 \text{ V} = 10.8 \text{ nC}$

→ Electric field $E = V/d = 100/3\text{mm}$ (same as before)

✓ Answer: (a) $V = 100 \text{ V}$, $C = 108 \text{ pF}$, $Q = 10.8 \text{ nC}$ (charge increases, field unchanged)

(b) Supply DISCONNECTED (charge stays fixed at $Q_0 = 1.8 \text{ nC}$):

→ Charge $Q = 1.8 \text{ nC}$ (fixed)

→ New voltage $V = Q/C_{\text{new}} = 1.8 \times 10^{-9} / 108 \times 10^{-12} = 16.67 \text{ V}$

✓ Answer: (b) $Q = 1.8 \text{ nC}$, $C = 108 \text{ pF}$, $V = 16.67 \text{ V}$ (voltage decreases)

💡 Note: Key insight: Supply connected → V constant; Supply disconnected → Q constant. These lead to very different outcomes!

2.10 12 pF capacitor connected to 50 V battery. Energy stored?

$$U = \frac{1}{2} CV^2 = \frac{1}{2} \times 12 \times 10^{-12} \times (50)^2$$

$$U = \frac{1}{2} \times 12 \times 10^{-12} \times 2500 = 1.5 \times 10^{-8} \text{ J}$$

✓ Answer: Energy stored = $1.5 \times 10^{-8} \text{ J} = 15 \text{ nJ}$

2.11 600 pF capacitor charged to 200 V, then connected to uncharged 600 pF. Energy lost?

$$\text{Initial energy: } U_i = \frac{1}{2} C_1 V^2 = \frac{1}{2} \times 600 \times 10^{-12} \times (200)^2 = 1.2 \times 10^{-5} \text{ J}$$

$$\text{Initial charge: } Q = C_1 V = 600 \times 10^{-12} \times 200 = 1.2 \times 10^{-4} \text{ C}$$

When connected, charge distributes equally (same capacitance):

$$Q_{\text{each}} = Q/2 = 0.6 \times 10^{-4} \text{ C}$$

$$\text{New voltage } V' = Q_{\text{each}}/C = 0.6 \times 10^{-4} / 600 \times 10^{-12} = 100 \text{ V}$$

$$\text{Final energy: } U_f = 2 \times \frac{1}{2} C V'^2 = C V'^2 = 600 \times 10^{-12} \times (100)^2 = 6 \times 10^{-6} \text{ J}$$

$$\text{Energy lost} = U_i - U_f = 12 \times 10^{-6} - 6 \times 10^{-6} = 6 \times 10^{-6} \text{ J}$$

✓ Answer: Energy lost = $6 \mu\text{J}$

💡 Note: Energy is lost as heat (and electromagnetic radiation) during the redistribution of charge. This is always positive — energy is never gained in such passive connections!

Chapter 3: Current Electricity

Key Formulas: $I = V/R$ | $R = \rho L/A$ | $R_T = R_0(1 + \alpha \Delta T)$ | Kirchhoff's Laws

💡 Note: Current electricity deals with charges in steady motion. Unlike electrostatics, energy is continuously dissipated as heat.

3.1 Car battery: emf = 12 V, internal resistance $r = 0.4 \Omega$. Maximum current?

Maximum current occurs when external resistance = 0 (short circuit).

$$I_{\text{max}} = \text{emf}/r = 12/0.4 = 30 \text{ A}$$

✓ Answer: Maximum current = 30 A

💡 Note: In practice, this maximum current is only theoretical. Drawing 30 A would damage the battery. Safety features like fuses protect against such overcurrents.

3.2 Battery (emf 10V, $r = 3\Omega$) connected to resistor, current = 0.5 A. Find R and terminal voltage.

Using emf equation: $\varepsilon = I(R + r)$

$$10 = 0.5 \times (R + 3) \rightarrow R + 3 = 20 \rightarrow R = 17 \Omega$$

✓ Answer: External resistance $R = 17 \Omega$

$$\text{Terminal voltage } V = \varepsilon - Ir = 10 - (0.5 \times 3) = 10 - 1.5 = 8.5 \text{ V}$$

✓ Answer: Terminal voltage = 8.5 V

💡 Note: Terminal voltage is always less than emf when current flows (due to internal resistance drop). The difference Ir is the lost voltage inside the battery.

3.3 Heating element: $R_0 = 100 \Omega$ at 27°C , $R = 117 \Omega$ at temperature T . $\alpha = 1.70 \times 10^{-4} \text{ }^\circ\text{C}^{-1}$. Find T .

$$R = R_0[1 + \alpha(T - T_0)]$$

$$117 = 100[1 + 1.70 \times 10^{-4} \times (T - 27)]$$

$$1.17 = 1 + 1.70 \times 10^{-4}(T - 27)$$

$$0.17 = 1.70 \times 10^{-4}(T - 27)$$

$$T - 27 = 0.17 / (1.70 \times 10^{-4}) = 1000$$

$$T = 1027 \text{ }^\circ\text{C}$$

✓ Answer: Temperature of element = $1027 \text{ }^\circ\text{C}$

💡 Note: This is why heating elements glow red-hot! The high temperature resistance limits current and converts electrical energy to heat efficiently.

3.4 Wire of length 15m, cross-section $6 \times 10^{-7} \text{ m}^2$, resistance 5 Ω . Find resistivity.

$$\rho = RA/L = (5 \times 6 \times 10^{-7}) / 15$$

$$\rho = 30 \times 10^{-7} / 15 = 2 \times 10^{-7} \Omega \cdot \text{m}$$

✓ Answer: Resistivity $\rho = 2 \times 10^{-7} \Omega \cdot \text{m}$

💡 Note: Resistivity is a material property — it doesn't depend on the shape or size of the sample, only on the type of material and temperature.

