Week 40

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

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A-Level Physics Name: ____________________ Score: ______

1. Electric field strength is the force per unit:

   ☐ positive charge

   ☐ mass

   ☐ area

   ☐ volume

2. Two plates 0.050 m apart have 200 V between them. What is the field strength?

   ______________ V/m

3. Coulomb's law gives the force between two point charges as:

   ☐ $\dfrac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$

   ☐ $\dfrac{Q_1Q_2}{4\pi\varepsilon_0 r}$

   ☐ $\dfrac{Q_1Q_2}{r}$

   ☐ $4\pi\varepsilon_0 Q_1Q_2r^2$

4. The field strength at distance r from a point charge Q is:

   ☐ $\dfrac{Q}{4\pi\varepsilon_0 r^2}$

   ☐ $\dfrac{Q}{4\pi\varepsilon_0 r}$

   ☐ $\dfrac{Qq}{4\pi\varepsilon_0 r^2}$

   ☐ $\dfrac{Q}{r}$

5. Electric potential at a point is the work per unit charge to bring a positive charge from:

   ☐ infinity

   ☐ the nearest charge

   ☐ the ground

   ☐ one metre away

6. A charge of 2.0 C feels a force of 6.0 N. What is the field strength?

   ______________ N/C

7. A uniform field between two plates points:

   ☐ from the + plate to the − plate

   ☐ from the − plate to the + plate

   ☐ along the plates

   ☐ in circles

8. Two charges of the same sign repel each other.

   ☐ True ☐ False

9. The field is 100 $\frac{\mathrm{N}}{\mathrm{C}}$ at distance r from a charge. What is it at $2r$?

   ________________ N/C

10. The two-mark definition of electric potential needs which elements? Select **all** that apply.

    ☐ work done per unit positive charge

    ☐ in bringing a small test charge from infinity to the point

    ☐ the potential is zero at infinity

    ☐ the charge must be stationary

    Tick every correct option.

A-Level Physics

1. **positive charge**

   $E = \dfrac{F}{q}$ — the force on each coulomb of a small positive test charge.

2. **4000 V/m**

   $E = \dfrac{V}{d} = \dfrac{200}{0.050} = 4000\ \dfrac{\text{V}}{\text{m}}$.

3. $\dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$

   Proportional to each charge, inversely proportional to the distance squared.

4. $\dfrac{Q}{4\pi\varepsilon_0 r^2}$

   From $E = F/q$ with Coulomb's force, the test charge cancels, leaving $E = \dfrac{Q}{4\pi\varepsilon_0 r^2}$.

5. **infinity**

   Like gravitational potential, it is measured from infinity, where the potential is taken as zero.

6. **3 N/C**

   $E = \dfrac{F}{q} = \dfrac{6.0}{2.0} = 3.0\ \dfrac{\text{N}}{\text{C}}$.

7. **from the + plate to the − plate**

   The field runs from high potential (+) toward low potential (−).

8. **True**

   Like charges repel; opposite charges attract — both along the line joining them.

9. **25 N/C**

   Inverse-square: $\dfrac{100}{2^2} = 25\ \dfrac{\text{N}}{\text{C}}$.

10. **work done per unit positive charge; in bringing a small test charge from infinity to the point; the potential is zero at infinity**

    Per unit positive charge, and from infinity. The zero at infinity is what makes the definition well posed; stationarity is not part of it.

18.1 Electric fields and field lines

Name: ______________ Class: __________ Date: ____________ **Total: 24 marks**

KEY WORDS electric field 电场 • field line 场线 • force 力 • electric field strength 电场强度 • point charge 点电荷

Objective

Build the skills to answer exam questions on the **electric field** — its definition and field lines.

You must be able to:

- define **electric field strength** as force per unit positive charge
- use $F = qE$
- represent an electric field with **field lines**

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.

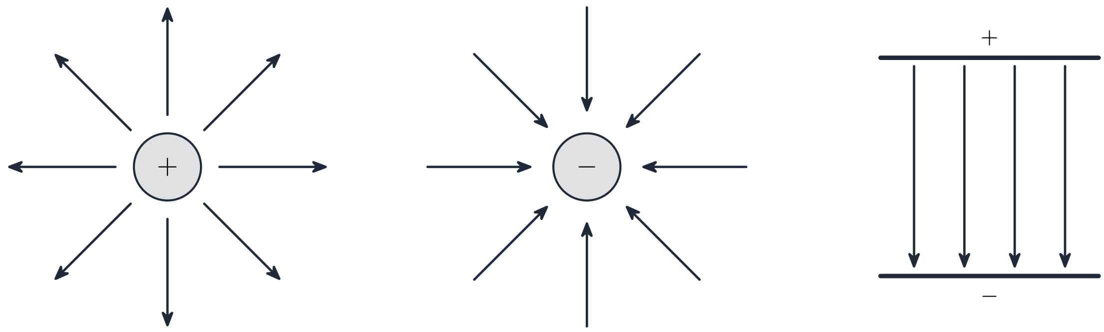
■ Field strength

The **electric field strength** is the force per unit **positive** charge:

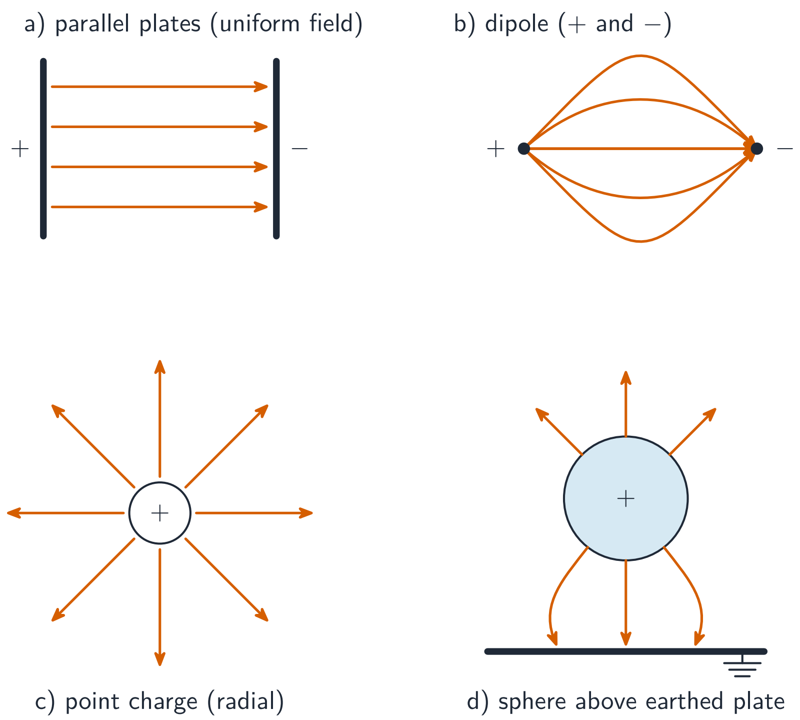
$$E = \frac{F}{q} \quad (\mathrm{N\ C^{-1} = V\ m^{-1}}), \qquad F = qE.$$

■ Field lines

Field lines point the way the force acts on a **positive** charge:



(a) + charge (b) − charge (c) uniform



Electric field line patterns

Outward from +, inward to −, and uniform between charged plates. Closer lines → stronger field.

2 Practice

Now apply the methods above.

2.1 Define **electric field strength**. [1]

2.2 State the unit of electric field strength. [1]

2.3 Write the equation for the **force** on a charge q in a field E. [1]

2.4 State the **direction** of the field lines around a **positive** point charge. [1]

3 Exam-style questions

3.1 Electric field strength is the force per unit: [1]

- **A** mass
- **B** positive charge
- **C** area
- **D** length

3.2 A charge of 2.0×10^{-6} C experiences a force of 0.10 N in a field. Find the **field strength**. [2]

3.3 Sketch the field lines around (a) a positive and (b) a negative point charge. [2]

3.4 Two parallel horizontal metal plates are 0.067 m apart in a vacuum, with a potential difference of 430 V between them. The upper plate is positive. An electron travels horizontally into the region between them at 2.6×10^7 m s^{-1}. Take $e = 1.60 \times 10^{-19}$ C.

