

Past-paper walk-through

Electric field of a point charge ■ 18.4

eXercise

Questions in this set

- 9702/44 N25 Q5 ■ 9 marks
- 9702/44 J25 Q5 ■ 10 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- **//** separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = “or words to that effect” – the wording need not match.

Question 5

9702/44 N25 ■ Q5 ■ 9 marks

(a) Explain why the electric potential near an isolated proton is positive. [3]

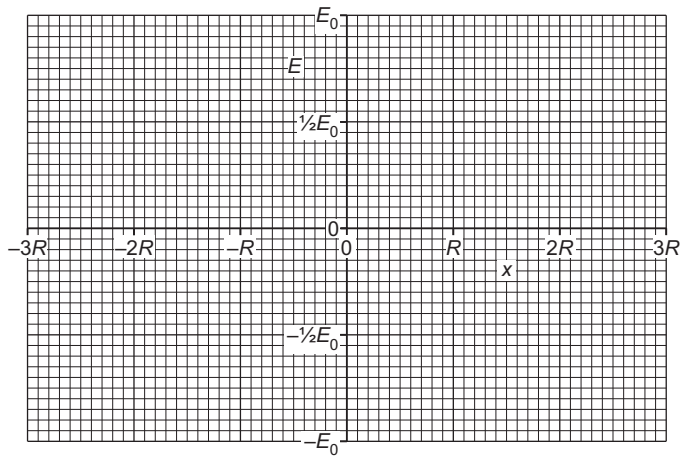
(b)(i) On Fig. 5.1, draw an arrow at point Q to show the direction of the electric field at that point. [1]

(b)(ii) On Fig. 5.2, sketch the variation of the electric field E with x for values of x between $x = -3R$ and $x = 3R$. Do **not** include the region inside the sphere between $x = -R$ and $x = R$. [3]

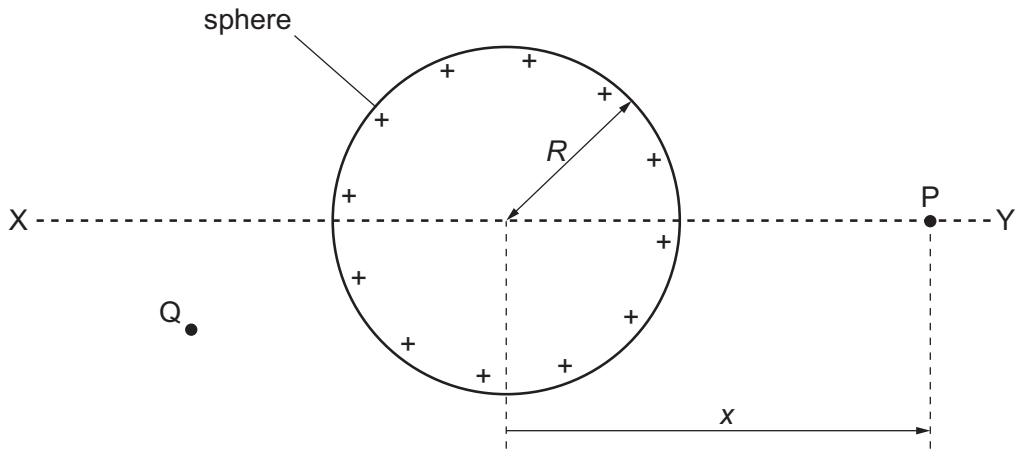
(c) The proton and the electron in a hydrogen atom are separated by a distance of 5.3×10^{-11} m.

Calculate the electric potential energy of the proton and the electron. [2]

Question 5



Question 5



Solution 5

(a)

Mark scheme

- potential is (defined as) zero at infinity (B1)
- proton has a positive charge and so repels another positive charge (B1)
- work is done on two (positive) charges to move them towards each other or work is done by two (positive) charges as they move apart from each other (B1)

Solution 5

(b)(i)

Worked steps

Outside a conducting sphere the field behaves as if all the charge were at the centre, so it points **radially**.

- Draw the arrow at Q pointing directly **away** from the centre of the sphere (the charge is positive), along the line joining the centre to Q.

Mark scheme

- arrow drawn through Q in a WSW direction directly away from the centre of the sphere (B1)

Solution 5

(b)(ii) Worked steps

Two regions, and they behave differently — that is what the three marks test.

- **Inside** the sphere ($-R < x < R$) the field is zero, so draw the curve along the axis there.
- **Outside**, $E \propto \frac{1}{x^2}$: the curve passes through (R, E_0) and falls to $\frac{1}{4}E_0$ at $2R$, flattening as x grows.
- Mirror it on the negative side, so the sketch spans $-3R$ to $3R$.

