

Exercise walk-through

18.5

Electric potential

A-Level Physics

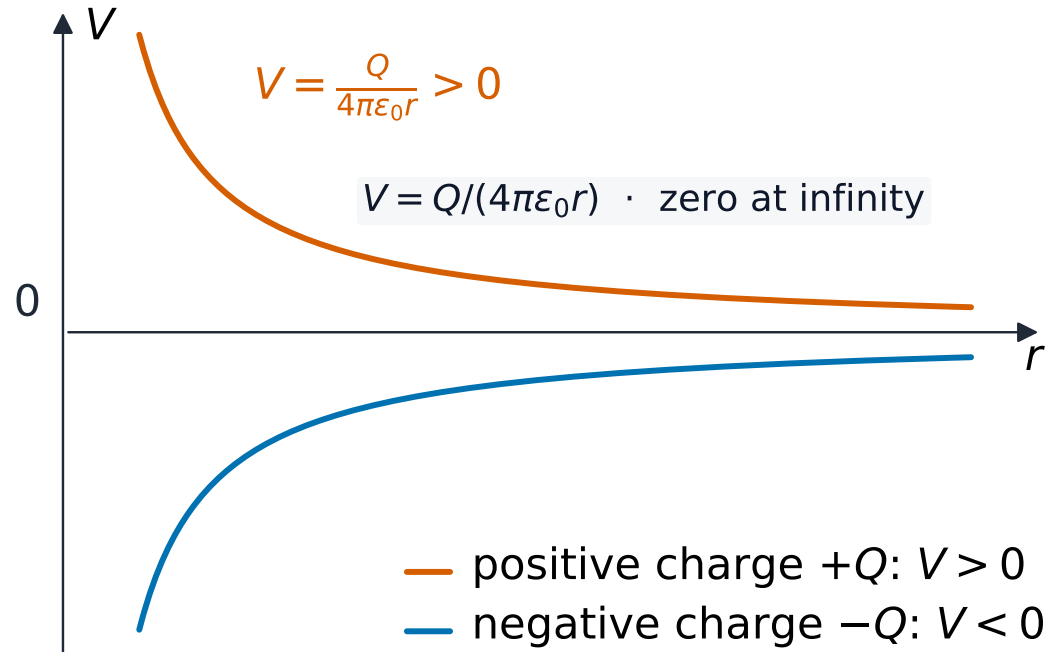
Electric potential

Electric potential is the work done per unit **positive** charge bringing a test charge in from **infinity** :

$$V = \frac{W}{q} = \frac{Q}{4\pi\epsilon_0 r}$$

Note $1/r$, **not** $1/r^2$. V is a **scalar** and takes the sign of Q – so several charges just **add**, signs and all, with no directions to resolve.

Electric potential, in detail



Potential falls as $1/r$, **not** $1/r^2$, and takes the sign of its charge – so several charges simply add, signs and all.

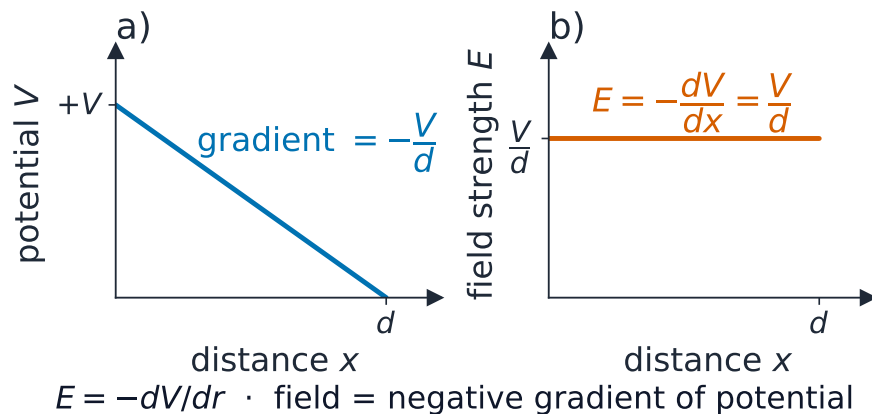
Worked example – potential near a charge

Find V at 4.0 cm from a point charge of +3.0 nC.

$$V = \frac{Q}{4\pi\epsilon_0 r} = \frac{(9.0 \times 10^9)(3.0 \times 10^{-9})}{0.040}$$
$$\approx 6.8 \times 10^2 \text{ V}$$

Same charge, same distance as the Coulomb example – but r appears to the **first** power here. Mixing up $1/r$ and $1/r^2$ is the standard slip.

Field is the potential gradient



The field is the **negative potential gradient**:

$$E = -\frac{dV}{dx}$$

- between plates V falls evenly $\Rightarrow E = V/d$, constant
- for a point charge

$$-\frac{dV}{dr} = \frac{Q}{4\pi\epsilon_0 r^2} = E$$

The minus sign says the field points **downhill** in potential – from high V to low.