(a) **Define** electric field strength. [1]

(b) **Describe** the pattern of the electric field between the plates, away from their edges, and **state** the direction of the field. [3]

(c) **Determine** the electric field strength between the plates. [2]

(d) **Determine** the magnitude and direction of the electric force on the electron. [3]

(e) **Describe** the path of the electron while it is between the plates, and after it leaves them. [3]

(f) A uniform magnetic field is now applied in the same region so that the electron passes through **undeviated**. **Determine** the flux density required, and **state** how the magnetic force must be directed. [3]

Solutions

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

2.1

- the **force per unit positive charge** on a small test charge ($E = F/q$)

2.2

- N C^{-1} (or V m^{-1})

2.3

- $F = qE$

2.4

- **outward** (away from the charge)

3.1 B

- field lines leave a **positive** charge

3.2

- $E = F/q$

$$E = \frac{0.10\ \text{N}}{2.0 \times 10^{-6}\ \text{C}} = \mathbf{5.0 \times 10^{4}}\ \text{N C}^{-1}$$

3.3

(a) radial lines pointing **outward** from the positive charge

(b) radial lines pointing **inward** to the negative charge

3.4

(a) the **force per unit positive charge** acting at that point

(b) the field lines are **straight, parallel and evenly spaced**, so the field is **uniform**

- they run from the **positive** plate to the negative one, i.e. vertically **downwards** here

(c) $E = V/d$

$$E = \frac{430\ \text{V}}{0.067\ \text{m}} = \mathbf{6.4 \times 10^{3}}\ \text{V m}^{-1}$$

(d) $F = Eq$

$$F = (6.4 \times 10^{3}\ \text{V m}^{-1})(1.60 \times 10^{-19}\ \text{C}) = \mathbf{1.0 \times 10^{-15}}\ \text{N}$$

- directed **upwards** — the field points down but the electron's charge is negative

(e) between the plates the horizontal velocity is unchanged while a constant vertical force acts, so the path is a **parabola** curving upwards, towards the positive plate

- beyond the plates there is no field, so it travels in a **straight line** in whatever direction it had on leaving

(f) undeviated means the magnetic force balances the electric one: $Bqv = Eq$, so $B = E/v$

$$B = \frac{6.4 \times 10^3 \text{ V m}^{-1}}{2.6 \times 10^7 \text{ m s}^{-1}} = \mathbf{2.5 \times 10^{-4}} \text{ T}$$

- the magnetic force must be **downwards**, opposite to the electric force on the electron

5 **(a)** Define electric field.

....

....

.... [2]

(b) Fig. 5.1 shows two parallel conducting plates that are in a vacuum. The plates are separated by a distance of 6.7 cm and have a potential difference (p.d.) of 430 V between them.

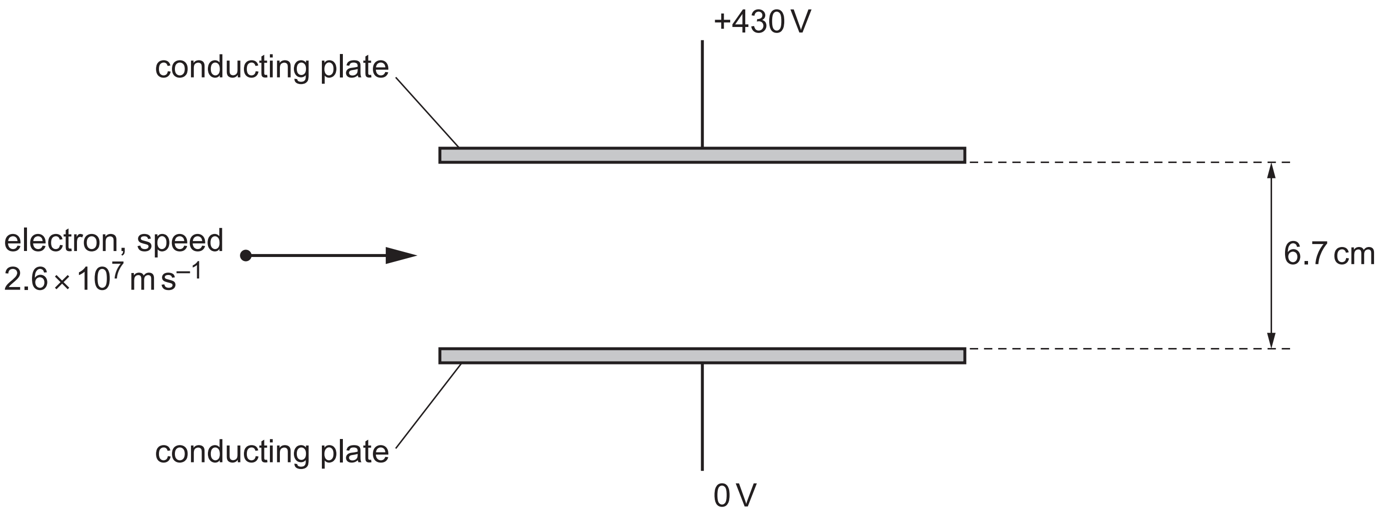


Fig. 5.1

(i) On Fig. 5.1, draw four field lines to represent the electric field between the plates. [2]

(ii) Determine the strength E of the electric field between the plates.

E = ... N C^{-1} [2]

(iii) An electron travels at a speed of 2.6×10^7 m s^{-1} towards the region between the plates, as shown in Fig. 5.1.

On Fig. 5.1, draw the path of the electron as it moves between and beyond the plates. [2]

(c) A uniform magnetic field is now applied in the region of the electric field in Fig. 5.1, so that the electron in **(b)(iii)** travels undeviated through the region.

(i) Determine the direction of the uniform magnetic field.

.... [1]

(ii) Explain, with reference to the forces exerted by the two fields on the electron, why the path of the electron is undeviated.

....

....

.... [2]

(iii) Determine the flux density B of the uniform magnetic field. Give a unit with your answer.

B = ... unit .... [2]

[Total: 13]

5 **(a)** Define electric field.

....

....

.... [2]

(b) Fig. 5.1 shows two parallel conducting plates that are in a vacuum. The plates are separated by a distance of 6.7 cm and have a potential difference (p.d.) of 430 V between them.

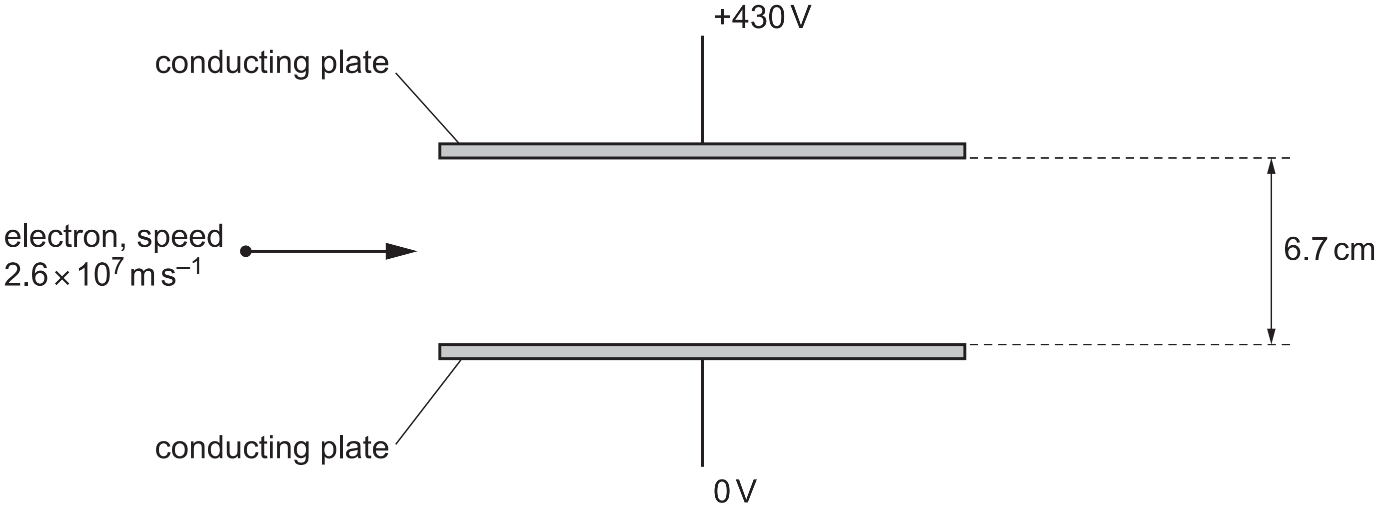


Fig. 5.1

(i) On Fig. 5.1, draw four field lines to represent the electric field between the plates. [2]

(ii) Determine the strength E of the electric field between the plates.