3.5 Silver wire: $R = 2.1 \Omega$ at 27.5°C , $R = 2.7 \Omega$ at 100°C . Find temperature coefficient α .

$$R_2 = R_1 [1 + \alpha (T_2 - T_1)]$$

$$2.7 = 2.1 [1 + \alpha (100 - 27.5)]$$

$$2.7/2.1 = 1 + \alpha \times 72.5$$

$$1.2857 = 1 + 72.5\alpha$$

$$0.2857 = 72.5\alpha$$

$$\alpha = 0.2857/72.5 \approx 3.94 \times 10^{-3} \text{ } ^\circ\text{C}^{-1} \approx 0.0039 \text{ } ^\circ\text{C}^{-1}$$

✓ Answer: $\alpha \approx 3.9 \times 10^{-3} \text{ } ^\circ\text{C}^{-1}$

3.6 Nichrome heater on 230V: initial current 3.2 A settling to 2.8 A. Room temp 27°C , $\alpha = 1.70 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$. Steady temperature?

Initial (at 27°C): $R_0 = V/I_0 = 230/3.2 = 71.875 \Omega$

Steady state: $R = V/I = 230/2.8 = 82.14 \Omega$

$$R = R_0 [1 + \alpha (T - 27)]$$

$$82.14 = 71.875 [1 + 1.70 \times 10^{-4} (T - 27)]$$

$$1.1428 = 1 + 1.70 \times 10^{-4} (T - 27)$$

$$0.1428 / 1.70 \times 10^{-4} = T - 27$$

$$T - 27 \approx 840 \rightarrow T \approx 867 \text{ } ^\circ\text{C}$$

✓ Answer: Steady temperature $\approx 867 \text{ } ^\circ\text{C}$

💡 Note: Nichrome is used in heaters because of its high resistivity, high melting point, and good oxidation resistance at high temperatures.

3.7 Network of resistors (Figure 3.20): Find current in each branch.

Applying Kirchhoff's Laws to the bridge network with 10V source and 10Ω , 5Ω , 10Ω , 5Ω resistors with 10Ω in middle branch:

Let currents in branches be I_1 , I_2 (using Kirchhoff's Current and Voltage Laws):

✓ Answer: Current in branch AB = $4/17 \text{ A}$, BC = $6/17 \text{ A}$, CD = $-4/17 \text{ A}$ (opposite direction), AD = $6/17 \text{ A}$, BD = $-2/17 \text{ A}$. Total current = $10/17 \text{ A}$

💡 Note: Negative values simply mean the assumed current direction was opposite to actual. Kirchhoff's laws always work — just be careful with signs.

3.8 Battery (emf 8V, $r = 0.5 \Omega$) being charged by 120V dc supply with series resistor 15.5Ω . Terminal voltage during charging? Purpose of series resistor?

During charging, conventional current flows INTO the positive terminal of the battery.

$$I = (120 - 8) / (15.5 + 0.5) = 112/16 = 7 \text{ A}$$

Terminal voltage during charging:

$$V_{\text{terminal}} = \text{emf} + Ir = 8 + 7 \times 0.5 = 8 + 3.5 = 11.5 \text{ V}$$

✓ Answer: Terminal voltage = 11.5 V

✓ Answer: Purpose of series resistor: Limits the charging current to a safe value. Without it, $I = 112/0.5 = 224 \text{ A}$ — dangerously high and would damage the battery.

3.9 Copper wire: $n = 8.5 \times 10^{28} \text{ m}^{-3}$, length 3m, area $2 \times 10^{-6} \text{ m}^2$, current 3A. Time for electron to drift end to end?

$$\text{Drift velocity: } v_d = I / (nAe)$$

$$v_d = 3 / (8.5 \times 10^{28} \times 2 \times 10^{-6} \times 1.6 \times 10^{-19})$$

$$v_d = 3 / (2.72 \times 10^4) \approx 1.1 \times 10^{-4} \text{ m/s}$$

$$\text{Time} = \text{Length}/v_d = 3 / (1.1 \times 10^{-4}) \approx 2.7 \times 10^4 \text{ s} \approx 7.5 \text{ hours}$$

✓ Answer: Time $\approx 2.7 \times 10^4 \text{ s}$ (about 7.5 hours!)

💡 Note: Electrons drift incredibly slowly — yet electricity "flows" instantly. Why? Because when a switch is flipped, the electric field propagates at nearly the speed of light, pushing ALL electrons simultaneously. It's like a water pipe — you don't wait for water molecules to travel from tap to mouth.

Chapter 4: Moving Charges & Magnetism

Key Formulas: $B = \mu_0 I / 2R$ (circular coil) | $B = \mu_0 I / 2\pi r$ (long wire) | $F = qv \times B$ | $\tau = NIAB \sin\theta$

💡 Note: Moving charges create magnetic fields, and magnetic fields exert forces on moving charges. $\mu_0 = 4\pi \times 10^{-7} \text{ T}\cdot\text{m/A}$

4.1 Circular coil: 100 turns, radius 8cm, current 0.40 A. Magnetic field at centre?

$$B = \mu_0 NI / 2R = (4\pi \times 10^{-7} \times 100 \times 0.40) / (2 \times 0.08)$$

$$B = (4\pi \times 10^{-7} \times 40) / 0.16 = \pi \times 10^{-4} \text{ T} \approx 3.14 \times 10^{-4} \text{ T}$$

✓ Answer: $B = \pi \times 10^{-4} \text{ T} \approx 3.14 \times 10^{-4} \text{ T}$

4.2 Long straight wire carrying 35 A. B at 20 cm from wire?

$$B = \mu_0 I / 2\pi r = (4\pi \times 10^{-7} \times 35) / (2\pi \times 0.20)$$

$$B = (2 \times 10^{-7} \times 35) / 0.20 = 7 \times 10^{-6} / 0.20 = 3.5 \times 10^{-5} \text{ T}$$

✓ Answer: $B = 3.5 \times 10^{-5} \text{ T}$

4.3 Horizontal wire carries 50 A northward. B at 2.5 m east of wire?

$$B = \mu_0 I / 2\pi r = (4\pi \times 10^{-7} \times 50) / (2\pi \times 2.5) = 4 \times 10^{-6} \text{ T}$$

Direction: Using right-hand rule (thumb points North = current direction), fingers curl upward at East side.

✓ Answer: $B = 4 \times 10^{-6} \text{ T}$ directed vertically upward

4.4 Overhead wire carries 90 A eastward. B at 1.5 m below the wire?

$$B = \mu_0 I / 2\pi r = (4\pi \times 10^{-7} \times 90) / (2\pi \times 1.5)$$

$$B = (2 \times 10^{-7} \times 90) / 1.5 = 1.2 \times 10^{-5} \text{ T}$$

Direction: Current flows East. Point is directly below. By right-hand rule, B points towards South.

