Unit 20 · Electric Field

ANSWER KEY · FOR TEACHERS

Full marks 37

Give the marks for the points in the marking scheme; an answer in other words that says the same is right.

1 Key words

1. field
2. test charge
3. field strength
4. meter
5. uniform
6. radial
7. flux
8. Gaussian surface

Each carries 0.5 mark. **K · 4**

2 Label the diagram

1. A⊥
2. $\Phi = EA\cos\theta$
3. normal
4. θ

Each carries 0.5 mark. **U · 2**

3 Multiple choice

i. **c.** meet the surface of a conductor at 90° **K · 1**

Lines start on + and end on −, never cross, and meet a conductor at right angles; they give the direction of the force, not the path.

ii. **c.** 2.0×10^4 V/m **A · 1**

$E = V/d = 500 \div 0.025 = 2.0 \times 10^4$ V/m.

iii. **c.** a parabola **U · 1**

A constant force across the plates and a constant speed along them give $y \propto x^2$, a parabola (like a ball thrown sideways).

iv. **b.** 1.0×10^3 N/C **A · 1**

$E \propto 1/r^2$: twice as far, a quarter as strong.

v. **a.** zero, though there is a field at the surface **U · 1**

Gauss's law counts only the net charge inside: $+3 - 3 = 0$, so the net flux is zero. The field on the surface isn't zero; as much flux goes in as comes out.

4 Very short answers

a. **MARKING SCHEME** **K · 1**

✓ $\Phi = q/\varepsilon_0$, q the net charge inside the closed surface.

b. **MARKING SCHEME** **U · 1**

✓ The field (force on a test charge) at a point has only one direction.

c. **MARKING SCHEME** **K · 1**

✓ N m^2/C (or V m).

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5 Short answers

a. MARKING SCHEME U · 2

- ✓ 1 V = 1 J/C = 1 N m/C.
- ✓ So 1 V/m = 1 N m/(C m) = 1 N/C.

b. MARKING SCHEME U · 2

- ✓ Its weight (about 9×10^{-30} N) is tiny next to the electric force eE (for example about 10^{-16} N in a lab field).
- ✓ The electric force is about 10^{14} times larger, so gravity makes no measurable difference.

c. MARKING SCHEME U · 2

- ✓ A point charge's lines spread out in three dimensions, over a sphere's area $4\pi r^2$: $E \propto 1/r^2$.
- ✓ A line's lines spread only round the line, over a cylinder's area $2\pi rl$: $E \propto 1/r$.

6 Long answer

ANSWER U · 4

By symmetry, the field of a positive sheet points straight away from it on both sides, the same size at equal distances. Choose as Gaussian surface a short cylinder through the sheet, its two flat ends, each of area A, parallel to it. The field runs along the curved side (no flux) and crosses each end at right angles: flux EA through each, 2EA in all. The charge enclosed is σA. Gauss's law: $2EA = \sigma A/\varepsilon_0$, so $E = \sigma/(2\varepsilon_0)$. The distance doesn't appear: the field is the same at every distance, a uniform field.

MARKING SCHEME

- ✓ Symmetry: the field is perpendicular to the sheet, equal on both sides; a cylinder through the sheet chosen as the Gaussian surface.
- ✓ Flux: zero through the curved side, EA through each end, 2EA in all.
- ✓ Charge enclosed σA; $2EA = \sigma A/\varepsilon_0$ gives $E = \sigma/(2\varepsilon_0)$.
- ✓ E doesn't depend on the distance: a uniform field.

7 Numerical problems

a. ANSWER A · 3

$E = F/q = 6.0 \times 10^{-4} \div 3.0 \times 10^{-9} =$ **2.0×10^5 N/C**, away from the sphere.
$E = kQ/r^2$, so $Q = Er^2/k = 2.0 \times 10^5 \times 0.30^2 \div 9.0 \times 10^9 =$ **$+2.0 \times 10^{-6}$ C** (positive, since the push is outwards).

MARKING SCHEME

- ✓ $E = F/q = 2.0 \times 10^5$ N/C.
- ✓ $Q = Er^2/k$.
- ✓ Q = +2.0 μC.

b. ANSWER A · 4

i. $E = V/d = 50 \div 0.010 =$ **5.0×10^3 V/m**.

ii. $y = eEL^2/(2mv^2) = 1.6 \times 10^{-19} \times 5.0 \times 10^3 \times 0.040^2 \div (2 \times 9.11 \times 10^{-31} \times (3.0 \times 10^7)^2) = 1.28 \times 10^{-18} \div 1.64 \times 10^{-15} =$ **7.8×10^{-4} m** (0.78 mm), towards the **positive** plate.

MARKING SCHEME

- ✓ $E = 5.0 \times 10^3$ V/m.
- ✓ $y = eEL^2/(2mv^2)$ with values put in.
- ✓ y = 0.78 mm.
- ✓ Towards the positive plate.

c. ANSWER A · 3

i. $\Phi = EA \cos\theta = 400 \times (0.30 \times 0.20) \times \cos 30^\circ =$ **20.8 N m²/C**.

ii. $q = \varepsilon_0\Phi = 8.85 \times 10^{-12} \times 2.26 \times 10^5 =$ **2.0×10^{-6} C**.

MARKING SCHEME

- ✓ $\Phi = EA \cos\theta$ with $A = 0.060$ m².
- ✓ $\Phi = 20.8$ N m²/C.
- ✓ $q = \varepsilon_0\Phi = 2.0$ μC.

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8 Think

ANSWER HA · 3

The car's metal body is a conductor. Charge on a conductor moves until there is no field inside the metal, and the charge stays on the outside surface; a closed metal shell keeps the field out of the space it encloses. So the lightning's current flows over the outside of the car to the ground, not through the people inside. A plastic body is an insulator: charges don't move freely in it, so it gives no such shield.

MARKING SCHEME

- ✓ In a conductor, charges move until the field inside is zero; the charge stays on the outer surface.
- ✓ The current flows round the outside of the metal body to the ground, leaving the inside free of field.
- ✓ A plastic (insulating) body gives no such protection.

9 Activity: Seeing a field's shape

(not marked)

WHAT STUDENTS SHOULD FIND

The grains line up along the field lines: straight out from a single point (radial), curving from one point to the other for opposite charges (the dipole pattern), and parallel, evenly spaced lines between the strips (a uniform field), curving out at their edges. The grains crowd nearest the points, where the field is strongest.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	7	15	12	3	**37**

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