E = ... $\mathrm{N\,C^{-1}}$ [2]

(iii) An electron travels at a speed of $2.6 \times 10^7\,\mathrm{m\,s^{-1}}$ towards the region between the plates, as shown in Fig. 5.1.

On Fig. 5.1, draw the path of the electron as it moves between and beyond the plates. [2]

(c) A uniform magnetic field is now applied in the region of the electric field in Fig. 5.1, so that the electron in **(b)(iii)** travels undeviated through the region.

(i) Determine the direction of the uniform magnetic field.

.... [1]

(ii) Explain, with reference to the forces exerted by the two fields on the electron, why the path of the electron is undeviated.

....

....

.... [2]

(iii) Determine the flux density *B* of the uniform magnetic field. Give a unit with your answer.

B = ... unit .... [2]

[Total: 13]

18.2 Uniform electric fields

Name: ______________ Class: __________ Date: ____________ **Total: 17 marks**

KEY WORDS electric field 电场 • uniform field 匀强场 • field line 场线 • electron 电子 • parabolic 抛物线

Objective

Build the skills to answer exam questions on **uniform electric fields** between parallel plates.

You must be able to:

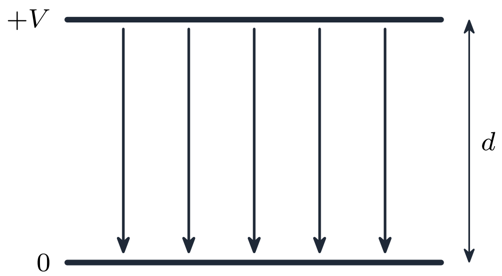
- use $E = V/d$ for the field between parallel plates
- describe the motion of a **charged particle** in a uniform field

1 Worked examples

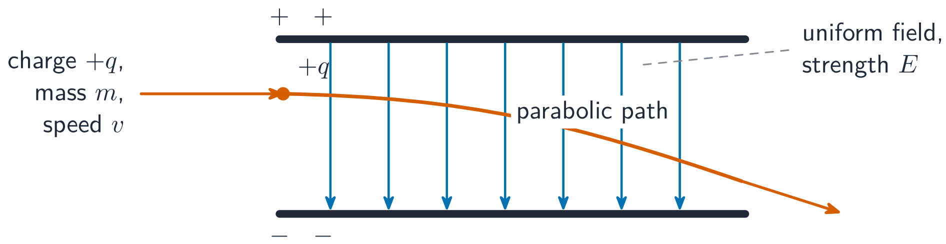
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Field between plates

Between parallel plates a distance d apart with p.d. V, the field is **uniform**:



$E = V/d$



A charge follows a parabola in a uniform field

$$E = \frac{V}{d} \quad (\mathrm{V\ m^{-1} = N\ C^{-1}}),$$

pointing from the **higher** to the **lower** potential plate.

Charged particle in the field

A charge in the field feels a **constant force** $F = qE$, so it has a **constant acceleration** $a = \frac{F}{m} = \frac{qE}{m}$. A particle entering **perpendicular** to the field follows a **parabolic** path (like a projectile in gravity); a particle released **from rest** accelerates straight along the field, towards the plate of **opposite** sign to its charge.

Worked example. Plates 5.0 mm apart, 200 V: $E = \frac{200}{5.0 \times 10^{-3}} = 4.0 \times 10^{4}\ \mathrm{V\ m^{-1}}$; force on an electron $= qE = (1.6 \times 10^{-19})(4.0 \times 10^{4}) = 6.4 \times 10^{-15}$ N; acceleration $a = \frac{F}{m} = \frac{6.4 \times 10^{-15}}{9.1 \times 10^{-31}} = 7.0 \times 10^{15}\ \mathrm{m\ s^{-2}}$.

2 Practice

Now apply the methods above.

2.1 Write the equation for the field strength between **parallel plates**. [1]

2.2 Two plates 5.0 mm apart have a p.d. of 200 V. Find the **field strength**. [2]

2.3 State the **direction** of the field between two charged plates. [1]

2.4 State the unit equal to V m^{-1}. [1]

3 Exam-style questions

3.1 The electric field between two parallel charged plates is: [1]

- **A** radial
- **B** uniform
- **C** zero
- **D** circular

3.2 Two plates 5.0 mm apart have a p.d. of 200 V. Calculate (a) the field strength, (b) the force on an electron in the gap. ($e = 1.6 \times 10^{-19}$ C.) [3]

3.3 Describe the **path** of an electron that enters the uniform field **perpendicular** to the field lines. [2]

3.4 State what happens to the force on a charge if the plate separation is **halved** (same p.d.). [1]

3.5 An electron is released from rest at the negative plate of two plates 8.0 mm apart with a p.d. of 250 V. ($e = 1.6 \times 10^{-19}$ C, $m_e = 9.1 \times 10^{-31}$ kg.)

(a) Calculate the field strength between the plates. [2]

(b) Calculate the **acceleration** of the electron. [3]

Solutions

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

2.1

- $E = V/d$

2.2

- $E = V/d$

$$E = \frac{200\ \text{V}}{5.0 \times 10^{-3}\ \text{m}} = \mathbf{4.0 \times 10^{4}}\ \text{V m}^{\mathbf{-1}}$$

2.3

- from the **higher-potential** plate to the **lower-potential** plate

2.4

- N C^{-1}

3.1 B

- parallel plates a small distance apart give a **uniform** field

3.2

(a) $E = V/d$

$$E = \frac{200\ \text{V}}{5.0 \times 10^{-3}\ \text{m}} = \mathbf{4.0 \times 10^{4}}\ \text{V m}^{\mathbf{-1}}$$

(b) $F = qE$

$$F = (1.6 \times 10^{-19}\ \text{C})(4.0 \times 10^{4}\ \text{V m}^{-1}) = \mathbf{6.4 \times 10^{-15}}\ \text{N}$$

3.3

- it follows a **parabolic** path
- constant velocity along the plates, constant acceleration across the field (like a projectile)

3.4

- the force **doubles** ($E = V/d$, so halving d doubles E and hence $F = qE$)

3.5

(a) $E = V/d$

$$E = \frac{250\ \text{V}}{8.0 \times 10^{-3}\ \text{m}} = \mathbf{3.1 \times 10^{4}}\ \text{V m}^{\mathbf{-1}}$$

(b) $F = qE$

$$F = (1.6 \times 10^{-19}\ \text{C})(3.1 \times 10^{4}\ \text{V m}^{-1}) = 5.0 \times 10^{-15}\ \text{N}$$

- $a = F/m$

$$a = \frac{5.0 \times 10^{-15}\ \text{N}}{9.1 \times 10^{-31}\ \text{kg}} = \mathbf{5.5 \times 10^{15}}\ \text{m s}^{\mathbf{-2}}$$

6 Two parallel metal plates X and Y are separated by a distance of 0.041 m, as shown in Fig. 6.1.

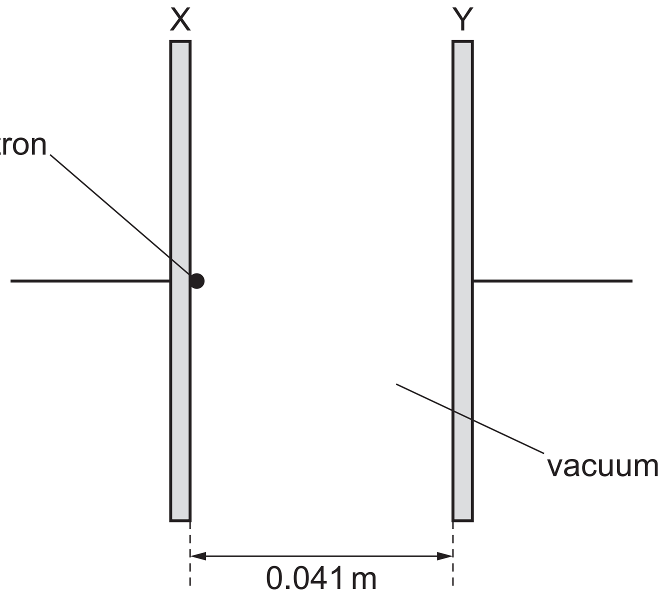


Fig. 6.1

There is a vacuum between the plates. An electron is at rest at the centre of plate X.

