Cambridge

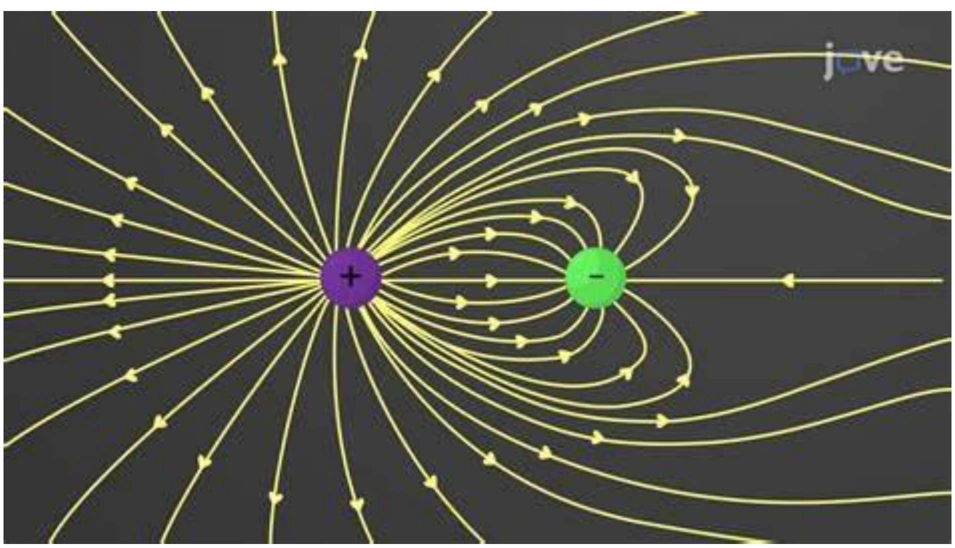
IGCSE

Physics

CODE: (9702)

Chapter 08

Electric fields



Attraction and repulsion

Static electricity is crucial for photocopying, dust precipitation, and crop-spraying, but can also cause shocks when discharged, as it builds up in our bodies and can cause discomfort when we touch it, such as when exiting a car or touching a door handle.

We explain these effects in terms of electric charge. Simple observations in the laboratory give us the following picture:

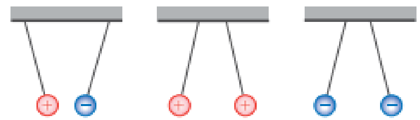


Figure 8.2 Attraction and repulsion between electric charges.

■ Objects are usually electrically neutral (uncharged), but they may become electrically charged,
■ There are two types of charge, which we call positive and negative.
■ Opposite types of charge attract one another; like charges repel (Figure 8.2).
■ A charged object may also be able to attract an uncharged one; this is a result of electrostatic induction.

Macroscopic observations describe phenomena observed in the laboratory without considering microscopic scale phenomena like atoms and electrons. Matter consists of three types of particles: electrons (negative charge), protons (positive), and neutrons (neutral). An uncharged object has equal numbers of protons and electrons, whose charges cancel out. When rubbed against another material, friction occurs, causing electrons to be rubbed onto one, resulting in a negative-charged material and a positive-charged material.

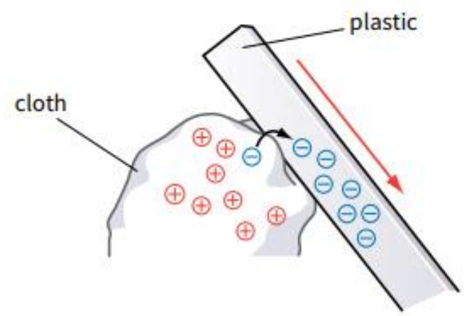


Figure 8.3 Friction can transfer electrons between materials.

