Unit 20 · Electric Field

HARDER PRACTICE QUESTIONS · ANSWER KEY

Full marks 31

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

1 Spot the error

ANSWER U · 3

$1/r^2$ is for a point charge. For a long line of charge, Gauss's law gives $E = \lambda/(2\pi\varepsilon_0 r)$, so $E \propto \mathbf{1/r}$: three times as far, a third as strong, $E = 6.0 \times 10^4 \div 3 = \mathbf{2.0 \times 10^4\ N/C}$.

MARKING SCHEME

- ✓ The error: a line of charge gives $E \propto 1/r$, not $1/r^2$.
- ✓ $E = \lambda/(2\pi\varepsilon_0 r)$ named (or the cylinder's area $2\pi rl$).
- ✓ $E = 2.0 \times 10^4$ N/C.

2 Work backwards

ANSWER A · 3

$E = V/d = 60 \div 0.015 = 4.0 \times 10^3$ V/m. From $y = eEL^2/(2mv^2)$: $v = \sqrt{(eEL^2/(2my))} = \sqrt{(1.6 \times 10^{-19} \times 4.0 \times 10^3 \times 0.030^2 \div (2 \times 9.11 \times 10^{-31} \times 1.5 \times 10^{-3}))} = \mathbf{1.5 \times 10^7\ m/s}$.

MARKING SCHEME

- ✓ $E = 4.0 \times 10^3$ V/m.
- ✓ $v^2 = eEL^2/(2my)$.
- ✓ $v = 1.5 \times 10^7$ m/s.

3 Check the readings

ANSWER HA · 3

Inside, $E \propto r$: 4.5 at 2.5 cm, 9.0 at 5.0 cm and 18 at 10 cm fit (doubling r doubles E). Outside, $E \propto 1/r^2$: at 20 cm, $18 \times (10/20)^2 = 4.5$ ✓; at 15 cm, $18 \times (10/15)^2 = \mathbf{8.0}$, not 12. The value at 15 cm is wrong.

MARKING SCHEME

- ✓ Inside values checked against $E \propto r$.
- ✓ Outside values checked against $E \propto 1/r^2$ from the surface value.
- ✓ The 15 cm value is wrong: it should be 8.0×10^5 N/C.

4 Predict, then explain

ANSWER HA · 3

Both are deflected the same way, towards the negative plate, and the **proton twice as much**. The deflection is $y = qEL^2/(2mv^2)$, proportional to q/m: the alpha particle has 2 times the charge and 4 times the mass, so q/m is half the proton's, and so is its deflection.

MARKING SCHEME

- ✓ Both towards the negative plate.
- ✓ The proton is deflected twice as much.
- ✓ $y \propto q/m$ at the same speed: the alpha's q/m is half.

5 Estimate it

ANSWER A · 3

i. A Gaussian sphere just above the ground: $E \times 4\pi R^2 = Q/\varepsilon_0$, so $Q = 4\pi\varepsilon_0 R^2 E = ER^2/k = 130 \times (6.4 \times 10^6)^2 \div 9.0 \times 10^9 \approx \mathbf{6 \times 10^5\ C}$.

ii. The field points down, into the Earth, so the charge is **negative**.

MARKING SCHEME

- ✓ $E \times 4\pi R^2 = Q/\varepsilon_0$ (or $E = kQ/R^2$).
- ✓ $Q \approx 6 \times 10^5$ C.
- ✓ Negative, since the field points inwards.

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6 Design it

ANSWER A · 3

$y = eV\,L^2/(2mdv^2)$, so $V = 2mdv^2y/(eL^2) = 2 \times 9.11 \times 10^{-31} \times 0.015 \times (2.0 \times 10^7)^2 \times 4.0 \times 10^{-3} \div (1.6 \times 10^{-19} \times 0.050^2) =$ **109 V**, about 110 V. If the beam enters midway, it has 7.5 mm to the plate, more than 4.0 mm, so it clears.

MARKING SCHEME

- ✓ $V = 2mdv^2y/(eL^2)$.
- ✓ $V \approx 110$ V.
- ✓ It clears: 4.0 mm is less than the 7.5 mm from the middle to a plate.

7 What if?

MARKING SCHEME A · 3

- ✓ Twice as large: still q/ε_0.
- ✓ Moved inside: still q/ε_0 (only the faces' shares change).
- ✓ A charge outside adds nothing to the total.

8 Show that

MARKING SCHEME A · 3

- ✓ $W = qEd = qV$.
- ✓ The work becomes kinetic energy: $\frac{1}{2}mv^2 = qV$.
- ✓ $v = 2.7 \times 10^7$ m/s.

9 Correct the misconceptions

ANSWER U · 3

1. A field line shows the direction of the **force** (and acceleration) at each point, not the path: a moving charge has momentum and needn't follow the line.
2. The field **doesn't** depend on the test charge: $E = F/q$, and doubling q doubles F.
3. Inside an insulating sphere charged through its volume, $E = kQr/a^3$: zero only at the **center**, growing in proportion to r. (It is zero everywhere inside a charged **conductor**.)

MARKING SCHEME

- ✓ Field lines give the force's direction, not the path.
- ✓ E is independent of the test charge.
- ✓ Inside the insulating sphere $E \propto r$, zero only at the center.

10 Think

ANSWER HA · 2

Each sheet's field is $\sigma/(2\varepsilon_0)$, away from the + plate and towards the − plate. Between the plates both point the same way (from + to −), so they add: σ/ε_0. Outside either plate they point in opposite directions and cancel: zero.

MARKING SCHEME

- ✓ Between the plates the two fields point the same way: $\sigma/(2\varepsilon_0) + \sigma/(2\varepsilon_0) = \sigma/\varepsilon_0$.
- ✓ Outside they are opposite and cancel.

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11 Make your own

HA · 2

ANSWER

For example Q = 10 nC at r = 0.095 m: $E = 9.0 \times 10^9 \times 10 \times 10^{-9} \div 0.095^2 = 1.0 \times 10^4$ N/C. Flux = Q/ε_0 $= 10 \times 10^{-9} \div 8.85 \times 10^{-12} = 1.1 \times 10^3$ N m^2/C, the same for any sphere round it.

MARKING SCHEME

- ✓ A charge and distance with kQ/r^2 worked out to 1.0×10^4 N/C.
- ✓ Flux Q/ε_0 for the chosen charge, the same for any radius.

Marks by level	Knowledge	Understanding	Application	Higher ability	Total
Marks	0	6	15	10	**31**

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