13 This question is about a simple a.c. generator as shown in Fig. 13.1.

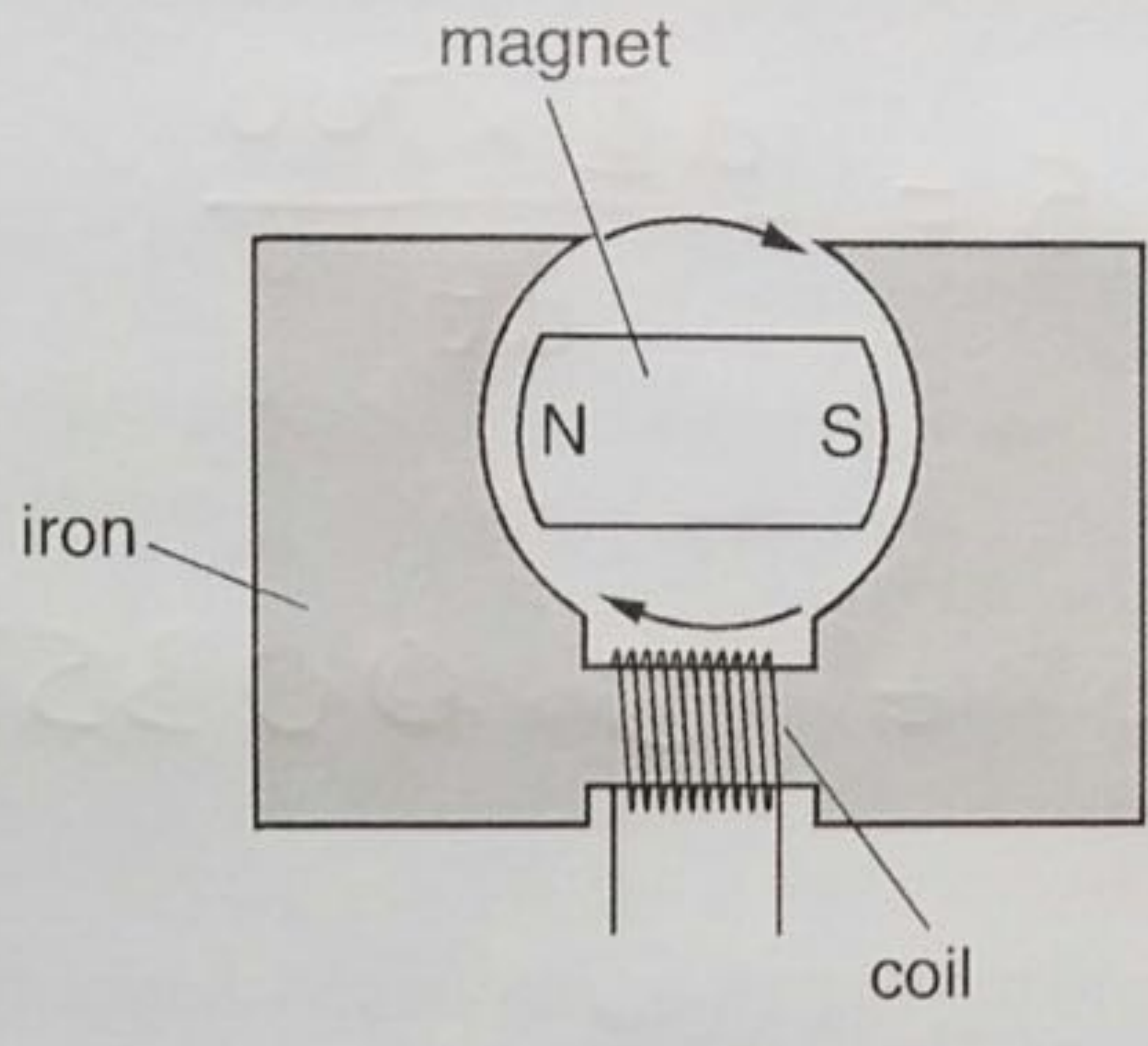


Fig. 13.1

Fig. 13.2 shows how the emf induced in the coil varies over time.

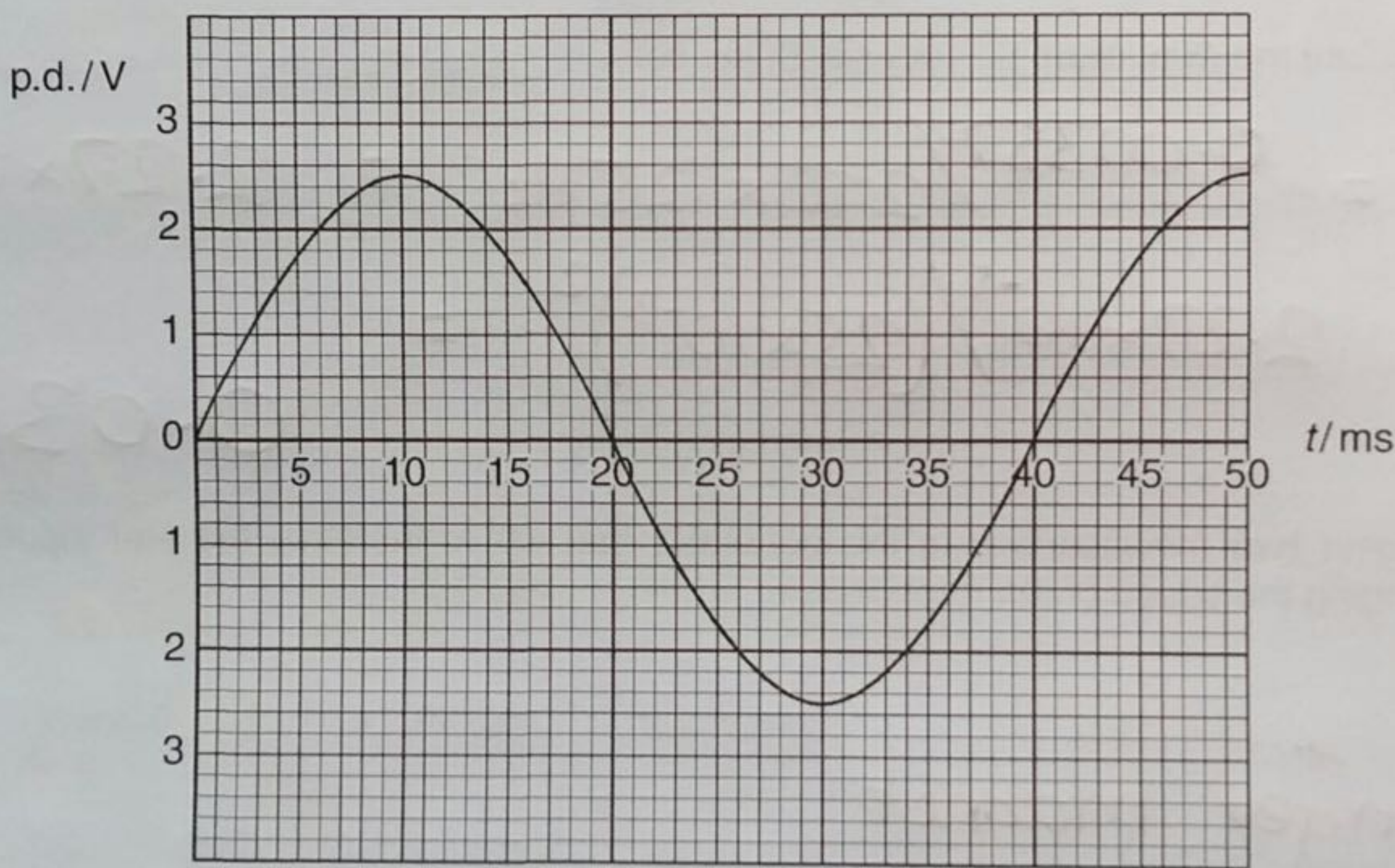


Fig. 13.2

(a) Use Fig. 13.2 to find the frequency f of the emf induced in the coil.

