Past-paper walk-through

Electric potential ▪ 18.5

eXercise

Questions in this set

- 9702/41 N25 Q5 ▪ 10 marks
- 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

9702/41 N25 ▪ Q5 ▪ 10 marks

(a) Define electric potential at a point. **[2]**

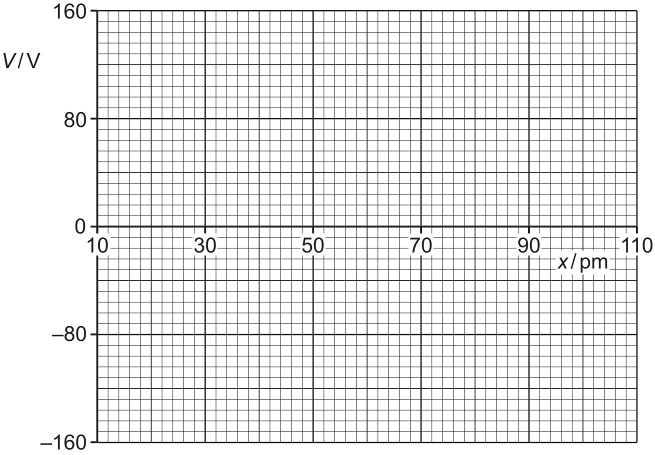
(b)(i) Show that the electric potential V at point P when $x = 10$ pm is equal to 130 V. **[2]**

(b)(ii) Calculate, to two significant figures, V when $x = 30$ pm. **[2]**

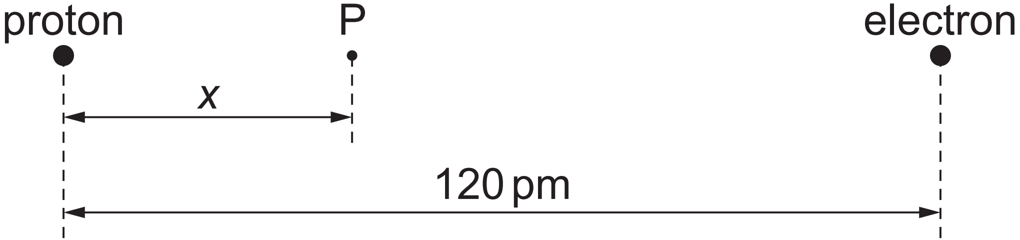
(b)(iii) On Fig. 5.1, draw a cross $(\times)$ at one position, other than infinity, where the electric potential is zero. **[1]**

(b)(iv) On Fig. 5.2, sketch the variation of V with x between $x = 10$ pm and $x = 110$ pm. **[3]**

Question 5



Question 5



Solution 5

(a)

Mark scheme

- work done per unit charge **B1**
- work (done) moving positive charge from infinity (to the point) **B1**

Solution 5

(b)(i) Worked steps

Potential is a **scalar**, so add the two contributions algebraically — no components, no angles. Each is $V = \dfrac{Q}{4\pi\varepsilon_0 r}$, and the electron's charge is negative.

- Proton, 10 pm away: $\dfrac{+1.60 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 10 \times 10^{-12}}$
- Electron, 110 pm away: $\dfrac{-1.60 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12} \times 110 \times 10^{-12}}$
- Adding, and taking the common factor out: $V = \dfrac{1.60 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12}} \times \left(\dfrac{1}{10} - \dfrac{1}{110}\right) \times 10^{12}$
- $V = 130$ V, as required.

Solution 5

Taking the constant outside the bracket is worth doing every time: it turns two full calculations into one, and the bracket is then just a difference of reciprocals. Note the two distances add to 120 pm — P lies **between** the charges.

Mark scheme

- potential (due to proton) $=$ (1.60 $\times$ 10–19) / (4π $\times$ 8.85 $\times$ 10–12 $\times$ 10 $\times$ 10–12) or potential (due to electron) $=$ (–1.60 $\times$ 10–19) / (4π $\times$ 8.85 $\times$ 10–12 $\times$ 110 $\times$ 10–12) **C1**
- V $=$ [(1.60 $\times$ 10–19) / (4π $\times$ 8.85 $\times$ 10–12)] $\times$ [(10–1 – 110–1) $\times$ 1012] $=$ 130 V **A1**

Solution 5

(b)(ii) Worked steps

Identical calculation, with P moved to $x = 30$ pm, so the distances are 30 pm and 90 pm.