A potential difference (p.d.) of 58 kV is applied across the plates. This causes the electron to accelerate towards plate Y.

(a) On Fig. 6.1, use the symbols + and – to indicate which of plates X and Y is the positive plate and which is the negative plate. [1]

(b) **(i)** Calculate the electric field strength E between the plates. Give a unit with your answer.

E = ... unit .... [2]

(ii) Determine the acceleration of the electron.

acceleration = ... $m\,s^{-2}$ [2]

(c) Many electrons are now accelerated from rest from plate X to plate Y in Fig. 6.1. When the electrons hit plate Y, the absorption of their kinetic energies results in the emission of electromagnetic waves.

(i) Show that the minimum wavelength of these electromagnetic waves is 21 pm.

[3]

(ii) State the region of the electromagnetic spectrum that contains these waves.

.... [1]

(iii) Explain how these electromagnetic waves may be used to form images of internal body structures.

....

....

....

.... [2]

[Total: 11]

6 An electric field and a magnetic field are used to form a velocity selector. Charged particles, called ions, pass into a region of uniform electric and magnetic fields that is between parallel plates, as shown in Fig. 6.1.

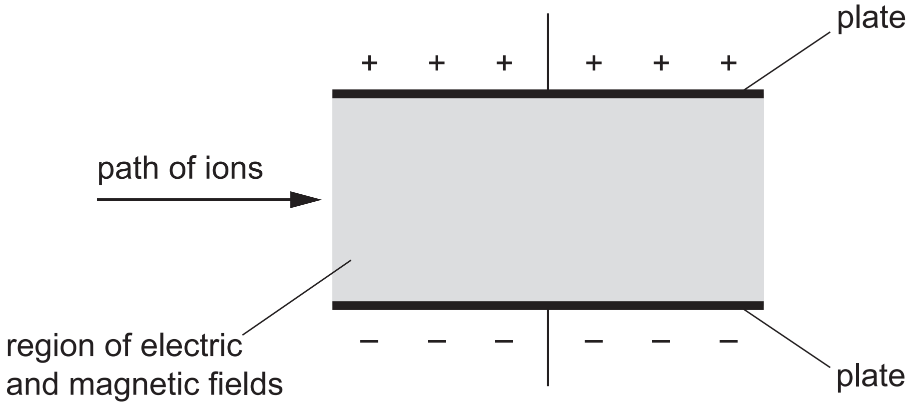


Fig. 6.1

(a) The potential difference (p.d.) between the plates of the velocity selector is V. The separation of the plates is d and the magnetic flux density is B.

Show that the speed u of ions that pass undeviated through the velocity selector is given by

$$u = \frac{V}{Bd}.$$

[2]

(b) Positive ions with kinetic energy 4.1×10^{-17} J and mass 3.2×10^{-27} kg pass undeviated through the velocity selector when V is equal to 980 V and d is equal to 3.6×10^{-2} m.

Determine B.

B = ... T [3]

(c) A proton passes undeviated through the velocity selector.

An alpha particle enters the velocity selector at the same speed as the proton.

State how the expression in **(a)** predicts that the alpha particle also passes undeviated through the velocity selector.

....

.... [1]

(d) By reference to Fig. 6.1 and to the forces acting on a positive ion, determine the direction of the magnetic field. Explain your reasoning.

....

....

....

....

....

.... [3]

(e) The positive ions in **(b)** enter the velocity selector with greater kinetic energy.

On Fig. 6.1, sketch the path of these ions. [2]

[Total: 11]

A-LEVEL PHYSICS • EXERCISE SHEET

18.3 Electric force between point charges

Name: ______________ Class: __________ Date: ____________ **Total: 23 marks**

KEY WORDS point charge 点电荷 • coulomb's law 库仑定律 • force 力

Objective

Build the skills to answer exam questions on **Coulomb's law** — the force between two point charges.

You must be able to:

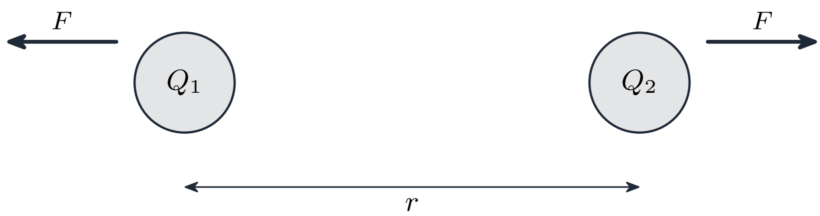
- use Coulomb's law $F = \dfrac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}$
- treat a charged sphere as a **point charge** at its centre

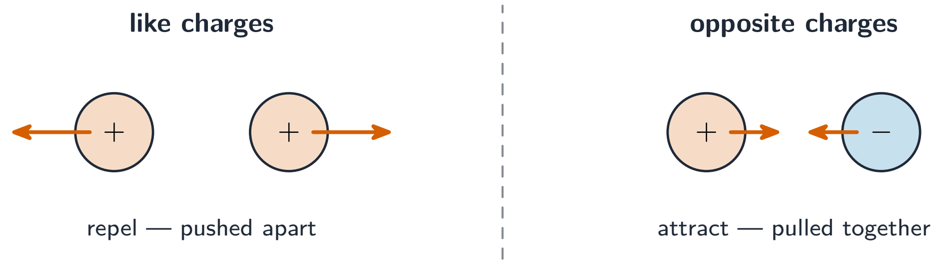
1 Worked examples

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.

■ Coulomb's law

Two point charges a distance r apart exert **equal, opposite** forces along the line joining them:





Coulomb force between point charges

$$F = \frac{Q_1 Q_2}{4\pi\varepsilon_0 r^2}, \qquad \frac{1}{4\pi\varepsilon_0} = 9.0 \times 10^9\ \mathrm{N\,m^2\,C^{-2}}.$$

Like charges repel; **opposite** charges attract. A charged sphere acts as a **point charge at its centre**.

Worked example. $+2.0$ nC and $+3.0$ nC, 4.0 cm apart:

$$F = \frac{(9.0 \times 10^9)(2.0 \times 10^{-9})(3.0 \times 10^{-9})}{(0.040)^2} = 3.4 \times 10^{-5}\ \mathrm{N}\ \text{(repulsive)}.$$

2 Practice

Now apply the methods above.

2.1 State **Coulomb's law**. [2]

2.2 State the value of $\dfrac{1}{4\pi\varepsilon_0}$. [1]

2.3 State whether **like** charges attract or repel. [1]

3 Exam-style questions

3.1 If the distance between two charges is **doubled**, the Coulomb force becomes: [1]

- **A** twice as large
- **B** half as large
- **C** one quarter as large
- **D** four times as large

3.2 Calculate the force between point charges of +2.0 nC and +3.0 nC placed 4.0 cm apart. [3]

3.3 Two charges of +5.0 nC are 2.0 cm apart. Calculate the force between them, and state whether it is attractive or repulsive. [3]

3.4 A simplified model of a helium atom has a nucleus of charge $+2e$ with two electrons in a circular orbit of radius 2.6×10^{-11} m around it. Take $e = 1.60 \times 10^{-19}$ C, $\frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^{9}$ m F^{-1} and the electron mass as 9.11×10^{-31} kg. Ignore the force between the two electrons.

