Unit 20

# Answers: Electric Field

## Quick checks

**1 c** Field lines never cross. Where two fields overlap they add as vectors, and the total field at each point has one direction, so only one line can pass through it.

**2 c** $E = F/q = 0.040/(2.0 \times 10^{-6}) = 2.0 \times 10^{4}$ N/C, to the east. On −4.0 μC: $F = qE = 4.0 \times 10^{-6} \times 2.0 \times 10^{4} = 0.080$ N, and a negative charge is pushed against the field: **to the west**. The field at the point is the same; only the charge put there changed.

**3 c** The force $eE$ has the same size on both, but the other direction (opposite charges). The deflection is $y = eEx^2/(2mv^2)$, inversely proportional to the mass, and a proton is about 1,840 times as heavy as an electron: it is deflected about 1,840 times less.

**4 b** $\Phi = EA\cos\theta = 500 \times 0.20 \times \cos 60^\circ = 100 \times 0.5 = 50$ N m²/C.

**5 c** Only the charge inside counts: $q = 5 - 2 + 1 = +4$ nC, so $\Phi = 4\ /\varepsilon_0$. The +10 nC outside changes the field on the surface, but every one of its lines that enters the surface leaves it again.

**6 b** For a line of charge $E \propto 1/r$: three times as far, a third as strong, $6.0 \times 10^4/3 = 2.0 \times 10^4$ N/C. ($6.7 \times 10^3$ N/C would be the answer for a point charge, $1/r^2$.)

**7 a** The field points down, so the force on a negative electron points **up**, constant in size and direction between the plates. The electron curves upwards along a parabola, and once past the plates, with no force, goes straight on: path **A**. B ignores the force; C bends nowhere, but a constant force must curve the path; D bends the wrong way.

**8 b** The field lines of a point charge are radial, and they point the way a positive test charge would be pushed: towards a negative charge, which attracts it. Electric field lines never form closed circles round a charge.

**9 b** $E = F/q$: the force on each coulomb of a positive test charge. Energy per unit charge is the potential (Unit 21).

**10 b** $V = Ed = 650 \times 0.12 = 78$ V. (7800 V comes from forgetting to turn 12 cm into meters.)

**11 d** $E = \dfrac{V}{d} = \dfrac{10}{0.05} = 200$ N/C. The field points from the higher potential to the lower, from the +10 V plate to the 0 V plate: **down**. (2 N/C comes from using 5 cm as 5 m.)

**6.**

1. **The arrows point the wrong way.** Field lines point the way a positive charge is pushed: from the **positive** plate to the **negative** plate. The student's arrows point from the negative (upright) plate to the positive (flat) one.
2. **The lines don't meet the plates at right angles.** Field lines always meet the surface of a conductor at 90°. The student's straight slanting lines meet both plates at 45°. The real lines leave the flat plate straight up, curve round, and arrive at the upright plate horizontally: they are curved, like quarter circles round the corner, and crowded together near the corner where the plates are closest.

**7.** i. The graph is a straight line through the origin, through the point $(8 \times 10^{27}\ \text{m}^{-2}, 1.0 \times 10^{21}\ \text{N/C})$:

$$= \frac{1.0 \times 10^{21}}{8 \times 10^{27\ -2}} = 1.25 \times 10^{-7\ 2}/$$

Since $E = kQ \times \dfrac{1}{r^2}$, the gradient is $kQ$:

$$Q = \frac{1.25 \times 10^{-7}}{8.99 \times 10^{9}} = 1.4 \times 10^{-17}$$

That is $1.39 \times 10^{-17} / 1.6 \times 10^{-19} \approx 87$ proton charges: an element with 87 protons (francium).

ii. The alpha particle carries away a charge of +2e, so the daughter nucleus has a smaller charge, 85e. The graph is **still a straight line through the origin** (its field is still $kQ/r^2$), but **less steep**: its gradient is 85/87 of the old one, about $1.22 \times 10^{-7}$ N m²/C.

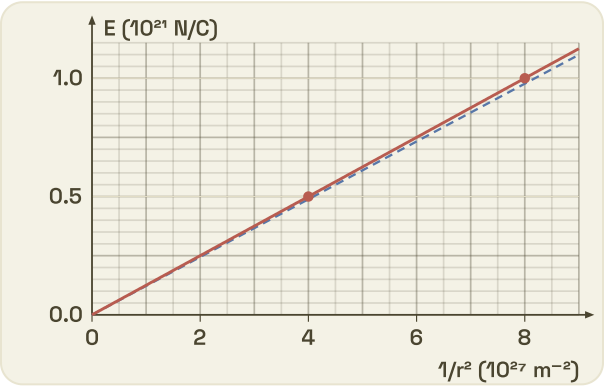



*Figure 20.23* *The daughter nucleus's line (dashed) is a little less steep.*

**8.** i. Volume: $\frac{4}{3}\pi r^3 = \frac{4}{3} \times 3.142 \times (1.27 \times 10^{-6})^3 = 8.58 \times 10^{-18}$ m³.
Mass: $m = 950 \times 8.58 \times 10^{-18} = 8.15 \times 10^{-15}$ kg; weight $mg = 8.15 \times 10^{-15} \times 9.8 = 7.99 \times 10^{-14}$ N.
Field: $E = \dfrac{V}{d} = \dfrac{1.50 \times 10^3}{2.10 \times 10^{-2}} = 7.14 \times 10^4$ V/m.
The drop is still, so the electric force balances the weight:

$$qE = mg \quad \Rightarrow \quad q = \frac{mg}{E} = \frac{7.99 \times 10^{-14}}{7.14 \times 10^4} = 1.12 \times 10^{-18} \approx 1.1 \times 10^{-18}$$

(The field points down, from the upper plate, which must be positive; the negative drop is pushed up, against the field.)

ii. $n = \dfrac{q}{e} = \dfrac{1.12 \times 10^{-18}}{1.6 \times 10^{-19}} = 7.0$: **7 electrons**. A whole number, as it must be: this is how Millikan showed in 1909–1913 that charge comes in lumps of $e$.