

Electric Charge, Field Lines & Electric Flux

Lesson Overview

Topic: electric field lines, and electric flux.

Learning Objectives — By the end of this lesson students will be able to:

- Describe what electric field lines represent and who introduced them.
- Draw and interpret field line patterns for single charges, like charges, and unlike charges.
- List and apply the key properties of electric field lines.
- Define electric flux and calculate it for perpendicular, angled, and general cases.

Materials Needed:

Balloons, small paper bits, cardboard/textbooks (for area-vector demo), whiteboard markers, mini whiteboards, True/False cards, printed exit tickets.

Lesson Flow (approximate):

Slide(s)	Time	Content
Slides 1–2	5 min	Hook and introduction to field lines from a point charge
Slide 3	5 min	Formal definition of electric field lines (Faraday)
Slides 4–5	14 min	Field patterns for charge pairs and properties of field lines
Slide 6	5 min	Introduction to electric flux and its importance
Slide 7	5 min	Area vectors and effective area concept
Slides 8–9	10 min	Calculating flux: perpendicular and angled cases
Slide 10	5 min	Summary with rain analogy and all three formulas
Slide 11	5 min	General case (integration), exit ticket, and homework

Warm-Up / Hook

Rub a balloon on hair or wool, hold it near small paper bits.

Ask: "What invisible force is at work here?"

Let students share observations to activate prior knowledge about static electricity.

Introduce today's goal: we will learn to visualise and measure the invisible force fields around charges.

Section 1: Field Lines from a Point Charge

Slide 2 of 11 | continued from hook

SAY / DO

Point to the +Q diagram. Explain that field lines radiate outward from a positive charge in all directions.

Emphasise: the density of lines shows field strength — closer to the charge means stronger field.

Arrows show the direction a tiny positive test charge would move if placed in the field.

****THINK-PAIR-SHARE (1 min)****

Ask: "Imagine placing a tiny positive test charge near $+Q$. Which way does it move? Does it accelerate more when close or far from $+Q$?"

Students discuss in pairs, then share out.

****MISCONCEPTION ALERT****

Students often believe field lines are real physical things. Stress that they are a visualisation tool — an imaginary map of the field.

****QUICK CHECK****

If we replaced $+Q$ with $-Q$, which way would the arrows point? (Inward, toward the negative charge.)

Section 2: Defining Electric Field Lines

Slide 3 of 11 | 5 min

****SAY / DO****

Read the definition aloud: imaginary curves showing the direction and relative strength of the electric field.

Highlight that a free positive test charge placed in the field would follow these curves.

Credit Michael Faraday for inventing the concept to make the invisible visible.

****GUIDED NOTE-TAKING****

Have students write the definition in their own words in notebooks.

Prompt: "Why do scientists build models like field lines rather than relying only on equations?"

(Models help us visualise, predict, and communicate.)

****DIFFERENTIATION****

For struggling learners: compare field lines to wind-direction arrows on a weather map — you can't see the wind, but the arrows show where it blows and how strong it is.

Section 3A: Field Patterns Between Charge Pairs

Slide 4 of 11 | 7 min

****SAY / DO****

Walk through the three diagrams:

- Like charges ($++$): lines curve away from each other; a neutral point exists between them.
- Like charges ($--$): same repelling pattern, arrows reversed (pointing inward at each charge).
- Unlike charges ($+-$): lines flow from positive to negative in smooth arcs — a dipole pattern.

****ACTIVITY — SKETCH & COMPARE (5 min)****

Split class into 3 groups. Group 1 draws $++$, Group 2 draws $--$, Group 3 draws $+-$.

Each group presents and explains. Compare sketches with the slide diagrams.

****DISCUSSION PROMPT****

"What do you notice about the space directly between two like charges? Why are there no field lines through that point?"

(The fields cancel — net $E = 0$ at the midpoint for equal like charges.)

****REAL-WORLD CONNECTION****

The + – dipole pattern underlies radio antennas, polar molecules like water, and many biological processes.

Section 3B: Properties of Electric Field Lines

Slide 5 of 11 | 7 min

****SAY / DO — walk through each property on the slide:****

1. Originate from positive charges, terminate at negative charges.
2. Continuous, smooth curves — no sharp corners.
3. Perpendicular to the charged surface at start and end.
4. Tangent at any point = direction of the E field there.
5. Two field lines NEVER cross (E can only have one direction at a point).
6. Denser lines = stronger field.

****ACTIVITY — MYTH OR FACT? (3 min)****

Read each statement; students hold up True / False cards:

- "Field lines can form closed loops." [FALSE in electrostatics]
- "If two lines crossed, the field would have two directions at one point." [TRUE — that's why crossing is impossible]
- "Closely spaced lines mean a weak field." [FALSE — closely spaced = strong]

****COMMON MISCONCEPTION****

Students may think lines can cross when two sources are present. Reinforce: two directions at one point is physically impossible.

****TRANSITION****

We have mastered field lines. Next question: how much field passes through a surface? This idea is called electric flux.

Section 4: Introducing Electric Flux

Slide 6 of 11 | 5 min

****SAY / DO****

Define flux: a measure of how much electric field passes through a surface.

Explain why it matters: flux is the foundation of Gauss's Law — one of Maxwell's four master equations of electromagnetism.

Gauss's Law lets us find E fields for symmetric charge distributions without complex integration.

****ANALOGY — HULA HOOP IN THE RAIN****

"Imagine holding a hula hoop in a rainstorm. How much rain passes through depends on how you angle it."

Electric flux works the same way — it measures how much electric field flows through a given surface.

****ENGAGEMENT****

Ask students to hold a notebook flat, then tilt it.

"If this notebook were in an electric field, which position lets more field lines through?"

This sets up the angle dependence we explore next.

