

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

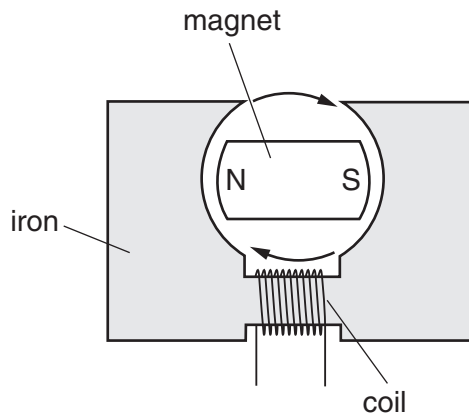


Fig. 13.1

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

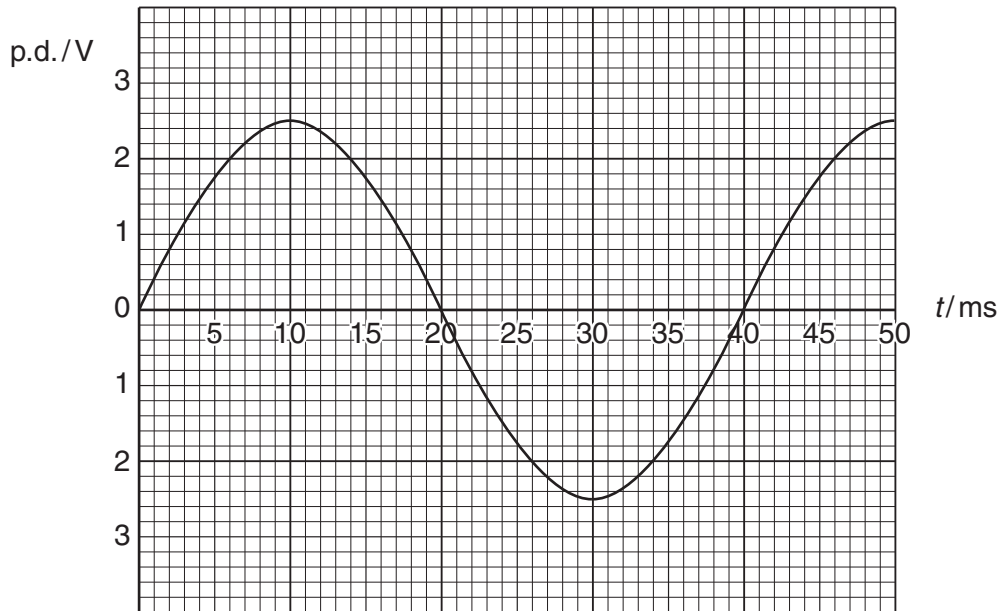


Fig. 13.2

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

$f = \dots\dots\dots$  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  $0.0036 \text{ Wb s}^{-1}$ .

[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

$$\text{rate of change of flux} = 2\pi f \times \text{maximum flux} \times \cos(2\pi ft).$$

The core has a cross section of  $25 \text{ mm} \times 25 \text{ mm}$ .

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

maximum flux density = ..... T [3]

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

[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.

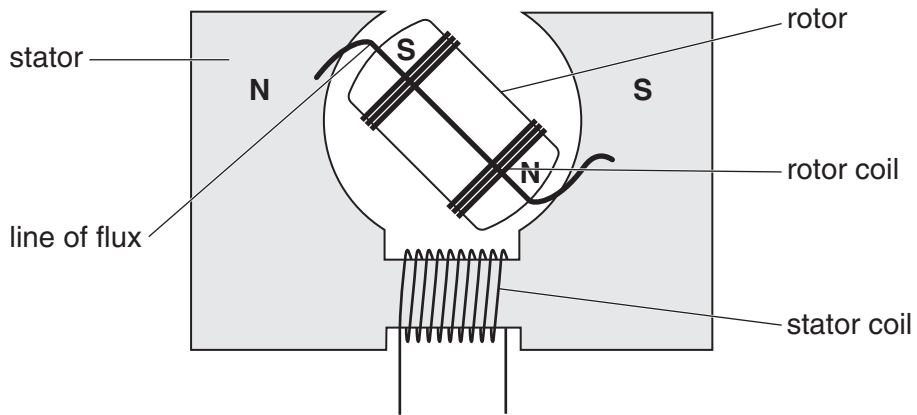


Fig. 10.1

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.

[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.

[3]

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

[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.

[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  $+2.5 \times 10^{-9} \text{ C}$ . Show that the potential at the surface of the sphere is about +5.6 kV.

