AP PHYSICS 2: ELECTROSTATICS

Comprehensive Revision & Study Guide

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Topic Revision Checklist

Use this checklist to self-assess your understanding of the core electrostatics syllabus. Aim to complete and master every topic before the scheduled mock examination.

Topic Area	Core Knowledge & Formulas	Mastered	Reviewing	Not Started
Coulomb's Law	Electrostatic force: $F_e = k_e \frac{\lvert q_1 q_2 \rvert}{r^2}$. Distinguish attractive vs. repulsive.	☑	☐	☐
Electric Fields	Field intensity of point charges: $E = k_e \frac{\lvert q \rvert}{r^2}$. Visualizing field lines.	☐	☑	☐
Superposition	Computing net field/force vectors: $\vec{E}_{net} = \sum \vec{E}_i$ using components.	☑	☐	☐
Electric Potential	Work done per unit charge: $V = k_e \frac{q}{r}$. Scalar summation of potentials.	☐	☐	☐
Equipotentials	Orthogonal mapping to field lines. Zero work done along equipotential paths.	☐	☑	☐
Capacitance	Parallel plate capacitance: $C = \kappa \varepsilon_0 \frac{A}{d}$. Stored energy: $U = \frac{1}{2} C V^2$.	☐	☐	☐

Key Concepts and Equations

Electrostatics is the study of charges at rest and forms the foundation of classical electromagnetism. Below is a summary of the core concepts, models, and equations required for the revision cycle.

Superposition Principle

The net electric field at any point is the vector sum of the fields produced by each individual charge:

$$\vec{E}_{net} = \sum_i \vec{E}_i = \sum_i k_e \frac{q_i}{r_i^2} \hat{r}_i$$

Warning: Potential V is a scalar and adds algebraically. Forces and fields are vectors; they must be resolved into components before summing.

Potential & Energy

Potential V from a point charge:

$$V = k_e \frac{q}{r}$$

Potential energy change ΔU for a moved charge q_0:

$$\Delta U = q_0 \Delta V$$

Work done by the conservative electric field:

$$W_{field} = -q_0 \Delta V$$

In a uniform electric field:

$$\Delta V = -E \Delta x$$

Properties of Conductors in Electrostatic Equilibrium

When a conductor is in electrostatic equilibrium, it exhibits the following characteristics:

- The electric field inside the conductor is zero everywhere.
- Any excess charge resides entirely on the outer surface of the conductor.
- The electric field just outside the conductor is perpendicular to its surface.
- The entire conductor is at a constant electric potential; its surface is an equipotential.

Worked Examples

Solve quantitative problems systematically: sketch the charge configuration, identify vector directions, state your algebraic formulas, and perform calculations with correct scientific notation.

Worked Example: Finding the Point of Zero Electric Field

Problem: Two point charges, $q_1 = +4.0\ \mu$C and $q_2 = -16.0\ \mu$C, are placed on the x-axis at $x = 0$ and $x = 2.0$ m, respectively. Find the coordinate on the x-axis where the net electric field is zero.

Solution: Let E_1 and E_2 be the magnitudes of the electric fields from q_1 and q_2. For the fields to cancel ($\vec{E}_1 + \vec{E}_2 = 0$), they must point in opposite directions and have equal magnitudes:

1. **Identify the Region:**
   - Between the charges ($0 < x < 2.0$ m), $\vec{E}_1$ (away from $+q_1$) points $+x$, and $\vec{E}_2$ (toward $-q_2$) also points $+x$. They cannot cancel.
   - To the right of q_2 ($x > 2.0$ m), $\vec{E}_2$ is always larger than $\vec{E}_1$ because q_2 has a larger charge magnitude and is closer. No cancelation is possible.
   - To the left of q_1 ($x < 0$), the fields point in opposite directions. Since the smaller charge q_1 is closer, the fields can cancel.
2. **Set up the Equation:** Let d be the distance to the left of q_1 (coordinate $x = -d$, with $d > 0$).

$$k_e \frac{|q_1|}{d^2} = k_e \frac{|q_2|}{(2.0 + d)^2}$$

3. **Solve for d:** Divide by k_e and take the square root of both sides:

$$\frac{\sqrt{|q_1|}}{d} = \frac{\sqrt{|q_2|}}{2.0 + d} \implies \frac{\sqrt{4.0}}{d} = \frac{\sqrt{16.0}}{2.0 + d} \implies \frac{2}{d} = \frac{4}{2.0 + d}$$

$$2(2.0 + d) = 4d \implies 4.0 + 2d = 4d \implies 2d = 4.0 \implies d = 2.0 \text{ m}$$

The coordinate where the field is zero is $x = -2.0$ m.