The concept of an electric field

An electric field is a force experienced by a charged object, where another magnet experiences a force. This concept is more familiar from the experience of magnets and the gravitational field, which is the force exerted on us by the Earth's gravitational field.
So we have:
■Electric fields – act on objects with electric charge
■Magnetic fields – act on magnetic materials, magnets and moving charges (including electric currents)
■■ Gravitational fields – act on objects with mass

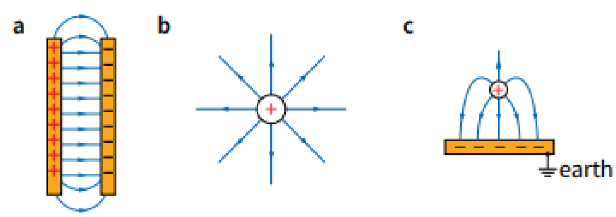


Figure 8.6 Field lines are drawn to represent an electric field. They show the direction of the force on a positive charge placed at a point in the field. **a** A uniform electric field is produced between two oppositely charged plates. **b** A radial electric field surrounds a charged sphere. **c** The electric field between a charged sphere and an earthed plate.

Representing electric fields

Electric fields can be represented using field lines, similar to magnetic fields. Figure 8.6 shows three key field shapes, indicating the direction and strength of the field. Arrows indicate the force on a positive charge.

■ A uniform field has the same strength at all points. Example: the electric field between oppositely charged parallel plates.

■ A radial field spreads outwards in all directions. Example: the electric field around a point charge or a charged sphere.

Electric field strength

For an electric field, we define electric field strength E as follows:

The **electric field strength** at a point is the force per unit charge exerted on a stationary positive charge at that point.

To define electric field strength, a positive test charge +Q is placed in the field and the electric force F is measured, illustrating the principle of testing with a charge.

From this definition, we can write an equation for E:

$$E = \frac{F}{Q}$$

It follows that the units of electric field strength are newtons per coulomb ($\mathrm{N\,C^{-1}}$).

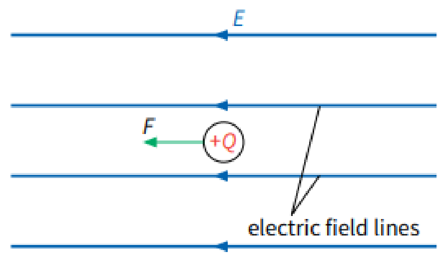


Figure 8.10 A field of strength *E* exerts force *F* on charge +*Q*.

The strength of a uniform field

he strength of the field between them depends on two factors:

- the voltage *V* between the plates – the higher the voltage, the stronger the field: $E \propto V$
- the separation *d* between the plates – the greater their separation, the weaker the field: $E \propto \frac{1}{d}$

These factors can be combined to give an equation for E:

$$E = -\frac{V}{d}$$

we are often interested in the **magnitude** of the electric field strength; hence we can write:

E = V/ d

From this equation, we can see that we can write the units of electric field strength as volts per metre ($\mathrm{V\,m^{-1}}$). Note:

$$1\,\mathrm{V\,m^{-1}} = 1\,\mathrm{N\,C^{-1}}$$

Worked example 2 shows how to solve problems involving uniform fields.

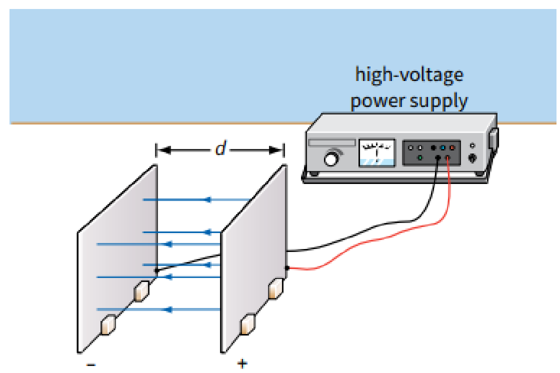


Figure 8.11 There is a uniform field between two parallel, charged plates.

Force on a charge

Now we can calculate the force F on a charge Q in the uniform field between two parallel plates. We have to combine the general equation for field strength

$E = \frac{F}{Q}$ with

the equation for the strength of a uniform field $E = -\frac{V}{d}$.