Section 5: The Area Vector Concept

Slide 7 of 11 | 5 min

****SAY / DO****

Every flat surface has an area vector (normal) pointing perpendicular to it.

Its magnitude equals the surface area.

The angle between the field direction and the area vector determines effective flux.

****HANDS-ON DEMO (use cardboard or textbooks)****

1. Hold flat, facing you (the "field source") — area vector aimed at you — MAXIMUM flux.

2. Tilt 45° — area vector angled away — LESS flux.

3. Turn edge-on — area vector perpendicular to field — ZERO flux.

****KEY EMPHASIS****

It's not total area that matters — it's effective area, which depends on $\cos(\theta)$.

****QUICK CHECK****

"If I double the surface area but turn it edge-on, what happens to flux?" (Zero — $\cos 90^\circ = 0$.)

Section 6A: Flux When the Field Is Perpendicular to the Surface

Slide 8 of 11 | 5 min

****SAY / DO****

When E is perpendicular to the surface, ALL field lines pass through — this is maximum flux.

Formula: $\phi = E \times A$ (simple multiplication, $\theta = 0$ so $\cos 0 = 1$).

****WORKED EXAMPLE (board)****

$E = 500 \text{ N/C}$, square surface side = 0.2 m.

$$A = 0.2 \times 0.2 = 0.04 \text{ m}^2$$

$$\phi = 500 \times 0.04 = \textbf{20 N}\cdot\textbf{m}^2\textbf{/C}$$

GUIDED PRACTICE (1 min)

$E = 300 \text{ N/C}$, rectangle $0.1 \text{ m} \times 0.5 \text{ m}$, field perpendicular.

Answer: $\phi = 300 \times 0.05 = \textbf{15 N}\cdot\textbf{m}^2\textbf{/C}$

SCAFFOLDING TIP

"Perpendicular to the surface" means E is PARALLEL to the area vector — both point the same way — so $\theta = 0^\circ$.

Section 6B: Flux When the Field Is at an Angle

Slide 9 of 11 | 5 min

SAY / DO

When the surface is tilted, only the perpendicular component of area contributes.

Formula: $\phi = EA \cos(\theta)$, where θ = angle between E and the outward normal.

At $\theta = 0^\circ$: $\phi = EA$ (maximum, matches Case 1). At $\theta = 90^\circ$: $\phi = 0$ (edge-on).

WORKED EXAMPLE

$$E = 400 \text{ N/C}, A = 0.05 \text{ m}^2, \theta = 60^\circ.$$

$$\phi = 400 \times 0.05 \times \cos(60^\circ) = 400 \times 0.05 \times 0.5 = \textbf{10 N}\cdot\textbf{m}^2\textbf{/C}$$

STUDENT PRACTICE (2 min)

$$E = 600 \text{ N/C}, A = 0.03 \text{ m}^2, \theta = 30^\circ.$$

Answer: $\phi = 600 \times 0.03 \times \cos(30^\circ) \approx \textbf{15.6 N}\cdot\textbf{m}^2\textbf{/C}$

CONCEPTUAL CHECK

"As you tilt from 0° to 90° , does flux increase or decrease?" (Decreases — fewer lines pass through.)

CALLBACK

"Remember tilting your notebook? Now you have the maths to calculate exactly how much flux changes."

Section 7: Flux Summary and Rain Analogy

Slide 10 of 11 | 5 min

SAY / DO

Reinforce the rain-through-a-window analogy:

- Window flat = max rain = $\phi = EA$.

- Window tilted = less rain = $\phi = EA \cos(\theta)$.

- Window edge-on = no rain = $\phi = 0$.

FORMULA RECAP

1. Perpendicular, uniform field: $\phi = EA$

2. At angle θ , uniform field: $\phi = EA \cos(\theta)$

3. General (non-uniform / curved): $\phi = \int \vec{E} \cdot d\vec{A}$

SI unit: $\text{N}\cdot\text{m}^2/\text{C}$ (or $\text{V}\cdot\text{m}$). Flux is a scalar.

WHITEBOARD ACTIVITY (3 min)

Students draw the rain analogy on mini whiteboards — three sketches (flat, tilted, edge-on) with matching formula beneath each. Share and compare.

EXIT TICKET PREVIEW

"Write one sentence explaining electric flux to a friend who has never studied physics. Must include the word 'surface'."

DIFFERENTIATION

For advanced students: hint that flux through a closed surface relates to the charge enclosed — a preview of Gauss's Law.

Section 8: General Case and Lesson Wrap-Up

Slide 11 of 11 | 5 min

SAY / DO

When E varies across the surface or the surface is curved, simple multiplication fails.

We break the surface into thousands of tiny flat tiles (dA), calculate flux through each, and sum — that sum is the integral.

General formula: $\phi = \int \vec{E} \cdot d\vec{A}$ (most powerful form).

BOARD RECAP — ALL THREE CASES

- Case 1: Perpendicular, uniform $\rightarrow \phi = EA$

- Case 2: Angled, uniform $\rightarrow \phi = EA \cos(\theta)$

- Case 3: General $\rightarrow \phi = \int \vec{E} \cdot d\vec{A}$

EXIT TICKET (3 min)

1. Draw field lines for two positive charges near each other.

2. $E = 200 \text{ N/C}$ through a 0.1 m^2 surface at 45° — calculate the flux.

3. In one sentence, explain why integration is needed for curved surfaces.

HOMEWORK

5 practice problems mixing all three flux cases + 1 conceptual question on field line properties.

LESSON REFLECTION (for the teacher)

Did the balloon hook engage students? Could they connect the rain analogy to the maths?

Did the notebook/cardboard demo help them grasp area vectors? Where did pacing feel rushed?

Adjust timing for next delivery based on where students struggled most.