$f = \frac{1}{T} = 1/40\times10^{-3}$ $f =$ ......25...... Hz **[1]**

(b) The coil has 700 turns. Using data from the graph, explain by doing suitable calculations why the maximum rate of change of flux in the coil is $0.0036\,\text{Wb}\,\text{s}^{-1}$.

$$\mathcal{E} = \frac{d\Phi N}{dt} \qquad 2.5 = \frac{d\Phi \times 700}{dt}$$

$$\therefore \frac{d\Phi}{dt} = \frac{2.5}{700} = 0.00357\ \text{Wbs}^{-1}$$

[3]

(c) Assuming that the emf and flux are changing sinusoidally with frequency f, the rate of change of flux at time t is given by the equation

rate of change of flux = $2\pi f \times$ maximum flux $\times \cos(2\pi f t)$. = 1 at max

The core has a cross section of 25 mm × 25 mm.

Calculate the **maximum** flux density in the core.

max flux $= 0.00357/2\pi \times 25\,\text{Hz} = 2.27\times10^{-5}\ \text{Wb}$

$B = \Phi/A = 2.27\times10^{-5}/(25\times10^{-3})^2 =$

maximum flux density = 0.036 T [3]

(d) Suggest **two** modifications to the generator that would increase the emf induced without changing the speed of the rotor.

- stronger magnet
- more turns
- smaller air gap
- larger cross sectional area of core
- laminate core
- make core from material with higher permeability

[2]

[Total: 9]

[Section B Total: 38]

Section B

10 This question is about the design of a simple d.c. motor as shown in Fig. 10.1.

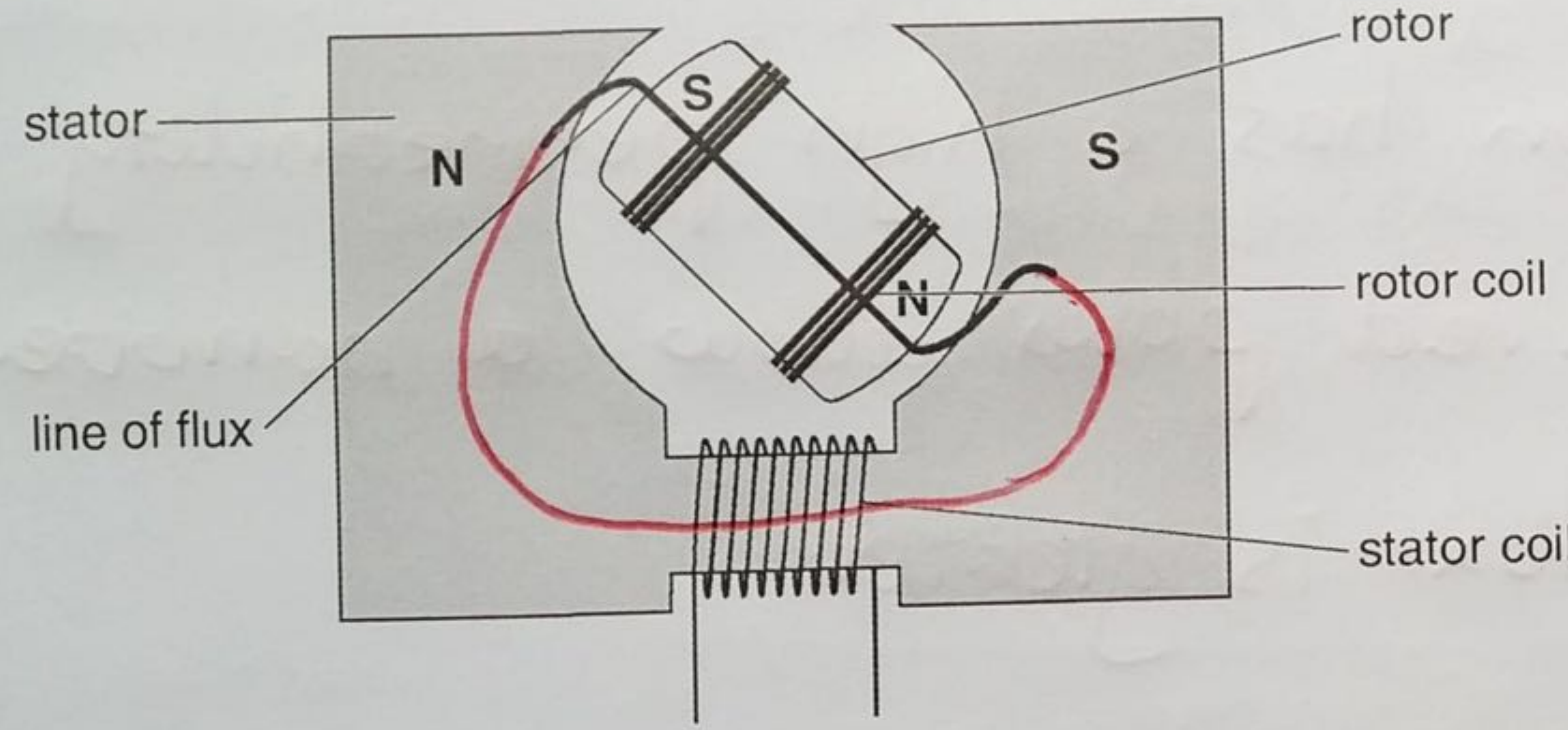


Fig. 10.1

Current in the stator coil produces a magnetic flux in the stator. There is also a current in the rotor coils. The rotor is turning anticlockwise.

(a) Part of a flux line is shown. Complete the flux line and explain how the shape of the line suggests that the rotor will experience an anti-clockwise force.

Loop stores energy if 'stretched'.
It will shorten when the rotor turns anticlockwise (reaching a lower energy state)

[2]

(b) The rotor is laminated; it is made of layers of iron separated by thin layers of insulator.

(i) Explain how the choice of an **iron** rotor together with **curved** poles on the stator help improve the performance of the motor.

Iron has a high permeability
Curved poles allow a narrower air gap
so flux is greater

[3]

(ii) Explain why **laminating** the iron rotor increases the flux in the magnetic circuit.

It reduces eddy currents that generate a B-field that opposes the motion.

[2]

(c) When the motor is first switched on there is a large current in the rotor coil, but as the rotor speeds up the current decreases. Use ideas about electromagnetic induction to explain why the current decreases.

At switch-on the rotor is not moving so there is no back emf. As it turns it cuts flux lines generating an emf that opposes the supply emf reducing the current in the coil.

[3]

[Total: 10]