✓ Answer: $B = 1.2 \times 10^{-5} \text{ T}$ directed towards South

4.5 Wire carrying 8A at 30° to uniform field $B = 0.15 \text{ T}$. Force per unit length?

$$F/L = BI \sin\theta = 0.15 \times 8 \times \sin 30^\circ = 0.15 \times 8 \times 0.5 = 0.6 \text{ N/m}$$

✓ Answer: Force per unit length = 0.6 N/m

4.6 3 cm wire carrying 10 A inside solenoid ($B = 0.27 \text{ T}$), perpendicular to axis. Magnetic force?

$$F = BIL = 0.27 \times 10 \times 0.03 = 0.081 \text{ N} \approx 8.1 \times 10^{-2} \text{ N}$$

✓ Answer: $F = 8.1 \times 10^{-2} \text{ N}$ (direction given by Fleming's left-hand rule)

4.7 Two parallel wires A (8A) and B (5A) same direction, separated 4cm. Force on 10cm of wire A?

Force per unit length between parallel wires: $F/L = \mu_0 I_1 I_2 / 2\pi d$

$$F = (\mu_0 I_1 I_2 / 2\pi d) \times L = (4\pi \times 10^{-7} \times 8 \times 5 / (2\pi \times 0.04)) \times 0.10$$

$$F = (2 \times 10^{-7} \times 40 / 0.04) \times 0.10 = 2 \times 10^{-4} \text{ N}$$

✓ Answer: $F = 2 \times 10^{-4} \text{ N}$ (attractive, since currents are in same direction)

4.8 Solenoid: 80 cm long, 5 layers $\times$ 400 turns, diameter 1.8 cm, current 8A. B at centre?

Total turns $N = 5 \times 400 = 2000$. Length $L = 0.80 \text{ m}$. $n = N/L = 2000/0.80 = 2500 \text{ turns/m}$

$$B = \mu_0 n I = 4\pi \times 10^{-7} \times 2500 \times 8$$

$$B = 4\pi \times 10^{-7} \times 20000 = 8\pi \times 10^{-3} \approx 2.51 \times 10^{-2} \text{ T}$$

✓ Answer: $B = 8\pi \times 10^{-3} \text{ T} \approx 2.5 \times 10^{-2} \text{ T}$

4.9 Square coil: 10cm side, 20 turns, 12 A, normal makes 30° with $B = 0.80 \text{ T}$. Torque?

$$\tau = NIAB \sin\theta = 20 \times 12 \times (0.10)^2 \times 0.80 \times \sin 30^\circ$$

$$\tau = 20 \times 12 \times 0.01 \times 0.80 \times 0.5 = 0.96 \text{ N}\cdot\text{m}$$

✓ Answer: Torque $\tau = 0.96 \text{ N}\cdot\text{m}$

4.10 Two moving coil meters M_1 ($R_1=10\Omega$, $N_1=30$, $A_1=3.6 \times 10^{-3} \text{ m}^2$, $B_1=0.25 \text{ T}$) and M_2 ($R_2=14\Omega$, $N_2=42$, $A_2=1.8 \times 10^{-3} \text{ m}^2$, $B_2=0.50 \text{ T}$). Find ratio of current sensitivity and voltage sensitivity.

Current sensitivity = NBA/k (k = spring constant, same for both)

$$CS_2/CS_1 = (N_2 B_2 A_2) / (N_1 B_1 A_1)$$

$$= (42 \times 0.50 \times 1.8 \times 10^{-3}) / (30 \times 0.25 \times 3.6 \times 10^{-3})$$

$$= (42 \times 0.50 \times 1.8) / (30 \times 0.25 \times 3.6) = 37.8/27 = 1.4$$

✓ Answer: (a) Current sensitivity ratio $M_2/M_1 = 1.4$

Voltage sensitivity = $NBA/(kR)$

$$VS_2/VS_1 = (N_2 B_2 A_2 / R_2) / (N_1 B_1 A_1 / R_1) = 1.4 \times (R_1/R_2) = 1.4 \times (10/14) = 1.0$$

✓ Answer: (b) Voltage sensitivity ratio $M_2/M_1 = 1.0$ (equal)

4.11 Electron shot at $4.8 \times 10^6 \text{ m/s}$ into uniform $B = 6.5 \text{ G}$ perpendicular to field. Radius of circular orbit?

The magnetic force provides centripetal force: $qvB = mv^2/r \rightarrow r = mv/(qB)$

Given: $v = 4.8 \times 10^6 \text{ m/s}$, $B = 6.5 \times 10^{-4} \text{ T}$, $m = 9.1 \times 10^{-31} \text{ kg}$, $q = 1.6 \times 10^{-19} \text{ C}$

$$r = mv/(qB) = (9.1 \times 10^{-31} \times 4.8 \times 10^6) / (1.6 \times 10^{-19} \times 6.5 \times 10^{-4})$$

$$r = 4.368 \times 10^{-24} / 1.04 \times 10^{-22} = 0.042 \text{ m} = 4.2 \text{ cm}$$

✓ Answer: Radius = 4.2 cm

💡 Note: The electron moves in a circle because magnetic force is always perpendicular to velocity — it changes direction but not speed, so kinetic energy is unchanged. No work is done by magnetic force!

4.12 Frequency of revolution of electron in Ex. 4.11. Does it depend on speed?

$$\text{Frequency } f = v / (2\pi r) = qB / (2\pi m)$$

$$f = (1.6 \times 10^{-19} \times 6.5 \times 10^{-4}) / (2\pi \times 9.1 \times 10^{-31})$$

$$f = 1.04 \times 10^{-22} / (5.71 \times 10^{-30}) \approx 1.82 \times 10^7 \text{ Hz} \approx 18 \text{ MHz}$$

✓ Answer: $f \approx 18 \text{ MHz}$. No, frequency does NOT depend on speed.

💡 Note: This remarkable property — cyclotron frequency being independent of speed — is the basis of the cyclotron accelerator! A faster particle has a larger radius but completes each circle in the same time.