$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

[2]

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

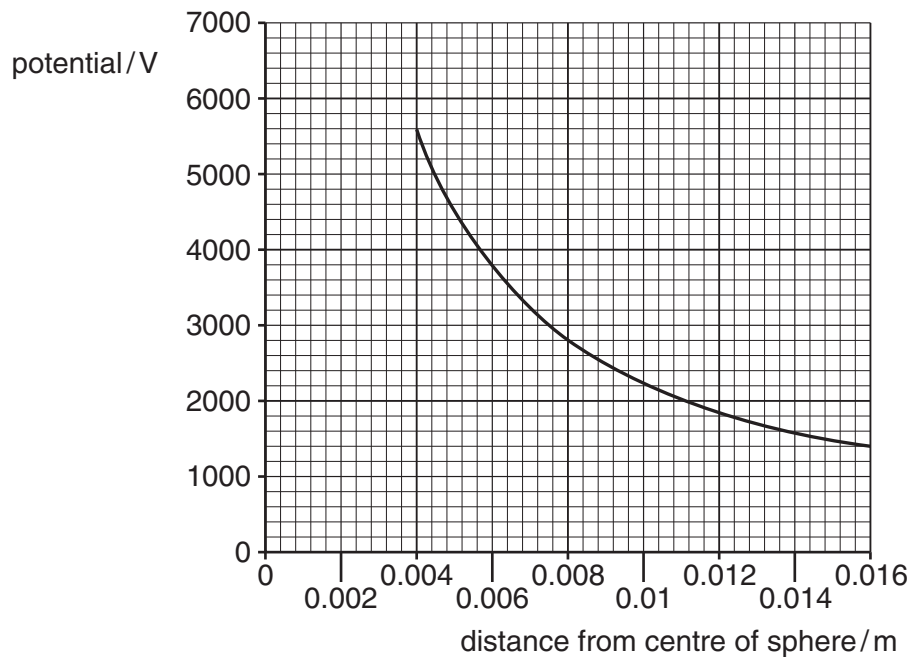


Fig. 11.2

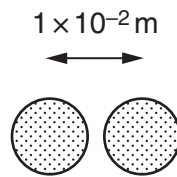
- (i) Explain how the graph could be used to show that the potential is inversely proportional to the distance from the centre of the sphere.

[2]

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

field strength = .....  $\text{NC}^{-1}$  [2]

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



**Fig. 11.3**

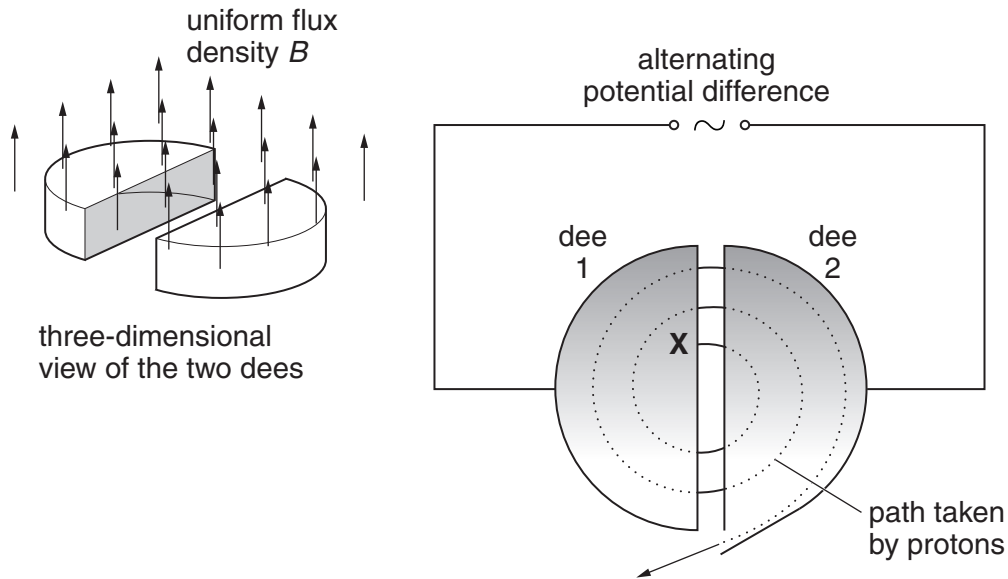
Using the equation  $F = \frac{kq_1q_2}{r^2}$  gives a value for the force between the spheres of  $5.6 \times 10^{-4} \text{ N}$ .

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

[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.

[1]

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

[2]

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

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

$$\text{electronic charge} = 1.6 \times 10^{-19} \text{ C}$$

[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  $9.6 \times 10^{-15} \text{ J}$  in a magnetic field of strength  $0.80 \text{ T}$ .

mass of proton =  $1.7 \times 10^{-27} \text{ kg}$   
 electronic charge =  $1.60 \times 10^{-19} \text{ C}$

radius = .....m [2]

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

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

rest energy of electron =  $0.511 \text{ MeV}$   
 rest energy of proton =  $938 \text{ MeV}$

[3]

[Total: 9]

[Section B Total: 42]



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.