(a) **State** Coulomb's law. [2]

(b) **Show that** the electric force between the nucleus and one electron is about 1.4×10^{-7} N. [2]

(c) This force provides the centripetal force on the electron. **Calculate** the speed of the orbiting electron. [3]

(d) **Determine** the period of the orbit. [2]

(e) **Determine** the ratio $\dfrac{\text{electric force on the electron}}{\text{gravitational force on the electron}}$, given that the nucleus has mass 6.6×10^{-27} kg and $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}, and **suggest** what your answer means for a model of the atom. [3]

Solutions

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

2.1

- the force between two **point charges** is **proportional to the product of the charges**
- and **inversely proportional to the square of their separation**

2.2

- $1/(4\pi\varepsilon_0) = 9.0 \times 10^9$ N m^2 C^{-2}

2.3

- they **repel**

3.1 C

- $F \propto 1/r^2$, so doubling r makes F **one quarter**

3.2

- $F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$

$$F = \frac{(9.0 \times 10^9 \text{ N m}^2\,\text{C}^{-2})(2.0 \times 10^{-9} \text{ C})(3.0 \times 10^{-9} \text{ C})}{(0.040 \text{ m})^2} = \mathbf{3.4 \times 10^{-5}} \text{ N}$$

3.3

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

$$F = \frac{(9.0 \times 10^9 \text{ N m}^2\,\text{C}^{-2})(5.0 \times 10^{-9} \text{ C})^2}{(0.020 \text{ m})^2} = \mathbf{5.6 \times 10^{-4}} \text{ N}$$

- **repulsive** (like charges)

3.4

(a) the electric force between two **point charges** is proportional to the **product of the charges**

- and inversely proportional to the **square of their separation**

(b) $F = Q_1Q_2/(4\pi\varepsilon_0 r^2)$

$$F = (8.99 \times 10^9 \text{ N m}^2\,\text{C}^{-2})\frac{(2 \times 1.60 \times 10^{-19} \text{ C})(1.60 \times 10^{-19} \text{ C})}{(2.6 \times 10^{-11} \text{ m})^2} \approx \mathbf{1.4 \times 10^{-7}} \text{ N}$$

(c) the electric force is the centripetal force: $mv^2/r = F$

$$v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{(1.36 \times 10^{-7} \text{ N})(2.6 \times 10^{-11} \text{ m})}{9.11 \times 10^{-31} \text{ kg}}} = \mathbf{2.0 \times 10^6} \text{ m s}^{-1}$$

(d) $T = 2\pi r/v$

$$T = \frac{2\pi(2.6 \times 10^{-11}\ \mathrm{m})}{2.0 \times 10^{6}\ \mathrm{m\ s^{-1}}} = \mathbf{8.2 \times 10^{-17}}\ \mathrm{s}$$

(e) $F_{\mathrm{grav}} = GMm/r^2$

$$F_{\mathrm{grav}} = \frac{(6.67 \times 10^{-11}\ \mathrm{N\ m^2\,kg^{-2}})(6.6 \times 10^{-27}\ \mathrm{kg})(9.11 \times 10^{-31}\ \mathrm{kg})}{(2.6 \times 10^{-11}\ \mathrm{m})^2} = 5.9 \times 10^{-46}\ \mathrm{N}$$

$$\frac{1.4 \times 10^{-7}\ \mathrm{N}}{5.9 \times 10^{-46}\ \mathrm{N}} = \mathbf{2 \times 10^{38}}$$

- gravity is utterly negligible on this scale, so a model of the atom can ignore it and keep only the electric force

2 A helium atom may be modelled as a nucleus surrounded by two electrons in diametrically opposite circular orbits, each of radius 170 pm, as shown in Fig. 2.1.

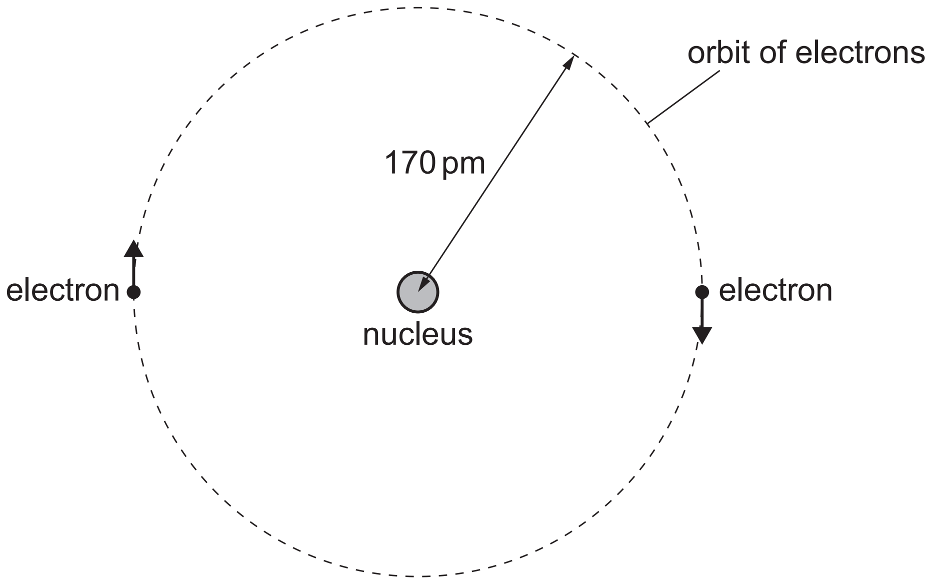


Fig. 2.1

(a) State Coulomb's law.

....

....

.... [2]

(b) (i) State the charge on the nucleus, in terms of the elementary charge e.

charge = ... e [1]

(ii) Show that the electric force between the nucleus and one of the electrons is 1.6×10^{-8} N.

[1]

(c) Assume that the force in **(b)(ii)** is the only force on the electrons.

(i) Calculate the speed of the orbiting electrons.

speed = ... $m\,s^{-1}$ [2]

(ii) Calculate the period of the orbit of the electrons.

period = ... s [2]

(d) In practice, the orbit of each electron is affected by the presence of the other electron.

(i) For the position of one of the electrons, determine the ratio

$$\frac{\text{electric field strength due to the other electron}}{\text{electric field strength due to the nucleus}}.$$

ratio = ... [2]

(ii) Use your answer in **(d)(i)** to suggest and explain how the orbit of the electron is affected by the presence of the other electron.

....

.... [1]

[Total: 11]

2 A helium atom may be modelled as a nucleus surrounded by two electrons in diametrically opposite circular orbits, each of radius 170 pm, as shown in Fig. 2.1.

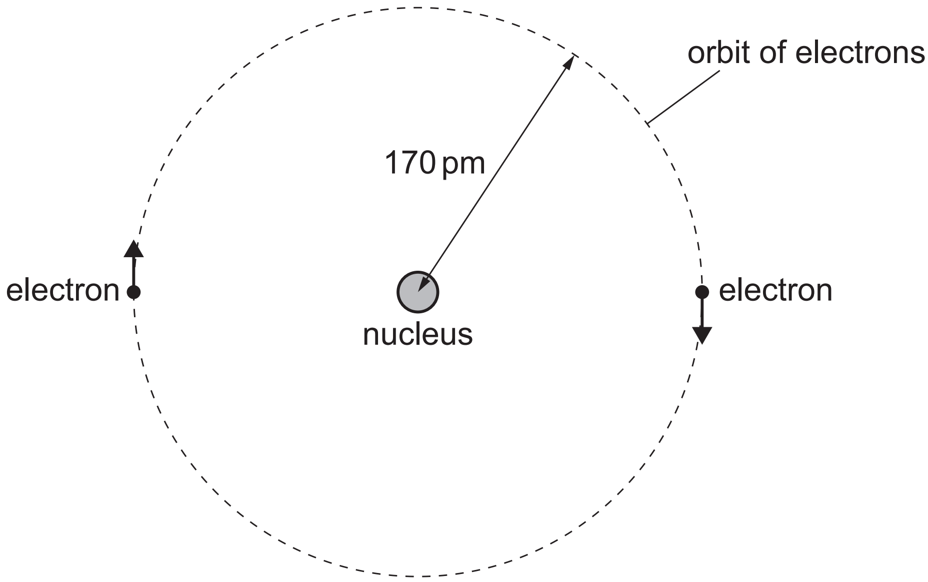


Fig. 2.1

(a) State Coulomb's law.

....

....

.... [2]

(b) **(i)** State the charge on the nucleus, in terms of the elementary charge *e*.

charge = ... *e* [1]

(ii) Show that the electric force between the nucleus and one of the electrons is 1.6×10^{-8} N.

[1]

(c) Assume that the force in **(b)(ii)** is the only force on the electrons.

(i) Calculate the speed of the orbiting electrons.

speed = ... $m\,s^{-1}$ [2]

(ii) Calculate the period of the orbit of the electrons.

period = ... s [2]

(d) In practice, the orbit of each electron is affected by the presence of the other electron.