4.13 (a) Circular coil: 30 turns, 8cm radius, 6A, suspended in 1.0T field at 60° to normal. Counter-torque needed? (b) Does shape matter?

$$(a) \tau = NIAB \sin\theta = 30 \times 6.0 \times \pi \times (0.08)^2 \times 1.0 \times \sin 60^\circ$$

$$\tau = 30 \times 6 \times 0.0201 \times 0.866 \approx 3.13 \text{ N}\cdot\text{m} \approx 3.1 \text{ N}\cdot\text{m}$$

✓ Answer: (a) Counter-torque needed = 3.1 N·m

✓ Answer: (b) No, the answer would not change. The torque formula $\tau = NIAB \sin\theta$ depends on the AREA enclosed, not the shape. A planar coil of the same area produces the same torque regardless of its shape.

Chapter 5: Magnetism & Matter

Key Formulas: $\tau = mB \sin\theta$ | $U = -\mathbf{m} \cdot \mathbf{B} = -mB \cos\theta$ | $B_{\text{axial}} = \mu_0 \cdot 2m / 4\pi r^3$ | $B_{\text{equatorial}} = -\mu_0 m / 4\pi r^3$

💡 Note: A bar magnet behaves like a magnetic dipole — analogous to an electric dipole but with no magnetic monopoles.

5.1 Bar magnet at 30° to $B = 0.25 \text{ T}$ experiences torque $4.5 \times 10^{-2} \text{ J}$. Magnetic moment?

$$\tau = mB \sin\theta \rightarrow m = \tau / (B \sin\theta)$$

$$m = (4.5 \times 10^{-2}) / (0.25 \times \sin 30^\circ) = (4.5 \times 10^{-2}) / (0.25 \times 0.5) = (4.5 \times 10^{-2}) / 0.125$$

$$m = 0.36 \text{ J/T}$$

✓ Answer: Magnetic moment $m = 0.36 \text{ J/T}$

5.2 Bar magnet $m = 0.32 \text{ JT}^{-1}$ in uniform $B = 0.15 \text{ T}$. (a) Stable equilibrium orientation, (b) Unstable orientation, and energy in each case?

(a) Stable equilibrium: Minimum potential energy $\rightarrow m$ parallel to B ($\theta = 0^\circ$)

$$U = -mB \cos 0^\circ = -mB = -0.32 \times 0.15 = -4.8 \times 10^{-2} \text{ J}$$

✓ Answer: (a) Stable: m parallel to B ($\theta = 0^\circ$), $U = -4.8 \times 10^{-2} \text{ J}$

(b) Unstable equilibrium: Maximum potential energy $\rightarrow m$ antiparallel to B ($\theta = 180^\circ$)

$$U = -mB \cos 180^\circ = +mB = +0.32 \times 0.15 = +4.8 \times 10^{-2} \text{ J}$$

✓ Answer: (b) Unstable: m antiparallel to B ($\theta = 180^\circ$), $U = +4.8 \times 10^{-2} \text{ J}$

💡 Note: Think of a compass: stable = needle aligned with Earth's field. Flip it 180° and it's unstable — it will snap back to stable position.

5.3 Solenoid: 800 turns, area $2.5 \times 10^{-4} \text{ m}^2$, current 3A . How does it act like a bar magnet? Magnetic moment?

$$m = NIA = 800 \times 3.0 \times 2.5 \times 10^{-4} = 0.60 \text{ A} \cdot \text{m}^2$$

✓ Answer: Magnetic moment $m = 0.60 \text{ J/T} = 0.60 \text{ A} \cdot \text{m}^2$

The solenoid acts like a bar magnet because it produces a magnetic field similar to a bar magnet: the field is strongest near the two ends (poles), loops around from one end to the other outside, and the field lines are identical to those of a bar magnet.

5.4 Solenoid from Ex 5.3 in horizontal field $B = 0.25 \text{ T}$, axis at 30° to B . Torque on solenoid?

Using $m = 0.60 \text{ JT}^{-1}$ (from the solenoid parameters in Ex 5.3):

$$\tau = mB \sin\theta = 0.60 \times 0.25 \times \sin 30^\circ = 0.60 \times 0.25 \times 0.5 = 0.075 \text{ N} \cdot \text{m}$$

✓ Answer: Torque = $7.5 \times 10^{-2} \text{ N} \cdot \text{m}$

5.5 Bar magnet $m = 1.5 \text{ JT}^{-1}$ aligned with $B = 0.22 \text{ T}$. (a) Work to turn: (i) normal, (ii) opposite? (b) Torque in each case?

(a) Work done = Change in potential energy: $W = \Delta U = U_{\text{final}} - U_{\text{initial}}$

Initial: $U_i = -mB \cos 0^\circ = -1.5 \times 0.22 = -0.33 \text{ J}$

(i) Turn to normal ($\theta = 90^\circ$): $U_f = -mB \cos 90^\circ = 0$

$$W_1 = 0 - (-0.33) = 0.33 \text{ J}$$

✓ Answer: (a)(i) Work = 0.33 J

(ii) Turn to opposite ($\theta = 180^\circ$): $U_f = -mB \cos 180^\circ = +0.33 \text{ J}$

$$W_2 = 0.33 - (-0.33) = 0.66 \text{ J}$$

✓ Answer: (a)(ii) Work = 0.66 J

(b)(i) At $\theta = 90^\circ$: $\tau = mB \sin 90^\circ = 1.5 \times 0.22 = 0.33 \text{ N}\cdot\text{m}$ (tends to align m with B)

✓ Answer: (b)(i) Torque = 0.33 N·m

(b)(ii) At $\theta = 180^\circ$: $\tau = mB \sin 180^\circ = 0$

✓ Answer: (b)(ii) Torque = 0 (unstable equilibrium — any small push will make it snap to stable)

5.6 Solenoid: 2000 turns, area $1.6 \times 10^{-4} \text{ m}^2$, current 4A. (a) Magnetic moment? (b) Force and torque in $B = 7.5 \times 10^{-2} \text{ T}$ at 30° ?

$$(a) \ m = NIA = 2000 \times 4.0 \times 1.6 \times 10^{-4} = 1.28 \text{ A}\cdot\text{m}^2$$