11 This question is about the electric field near a positively-charged sphere.

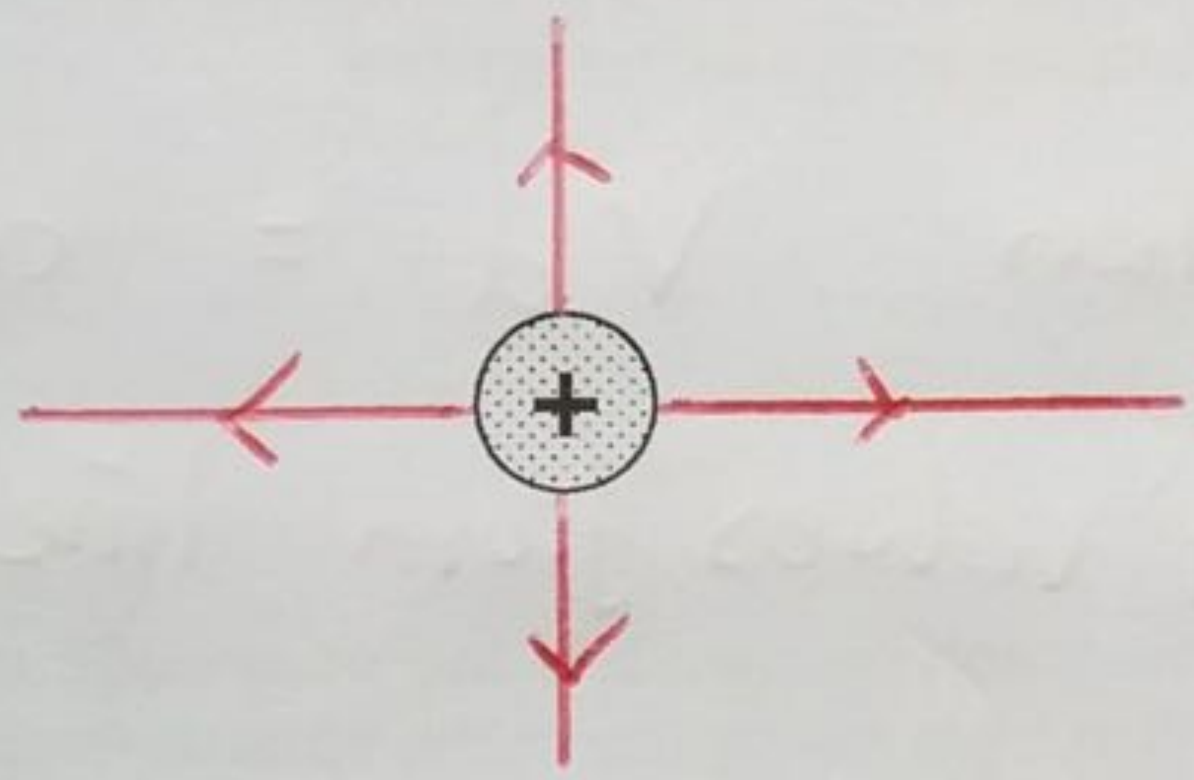


Fig. 11.1

Fig. 11.1 shows an isolated, positively-charged metal sphere.

(a) On Fig. 11.1 draw four field lines from the surface of the sphere. **[2]**

(b) The radius of the sphere is 4.0 mm and the charge on it is $+2.5 \times 10^{-9}$ C.
Show that the potential at the surface of the sphere is about +5.6 kV.

$$k = \frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 \, \mathrm{N\,m^2\,C^{-2}}$$

$$V_{elec} = \frac{kQ}{r} = \frac{9 \times 10^9 \times 2.5 \times 10^{-9}}{4 \times 10^{-3}} = 5625\,V$$

[2]

(c) The graph in Fig. 11.2 gives the potential at increasing distance from the sphere.

$\Delta V = 5100 - 100$
$= 5000\,V$

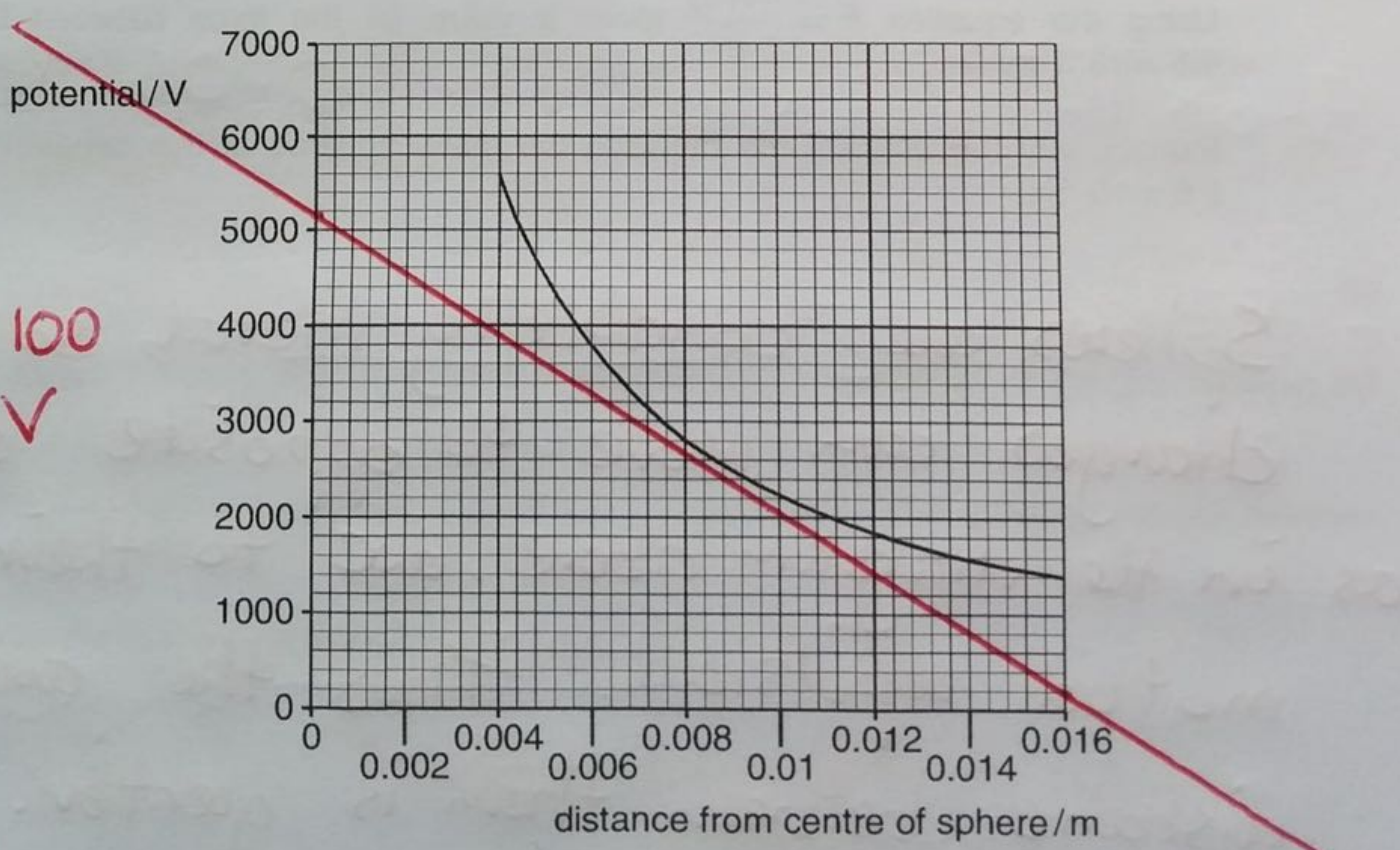


Fig. 11.2

$\Delta d = 0.016\,m$

(i) Explain how the graph could be used to show that the potential is inversely proportional to the distance from the centre of the sphere.

If $V \propto 1/d$ then Vd = constant

Plug in pairs of values from line and see if

[2]

(ii) Use data from the graph to calculate the magnitude of the electric field strength at a distance of 0.0080 m from the centre of the sphere. Explain your method clearly.

$E = \Delta V / \Delta d$ (gradient)

$= 5000\,\text{V} / 0.016\,\text{m}$

field strength = 3.1×10^5 NC^{-1} **[2]**

(d) The sphere is brought near an identically charged metal sphere as shown in Fig. 11.3.

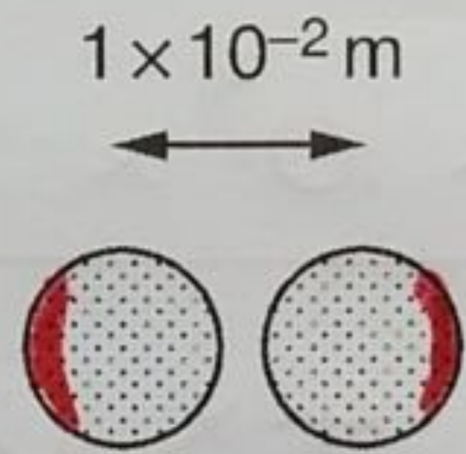


Fig. 11.3

Using the equation $F = \frac{kq_1q_2}{r^2}$ gives a value for the force between the spheres of 5.6×10^{-4} N.

Explain why the actual force between the metal spheres at this separation is less than 5.6×10^{-4} N.

Spheres are conducting metal so charges can move to opposite sides as in the diagram above. due to their mutual repulsion. Thus the average distance between them is greater.

