A-LEVEL PHYSICS • EXERCISE SHEET

18.5 Electric potential

Name: ____________ Class: ________ Date: __________ **Total: 27 marks**

KEY WORDS electric potential 电势 • electric potential energy 电势能 • potential gradient 电势梯度 • point charge 点电荷 • test charge 检验电荷

Objective

Build the skills to answer exam questions on **electric potential** and electric potential energy.

You must be able to:

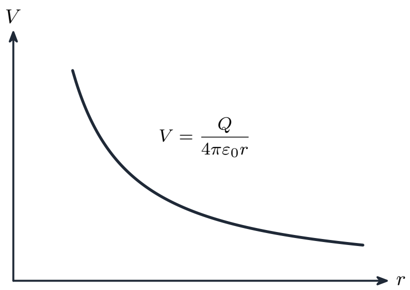
- define **electric potential** and use $V = \dfrac{Q}{4\pi\varepsilon_0 r}$
- use $E_\mathrm{P} = \dfrac{Qq}{4\pi\varepsilon_0 r}$ and $E = -$potential gradient

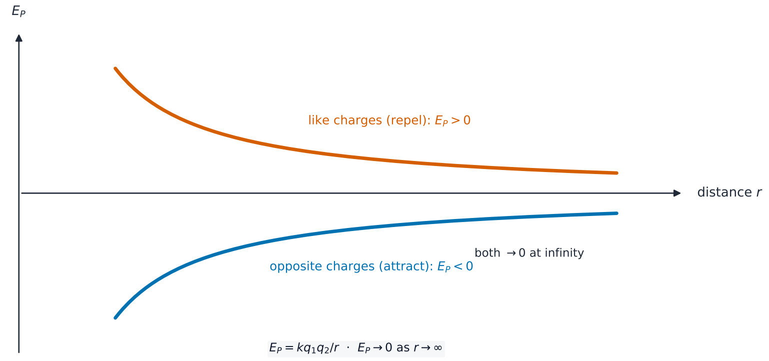
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

Electric potential

Electric potential at a point is the **work done per unit positive charge** to bring a small test charge from **infinity** to that point (zero at infinity):





Electric potential energy near a charge

$$V = \frac{Q}{4\pi\varepsilon_0 r}, \qquad E_\mathrm{P} = \frac{Qq}{4\pi\varepsilon_0 r}, \qquad E = -\frac{\Delta V}{\Delta r}.$$

For a **positive** charge $V > 0$ (falling to zero); for a **negative** charge $V < 0$.

Adding potentials (a scalar)

Potential is a **scalar**, so the total potential from several charges is the **algebraic sum** (keep the signs) — no directions or vectors:

$$V = \sum \frac{Q_i}{4\pi\varepsilon_0 r_i}.$$

Worked example. Point P is 0.10 m from a +4.0 nC charge and 0.20 m from a +6.0 nC charge: $V = \dfrac{(9.0\times10^9)(4.0\times10^{-9})}{0.10} + \dfrac{(9.0\times10^9)(6.0\times10^{-9})}{0.20} = 360 + 270 =$ 630 V.

Between a **positive** and a **negative** charge, the potentials have opposite sign, so there is a point where they **cancel** ($V = 0$): where $\dfrac{|Q_1|}{r_1} = \dfrac{|Q_2|}{r_2}$.

2 Practice

Now apply the methods above.

2.1 Define **electric potential**. [1]

2.2 Write the equation for the potential V due to a point charge. [1]

2.3 Write the equation for the **electric potential energy** of two point charges. [1]

2.4 State the relationship between the **field** E and the **potential gradient**. [1]

3 Exam-style questions

3.1 The electric potential at **infinity** is: [1]

- **A** a maximum
- **B** zero
- **C** always negative
- **D** infinite

3.2 Calculate the electric potential at 0.050 m from a +3.0 nC point charge. ($\frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9$.) [3]

3.3 Calculate the electric potential energy of a +2.0 nC and a +3.0 nC charge placed 4.0 cm apart. [2]

3.4 State **one** difference between the electric potential near a **positive** charge and near a **negative** charge. [1]

3.5 A +5.0 nC charge is at point A and a −2.0 nC charge is at point B, 0.21 m away on the line AB.

(a) Explain why the total potential is found by **adding** the two potentials, including their signs. [1]

(b) Find the distance from A, on the line AB, where the total potential is **zero**. [3]

3.6 Two point charges are fixed on a straight line. Charge A, of +4.0 pC, is at the origin; charge B, of −1.0 pC, is at $x = +40$ pm. Take $\dfrac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9$ m F^{-1}.