- $V = \dfrac{1.60 \times 10^{-19}}{4\pi \times 8.85 \times 10^{-12}} \times \left(\dfrac{1}{30} - \dfrac{1}{90}\right) \times 10^{12}$
- $V = +32$ V

Solution 5

The sign is **positive**: P is still nearer the proton, so the proton's contribution wins. The question asks for two significant figures, so 32 V, not 31.96.

Mark scheme

- $V = [(1.60 \times 10–19) \ / \ (4\pi \times 8.85 \times 10–12)] \times [(30–1 – 90–1) \times 1012]$ **C1**
- $= (+)\ 32$ V **A1**

Solution 5

(b)(iii) Worked steps

Potential is zero where the two contributions cancel exactly — equal magnitudes, opposite signs.

- $\dfrac{Q}{4\pi\varepsilon_0 r_1} = \dfrac{Q}{4\pi\varepsilon_0 r_2}$ requires $r_1 = r_2$, because the charges are equal in magnitude.
- So the cross goes **midway between the electron and the proton**, at $x = 60$ pm.

Solution 5

This works only because the two charges have the same magnitude. With unequal charges the zero sits closer to the smaller one, and it is found from $\frac{Q_1}{r_1} = \frac{Q_2}{r_2}$.

Do not mark the point where the *field* is zero — for two opposite charges there is no such point between them at all, since both fields push the same way.

Mark scheme

- cross drawn midway between the electron and the proton **B1**

Solution 5

(b)(iv) Worked steps

Potential is a **scalar**, so the potentials of the two charges simply add — no components, no directions. That single fact gives the whole shape.
The mark scheme names three features, and each is one mark:

1. The curve runs from $(10, +130)$ **to** $(110, -130)$ — positive near the positive charge, negative near the negative one, and equal in magnitude at the two ends because the arrangement is symmetric.
2. It **gets shallower until** $x = 60$ **pm, crosses zero there, then gets steeper again** — at the midpoint the two contributions are equal and opposite, so they cancel exactly.
3. It **passes through** $(30, +32)$ **and** $(90, -32)$ — again symmetric about the midpoint.

Solution 5

Two things to get right in the drawing. The curve is **steepest at the ends**, where you are closest to a charge and $V \propto 1/r$ is changing fastest, and flattest in the middle. And it crosses the axis cleanly rather than levelling off along it: the potential is zero at exactly one point, not over a region.

Solution 5

Do not confuse this with the **field strength** graph. E is a vector, the two contributions there point the same way in between the charges, and it never falls to zero — it has a minimum at the midpoint and no crossing at all.

Mark scheme

- line from (10, +130) to (110, –130) **B1**
- curve getting shallower until $x = 60$ pm, crossing $V = 0$ at (60, 0) and then getting steeper after $x = 60$ pm **B1**
- curve passing through (30, $\pm$32) and (90, $\pm$32) **B1**

Question 5

9702/44 N25 ▪ Q5 ▪ 9 marks

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

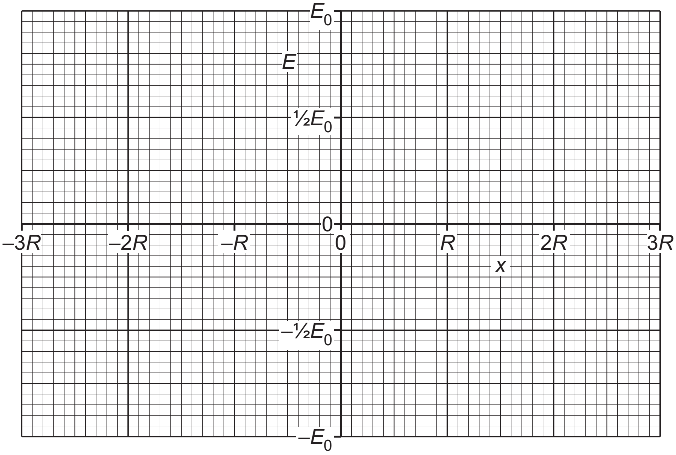
(b)(i) On Fig. 5.1, draw an arrow at point Q to show the direction of the electric field at that point. **[1]**