[2]

[Total: 10]

13 This question is about a cyclotron, an early form of particle accelerator. It consists of two hollow semi-circular metal 'dees' in a uniform magnetic field of 0.80 T in a vacuum. The dees are separated by a gap as shown in Fig. 13.1.

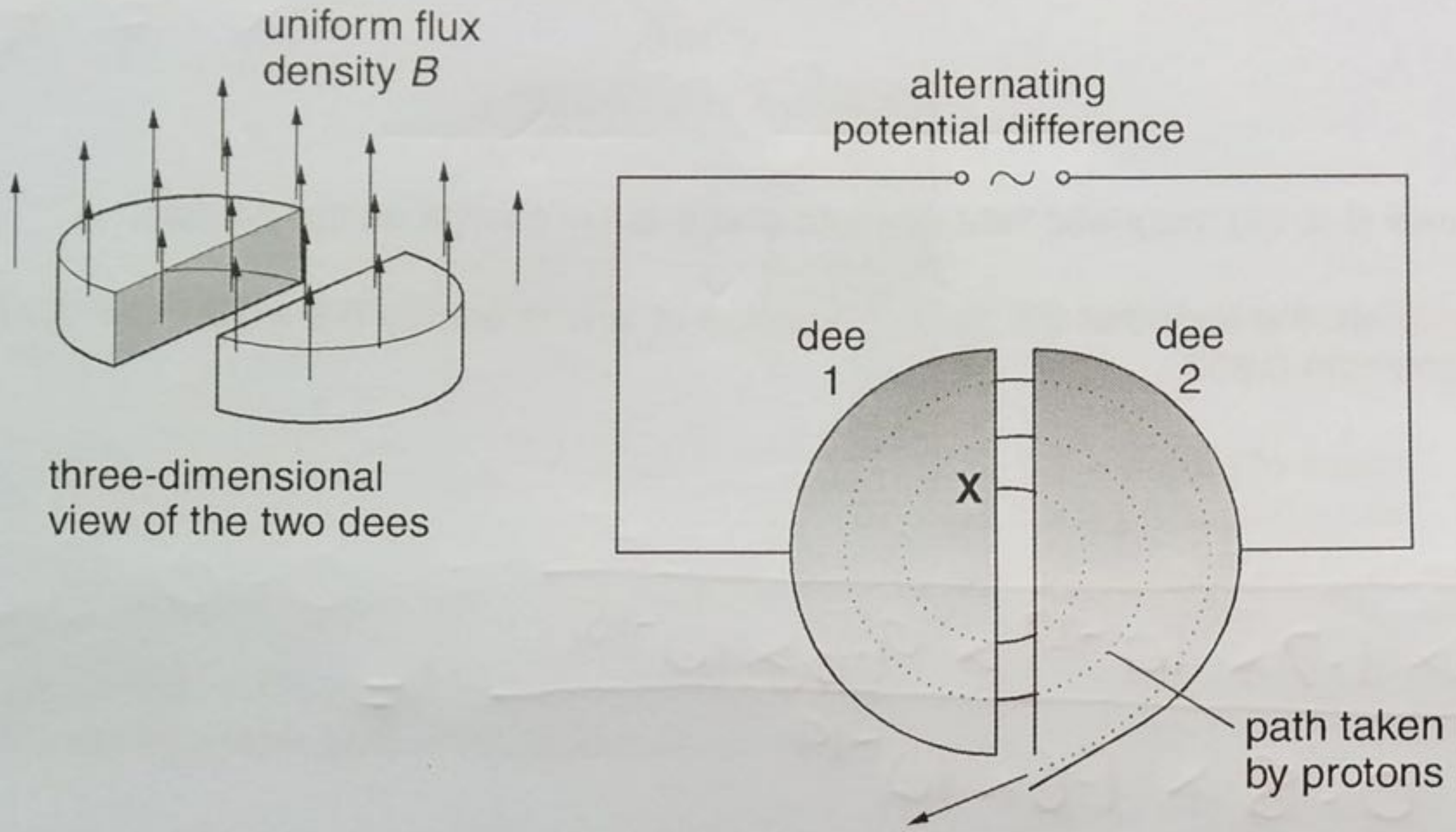


Fig. 13.1

Protons are injected into the gap between the dees at **X** and are accelerated by the potential difference between the dees. The magnetic field is directed out of the paper in Fig. 13.1 and the protons move in a circular path through the dees. There is no electric field inside the dees.

(a) **(i)** State why it is necessary to have a vacuum inside the cyclotron.

stop proton - air molecule collisions

[1]

(ii) Explain why the protons move in a circular path with constant speed inside a dee.

Force on protons from magnetic field is perpendicular to motion → circular motion

[2]

(b) The protons are accelerated through a p.d. of 400 V each time they cross the gap between the dees.

Show that a proton will have gained an energy of 9.6×10^{-15} J after crossing the gap between the dees 150 times.

electronic charge = 1.6×10^{-19} C

$E = VQ = 400 \times 1.6 \times 10^{-19} \times 150$

$= 9.6 \times 10^{-15}$ J

[1]

(c) The radius r of the path of a particle of mass m and kinetic energy E_k in a dee is given by the equation

$$r = \frac{\sqrt{2mE_k}}{Bq}$$

where B is the magnetic field strength and q is the charge on the particle.

Calculate the radius of the path of a proton of kinetic energy 9.6×10^{-15} J in a magnetic field of strength 0.80 T.

mass of proton = 1.7×10^{-27} kg
electronic charge = 1.60×10^{-19} C

$$r = \frac{\sqrt{2 \times 1.7 \times 10^{-27} \times 9.6 \times 10^{-15}}}{0.8 \times 1.6 \times 10^{-19}} =$$

radius = 0.045 m **[2]**

(d) Cyclotrons are not used to accelerate electrons because electrons show relativistic behaviour at the energies reached.

Use the relativistic factor γ to explain why an electron of kinetic energy 9.6×10^{-15} J shows relativistic behaviour to a greater extent than a proton of the same kinetic energy.

rest energy of electron = 0.511 MeV
rest energy of proton = 938 MeV

$$9.6 \times 10^{-15} / 1.6 \times 10^{-19} = 0.06 \text{ MeV}$$

$$\gamma = \frac{E_T}{E_R} = \quad e^- \ \frac{0.511 + 0.06}{0.511} = 1.12$$

[3]

[Total: 9]

[Section B Total: 42]

$$p^+ = \frac{938 + 0.06}{938} \approx 1.00$$

10 This question is about transformers.

Fig. 10.1 shows a transformer consisting of two coils wound on a laminated iron core. This consists of thin sheets of iron separated by layers of insulating material.