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

(b) **Show that** the electric potential due to charge A alone, at $x = 10$ pm, is about 3.6 V. [2]

(c) **Calculate**, to two significant figures, the **total** potential at $x = 10$ pm due to both charges. [3]

(d) **Determine** the position on the line **between** the two charges at which the total electric potential is **zero**. [3]

(e) **State and explain** whether the electric **field** is also zero at that position. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the **work done per unit positive charge** in bringing a small test charge from **infinity** to that point

2.2

- $V = Q/(4\pi\varepsilon_0 r)$

2.3

- $E_\text{P} = Qq/(4\pi\varepsilon_0 r)$

2.4

- the field is the **negative of the potential gradient**: $E = -\Delta V/\Delta r$

3.1 B

- electric potential is defined as **zero** at infinity

3.2

- $V = Q/(4\pi\varepsilon_0 r)$

$$V = \frac{(9.0\times10^{9}\ \text{N m}^2\,\text{C}^{-2})(3.0\times10^{-9}\ \text{C})}{0.050\ \text{m}} = \mathbf{540}\ \text{V}$$

3.3

- $E_\text{P} = Qq/(4\pi\varepsilon_0 r)$

$$E_\text{P} = \frac{(9.0\times10^{9}\ \text{N m}^2\,\text{C}^{-2})(2.0\times10^{-9}\ \text{C})(3.0\times10^{-9}\ \text{C})}{0.040\ \text{m}} = \mathbf{1.35\times10^{-6}}\ \text{J}$$

3.4

- near a **positive** charge the potential is **positive**; near a **negative** charge it is **negative**

3.5

(a) potential is a **scalar**, so the contributions simply add (algebraically, keeping their signs) — there are no directions to resolve

(b) $V = 0$ where the magnitudes cancel

$$\frac{5.0}{x} = \frac{2.0}{0.21\ \text{m} - x}$$

$$5.0(0.21\ \text{m} - x) = 2.0x \Rightarrow 1.05\ \text{m} = 7.0x$$

- $x = \mathbf{0.15}$ m from A

3.6

(a) the **work done per unit positive charge** in bringing a small test charge from **infinity** to that point

(b) $V = Q/(4\pi\varepsilon_0 r)$

$$V = \frac{(8.99 \times 10^9\ \mathrm{N\ m^2\ C^{-2}})(4.0 \times 10^{-12}\ \mathrm{C})}{10 \times 10^{-12}\ \mathrm{m}} \approx \mathbf{3.6}\ \mathrm{V}$$

(c) B is 30 pm away

$$V_\mathrm{B} = \frac{(8.99 \times 10^9\ \mathrm{N\ m^2\ C^{-2}})(-1.0 \times 10^{-12}\ \mathrm{C})}{30 \times 10^{-12}\ \mathrm{m}} = -0.30\ \mathrm{V}$$

- potential is a **scalar**, so the two simply add: $V = 3.6\ \mathrm{V} - 0.30\ \mathrm{V} = \mathbf{3.3}\ \mathrm{V}$

(d) let the point be x from A, so it is $(40 - x)$ from B

$$\frac{4.0}{x} = \frac{1.0}{40\ \mathrm{pm} - x}$$

$$4.0(40\ \mathrm{pm} - x) = x \Rightarrow 160\ \mathrm{pm} = 5.0x$$

- $x = \mathbf{32}$ pm from A

(e) **no**

- potential is a scalar and cancels there, but the fields of the two charges at that point both point in the **same direction** (away from the positive charge and towards the negative one), so they add rather than cancel