

ELECTRIC FIELDS — LESSON PLAN

Speaker Notes | AP/IB Physics | 45–50 minutes

Slide 1: Electric Field

Learning Objectives

- Define the electric field and explain its physical meaning as force per unit positive test charge.
- Apply Coulomb's Law to calculate the electric force between point charges.
- Describe and sketch electric field lines for positive and negative charges.
- Apply the superposition principle to find the net electric field from multiple charges.
- Solve problems involving electric fields at specific points due to charge configurations.

Opening (~2 min):

Welcome students and frame the lesson: 'Today we move beyond forces between individual charges to a powerful idea — the electric field. Instead of asking what force one charge exerts on another, we ask: what does a charge do to the space around it?'

Remind students of prior knowledge: Coulomb's Law ($F = kQq/r^2$), the concept of action at a distance, and the sign conventions for charge.

Slide 2: Source Charge and Test Charge

Introducing the Setup (~3 min):

Present the scenario: a source charge Q and a small test charge q placed nearby.

Key talking points:

- Explain that Q is our 'source' — the charge creating the field — and q is a small positive 'test charge' we use to probe the field.
- By Coulomb's Law, Q exerts a force on q : $F = kQq/r^2$, directed along the line joining them.
- If both charges are positive, the force on q is repulsive — directed away from Q .
- Emphasize that the test charge must be small enough not to disturb Q 's field (this is a key AP/IB concept).

Ask students: 'What determines the magnitude and direction of this force?' (Answer: the distance r and the signs of the charges.)

Transition: 'Let's see what happens when we move q to different locations around Q .'

Slide 3: Exploring Different Positions

Exploring Different Positions (~2 min):

Now move the test charge q to a different location relative to Q .

Key talking points:

- The force on q changes depending on where we place it — both in magnitude and direction.
- By Coulomb's Law, $F = kQq/r^2$, the force depends on the separation distance r .
- The direction of the force is always along the line connecting the two charges.

- Ask students: "If Q is positive, which way does q get pushed?" (Answer: directly away from Q , since like charges repel.)

Slide 4: Inverse-Square Relationship

Varying Distance — Inverse Square Relationship (~2 min):

Continue placing q at different distances from Q to build intuition for the inverse-square law.

Key talking points:

- When you double the distance r , the force drops to $1/4$ of its original value (inverse square).
- When you halve the distance, the force quadruples.
- This $1/r^2$ dependence is critical — it shows up on nearly every AP/IB exam.

Quick check: 'If the force at distance d is F , what is the force at distance $3d$?' (Answer: $F/9$.)

Draw a quick table on the board: $r, 2r, 3r \rightarrow F, F/4, F/9$ to make the pattern visual.

Transition: 'We keep talking about the force on q — but what if we want to describe what Q does to space itself, independent of the test charge?'

Slide 5: Building the Field Concept

Building Toward the Field Concept (~2 min):

This is the pivotal conceptual transition — from force between two charges to the field created by one charge.

Key talking points:

- So far, we've been calculating force, which depends on BOTH charges (Q and q).
- But notice: if we divide the force by q , we get $F/q = kQ/r^2$, which depends only on Q and the position.
- This ratio F/q is the same no matter what test charge we use — it's a property of the space around Q .
- This is the electric field: it tells us what WOULD happen to any charge placed at that point.

Analogy: 'Think of the electric field like a weather map showing wind patterns. The wind exists whether or not you put a flag in it — but the flag reveals the wind's direction and strength.'

Ask students: 'Why do we divide by q instead of Q ?' (Because we want a quantity that describes Q 's influence on space, independent of the probe.)

Slide 6: Formalizing the Concept

Formalizing the Concept (~2 min):

Wrap up the conceptual buildup before moving to the formal definition.

Key talking points:

- We've now seen that placing a test charge at various points around Q reveals a pattern.
- At every point, there's a force waiting to act on any charge placed there.
- The electric field $E = F/q$ gives us a complete map of this influence.
- E is a vector field — it has a value (magnitude and direction) at every point in space.

Important AP/IB distinction: The field EXISTS at a point even if no test charge is present. The test charge is just a thought experiment to define and measure the field.

Transition: 'Let's now write down the formal definition and its units.'