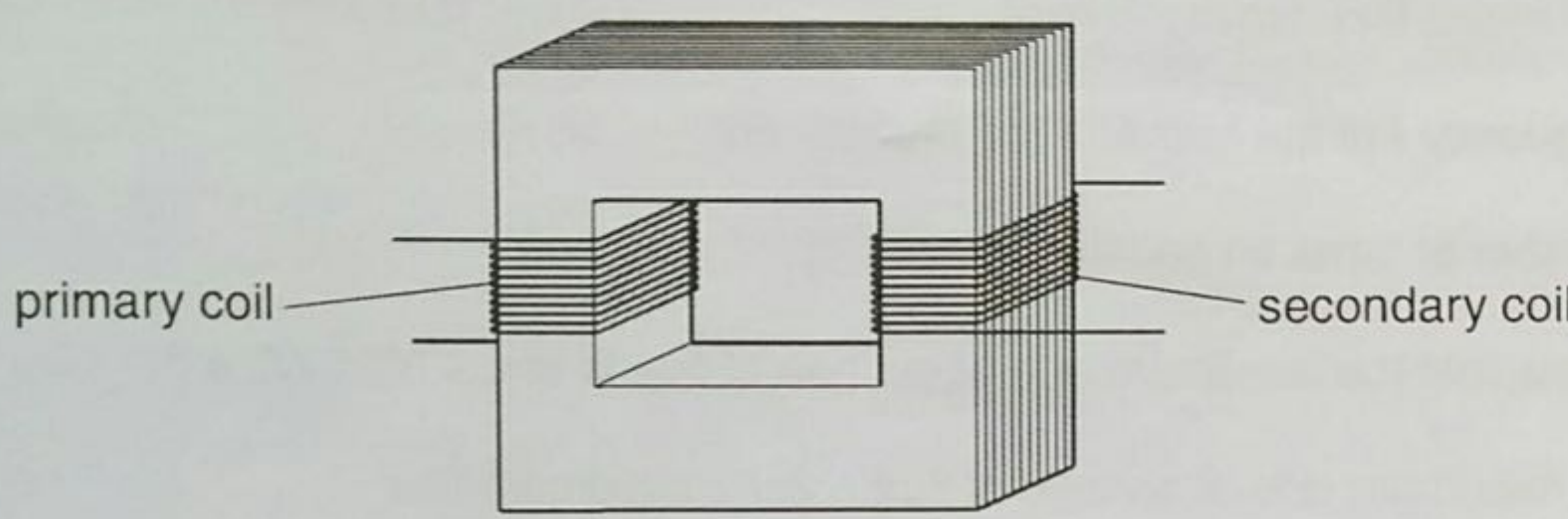
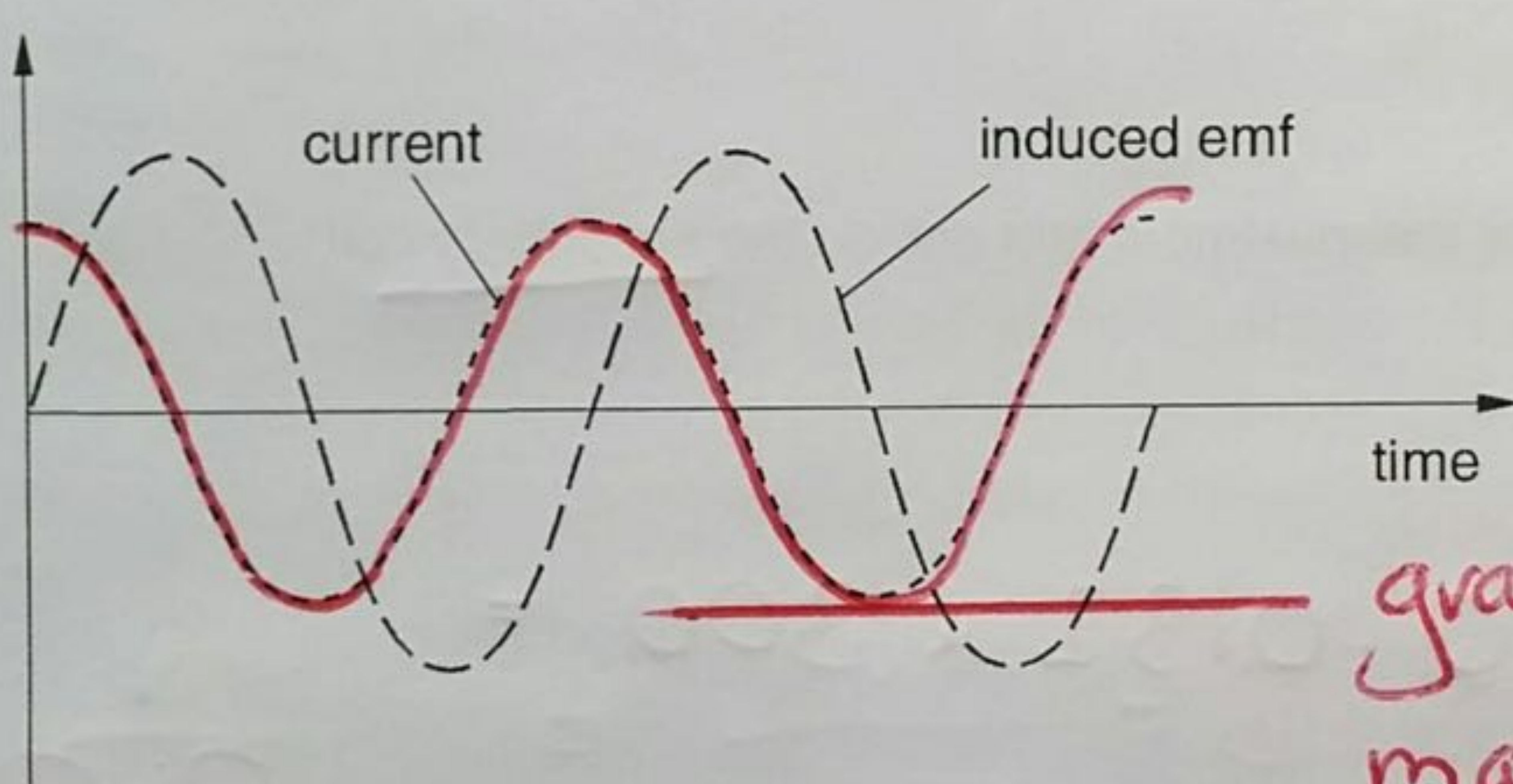


Fig. 10.1

The graph in Fig. 10.2 shows how the current in the primary coil and the induced emf in the secondary coil vary with time. There is no current in the secondary coil.



gradient = 0 at max I.

Fig. 10.2

(a) (i) On Fig. 10.2 sketch a graph to show how the flux in the secondary coil varies with time. **[2]**

(ii) Use the relationship between induced emf and rate of change of flux to explain why the induced emf in the secondary coil is zero when the current in the primary coil is a maximum.

$\varepsilon = \frac{d\Phi N}{dt}$

At max I current gradient is zero so rate of change of V and hence flux is zero

[2]

$\Phi = BA$

(b) Here are some data about the transformer:

cross-sectional area of core	$= 6.0 \times 10^{-4}\ \mathrm{m}^2$
maximum flux density in core	$= 7.0 \times 10^{-2}\ \mathrm{T}$
frequency f of the circuit in the primary coil	$= 50\ \mathrm{Hz}$
number of turns on secondary coil	$= 300$

$\times \;= 4.2\times10^{-5}\ \mathrm{Wb}$

(i) Show that the maximum rate of change of flux is about 0.01 Wb s^{-1}.

maximum rate of change of flux = $2\pi f \times$ maximum flux

$2\pi \times 50 \times 4.2\times10^{-5} = 0.0132\ \mathrm{Wb\,s^{-1}}$

[2]

(ii) Calculate the maximum emf across the secondary coil.

$\varepsilon = \dfrac{d\Phi N}{dt} = 0.0132 \times 300 =$

maximum emf = 3.96 V **[2]**

(c) The laminated core is replaced with a solid core of the same material. Nothing else is changed. It is observed that the maximum emf across the secondary coil is now lower than that calculated in **(b) (ii)**. Explain why this is the case.

Eddy current induced by the changing flux generate their own flux which opposes the flux in the core so reducing the max flux in core.

[3]

[Total: 11]

11 This question is about a machine used to accelerate electrons.

Fig. 11.1 shows that the machine has three main components. The electrons are first accelerated to an energy of 100 MeV in a linear accelerator. They are then further accelerated to 3 GeV in the booster synchrotron. The 3 GeV electrons then follow an approximately circular path in the storage ring. Electrons are continually added to the storage ring. When enough electrons are stored they are deflected out of the storage ring into the experimental area.