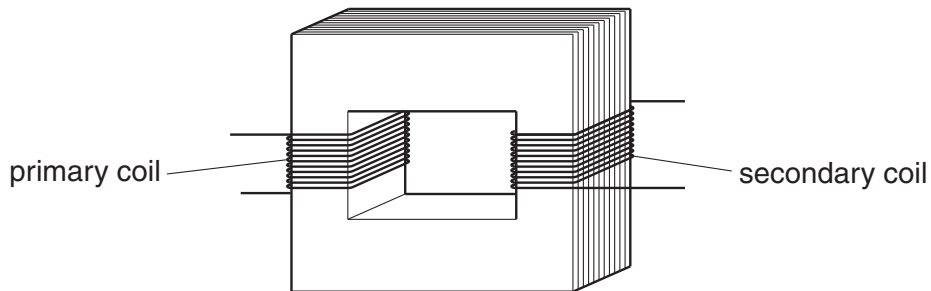


Fig. 10.1

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.

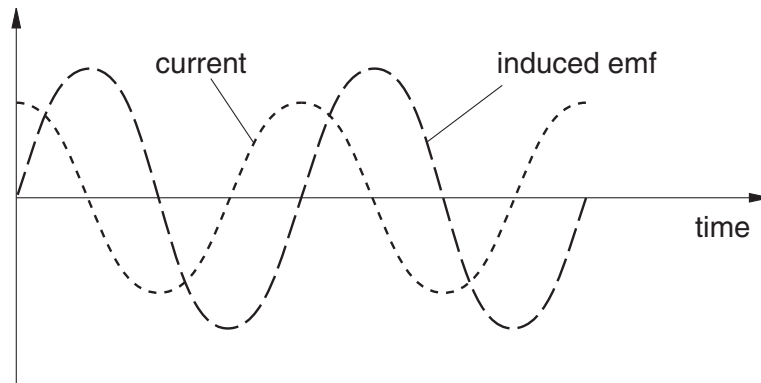


Fig. 10.2

- (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.

[2]

(b) Here are some data about the transformer:

cross-sectional area of core =  $6.0 \times 10^{-4} \text{ m}^2$

maximum flux density in core =  $7.0 \times 10^{-2} \text{ T}$

frequency  $f$  of the circuit in the primary coil = 50 Hz

number of turns on secondary coil = 300

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

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

[2]

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

maximum emf = ..... 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.

[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.

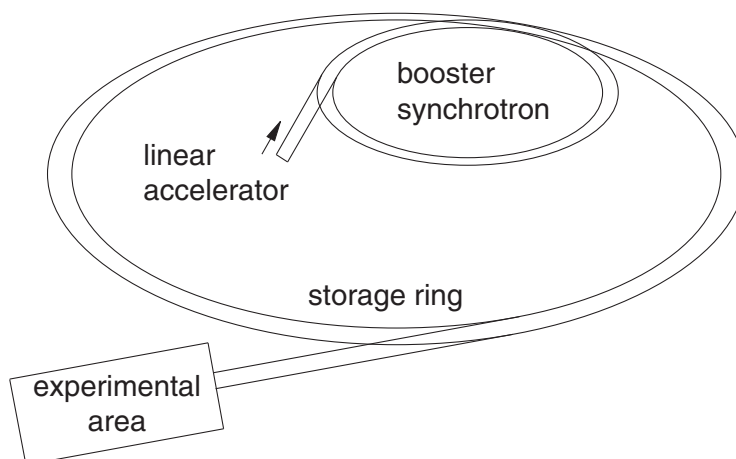


Fig. 11.1

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

$$m_e = 9.1 \times 10^{-31} \text{ kg}$$

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

$$c = 3.0 \times 10^8 \text{ m s}^{-1}$$

[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

$$\frac{\text{momentum of a 3 GeV electron}}{\text{momentum of a 100 MeV electron}}$$

ratio = ..... [1]

- (c) Fig. 11.2 shows two electrons,  $e_1$  and  $e_2$  moving through a magnetic field acting into the paper. The arrows labelled  $v$  indicate the velocities of the electrons.

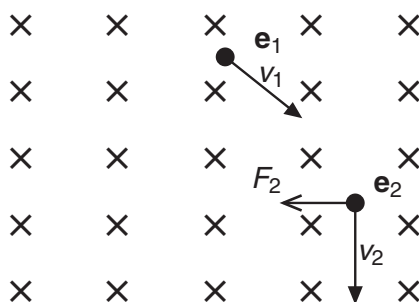


Fig. 11.2

Draw a second arrow on  $e_1$  to show the direction of the force on  $e_1$  due to the magnetic field. The force  $F_2$  on  $e_2$  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.