✓ Answer: (a) Magnetic moment = $1.28 \text{ A}\cdot\text{m}^2$ along axis (right-hand screw rule)

(b) Force: In a UNIFORM field, force on a magnetic dipole = 0 (only in non-uniform field does net force exist).

$$\text{Torque } \tau = mB \sin \theta = 1.28 \times 7.5 \times 10^{-2} \times \sin 30^\circ = 1.28 \times 0.075 \times 0.5 = 0.048 \text{ N}\cdot\text{m}$$

✓ Answer: (b) Force = 0; Torque = 0.048 N·m

5.7 Bar magnet $m = 0.48 \text{ JT}^{-1}$. Field at 10 cm from centre on: (a) axis, (b) equatorial line?

Given: $m = 0.48 \text{ J/T}$, $r = 0.10 \text{ m}$

$$(a) \ B_{\text{axial}} = \mu_0 \cdot 2m / 4\pi r^3 = (10^{-7} \times 2 \times 0.48) / (0.10)^3$$

$$B_{\text{axial}} = 9.6 \times 10^{-8} / 10^{-3} = 9.6 \times 10^{-5} \text{ T} = 0.96 \text{ G}$$

✓ Answer: (a) $B_{\text{axial}} = 0.96 \text{ G}$ along South-to-North direction

$$(b) \ B_{\text{equatorial}} = \mu_0 \cdot m / 4\pi r^3 = (10^{-7} \times 0.48) / (0.10)^3$$

$$B_{\text{equatorial}} = 4.8 \times 10^{-8} / 10^{-3} = 4.8 \times 10^{-5} \text{ T} = 0.48 \text{ G}$$

✓ Answer: (b) $B_{\text{equatorial}} = 0.48 \text{ G}$ directed opposite to m (North-to-South)

💡 Note: Axial field is exactly twice the equatorial field at the same distance. Equatorial field direction is opposite to the dipole moment.

Chapter 6: Electromagnetic Induction

Key Formulas: $\varepsilon = -N \cdot d\Phi/dt$ | $\varepsilon = -L \cdot dI/dt$ | $M \cdot dI_2/dt = \varepsilon_1$ | $\Phi = BA \cos\theta$

💡 Note: Faraday's law: A CHANGING magnetic flux induces an EMF. A constant flux — no matter how large — induces nothing!

6.1 Predict direction of induced current in figures 6.15 (a) to (f).

Using Lenz's Law: Induced current opposes the change in flux causing it.

✓ Answer: (a) Along qrpq (b) Along prq and yzx (c) Along yzx (d) Along zyx (e) Along xry (f) No induced current (field lines lie in plane of loop — no flux through loop)

💡 Note: For (f): Flux = $BA \cos\theta$. When B is parallel to the plane of the loop, $\theta = 90^\circ$ and flux = 0. No change in flux means no induced EMF.

6.2 Lenz's law: (a) Wire of irregular shape → circular. (b) Circular loop → narrow straight wire.

(a) A circle has the maximum area for a given perimeter. As the wire becomes circular, area increases → flux increases → by Lenz's law, induced current opposes the increase → induced current flows to create field opposing external B.

✓ Answer: (a) Induced current flows to create a magnetic field opposing the external field (current in such a direction to reduce the increasing flux).

(b) As loop becomes narrow wire, area decreases → flux decreases → induced current opposes decrease → flows to maintain flux.

✓ Answer: (b) Induced current flows to create a field in the same direction as external B (to oppose the decreasing flux).

6.3 Long solenoid (15 turns/cm), small loop area 2 cm^2 inside. Current changes from 2A to 4A in 0.1s. Induced emf?

Turns per unit length: $n = 15 \text{ turns/cm} = 1500 \text{ turns/m}$

$$B = \mu_0 n I \rightarrow dB/dt = \mu_0 n \cdot dI/dt = 4\pi \times 10^{-7} \times 1500 \times (4 - 2)/0.1$$

$$dB/dt = 4\pi \times 10^{-7} \times 1500 \times 20 = 12\pi \times 10^{-3} \text{ T/s}$$

$$|\varepsilon| = A \cdot dB/dt = 2 \times 10^{-4} \times 12\pi \times 10^{-3} \approx 7.54 \times 10^{-6} \text{ V} \approx 7.5 \times 10^{-6} \text{ V}$$

✓ Answer: Induced emf $\approx 7.5 \mu\text{V}$

6.4 Rectangular loop (8cm×2cm) moving out of $B = 0.3\text{T}$. velocity 1 cm/s. emf when moving normal to: (a) longer side, (b) shorter side?

(a) Moving normal to longer side (8 cm side cuts field lines):

$$\varepsilon = Bvl = 0.3 \times 0.01 \times 0.08 = 2.4 \times 10^{-4} \text{ V}$$

Time to exit: $t = \text{width}/v = 0.02/0.01 = 2 \text{ s}$

✓ Answer: (a) $\text{emf} = 2.4 \times 10^{-4} \text{ V}$, lasting 2 s

(b) Moving normal to shorter side (2 cm side cuts field lines):

$$\epsilon = Bvl = 0.3 \times 0.01 \times 0.02 = 0.6 \times 10^{-4} \text{ V}$$

Time to exit: $t = \text{length}/v = 0.08/0.01 = 8 \text{ s}$

✓ Answer: (b) $\text{emf} = 0.6 \times 10^{-4} \text{ V}$, lasting 8 s

6.5 Rod (1m) rotates with $\omega = 400 \text{ rad/s}$ about one end in uniform $B = 0.5 \text{ T}$ parallel to axis. emf between centre and ring?

For a rotating rod, $\text{emf} = \frac{1}{2} B \omega l^2$

$$\epsilon = \frac{1}{2} \times B \times \omega \times l^2 = \frac{1}{2} \times 0.5 \times 400 \times (1)^2 = 100 \text{ V}$$

✓ Answer: $\text{emf} = 100 \text{ V}$

💡 Note: The rod sweeps out area as it rotates. Each element dr at distance r from pivot has velocity $v = \omega r$, contributing $d\epsilon = Bvdr = B\omega r \cdot dr$. Integrating: $\epsilon = \frac{1}{2} B \omega l^2$.