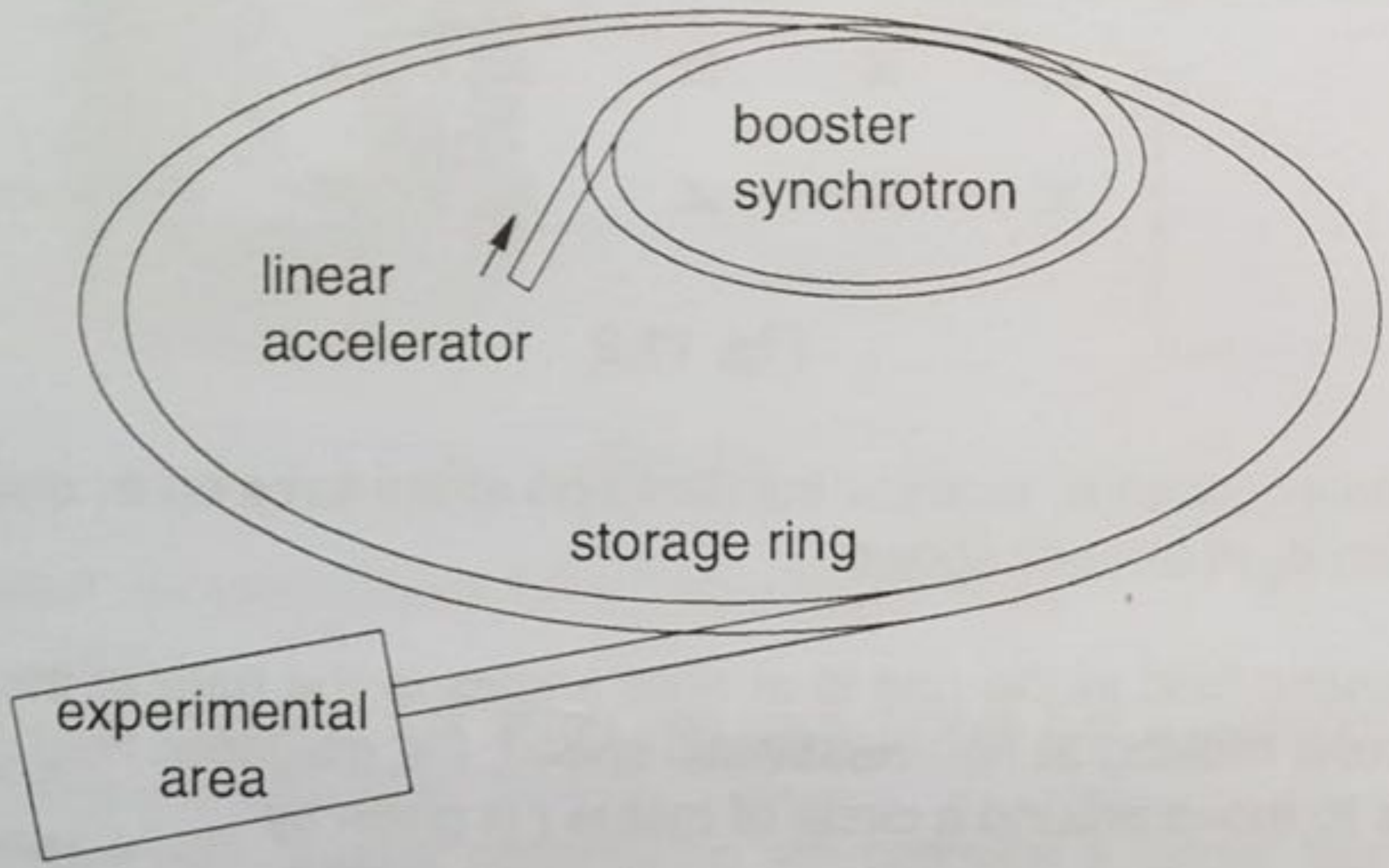


Fig. 11.1

(a) Show that the 100 MeV electrons have about 200 times their rest energy when they leave the linear accelerator.

$m_e = 9.1 \times 10^{-31}$ kg $\rightarrow$ $E = mc^2 = 9.1 \times 10^{-31} \times (3 \times 10^8)^2$
$e = 1.6 \times 10^{-19}$ C
$c = 3.0 \times 10^8$ m s^{-1}

$= 8.19 \times 10^{-14}$ J

$8.19 \times 10^{-14} / 1.6 \times 10^{-19} = 0.512$ MeV

$100 / 0.512 = 195$

[3]

(b) The electrons leave the linear accelerator at near-light speeds. The momentum p of a particle travelling at a speed approaching that of light is given by the approximation

$$p \approx E/c$$

where E is the energy of the particle and c is the velocity of light.

Estimate the ratio

$$\frac{\text{momentum of a 3 GeV electron}}{\text{momentum of a 100 MeV electron}} = \frac{3 \times 10^9}{100 \times 10^6} =$$

cs cancel
in ratio

ratio = 30 [1]

(c) Fig. 11.2 shows two electrons, $\mathbf{e}_1$ and $\mathbf{e}_2$ moving through a magnetic field acting into the paper. The arrows labelled *v* indicate the velocities of the electrons.

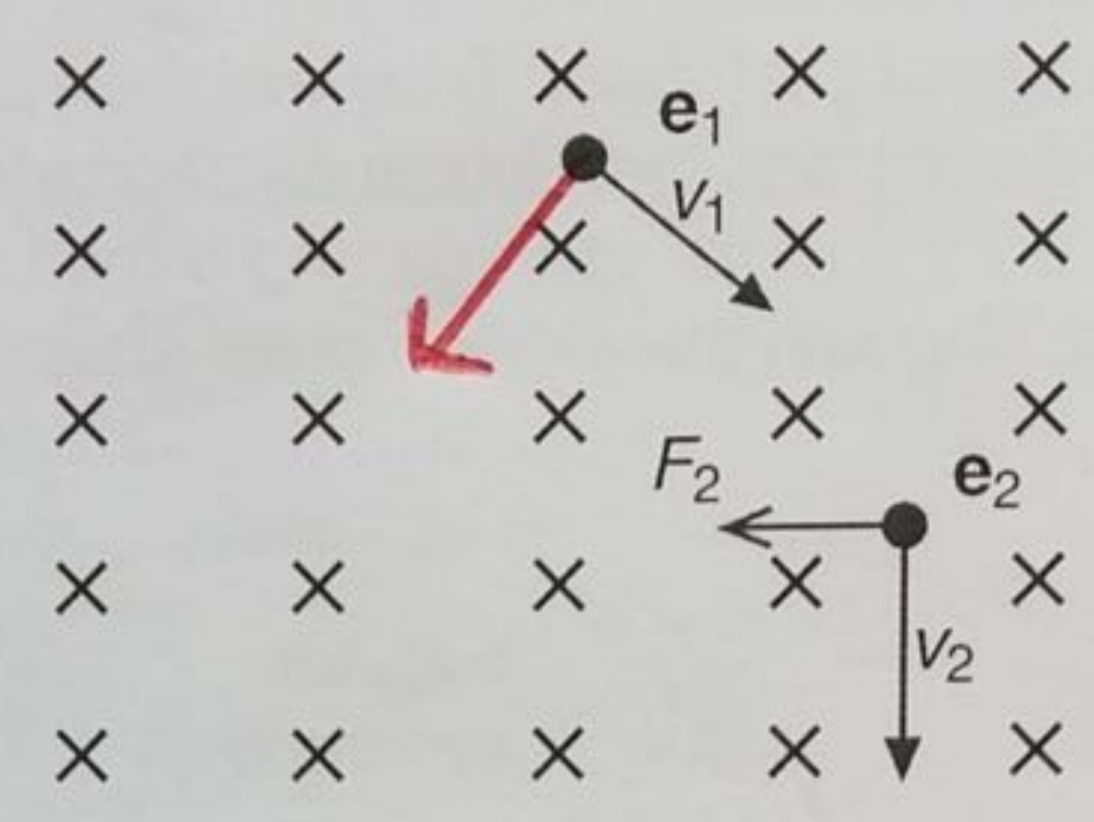


Fig. 11.2

Draw a second arrow on $\mathbf{e}_1$ to show the direction of the force on $\mathbf{e}_1$ due to the magnetic field. The force F_2 on $\mathbf{e}_2$ is already shown. **[1]**

(d) (i) The magnetic field in the ring is at right angles to the path of the electrons. Show that, for electrons moving at non-relativistic speed, the magnetic field strength *B* required for electrons to move around a circle of radius *r* is given by

$$B = \frac{mv}{er}$$

where m = mass of electron
v = velocity of electron
e = charge on electron.

$$\frac{mv^2}{r} = Bev \quad \therefore \quad B = \frac{mv^2}{rev} = \frac{mv}{er}$$

[1]

(ii) For electrons moving at near-light speeds the magnetic field required is given by

$$B = \frac{E}{cer}$$

where E = electron energy
c = speed of light.