Worked Example: Parallel-Plate Capacitor with Dielectric

Problem: A parallel-plate capacitor with plate area $A = 5.0 \times 10^{-2}$ m^2 and plate separation $d = 1.0$ mm is connected to a 15.0 V battery. A sheet of dielectric material ($\kappa = 4.0$) is inserted, filling the gap. Calculate the new capacitance and the electrical energy stored in the capacitor.

Solution:

1. **Calculate the Capacitance (C):** Use $\varepsilon_0 = 8.85 \times 10^{-12}$ C$^2/(\text{N} \cdot \text{m}^2)$ and $\kappa = 4.0$:

$$C = \kappa\varepsilon_0 \frac{A}{d} = 4.0 \times \left(8.85 \times 10^{-12}\right) \frac{5.0 \times 10^{-2}}{1.0 \times 10^{-3}}$$

$$C = 1.77 \times 10^{-9}\ \text{F} = 1.77\ \text{nF}$$

2. **Calculate the Stored Energy (U):** Since the battery remains connected, the voltage remains constant at $V = 15.0$ V:

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\left(1.77 \times 10^{-9}\ \text{F}\right)\left(15.0\ \text{V}\right)^2$$

$$U = \frac{1}{2}\left(1.77 \times 10^{-9}\right)(225.0) = 1.99 \times 10^{-7}\ \text{J} \approx 0.20\ \mu\text{J}$$

The new capacitance is 1.77 nF, and the stored energy is 0.20 μJ.

Self-Test Questions

Test your knowledge with these representative problems. Answer all questions independently before reviewing the solutions in the answer key below.

Questions

Q1. A point charge $q_1 = +5.0$ nC is located at the origin. A second point charge $q_2 = -3.0$ nC is located on the y-axis at $y = 0.30$ m.

(a) Compute the magnitude of the electrostatic force between the two charges.

(b) State whether this force is attractive or repulsive.

Q2. A capacitor with capacitance C_0 is fully charged by a battery to a potential difference V_0. The capacitor is then disconnected from the battery. If the plate separation d is subsequently doubled, determine what happens to:

(a) The charge Q on the plates.

(b) The capacitance C.

(c) The potential difference V between the plates.

Q3. A uniform electric field of magnitude $E = 3.0 \times 10^3$ V/m points in the $+x$ direction. A test charge $q = +2.0\ \mu$C is moved from $x = 0.20$ m to $x = 0.80$ m along a straight path.

(a) Find the potential difference $\Delta V = V_f - V_i$.

(b) Calculate the work done on the charge by the electric field.

Answer Key & Detailed Solutions

- **A1:**
  1. Apply Coulomb's Law:
  $$F_e = k_e \frac{|q_1 q_2|}{r^2} = (8.99 \times 10^9)\frac{(5.0 \times 10^{-9})(3.0 \times 10^{-9})}{(0.30)^2}$$
  $$F_e = (8.99 \times 10^9)\frac{1.5 \times 10^{-17}}{0.09} = 1.50 \times 10^{-6}\ \text{N}$$
  2. The force is **attractive** because the charges are of opposite signs.
- **A2:**
  1. The charge remains constant ($Q' = Q_0$) because the capacitor is disconnected; there is no pathway for charge to leave.
  2. Capacitance is $C = \varepsilon_0 \frac{A}{d}$. Doubling d halves the capacitance ($C' = \frac{1}{2}C_0$).
  3. Potential difference is $V = \frac{Q}{C}$. Since Q is constant and C is halved, the potential difference doubles ($V' = 2V_0$).
- **A3:**
  1. In a uniform field, $\Delta V = -E\Delta x = -(3.0 \times 10^3\ \text{V/m})(0.80 - 0.20\ \text{m}) = -1800$ V.
  2. The work done by the field is:
  $$W_{field} = -q\Delta V = -(2.0 \times 10^{-6}\ \text{C})(-1800\ \text{V}) = +3.6 \times 10^{-3}\ \text{J} = 3.6\ \text{mJ}$$

References

[1] Meridian Academic Board. *AP Physics Course Preparation Guide*. Meridian Academic Press, 2025.

[2] Arthur Jenkins and Elena Rostova. *Fundamentals of Electrostatics and Electromagnetism*. Apex Publishing, 2nd edition, 2022.