Slide 7: Electric Field Definition

Formal Definition — Electric Field (Positive Source) (~4 min):

This is the core definition slide. Slow down and be precise.

State the definition clearly: 'The electric field at a point is defined as the electrostatic force acting per unit positive charge placed at that point: $E = F/q$.'

Key talking points:

- For a point charge Q : $E = kQ/r^2$, where r is the distance from Q to the field point P .
- Units: Newtons per Coulomb (N/C), which is equivalent to Volts per meter (V/m) — both appear on AP/IB exams.
- Direction: For a positive source charge Q , the field points AWAY from Q (radially outward).
- The field is defined using a positive test charge by convention — this sets the direction.

Work through a quick example: 'Find E at a point 0.3 m from a $+2\ \mu\text{C}$ charge.' ($E = 9 \times 10^9 \times 2 \times 10^{-6} / 0.09 = 2 \times 10^5$ N/C, directed away from Q .)

Pause for questions before moving to negative charges.

Slide 8: Electric Field Due to a Negative Charge

Electric Field Due to a Negative Charge (~3 min):

Now contrast with the field from a negative source charge.

Key talking points:

- For a negative charge $-Q$, the force on a positive test charge is attractive — directed TOWARD $-Q$.
- Therefore, E points TOWARD a negative source charge (radially inward).
- The magnitude formula is the same: $E = k|Q|/r^2$. Only the direction changes.
- This is a common source of sign errors on exams — emphasize direction carefully.

Comparison: Draw two diagrams side by side on the board — E vectors radiating outward from $+Q$, and inward toward $-Q$.

Quick conceptual check: 'A $-5\ \mu\text{C}$ charge is at the origin. What is the direction of E at a point to the right of the charge?' (Answer: to the LEFT, toward the negative charge.)

Transition: 'We can visualize these field directions using electric field lines.'

Slide 9: Electric Field Lines

Electric Field Lines (~5 min):

This is a visual and conceptual slide — take time to let students study the diagrams.

Key rules to emphasize (all are testable on AP/IB):

- Field lines originate on positive charges and terminate on negative charges.
- The density of lines (how close together they are) indicates field strength — closer lines mean stronger field.
- Field lines NEVER cross — if they did, the field would have two directions at one point, which is physically impossible.
- The direction of the field at any point is tangent to the field line at that point.

Walk through the diagrams:

- Positive charge: lines radiate outward symmetrically, like a starburst.
- Negative charge: lines converge inward, like arrows pointing at the center.

Common exam question: 'Where is the field strongest in this diagram?' → Where lines are closest together (near the charge).

Optional: If using PhET, show the simulation now to let students see field lines form dynamically around placed charges.

Transition: 'Now let's think more deeply about what the field does to the space around a charge.'

Slide 10: Discussion on Electric Field

Discussion: What Happens to Space Around a Charge? (~5 min):

This is an interactive discussion slide. Pose the question and let students think before guiding them.

Key talking points:

- A charge modifies the space around it — it creates an electric field that extends in all directions.
- Any other charge entering this region will experience a force, even though the charges don't touch.
- This is the field model of interaction: Charge → Field → Force on another charge.
- The field is real — it carries energy and can do work. It's not just a mathematical convenience.

Facilitate discussion:

- Ask: 'How is the electric field different from the gravitational field you studied earlier?' (Both are inverse-square, but electric fields can attract OR repel; gravity only attracts.)
- Ask: 'Does the field exist at a point where no charge is present?' (Yes! The field exists everywhere around Q.)
- Connect to the diagram: the field at point P depends on the source charge Q and the distance r.

This is a good moment to check for understanding before moving to superposition.

Slide 11: Superposition Principle of Fields

Superposition Principle (~5 min):

Introduce the key principle for handling multiple charges — essential for AP/IB problem-solving.

State the principle: 'The net electric field at any point is the vector sum of the individual electric fields produced by each source charge.'

Key talking points:

- $E_{\text{net}} = E_1 + E_2 + E_3 + \dots$ (vector addition, NOT scalar!)
- Each charge contributes independently — the field from q_1 is unaffected by the presence of q_2 .
- You must consider both magnitude AND direction when adding fields.
- Opposite charges create fields that may partially cancel; same-sign charges create fields that may reinforce.