The storage ring has a radius of 89 m. Calculate the value of *B* required for 3 GeV electrons to follow this path.

$$B = \frac{3\times10^{9}\times1.6\times10^{-19}}{3\times10^{8}\times1.6\times10^{-19}\times89} = \frac{10}{89} =$$

$B =$ ....0.112.... T **[2]**

[Total: 8]

7 Fig. 7.1 shows a simple magnetic circuit and a simple electric circuit.

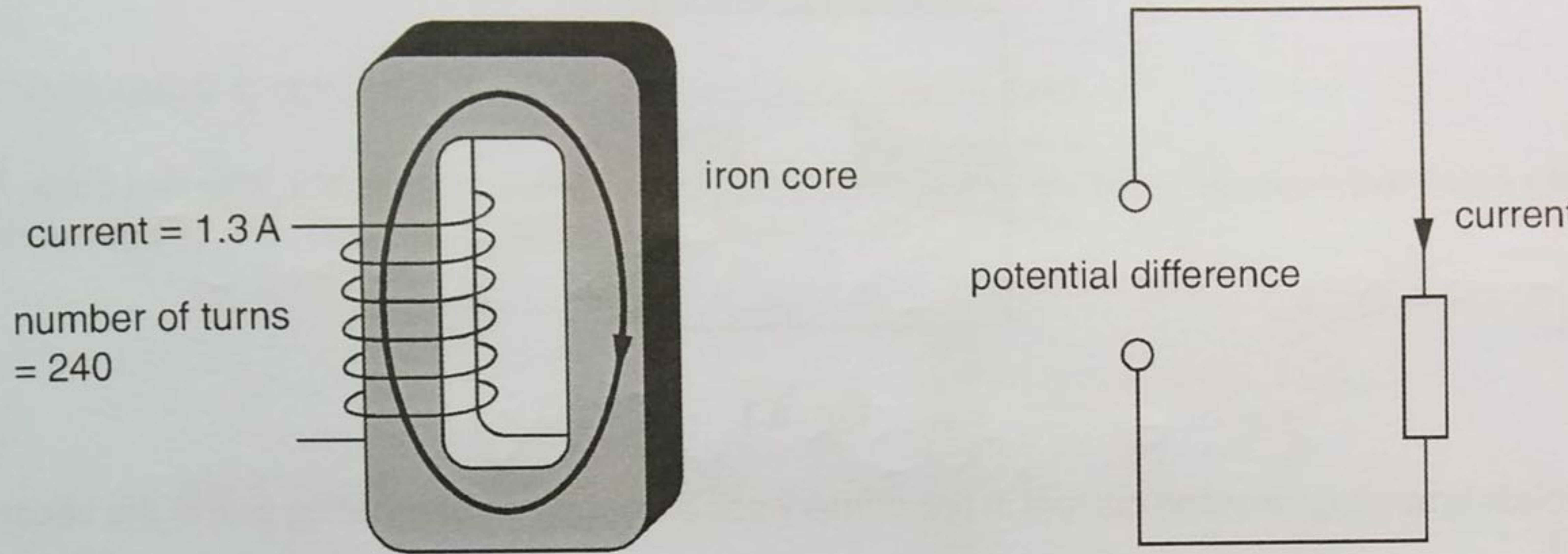


Fig. 7.1

In the magnetic circuit, current turns = 1.3 × 240 = 312 A turns.

The current produces a magnetic flux in the iron core, where flux = permeance × current turns.

(a) A magnetic circuit with greater permeance will produce a larger flux for the same current turns. Suggest **two** ways in which the permeance of the magnetic circuit could be increased.

increase → permeability of material
→ cross-sectional area **[2]**

(b) The magnetic circuit is analogous to the electric circuit. Complete the table below.

magnetic circuit	electric circuit
current turns	potential difference
flux	current
permeance of circuit	conductance

[1]

8 Fig. 8.1 shows a simple transformer.

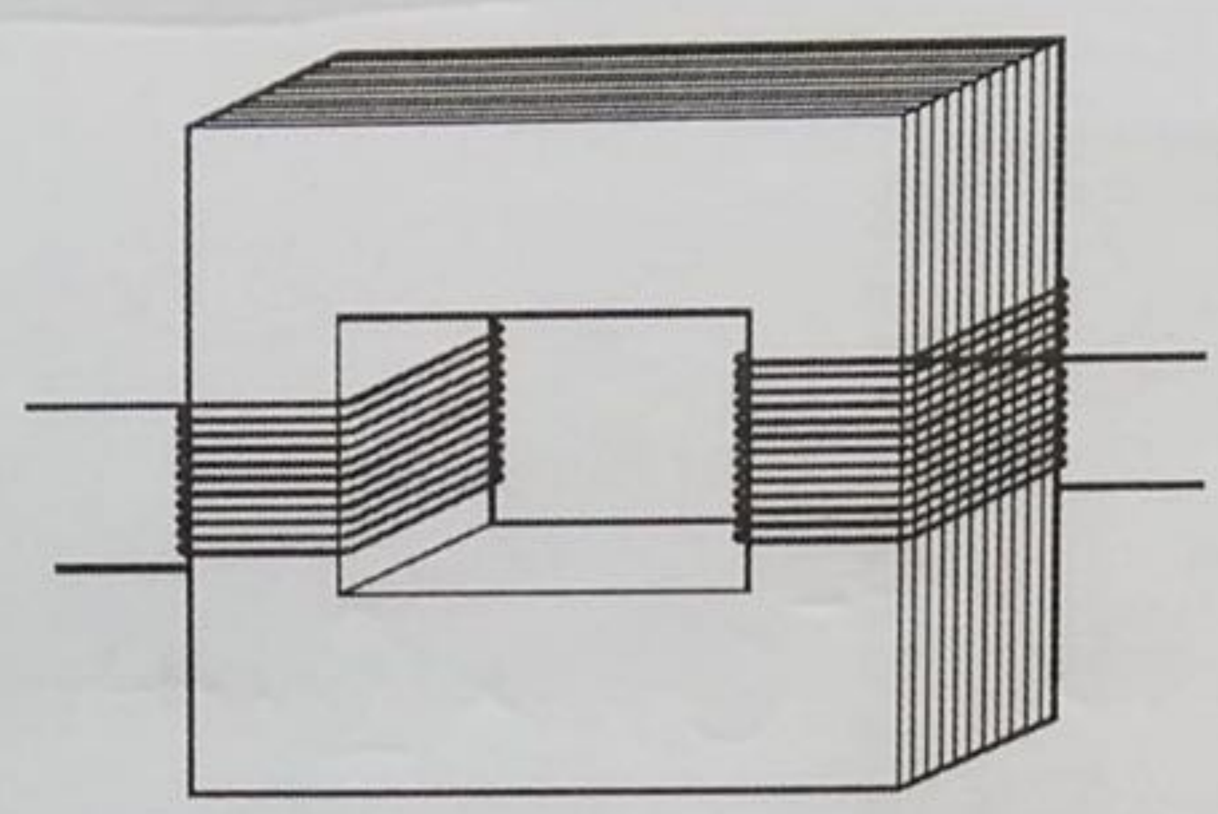


Fig. 8.1

Explain how an alternating current in the primary coil produces an alternating emf in the secondary coil.

Consider the behaviour of the flux in the core in your answer

Changing (ac) current in primary creats changing flux in core. The changing flux in the core induces an emf in the secondary coil

$$\varepsilon = d\Phi N / dt$$

[3]

[Section A Total: 20]

Section B

9 This question is about the force on an object in an electric field.

A small ball with a metallic coating is hung from an insulating spring between two metal plates as shown in Fig. 9.1. The ball is initially uncharged.