This gives:

$$F = QE = -\frac{QV}{d}$$

For an electron with charge $-e$, this becomes:

$$F = \frac{eV}{d}$$

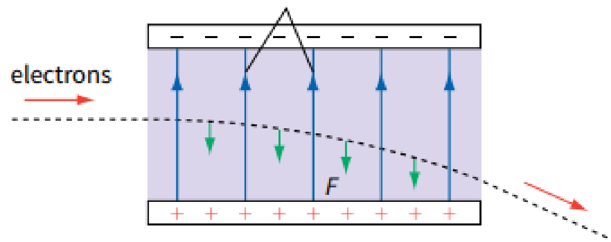


Figure 8.14 The parabolic path of a moving electron in a uniform electric field.

Figure 8.14 illustrates a situation where a beam of electrons enters space between charged parallel plates. The electron is pushed downwards due to the negative relative position of the upper and lower plates. This causes the electron to accelerate downwards, following a curved path, a parabola.

The force on an electron is constant at all points between plates and always downwards, resembling a ball thrown horizontally in Earth's gravitational field. The electron's electric force is negligible compared to gravity's force.

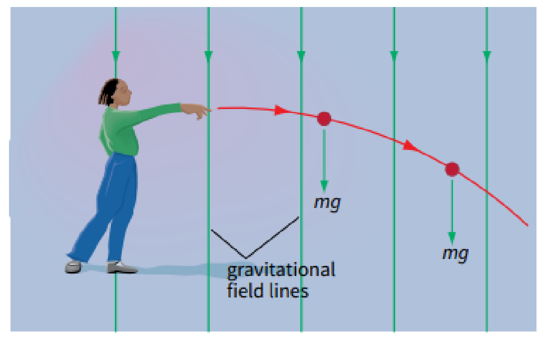


Figure 8.15 A ball, thrown in the uniform gravitational field of the Earth, follows a parabolic path.

Revision questions

1) a) Complete the table of quantities related to fields. In the second column, write an SI unit for each quantity. In the third column indicate whether the quantity is a scalar or a vector.

quantity	SI unit	scalar or vector
gravitational potential		
electric field strength		
magnetic flux density		

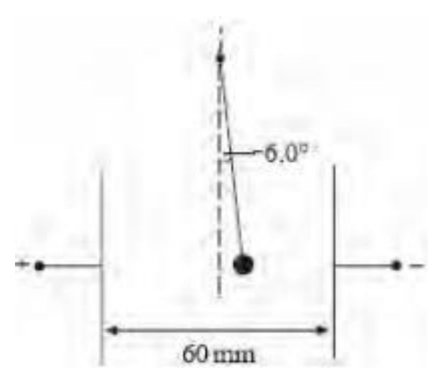
(b) (i) A charged particle is held in equilibrium by the force resulting from a vertical electric field. The mass of the particle is 4.3×10^{-9} kg and it carries a charge of magnitude 3.2×10^{-12} C. Calculate the strength of the electric field.

(ii) If the electric field acts upwards, state the sign of the charge carried by the particle

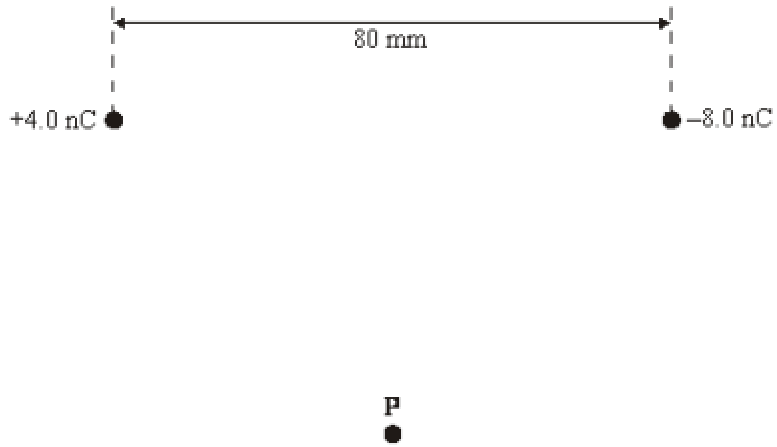
2) A small charged sphere of mass 2.1×10^{-4} kg, suspended from a thread of insulating material, was placed between two vertical parallel plates 60 mm apart. When a potential difference of 4200 V was applied to the plates, the sphere moved until the thread made an angle of 6.0° to the vertical, as shown in the diagram below.