(i) For the position of one of the electrons, determine the ratio

$$\frac{\text{electric field strength due to the other electron}}{\text{electric field strength due to the nucleus}}.$$

ratio = ... [2]

(ii) Use your answer in **(d)(i)** to suggest and explain how the orbit of the electron is affected by the presence of the other electron.

....

.... [1]

[Total: 11]

4 **(a)** State Coulomb's law.

....

....

....

.... [2]

(b) A charged sphere X is supported on an insulating stand. A second charged sphere Y is suspended by an insulating thread so that sphere Y is in equilibrium at the position shown in Fig. 4.1.

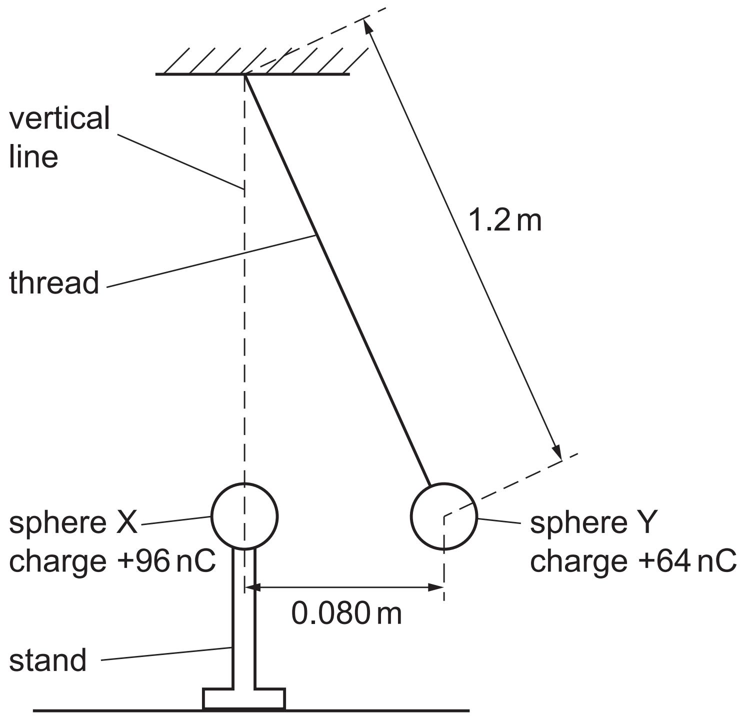


Fig. 4.1

The charge on sphere X is +96 nC and the charge on sphere Y is +64 nC.
Assume that the spheres behave as point charges.

The length of the thread is 1.2 m and the centres of sphere X and sphere Y are separated horizontally by a distance of 0.080 m.

(i) On Fig. 4.2, draw and label all the forces acting on sphere Y.

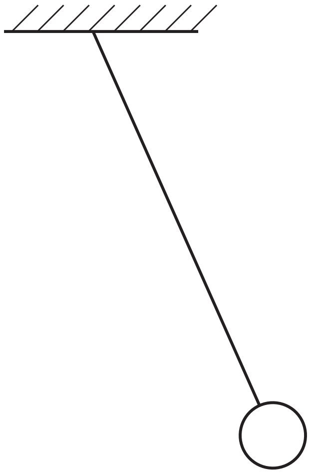


Fig. 4.2

[1]

(ii) Determine the mass of sphere Y.

mass = ... kg [4]

(iii) Calculate the total electric potential energy stored between X and Y.

energy = ... J [1]

(c) An electron enters the region between two parallel plates P and Q, that are separated by a distance of 18 mm, as shown in Fig. 4.3.

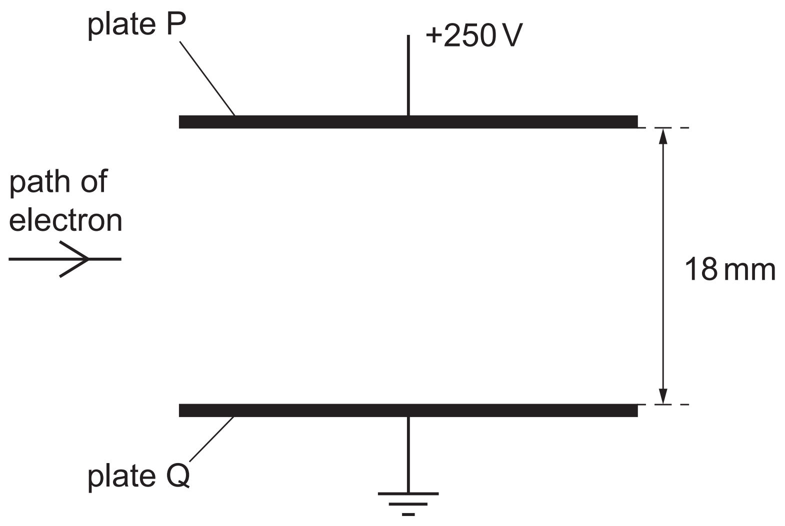


Fig. 4.3

The space between the plates is a vacuum.
The potential difference between the plates is 250 V. The electric field may be assumed to be uniform in the region between the plates and zero outside this region.

(i) State the direction of the electric force on the electron when between the plates.

.... [1]

(ii) Determine the magnitude of the force acting on the electron due to the electric field.

force = ... N [2]

(iii) Explain why the electron does **not** follow a circular path.

....

.... [1]

[Total: 12]

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

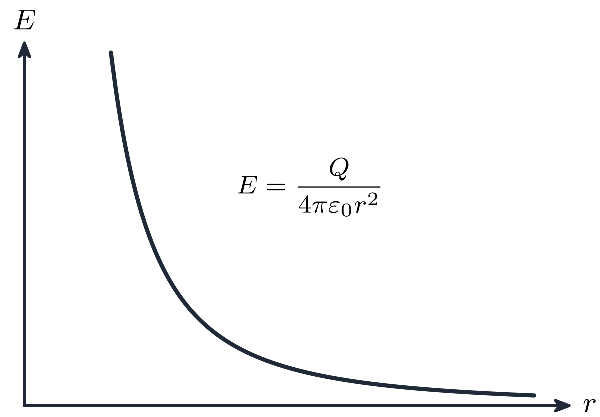
1 Worked examples

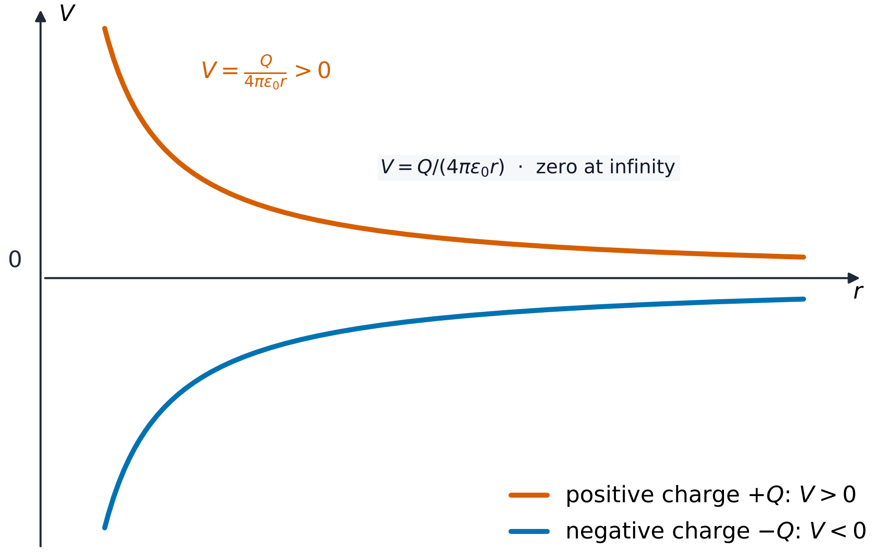
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ 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

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

....

....

....

....

.... [3]

(b) An isolated metal sphere is positively charged and has radius R, as shown in Fig. 5.1.