6.6 Horizontal wire 10m falling at 5 m/s through Earth's $B_H = 0.3 \times 10^{-4} \text{ T}$. (a) Instantaneous emf? (b) Direction? (c) Higher potential end?

$$(a) \quad \epsilon = Bvl = 0.3 \times 10^{-4} \times 5.0 \times 10 = 1.5 \times 10^{-3} \text{ V} = 1.5 \text{ mV}$$

✓ Answer: (a) $\epsilon = 1.5 \text{ mV}$

(b) Wire falls vertically (South), B_H points North. $F = qv \times B$: velocity $\times B$ gives force on positive charges towards East.

✓ Answer: (b) emf directed from West to East (in wire)

✓ Answer: (c) Eastern end is at higher potential

6.7 Current falls from 5A to 0A in 0.1s. Average emf = 200V. Estimate self-inductance.

$$|\epsilon| = L |dI/dt| \rightarrow L = |\epsilon| / |dI/dt|$$

$$L = 200 / (5/0.1) = 200/50 = 4 \text{ H}$$

✓ Answer: Self-inductance $L = 4 \text{ H}$

6.8 Two coils with $M = 1.5 \text{ H}$. Current in coil 1 changes from 0 to 20A in 0.5s. Change of flux linkage with coil 2?

Method 1: Use $\epsilon_{12} = M \times dI/dt$ and also $\epsilon_{12} = N_2 \times d\Phi/dt$

$$\text{Change in flux linkage} = M \times \Delta I = 1.5 \times 20 = 30 \text{ Wb}$$

✓ Answer: Change of flux linkage = 30 Wb

Chapter 7: Alternating Current

Key Formulas: $I_{rms} = I_m/\sqrt{2}$ | $V_{rms} = V_m/\sqrt{2}$ | $X_L = \omega L$ | $X_C = 1/\omega C$ | $Z = \sqrt{R^2 + (X_L - X_C)^2}$

💡 Note: AC circuits use rms values for most calculations. At resonance ($\omega_0 = 1/\sqrt{LC}$), impedance is minimum and current is maximum.

7.1 100 Ω resistor connected to 220V, 50Hz supply. (a) rms current? (b) Net power consumed over full cycle?

$$(a) \quad I_{rms} = V_{rms}/R = 220/100 = 2.2 \text{ A}$$

✓ Answer: (a) $I_{rms} = 2.2 \text{ A}$

$$(b) \quad P = V_{rms} \times I_{rms} = 220 \times 2.2 = 484 \text{ W} \quad \text{OR} \quad P = V^2/R = 220^2/100 = 484 \text{ W}$$

✓ Answer: (b) Net power = 484 W

7.2 (a) Peak voltage = 300V. rms voltage? (b) rms current = 10A. Peak current?

$$(a) \quad V_{rms} = V_{peak}/\sqrt{2} = 300/\sqrt{2} = 300/1.414 \approx 212.1 \text{ V}$$

✓ Answer: (a) $V_{rms} \approx 212 \text{ V}$

$$(b) \quad I_{peak} = I_{rms} \times \sqrt{2} = 10 \times \sqrt{2} = 14.14 \text{ A}$$

✓ Answer: (b) Peak current $\approx 14.1 \text{ A}$

7.3 44 mH inductor connected to 220V, 50Hz. rms current?

$$X_L = \omega L = 2\pi fL = 2\pi \times 50 \times 44 \times 10^{-3} = 13.82 \text{ } \Omega$$

$$I_{rms} = V_{rms}/X_L = 220/13.82 \approx 15.9 \text{ A}$$

✓ Answer: $I_{rms} \approx 15.9 \text{ A}$

💡 Note: A pure inductor has no resistance. It allows current but with a 90° phase lag. Power consumed by pure inductor = 0 (over complete cycle).

7.4 60 μF capacitor connected to 110V, 60Hz. rms current?

$$X_C = 1/(\omega C) = 1/(2\pi \times 60 \times 60 \times 10^{-6}) = 1/(22619 \times 10^{-6}) = 44.2 \text{ } \Omega$$

$$I_{rms} = V_{rms}/X_C = 110/44.2 \approx 2.49 \text{ A}$$

✓ Answer: $I_{rms} \approx 2.49 \text{ A}$

7.5 Net power absorbed by inductor (Ex. 7.3) and capacitor (Ex. 7.4) over complete cycle?

✓ Answer: Net power absorbed by BOTH = 0 (zero) over a complete cycle.

Explanation: For a pure inductor, current leads/lags voltage by 90° . Power = $V_{rms} \times I_{rms} \times \cos\phi = V \times I \times \cos 90^\circ = 0$. Similarly for pure capacitor. Energy stored in L and C during one half-cycle is returned to the source in the next half-cycle.

7.6 Charged 30 μF capacitor connected to 27 mH inductor. Angular frequency of free oscillations?

$$\omega_0 = 1/\sqrt{LC} = 1/\sqrt{(27 \times 10^{-3} \times 30 \times 10^{-6})}$$

$$\omega_0 = 1/\sqrt{(810 \times 10^{-9})} = 1/(28.46 \times 10^{-6} \times 10^3 \dots \text{let me recalc})$$

$$LC = 27 \times 10^{-3} \times 30 \times 10^{-6} = 810 \times 10^{-9}$$

$$\sqrt{LC} = \sqrt{(810 \times 10^{-9})} = 28.46 \times 10^{-5} \dots = 2.846 \times 10^{-4} \dots \text{recalc:}$$

$$\sqrt{(8.1 \times 10^{-7})} = 9 \times 10^{-4} / \sqrt{(1.11)} \approx \text{let's compute directly:}$$

$$\omega_0 = 1/\sqrt{(810 \times 10^{-9})} = 1/(9 \times 10^{-4} \times \sqrt{1}) = 1/(9 \times 10^{-4}) \dots$$

$$810 \times 10^{-9} = 8.1 \times 10^{-7}; \sqrt{(8.1 \times 10^{-7})} \approx 9 \times 10^{-4}; \omega_0 = 1/(9 \times 10^{-4}) \approx 1.1 \times 10^3 \text{ rad/s}$$

✓ Answer: $\omega_0 \approx 1.1 \times 10^3 \text{ rad/s}$

💡 Note: This is an LC oscillator — energy swings back and forth between electric field in C and magnetic field in L, like a pendulum.

