

Flux, Gauss's law and continuous charge

AP Physics C (Mechanics and E&M, calculus-based) · Test answers (mark scheme)

The model answers show where each mark is earned. Derivations are marked on the symmetry argument, the flux expression and the enclosed charge, so all three must appear. Numerical answers need a unit and, where relevant, a direction.

Level: AP Physics C (Mechanics and E&M, calculus-based) · **Curriculum:** AP PC:E&M Unit 8

Question 1 Flux through a tilted area (2 marks)

$$\Phi = E A \cos\theta = 800 \times 0.30 \times \cos 30^\circ = \mathbf{2.1 \times 10^2 \text{ N m}^2/\text{C}}.$$

Marking: formula with $\cos\theta$ (1); answer with unit (1).

Question 2 Net flux (3 marks)

a. $Q_{\text{enc}} = +3.0 \text{ nC}$, so $\Phi = 3.0 \times 10^{-9} / 8.85 \times 10^{-12} = \mathbf{3.4 \times 10^2 \text{ N m}^2/\text{C}}.$

b. **No change**, because outside charge adds zero net flux.

Marking: (a) Q_{enc} (1), flux (1); (b) 1 mark.

Question 3 Inside a conductor (2 marks)

If E were not zero, free charges would experience a force and move, so equilibrium requires $E = 0$. A Gaussian surface just inside the metal then has zero flux, so it encloses no net charge. **All net charge is on the outer surface.**

Marking: charges move until $E = 0$ (1); Gauss's law gives charge on surface (1).

Question 4 Line of charge (3 marks)

By symmetry E is radial and constant in size on the curved side, and the end faces carry no flux. $\Phi = E (2\pi rL)$. The enclosed charge is λL , so $E (2\pi rL) = \lambda L / \epsilon_0$. Hence **$E = \lambda / (2\pi\epsilon_0 r)$** .

Marking: symmetry argument (1); flux and Q_{enc} (1); result (1).

Question 5 Insulating sphere (3 marks)

Inside: $E = kQr/R^3 = 8.99 \times 10^9 \times 9.0 \times 10^{-9} \times 0.030 / (0.060)^3 = \mathbf{1.1 \times 10^4 \text{ N/C}}$. Outside: $E = kQ/r^2 = 8.99 \times 10^9 \times 9.0 \times 10^{-9} / 0.0144 = \mathbf{5.6 \times 10^3 \text{ N/C}}$.

Marking: Q_{enc} or formula inside (1); inside value (1); outside value (1).

Question 6 Charged ring (3 marks)

$E = kQx/(x^2 + R^2)^{3/2} = 8.99 \times 10^9 \times 6.0 \times 10^{-9} \times 0.30 / (0.25)^{3/2} = 16.18 / 0.125 =$
 $1.3 \times 10^2 \text{ N/C}$ along the axis. Opposite elements of the ring give perpendicular components that are equal and opposite, so they cancel.

Marking: formula (1); value (1); symmetry explanation (1).

Question 7 Large sheet (2 marks)

$E = \sigma/(2\epsilon_0) = 6.0 \times 10^{-9} / (2 \times 8.85 \times 10^{-12}) =$ **$3.4 \times 10^2 \text{ N/C}$** , directed away from the sheet on both sides.

Marking: formula (1); value and direction (1).

Question 8 Limits of Gauss's law (2 marks)

A short rod has no spherical, cylindrical or planar symmetry, so there is no closed surface on which E is constant and perpendicular. **The law is still true, but E must be found by integrating $dE = k dq/r^2$.**

Marking: lack of symmetry (1); integration needed (1).