A-LEVEL PHYSICS • EXERCISE SHEET

18.4 Electric field of a point charge

Name: ____________ Class: ________ Date: __________ **Total: 22 marks**

KEY WORDS electric field 电场 • electric field strength 电场强度 • gravitational field 重力场 • force 力 • point charge 点电荷

Objective

Build the skills to answer exam questions on the **electric field of a point charge**.

You must be able to:

- use $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$
- compare electric and gravitational fields

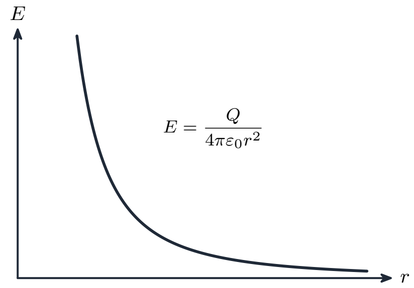
1 Worked examples

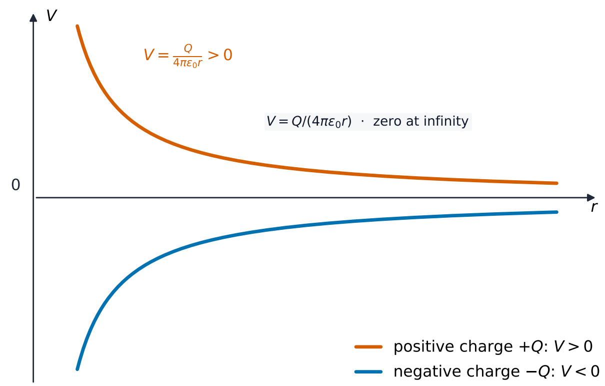
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Field of a point charge

$$E = \frac{Q}{4\pi\varepsilon_0 r^2}.$$

It points **out** from a positive charge and **in** to a negative one, and falls as an **inverse square**:





The radial field of a point charge

This is just like the **gravitational** field $g = GM/r^2$ — except gravity is **always attractive**, while the electric field can be attractive or repulsive.

2 Practice

Now apply the methods above.

2.1 Write the equation for the field strength E due to a **point charge**. [1]

2.2 State how E varies with distance r from a point charge. [1]

2.3 Find the field strength at 0.10 m from a +5.0 nC point charge. ($\frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9$.) [2]

3 Exam-style questions

3.1 Both the electric field of a point charge and the gravitational field of a point mass vary with distance as: [1]

- **A** $1/r$
- **B** $1/r^2$
- **C** r
- **D** r^2

3.2 Calculate the electric field strength at 2.0 cm from a point charge of +8.0 nC. [3]

3.3 State **one** similarity and **one** difference between an electric field and a gravitational field. [2]

3.4 An isolated solid metal sphere of radius R carries a positive charge $+Q$. Point Q lies outside the sphere, a distance $2R$ from its centre.

(a) **Explain** why the electric potential everywhere near an isolated **positive** charge is positive. [2]

(b) **State** the direction of the electric field at point Q, and **state** how the field inside the metal sphere compares with it. [2]

(c) On the axes below, **sketch** the variation of the electric field strength E with distance x from the centre of the sphere, for x from 0 to $4R$. [3]

(d) The field strength at the surface of the sphere is E_0. **Determine**, in terms of E_0, the field strength at point Q. [2]

(e) A second identical sphere carrying the same charge is now placed with its centre $6R$ from the centre of the first. **Determine** the position on the line joining their centres at which the resultant field is zero, and **state** what the potential is there compared with the potential at the surface of either sphere. [3]

Solutions

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

2.1

- $E = Q/(4\pi\varepsilon_0 r^2)$

2.2

- $E \propto 1/r^2$ (inverse-square)

2.3

- $E = Q/(4\pi\varepsilon_0 r^2)$

$$E = \frac{(9.0 \times 10^9\ \mathrm{N\ m^2\,C^{-2}})(5.0 \times 10^{-9}\ \mathrm{C})}{(0.10\ \mathrm{m})^2} = \mathbf{4.5 \times 10^3}\ \mathrm{N\ C^{-1}}$$

3.1 B

- $E \propto 1/r^2$

3.2

- $E = Q/(4\pi\varepsilon_0 r^2)$

$$E = \frac{(9.0 \times 10^9\ \mathrm{N\ m^2\,C^{-2}})(8.0 \times 10^{-9}\ \mathrm{C})}{(0.020\ \mathrm{m})^2} = \mathbf{1.8 \times 10^5}\ \mathrm{N\ C^{-1}}$$

3.3

- similarity: both follow an **inverse-square** law (radial field around a point source)
- difference: the electric force can be **attractive or repulsive**, but gravity is **always attractive**

3.4

(a) potential is the work done per unit positive charge bringing a test charge from infinity

- a positive charge **repels** the test charge, so external work must be done **on** it to bring it closer, making the potential positive everywhere around the charge

(b) at Q the field points **radially away** from the sphere, i.e. directly outwards along the line from the centre

- inside the metal the field is **zero** — the charge resides on the surface and the interior is field-free

(c) $E = 0$ from $x = 0$ to $x = R$, drawn along the axis

- a **discontinuous jump** to the maximum E_0 at $x = R$
- then an inverse-square decay for $x > R$, falling to $E_0/4$ at $2R$ and $E_0/16$ at $4R$

(d) outside the sphere it behaves as a point charge at its centre, so $E \propto 1/x^2$

- at $2R$ the field is $E_0/4$

(e) by symmetry the fields cancel at the **midpoint**, $3R$ from each centre

- the potentials, being scalars, **add** there, so the potential is not zero — it is smaller than at either surface but still positive