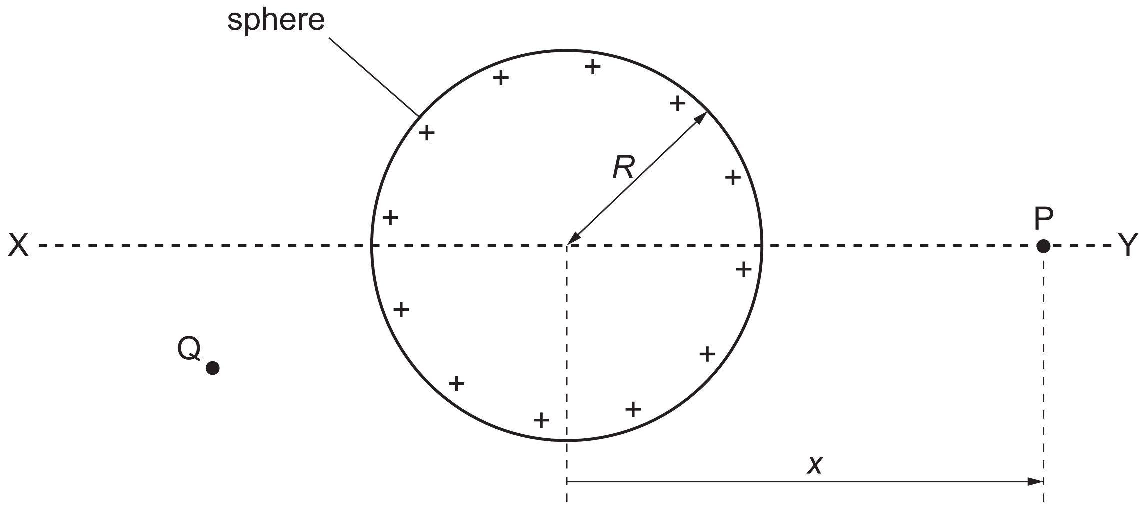


Fig. 5.1

Line XY passes through the centre of the sphere.
Point P lies on line XY at a variable displacement x from the centre of the sphere.
Point Q is at a fixed position that is not on line XY.

The electric field strength at the surface of the sphere is E_0.

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

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

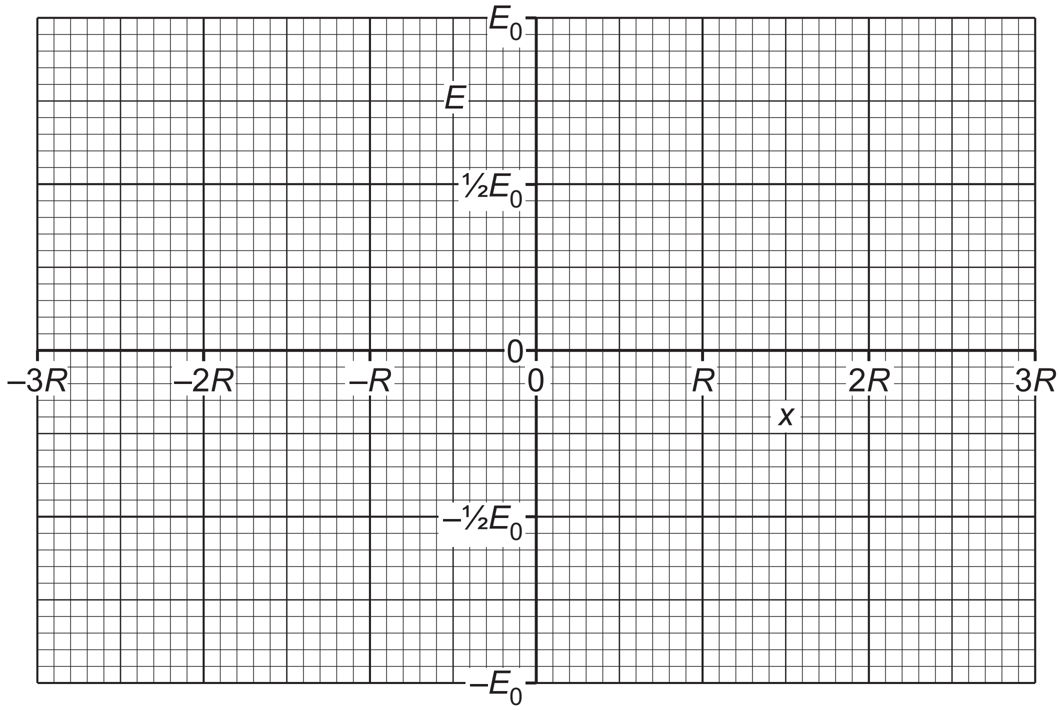


Fig. 5.2

[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.

electric potential energy = ... J [2]

[Total: 9]

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

....

....

.... [2]

(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 $3r$ from the centre of the sphere, the electric field strength is 2.0×10^5 N C^{-1}.

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

electric field strength = ... N C^{-1} [2]

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

[2]

(iii) Calculate the charge on the sphere.

charge = ... C [2]

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

capacitance = ... F [2]

[Total: 10]

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:

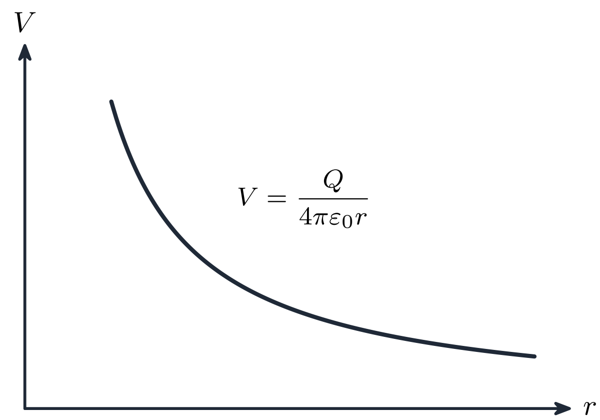
- define **electric potential** and use $V = \dfrac{Q}{4\pi\varepsilon_0 r}$
- use $E_\mathrm{P} = \dfrac{Qq}{4\pi\varepsilon_0 r}$ and $E = -$potential gradient

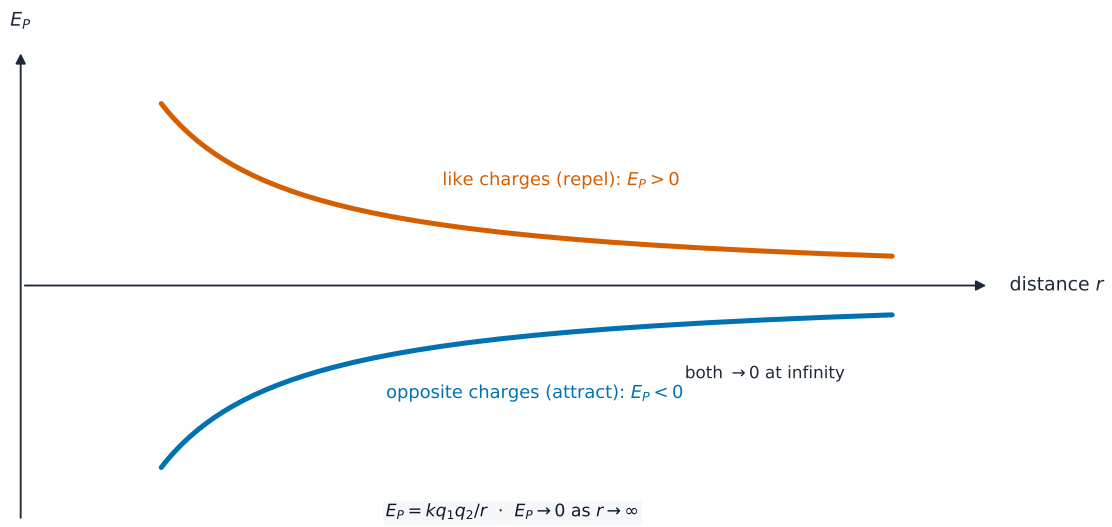
1 Worked examples

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

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

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

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

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

3.3

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

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

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

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

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

- $x = \mathbf{0.15}$ 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) $V = Q/(4\pi\varepsilon_0 r)$

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

(c) B is 30 pm away

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

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

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

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

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

- $x = \mathbf{32}$ 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

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

....

....

.... [2]

(b) A hydrogen atom may be considered to consist of a proton and an electron separated by a distance of 120 pm, as shown in Fig. 5.1.