Walk through the diagram: Show how E vectors from multiple charges (q_1 , q_2 , $-q_3$, ... $-q_n$) are added at point P.

Problem-solving strategy (write on board):

1. Identify all source charges and the field point P.

2. Calculate E from each charge separately (magnitude and direction).

3. Resolve into x and y components.

4. Add components: $E_x(\text{net}) = \Sigma E_x$, $E_y(\text{net}) = \Sigma E_y$.

5. Find magnitude and direction of E_{net} .

Transition: 'Let's apply this to a concrete problem.'

Slide 12: Charges on a Square

Problem Setup: Charges on a Square (~3 min):

Read the problem aloud and let students draw their own diagrams before revealing the solution.

Problem: Two equal charges $+2q$ are placed at opposite corners (A and B) of a square of side a . A third charge $-q$ is placed at the third corner (C). Find the electric field at the fourth corner (P).

Guide the setup:

- Label the corners: A (top-left), B (bottom-right) have charge $+2q$; C (bottom-left) has charge $-q$; P (top-right) is the field point.
- Identify the distances: A to P = a (horizontal), C to P = a (vertical), B to P = $a\sqrt{2}$ (diagonal).
- Each charge contributes a field at P — we need to find all three and add them as vectors.

Ask students: 'Which direction does the field from charge A point at P?' (Away from A, so to the right.)

'Which direction does the field from charge C point at P?' (Toward C, so downward — because C is negative.)

'What about charge B?' (Away from B, along the diagonal toward P — at 45° above horizontal.)

Give students 2 minutes to attempt the calculation before proceeding.

Slide 13: Solution Part 1

Solution Part 1 — Individual Field Contributions (~4 min):

Walk through each field contribution step by step.

Field from A ($+2q$) at P:

- Distance: a
- Magnitude: $E_A = k(2q)/a^2 = 2kq/a^2$
- Direction: to the right ($+x$ direction), since $+2q$ repels the positive test charge at P.

Field from C ($-q$) at P:

- Distance: a
- Magnitude: $E_C = kq/a^2$
- Direction: downward ($-y$ direction), toward C, since $-q$ attracts the positive test charge.

Field from B ($+2q$) at P:

- Distance: $a\sqrt{2}$ (diagonal of the square)
- Magnitude: $E_B = k(2q)/(a\sqrt{2})^2 = k(2q)/(2a^2) = kq/a^2$
- Direction: along the diagonal from B toward P. Resolve into components:

$$E_{Bx} = E_B \cos 45^\circ = (kq/a^2)(1/\sqrt{2})$$

$$E_{By} = E_B \sin 45^\circ = (kq/a^2)(1/\sqrt{2})$$

Pause and verify: 'Does everyone see why E_B has both x and y components?'

Slide 14: Solution Part 2

Solution Part 2 — Vector Sum and Final Answer (~4 min):

Now add all the components to find E_{net} at P.

x-components:

- $E_x = E_A + E_{Bx} = 2kq/a^2 + (kq/a^2)(1/\sqrt{2}) = (kq/a^2)(2 + 1/\sqrt{2})$

y-components:

- $E_y = -E_C + E_{By} = -kq/a^2 + (kq/a^2)(1/\sqrt{2}) = (kq/a^2)(-1 + 1/\sqrt{2})$

Magnitude: $E_{net} = \sqrt{E_x^2 + E_y^2}$

Direction: $\phi = \tan^{-1}(E_y / E_x)$, measured from the +x axis.

Key takeaways for students:

- Superposition requires careful vector decomposition — don't just add magnitudes!
- The diagonal distance $a\sqrt{2}$ is a common geometry in square configurations.
- Signs matter: negative charges reverse the field direction (toward the charge).

Closing (~2 min):

Summarize the lesson: 'Today we defined the electric field as $E = F/q$, learned to visualize it with field lines, and applied superposition to find the net field from multiple charges.'

Homework: Assign practice problems on electric field calculations and field line sketching from the textbook. Recommend reviewing Coulomb's Law vector problems.

Preview next lesson: 'Next time, we'll explore electric field due to continuous charge distributions and introduce Gauss's Law.'