(a) Show that the electrostatic force F on the sphere is given by F = mg tan 6.0°, where m is the mass of the sphere

(b) Calculate the charge on the sphere



3) (a) (i) Define the electric field strength, E, at a point in an electric field
(ii) State whether E is a scalar or a vector quantity
(b) Point charges of +4.0 nC and –8.0 nC are placed 80 mm apart, as shown in the figure below



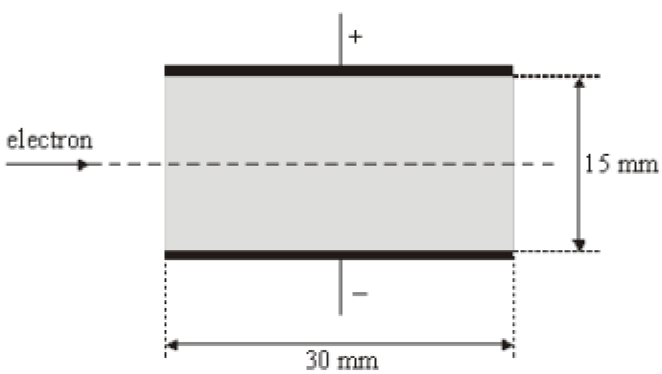
i) Calculate the magnitude of the force exerted on the +4.0 nC charge by the –8.0 nC charge
(ii) Determine the distance from the +4.0 nC charge to the point, along the straight line between the charges, where the electric potential is zero

(c) Point P in the figure above is equidistant from the two charges.

(i) Draw two arrows on the figure above at P to represent the directions and relative magnitudes of the components of the electric field at P due to each of the charges.

(ii) Hence draw an arrow, labelled R, on the figure above at P to represent the direction of the resultant electric field at P.

4) a) An electron travels at a speed of 3.2×10^{7} ms–1 in a horizontal path through a vacuum. The electron enters the uniform electric field between two parallel plates, 30 mm long and 15 mm apart, as shown in the figure below. A potential difference of 1400 V is maintained across the plates, with the top plate having positive polarity. Assume that there is no electric field outside the shaded area



(i) Show that the electric field strength between the plates is 9.3×10^{4} Vm^{-1}
(ii) Calculate the time taken by the electron to pass through the electric field
(b) Determine the magnitude and direction of the velocity of the electron at the point where it leaves the field.

5) Define electric field strength at a point in space.

b) Fig. 1 shows a square flat coil of insulated wire placed in a region of a uniform magnetic field of flux density B. The direction of the field is vertically out of the paper. The coil of side x has N turns.

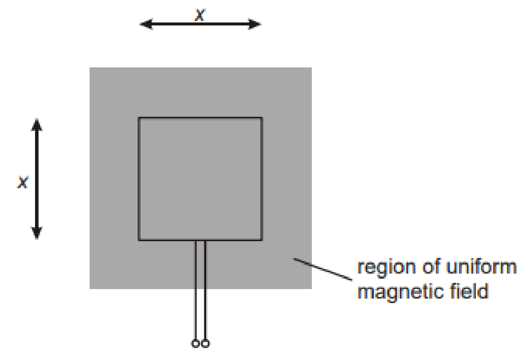


Fig. 1

(a) (i) Define the term magnetic flux

(ii) Show that the magnetic flux linkage of the coil in Fig. 1 is NBX^2

6) The coil of side x = 0.020 m is placed at position Y in Fig. 2 The ends of the 1250 turn coil are connected to a voltmeter. The coil moves sideways steadily through the region of magnetic field of flux density 0.032 T at a speed of 0.10 m s–1 until it reaches position Z. The motion takes 1.0 s.