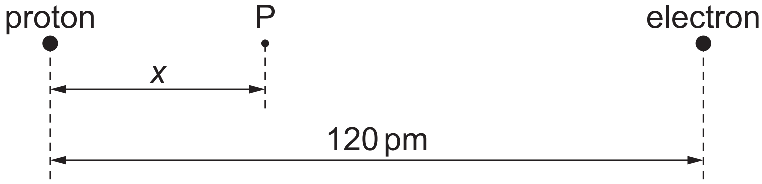


Fig. 5.1

The two particles may be considered as point charges.

Point P lies on the line joining the electron and the proton and is at a variable distance *x* from the proton.

(i) Show that the electric potential *V* at point P when $x = 10\,\text{pm}$ is equal to 130 V.

[2]

(ii) Calculate, to two significant figures, *V* when $x = 30\,\text{pm}$.

V = ...V [2]

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

(iv) On Fig. 5.2, sketch the variation of V with x between x = 10 pm and x = 110 pm.

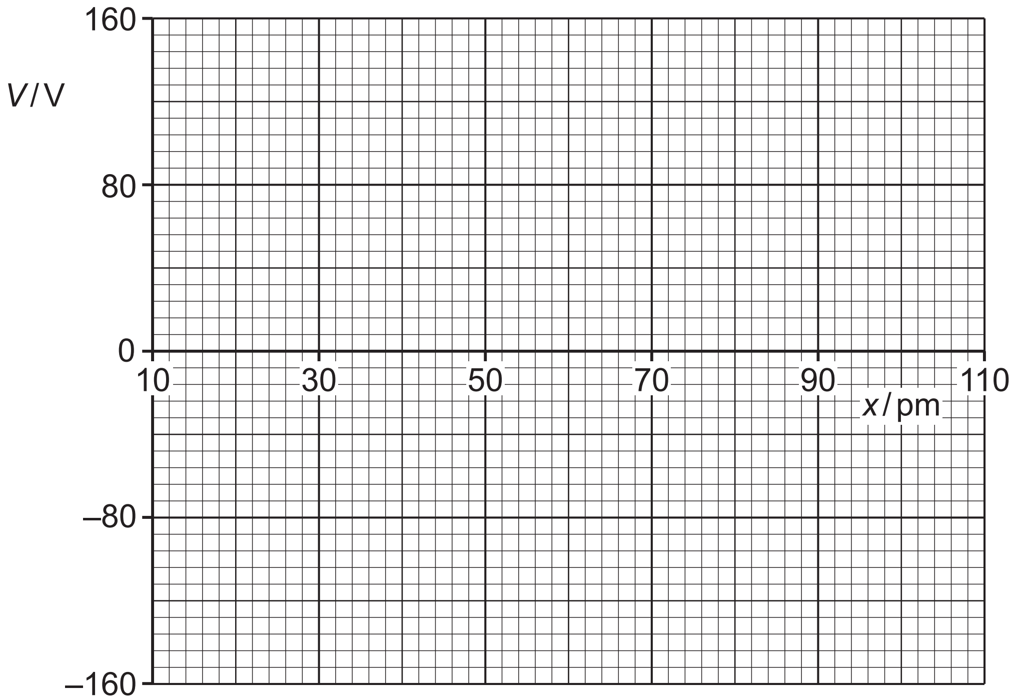


Fig. 5.2

[3]

[Total: 10]

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

....

....

....

....

.... [3]

(b) An isolated metal sphere is positively charged and has radius R, as shown in Fig. 5.1.

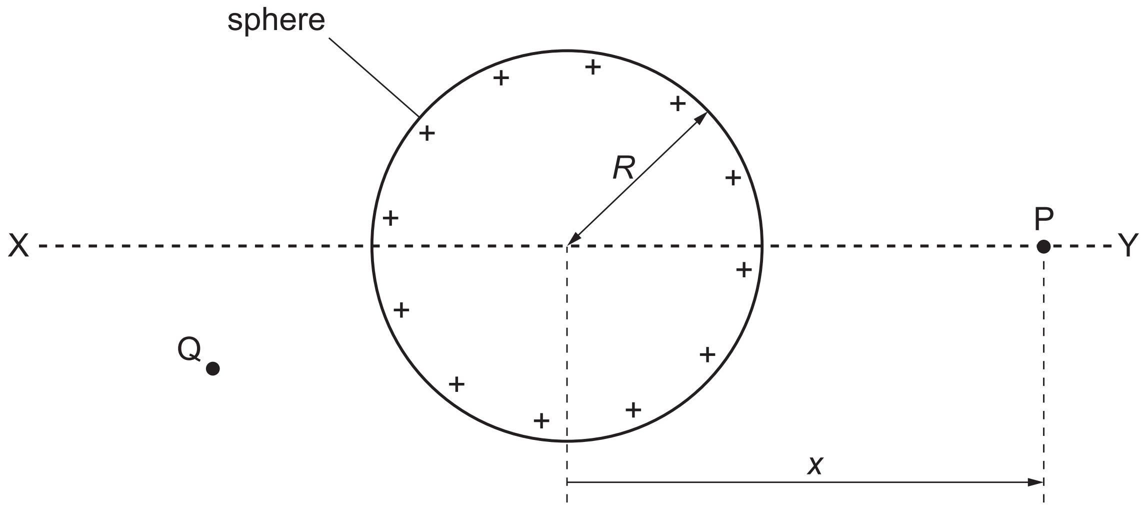


Fig. 5.1

Line XY passes through the centre of the sphere.
Point P lies on line XY at a variable displacement x from the centre of the sphere.
Point Q is at a fixed position that is not on line XY.

The electric field strength at the surface of the sphere is E_0.

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

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

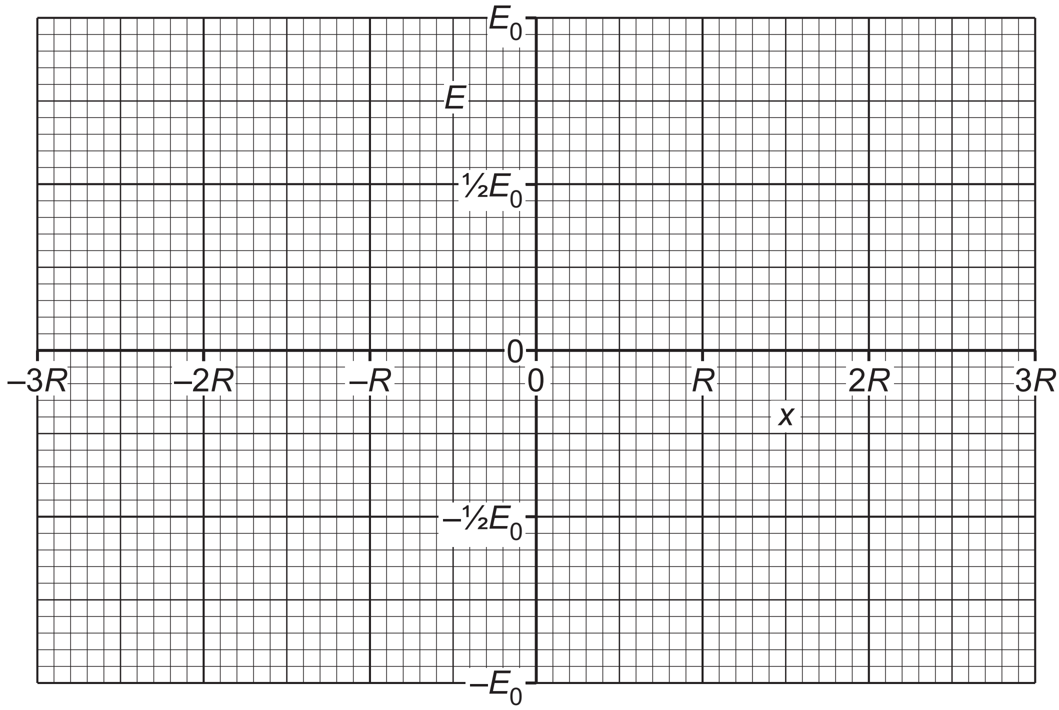


Fig. 5.2

[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.

electric potential energy = ... J [2]

[Total: 9]

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

....

....

.... [2]

(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 2.0×10^5 N C^{-1}.

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

electric field strength = ... N C^{-1} [2]

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

[2]

(iii) Calculate the charge on the sphere.

charge = ... C [2]

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

capacitance = ... F [2]

[Total: 10]