[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 89m. Calculate the value of  $B$  required for 3GeV electrons to follow this path.

$$B = \dots\dots\dots \text{T} [2]$$

[Total: 8]

Turn over

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

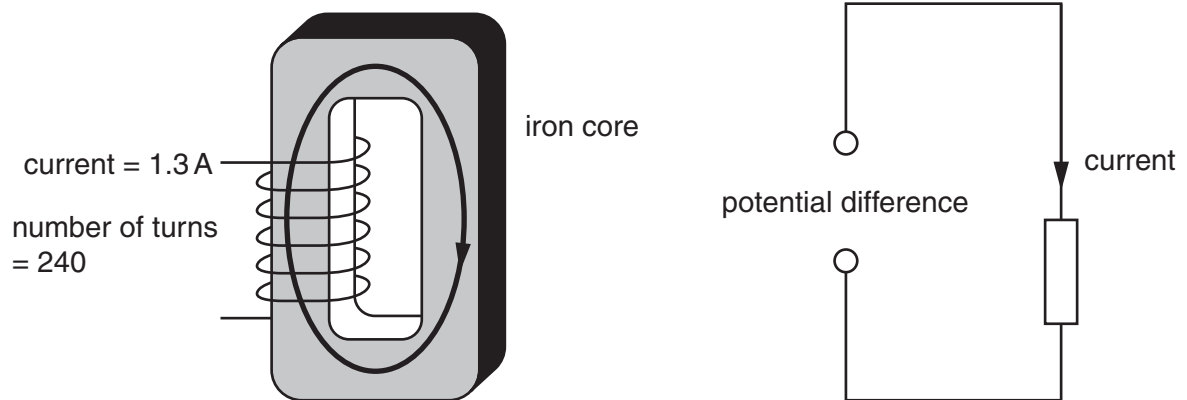


Fig. 7.1

In the magnetic circuit, current turns =  $1.3 \times 240 = 312 \text{ A turns}$ .

The current produces a magnetic flux in the iron core, where flux = permeance  $\times$  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.

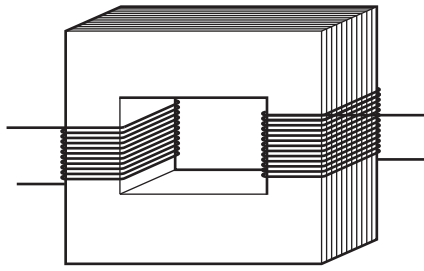
[2]

(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	

[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

[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.

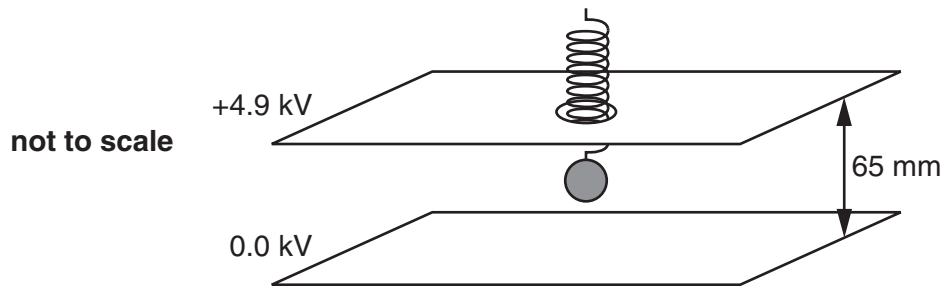


Fig. 9.1

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  $8 \times 10^4 \text{ V m}^{-1}$ .

[2]

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

[2]

(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  $1\mu\text{N}$ .

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

[2]

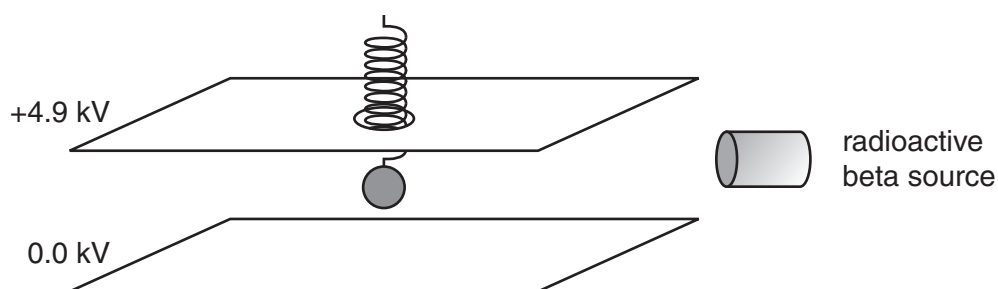
(ii) Use your answers to (a) and (c)(i) to estimate to one significant figure the number of electrons removed from the ball when it is given the positive charge.

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

number of electrons = ..... [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.*

[4]

[Total: 13]