Electric potential energy

A charge q where the potential is V has $E_P = qV$; for two point charges

$$E_P = \frac{Qq}{4\pi\epsilon_0 r}$$

- like: $E_P > 0$ – energy released if they fly apart
- opposite: $E_P < 0$ – a **bound** well

Both tend to **zero** as $r \rightarrow \infty$ – that is the choice of zero, exactly as for gravity.

Exercises 2.1-2.3

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]

Exercises 2.1·2.3

2.1 Define **electric potential**.

[1]

2.1

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

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

[1]

2.2

- $V = Q/(4\pi\epsilon_0 r)$

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

[1]

2.3

- $E_P = Qq/(4\pi\epsilon_0 r)$

Exercises 2.4·3.1

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

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

☐

A a maximum

B zero

C always negative

D infinite

Exercises 2.4·3.1

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

2.4

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

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

☐

A a maximum

B zero

C always negative

D infinite

3.1 B

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

Exercises 3.2·3.3

3.2 Calculate the electric potential at 0.050 m from a +3.0 nC point charge. ($\frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9$.) [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]

Exercises 3.2-3.3

3.2 Calculate the electric potential at 0.050 m from a +3.0 nC point charge. ($\frac{1}{4\pi\epsilon_0} = 9.0 \times 10^9$.) [3]

3.2

- $V = Q/(4\pi\epsilon_0 r)$

$$V = \frac{Q}{4\pi\epsilon_0 r} = \frac{(9.0 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(3.0 \times 10^{-9} \text{ C})}{0.050 \text{ m}} = \mathbf{540 \text{ V}}$$

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

3.3

- $E_P = Qq/(4\pi\epsilon_0 r)$

$$E_P = \frac{Qq}{4\pi\epsilon_0 r} = \frac{(9.0 \times 10^9)(2.0 \times 10^{-9})(3.0 \times 10^{-9})}{0.040} = \mathbf{1.35 \times 10^{-6} \text{ J}}$$

Exercise 3.4

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

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3.4

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

Exercise 3.5 (a)

3.5 A $+5.0 \text{ nC}$ 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]

Exercise 3.5 (a)

3.5 A $+5.0 \text{ nC}$ 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]

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

Exercise 3.5 (b)

3.5 A $+5.0 \text{ nC}$ charge is at point A and a -2.0 nC charge is at point B, 0.21 m away on the line AB.

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

Exercise 3.5 (b)

3.5 A $+5.0 \text{ nC}$ charge is at point A and a -2.0 nC charge is at point B, 0.21 m away on the line AB.

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

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

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

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

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

Exercise 3.6 (a)

3.6 Two point charges are fixed on a straight line. Charge A, of $+4.0 \text{ pC}$, is at the origin; charge B, of -1.0 pC , is at $x = +40 \text{ pm}$. Take $\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$.

(a) **Define the electric potential** at a point.

[2]

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3.6 Two point charges are fixed on a straight line. Charge A, of $+4.0 \text{ pC}$, is at the origin; charge B, of -1.0 pC , is at $x = +40 \text{ pm}$. Take $\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$.

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

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

Exercise 3.6 (b)

3.6 Two point charges are fixed on a straight line. Charge A, of $+4.0 \text{ pC}$, is at the origin; charge B, of -1.0 pC , is at $x = +40 \text{ pm}$. Take $\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$.

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

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

(b) $V = Q/(4\pi\epsilon_0 r)$

$$V = \frac{Q}{4\pi\epsilon_0 r} = \frac{(8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(4.0 \times 10^{-12} \text{ C})}{10 \times 10^{-12} \text{ m}} \approx \mathbf{3.6 \text{ V}}$$

Exercise 3.6 (c)

3.6 Two point charges are fixed on a straight line. Charge A, of $+4.0 \text{ pC}$, is at the origin; charge B, of -1.0 pC , is at $x = +40 \text{ pm}$. Take $\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$.

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

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

(c) B is 30 pm away

$$V_B = \frac{Q}{4\pi\epsilon_0 r} = \frac{(8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2})(-1.0 \times 10^{-12} \text{ C})}{30 \times 10^{-12} \text{ m}} = -0.30 \text{ V}$$

- potential is a **scalar**, so the two simply add: $V = V_A + V_B = 3.6 \text{ V} + (-0.30 \text{ V}) = \mathbf{3.3 \text{ V}}$

Exercise 3.6 (d)

3.6 Two point charges are fixed on a straight line. Charge A, of $+4.0 \text{ pC}$, is at the origin; charge B, of -1.0 pC , is at $x = +40 \text{ pm}$. Take $\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$.

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

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

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

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

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

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

Exercise 3.6 (e)

3.6 Two point charges are fixed on a straight line. Charge A, of $+4.0 \text{ pC}$, is at the origin; charge B, of -1.0 pC , is at $x = +40 \text{ pm}$. Take $\frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \text{ m F}^{-1}$.

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

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

(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