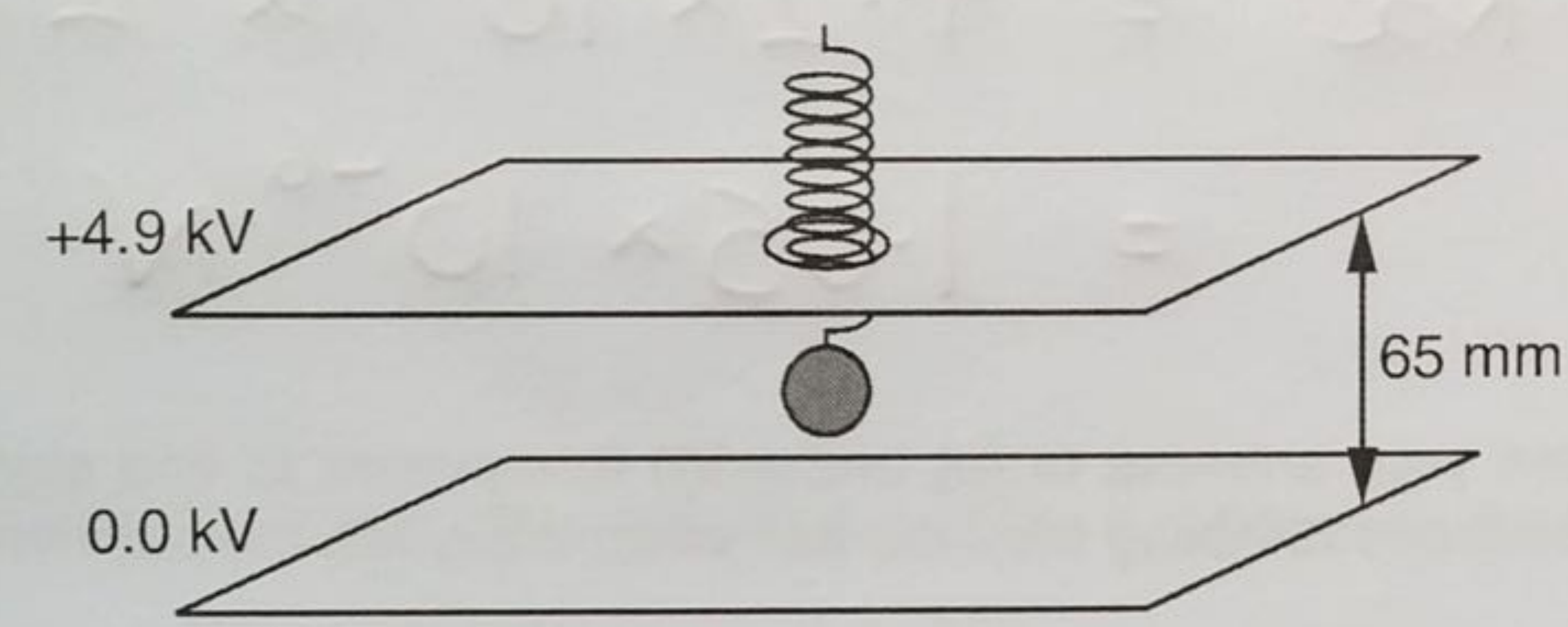


Fig. 9.1

The separation of the plates is 65 mm. There is a potential difference of 4.9 kV between the plates. This produces a uniform electric field.

(a) Show that the strength of the field is about $8 \times 10^4\,\mathrm{V\,m^{-1}}$.

$$E = V/d = 4.9 \times 10^3 / 65 \times 10^{-3}$$

$$= 7.54 \times 10^4\ \mathrm{Vm^{-1}}$$

[2]

(b) Show that the units $\mathrm{V\,m^{-1}}$ are equivalent to the units $\mathrm{N\,C^{-1}}$.

$$\mathrm{Vm^{-1}} \xrightarrow{V = JC^{-1}} \mathrm{JC^{-1}m^{-1}} \xrightarrow{J = Nm} \mathrm{NmC^{-1}m^{-1}}$$

[2]

$$\mathrm{NC^{-1}}$$

(c) The ball is now given a positive charge. The ball moves towards the lower plate, extending the spring by 2.5 mm.

(i) Show that the force on the ball due to the electric field is about 1 μN.

stiffness constant of spring $k = 4.2 \times 10^{-4}\,\mathrm{N\,m^{-1}}$

$$F = kx = 4.2 \times 10^{-4} \times 2.5 \times 10^{-3}$$

$$= 1.05 \times 10^{-6}\,N$$

[2]

(ii) Use your answers to **(a)** and **(c)(i)** to estimate to one significant figure the number of electrons removed from the ball when it is given the positive charge.

$e = 1.6 \times 10^{-19}\,\mathrm{C}$

$$E = F/q \therefore q = F/E = \frac{1.05 \times 10^{-6}}{7.54 \times 10^{4}} = 1.39 \times 10^{-11}\,C$$

$$1.39 \times 10^{-11} / 1.6 \times 10^{-19} = 8.7 \times 10^{7}$$

number of electrons = 9×10^{7} [3]

(d) A radioactive beta source is placed near the apparatus as shown in Fig. 9.2. Nothing else is changed.

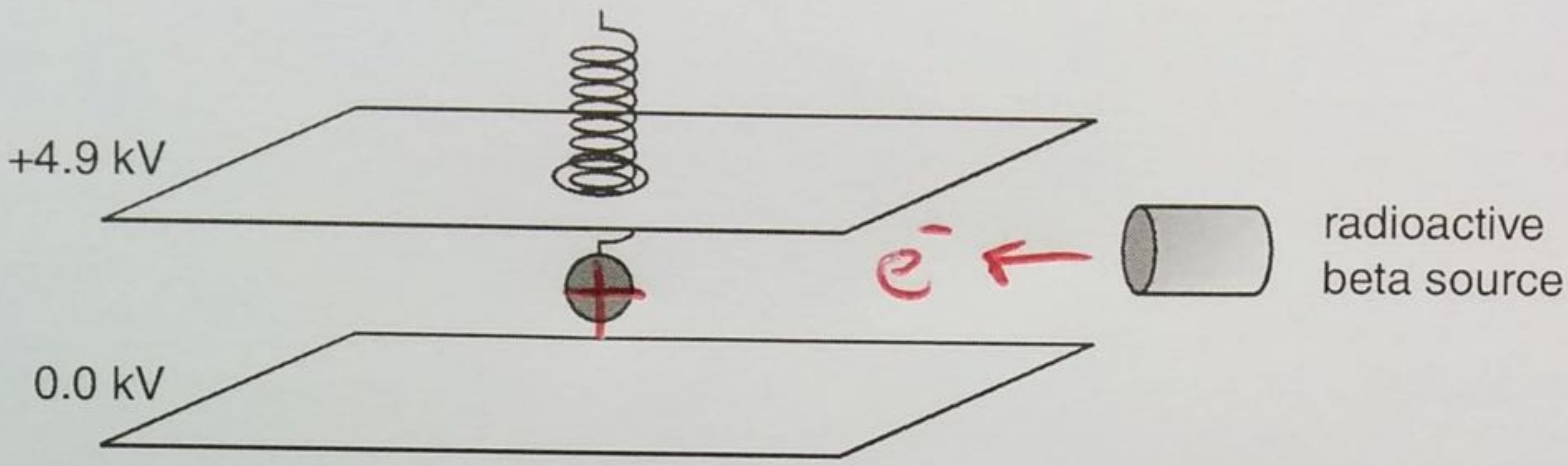


Fig. 9.2

Suggest and explain how this might affect the position of the ball between the plates.

Your answer should use the correct terms in a logical order.

The negative charge from the β particles or from electrons from ionized air molecules will neutralise the positive charge on the ball. This will reduce the downwards force on the ball in the electric field so it will move up towards its equlibrium position.

[4]

[Total: 13]