7.7 Series LCR: $R=20\Omega$, $L=1.5\text{H}$, $C=35\mu\text{F}$, 200V source at natural frequency. Average power transferred per cycle?

At resonance, $X_L = X_C \rightarrow$ impedance $Z = R$ only.

$$I_{\text{rms}} = V_{\text{rms}}/R = 200/20 = 10 \text{ A}$$

$$P = I_{\text{rms}}^2 \times R = (10)^2 \times 20 = 2000 \text{ W}$$

✓ Answer: Average power = 2000 W

💡 Note: At resonance, power factor $\cos\phi = 1$ (maximum power transfer). The inductance and capacitance cancel each other — the circuit behaves as a pure resistor.

7.8 Series LCR: $L=5\text{H}$, $C=80\mu\text{F}$, $R=40\Omega$, 230V source. (a) Resonance frequency? (b) Impedance and current amplitude at resonance? (c) rms voltage drops? Show $V_L + V_C = 0$.

$$\begin{aligned} \text{(a) } \omega_0 &= 1/\sqrt{LC} = 1/\sqrt{(5 \times 80 \times 10^{-6})} = 1/\sqrt{(4 \times 10^{-4})} = \\ &= 1/(0.02) = 50 \text{ rad/s} \end{aligned}$$

✓ Answer: (a) Resonance frequency $\omega_0 = 50 \text{ rad/s}$

(b) At resonance, $Z = R = 40 \Omega$

$$I_{\text{rms}} = V_{\text{rms}}/Z = 230/40 = 5.75 \text{ A}$$

$$I_{\text{amplitude}} = I_{\text{rms}} \times \sqrt{2} = 5.75 \times 1.414 = 8.13 \text{ A}$$

✓ Answer: (b) $Z = 40 \Omega$, $I_{\text{amplitude}} \approx 8.13 \text{ A}$

(c) rms voltage drops:

$$V_R = I_{\text{rms}} \times R = 5.75 \times 40 = 230 \text{ V}$$

$$X_L = \omega_0 L = 50 \times 5 = 250 \Omega; \quad V_L = I_{\text{rms}} \times X_L = 5.75 \times 250 = 1437.5 \text{ V}$$

$$X_C = 1/(\omega_0 C) = 1/(50 \times 80 \times 10^{-6}) = 1/0.004 = 250 \Omega; \quad V_C = 5.75 \times 250 = 1437.5 \text{ V}$$

$$V_{LC} = V_L - V_C = 1437.5 - 1437.5 = 0 \checkmark \text{ (they cancel since } X_L = X_C \text{ at resonance)}$$

✓ Answer: (c) $V_R = 230 \text{ V}$, $V_L = V_C = 1437.5 \text{ V}$, $V_L + V_C = 0 \checkmark$

💡 Note: Remarkably, even though individual voltages across L and C are huge (1437.5 V each — much larger than source 230 V!), they exactly cancel. This is why resonance can be dangerous in circuits!

Chapter 8: Electromagnetic Waves

Key Formulas: $c = 1/\sqrt{\mu_0\epsilon_0} = 3 \times 10^8 \text{ m/s}$ | $E = cB$ | $c = v\lambda$ | $i_d = \epsilon_0 \cdot d\Phi_E/dt$

💡 Note: Electromagnetic waves don't need a medium — they are self-sustaining oscillations of E and B fields, perpendicular to each other and to the direction of propagation.

8.1 Capacitor (circular plates, $r=12\text{cm}$, separation 5cm) being charged at 0.15A .
(a) Capacitance and dV/dt ? (b) Displacement current? (c) Kirchhoff's junction rule validity?

Given: Radius = 0.12 m , $d = 5 \text{ cm} = 0.05 \text{ m}$, $I = 0.15 \text{ A}$

$$(a) \ C = \epsilon_0 A/d = (8.85 \times 10^{-12} \times \pi \times 0.12^2) / 0.05$$

$$C = (8.85 \times 10^{-12} \times 4.52 \times 10^{-2}) / 0.05 = 8.0 \times 10^{-12} \text{ F} = 8.0 \text{ pF}$$

$$dV/dt = I/C = 0.15 / (8 \times 10^{-12}) = 1.875 \times 10^{10} \text{ V/s} \approx 1.9 \times 10^{10} \text{ V/s}$$

✓ Answer: (a) $C \approx 8.0 \text{ pF}$, $dV/dt \approx 1.9 \times 10^{10} \text{ V/s}$

✓ Answer: (b) Displacement current = conduction current = 0.15 A
(Kirchhoff's consistency requires this)

✓ Answer: (c) Yes, Kirchhoff's junction rule is valid. The conduction current in the wire equals the displacement current between the plates. The total current (conduction + displacement) is continuous.

💡 Note: Displacement current is a revolutionary concept by Maxwell — even though no charges actually flow between capacitor plates, there is an effective current due to changing electric flux.

8.2 Parallel plate capacitor ($R=6\text{cm}$, $C=100\text{pF}$) connected to 230V at $\omega=300 \text{ rad/s}$. (a) rms conduction current? (b) Equal to displacement current? (c) B amplitude at 3cm from axis?

$$(a) \ X_C = 1/(\omega C) = 1/(300 \times 100 \times 10^{-12}) = 1/(3 \times 10^{-8}) = 3.33 \times 10^7 \ \Omega$$

$$I_{\text{rms}} = V_{\text{rms}}/X_C = 230/(3.33 \times 10^7) = 6.9 \times 10^{-6} \text{ A} = 6.9 \ \mu\text{A}$$

✓ Answer: (a) $I_{\text{rms}} = 6.9 \ \mu\text{A}$

✓ Answer: (b) Yes, conduction current = displacement current. Maxwell's modification ensures this continuity.

(c) At $r = 3 \text{ cm} < R = 6 \text{ cm}$ (inside plates region):

$B \times 2\pi r = \mu_0 \cdot i_d \times \pi r^2 / \pi R^2$ (only fraction of displacement current enclosed)

$$B = \mu_0 \cdot I_d \cdot r / (2\pi R^2) = (4\pi \times 10^{-7} \times 6.9 \times 10^{-6} \times 0.03) / (2\pi \times 0.06^2)$$

$$B \approx 1.63 \times 10^{-11} \text{ T}$$

✓ Answer: (c) B amplitude $\approx 1.63 \times 10^{-11}$ T

8.3 What physical quantity is same for X-rays (10^{-10} m), red light (6800Å), and radiowaves (500m)?

✓ Answer: Speed in vacuum: All electromagnetic waves travel at $c = 3 \times 10^8$ m/s in vacuum, regardless of wavelength. Speed is the same for all.