(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]**

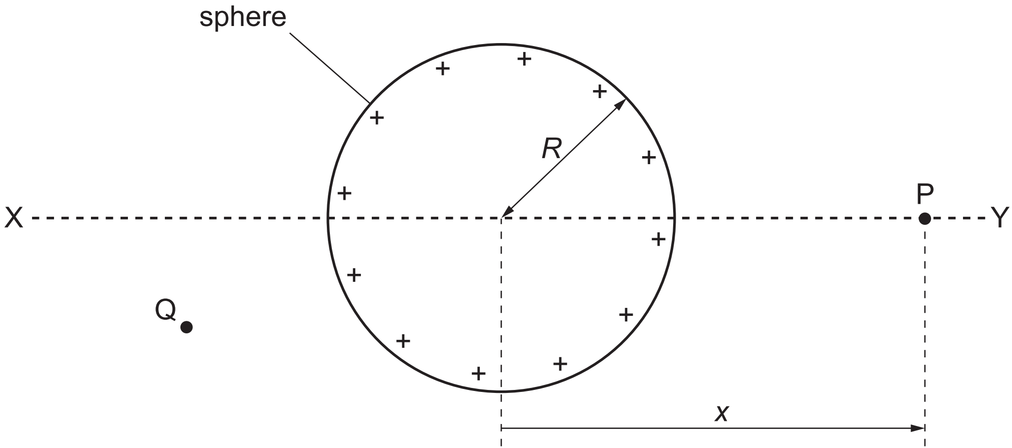
(c) The proton and the electron in a hydrogen atom are separated by a distance of 5.3×10^{-11} m.

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**, $E \propto \dfrac{1}{x^2}$: 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 (±R, ±E0) and (±2R, ±¼E0) **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 $E_P = \dfrac{Qq}{4\pi\varepsilon_0 r}$, and the charges have **opposite** signs, so the energy is negative.

- $E_P = -\dfrac{(1.60 \times 10^{-19})^2}{4\pi \times 8.85 \times 10^{-12} \times 5.3 \times 10^{-11}}$
- $E_P = -4.3 \times 10^{-18}$ J

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 / [4π $\times$ 8.85 $\times$ 10–12 $\times$ (5.3 $\times$ 10–11)] **C1**
- $=$ –4.3 $\times$ 10–18 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 9.0×10^4 V. At a distance of 3*r* from the centre of the sphere, the electric field strength is $2.0 \times 10^5\,\mathrm{N\,C^{-1}}$.

(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 $3^2 = 9$.
- $E = 9 \times 2.0 \times 10^5$
- $E = 1.8 \times 10^6$ N C^{-1}

Mark scheme

- electric field strength inversely proportional to distance2
- E = 32 × 2.0 × 105
- = 1.8 × 106 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.

- $V = \dfrac{Q}{4\pi\varepsilon_0 r}$ and $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$, so $\dfrac{V}{E} = r$.
- $r = \dfrac{9.0 \times 10^4}{1.8 \times 10^6}$
- $r = 0.050$ m (5.0 cm)

Solution 5

Mark scheme

- $V = Q\,/\,4\pi\varepsilon 0r$ and $E = Q\,/\,4\pi\varepsilon 0r2$ (so $E = V\,/\,r$)
- $r = (9.0 \times 104)\,/\,(1.8 \times 106) = 0.050\,\mathrm{m} = 5.0\,\mathrm{cm}$

Solution 5

(b)(iii)

Worked steps

- Rearranging the potential: $Q = 4\pi\varepsilon_0 Vr$.
- $Q = 4\pi \times 8.85 \times 10^{-12} \times 9.0 \times 10^4 \times 0.050$
- $Q = 5.0 \times 10^{-7}$ C

Mark scheme

- Q $= 4\pi\varepsilon$0Vr
- $=$ 4π $\times$ 8.85 $\times$ 10–12 $\times$ 9.0 $\times$ 104 $\times$ 0.050
- $=$ 5.0 $\times$ 10–7 C

Solution 5

(b)(iv) Worked steps

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

- $C = \dfrac{Q}{V} = \dfrac{5.0 \times 10^{-7}}{9.0 \times 10^{4}}$
- $C = 5.6 \times 10^{-12}$ 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

- $C = Q\,/\,V$
- $= (5.0 \times 10–7)\,/\,(9.0 \times 104)$
- $= 5.6 \times 10–12\,\mathrm{F}$
- 9702/44
- May/June 2025