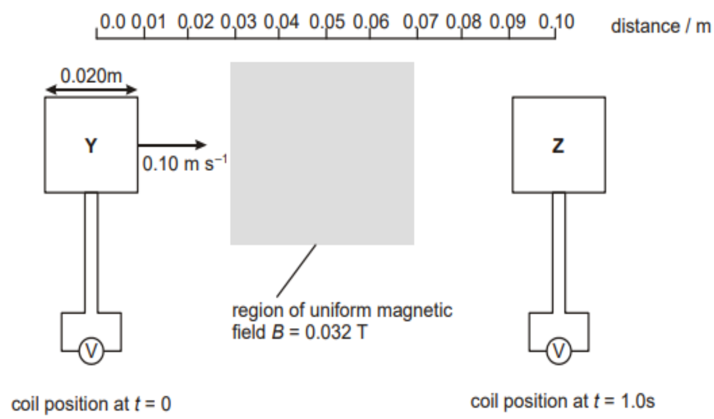


Fig. 2

(i) Show that the voltmeter reading as the coil enters the field region, after t = 0.20s, is 80 mV. Explain your reasoning fully

(ii) On Fig. 3, draw a graph of the voltmeter reading against time for the motion of the coil from Y to Z. Label the y-axis with a suitable scale.

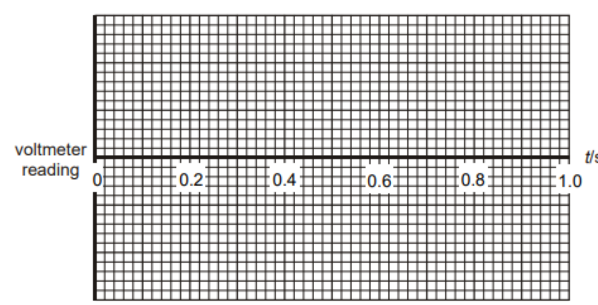


Fig. 3

7) In this question, two marks are available for the quality of written communication. To explain the laws of electromagnetic induction (Faraday's law and Lenz's law) Faraday introduced the concept of magnetic flux. Describe how the flux model is used in these laws. Start by defining magnetic flux and magnetic flux linkage.

8) This question is about electric forces.

A very small negatively-charged conducting sphere is suspended by an insulating thread from support S. It is placed close to a vertical metal plate carrying a positive charge. The sphere is attracted towards the plate and hangs with the thread at an angle of 20° to the vertical as shown in Fig. 1.

(a) Draw at least five electric field lines on Fig. 1 to show the pattern of the field between the plate and the sphere.

(b) The sphere of weight 1.0×10^{-5} N carries a charge of -1.2×10^{-9} C.

(i) Show that the magnitude of the attractive force between the sphere and the plate is about 3.6×10^{-6} N.

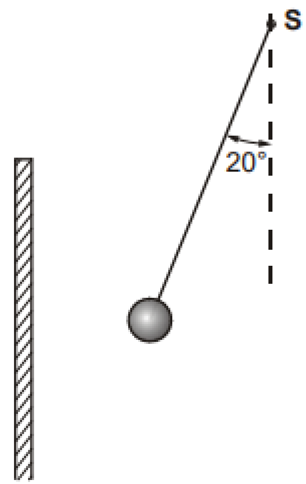


Fig. 1

(ii) Hence show that the value of the electric field strength at the sphere, treated as a point charge, is 3.0×10^3 in SI units. State the unit.

(c) The plate is removed. Fig. 2 shows an identical sphere carrying a charge of $+1.2 \times 10^{-9}$ C, mounted on an insulating stand. It is placed so that the hanging sphere remains at 20° to the vertical.

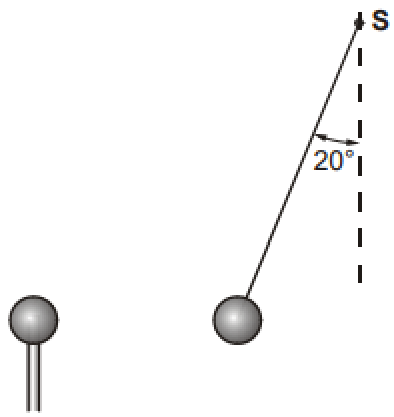


Fig. 2

Treating the spheres as point charges, calculate the distance r between their centres