💡 Note: This is a fundamental insight — all EM waves, from gamma rays to radio waves, travel at the same speed c in vacuum. Only their frequencies (and hence energies and interactions with matter) differ.

8.4 EM wave travels in vacuum along z-direction. What about E and B field directions? If frequency = 30 MHz, find wavelength.

✓ Answer: E and B must be perpendicular to each other AND to the direction of propagation (z). So E and B lie in the xy-plane. E and B are perpendicular to z, and to each other.

$$\lambda = c/f = (3 \times 10^8) / (30 \times 10^6) = 10 \text{ m}$$

✓ Answer: Wavelength $\lambda = 10$ m

8.5 Radio can tune 7.5 MHz to 12 MHz. Corresponding wavelength band?

$$\lambda_1 = c/f_1 = (3 \times 10^8) / (7.5 \times 10^6) = 40 \text{ m}$$

$$\lambda_2 = c/f_2 = (3 \times 10^8) / (12 \times 10^6) = 25 \text{ m}$$

✓ Answer: Wavelength band: 25 m to 40 m

8.6 Charged particle oscillates at 10^9 Hz. Frequency of EM waves produced?

✓ Answer: Frequency of EM waves = 10^9 Hz (1 GHz). EM waves have the same frequency as the oscillating source.

💡 Note: This is in the microwave range (GHz frequencies). This is why microwave ovens use GHz frequencies — they are produced by oscillating charges in magnetrons.

8.7 $B_0 = 510$ nT in harmonic EM wave. Electric field amplitude E_0 ?

$$E_0 = cB_0 = 3 \times 10^8 \times 510 \times 10^{-9} = 153 \text{ V/m}$$

✓ Answer: $E_0 = 153$ V/m

8.8 EM wave: $E_0 = 120$ N/C, $\nu = 50$ MHz. (a) Find B_0 , ω , k , λ . (b) Expressions for E and B.

$$B_0 = E_0/c = 120 / (3 \times 10^8) = 4 \times 10^{-7} \text{ T}$$

$$\omega = 2\pi\nu = 2\pi \times 50 \times 10^6 = 3.14 \times 10^8 \text{ rad/s}$$

$$\lambda = c/\nu = 3 \times 10^8 / (50 \times 10^6) = 6 \text{ m}$$

$$k = 2\pi/\lambda = 2\pi/6 = 1.05 \text{ rad/m}$$

✓ Answer: (a) $B_0 = 4 \times 10^{-7}$ T, $\omega = 3.14 \times 10^8$ rad/s, $k = 1.05$ rad/m, $\lambda = 6$ m

(b) If wave propagates along z-axis and E is along x-axis:

$$\mathbf{E} = 120 \sin(1.05z - 3.14 \times 10^8 t) \hat{x} \text{ N/C}$$

$$\mathbf{B} = 4 \times 10^{-7} \sin(1.05z - 3.14 \times 10^8 t) \hat{y} \text{ T}$$

✓ Answer: (b) As above (E along x, B along y, propagation along z)

8.9 Photon energy $E = h\nu$ for different parts of EM spectrum. How do energies relate to sources?

Using $h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s} = 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$:

Radio waves (MHz): $E \sim 10^{-7} \text{ eV} \rightarrow$ produced by electron oscillations in antennas

Microwaves (GHz): $E \sim 10^{-4} \text{ eV} \rightarrow$ molecular rotations

Infrared (THz): $E \sim 0.01 \text{ eV} \rightarrow$ molecular vibrations / heat

Visible (400-700 THz): $E \sim 1\text{-}3 \text{ eV} \rightarrow$ atomic electron transitions

X-rays (10^{18} Hz): $E \sim \text{keV} \rightarrow$ inner electron transitions in heavy atoms

Gamma rays (10^{21} Hz): $E \sim \text{MeV} \rightarrow$ nuclear transitions

✓ Answer: Higher frequency = higher photon energy. Gamma photons (MeV) come from nuclear transitions; visible photons (eV) from atomic transitions; radio photons (neV) from antenna oscillations.

8.10 EM wave: frequency $2 \times 10^{10} \text{ Hz}$, E amplitude 48 V/m . (a) Wavelength? (b) B amplitude? (c) Show energy densities of E and B are equal.

$$(a) \lambda = c/f = 3 \times 10^8 / (2 \times 10^{10}) = 0.015 \text{ m} = 1.5 \text{ cm}$$

✓ Answer: (a) Wavelength = 1.5 cm (microwave range)

$$(b) B_0 = E_0/c = 48 / (3 \times 10^8) = 1.6 \times 10^{-7} \text{ T}$$

✓ Answer: (b) $B_0 = 1.6 \times 10^{-7} \text{ T}$

(c) Energy density of E field: $u_E = \frac{1}{2} \epsilon_0 E^2$ (average = $\frac{1}{2} \epsilon_0 E_0^2 / 2 = \epsilon_0 E_0^2 / 4$)

Energy density of B field: $u_B = B^2 / (2\mu_0)$ (average = $B_0^2 / 4\mu_0$)

$$\frac{u_E}{u_B} = (\epsilon_0 E_0^2 / 4) / (B_0^2 / 4\mu_0) = \epsilon_0 \mu_0 (E_0 / B_0)^2 = \epsilon_0 \mu_0 \times c^2 = (1/c^2) \times c^2 = 1 \quad \checkmark$$

Since $c = 1/\sqrt{\mu_0 \epsilon_0}$, we have $\epsilon_0 \mu_0 = 1/c^2$, and $E_0/B_0 = c$. Therefore $u_E = u_B$. ✓

✓ Answer: (c) Average energy density of E field = Average energy density of B field — proved using $c = E_0/B_0$ and $c = 1/\sqrt{\mu_0 \epsilon_0}$.

— End of Solutions —