Solution 5

Mark scheme

- curve in at least one quadrant passing through $(\pm R, \pm E_0)$ and $(\pm 2R, \pm \frac{1}{4}E_0)$ (B1)
- curve between $-3R$ and $-R$ of increasing magnitude of gradient and curve between R and $3R$ of decreasing magnitude of gradient (B1)
- two lines drawn, one in the top right quadrant, the other in the bottom left quadrant (B1)

Solution 5

(c) Worked steps

Electric potential energy of two point charges is $E_P = \frac{Qq}{4\pi\epsilon_0 r}$, and the charges have **opposite** signs, so the energy is negative.

$$\begin{aligned} \blacksquare E_P &= -\frac{(1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 5.3 \times 10^{-11}} \\ \blacksquare E_P &= -4.3 \times 10^{-18} \text{ J} \end{aligned}$$

Solution 5

The minus sign is the physics, not a slip: it says work must be done to pull the electron away from the proton.

Mark scheme

- $EP = - (1.60 \times 10^{-19})^2 / [4\pi \times 8.85 \times 10^{-12} \times (5.3 \times 10^{-11})]$ **C1**
- $= -4.3 \times 10^{-18} \text{ J}$ **A1**

Question 5

9702/44 J25 ■ Q5 ■ 10 marks

5 (a) Define electric potential at a point.

Question 5

- (b)** An isolated solid metal sphere of radius r is given a positive charge.

The potential at the surface of the sphere is $9.0 \times 10^4 \text{ V}$. At a distance of $3r$ from the centre of the sphere, the electric field strength is $2.0 \times 10^5 \text{ N C}^{-1}$.

- (i)** Determine the electric field strength at the surface of the sphere.

Question 5

- (ii) Show that the radius of the sphere is 5.0 cm.

Question 5

[2]

- (iii) Calculate the charge on the sphere.

Question 5

(iv) Use your answer in **(b)(iii)** to determine the capacitance of the sphere.

Question 5

[Total: 10]

Solution 5

(a)

Mark scheme

- work done per unit charge
- work done (on charge) in moving positive charge from infinity (to the point)

Solution 5

(b)(i)

Worked steps

Outside a charged sphere the field is that of a point charge, so it follows an inverse **square** law.

- Going from $3r$ in to r divides the distance by 3, so the field is multiplied by $3^2 = 9$.
- $E = 9 \times 2.0 \times 10^5$
- $E = 1.8 \times 10^6 \text{ N C}^{-1}$

Mark scheme

- electric field strength inversely proportional to distance²
- $E = 32 \times 2.0 \times 10^5$
- $= 1.8 \times 10^6 \text{ N C}^{-1}$

Solution 5

(b)(ii) Worked steps

The two quantities you now know at the same place are related in a way that cancels the charge.

$$\blacksquare V = \frac{Q}{4\pi\epsilon_0 r} \text{ and } E = \frac{Q}{4\pi\epsilon_0 r^2}, \text{ so } \frac{V}{E} = r.$$

$$\blacksquare r = \frac{9.0 \times 10^4}{1.8 \times 10^6}$$

$$\blacksquare r = 0.050 \text{ m (5.0 cm)}$$

Solution 5

Mark scheme

- $V = Q / 4\pi\epsilon_0 r$ and $E = Q / 4\pi\epsilon_0 r^2$ (so $E = V / r$)
- $r = (9.0 \times 10^4) / (1.8 \times 10^6) = 0.050 \text{ m} = 5.0 \text{ cm}$

Solution 5

(b)(iii)

Worked steps

- Rearranging the potential: $Q = 4\pi\epsilon_0 Vr$.
- $Q = 4\pi \times 8.85 \times 10^{-12} \times 9.0 \times 10^4 \times 0.050$
- $Q = 5.0 \times 10^{-7} \text{ C}$

Mark scheme

- $Q = 4\pi\epsilon_0 Vr$
- $= 4\pi \times 8.85 \times 10^{-12} \times 9.0 \times 10^4 \times 0.050$
- $= 5.0 \times 10^{-7} \text{ C}$

Solution 5

(b)(iv) Worked steps

An isolated sphere has a capacitance: the charge it holds per volt of its own potential.

$$\blacksquare C = \frac{Q}{V} = \frac{5.0 \times 10^{-7}}{9.0 \times 10^4}$$

$$\blacksquare C = 5.6 \times 10^{-12} \text{ F}$$

Solution 5

About 5.6 pF for a 5 cm sphere — worth noticing how small that is, and why practical capacitors put two plates close together instead.

Mark scheme

- $C = Q / V$
- $= (5.0 \times 10^{-7}) / (9.0 \times 10^4)$
- $= 5.6 \times 10^{-12} \text{ F}$
- 9702/44
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