TOPIC 25 Charged Particles

In B Field

1 When an electron moving with constant speed in a vacuum enters a magnetic field in a direction at right angles to the field, its subsequent path is

A a straight line parallel to the field.
B a parabola in a plane normal to the field.
C a circle in a plane normal to the field.
D undeviated.
E a spiral with the direction of the field as axis.

J76/II/20

2 If a stationary electron is subjected to a uniform magnetic field it will be

A accelerated in the direction of the field.
B caused to move in a circular path.
C caused to move in an elliptical path.
D caused to oscillate about a fixed point.
E unaffected.

N76/II/23

3 Doubly-ionised oxygen atoms (O^{2-}) and singly-ionised lithium atoms (Li^{+}) are travelling with the same speed, perpendicular to a uniform magnetic field which causes them to move in circular orbits. The relative atomic masses of oxygen and lithium are 16 and 7 respectively.

What is the ratio $\dfrac{\text{radius of } O^{2-} \text{ orbit}}{\text{radius of } Li^{+} \text{ orbit}}$?

A $\frac{16}{7}$ **B** $\frac{8}{7}$ **C** $\frac{7}{8}$ **D** $\frac{7}{16}$ **E** $\frac{7}{32}$

N77/II/19; J86/I/27

4 A particle, of mass m, charge q and speed v, enters a uniform magnetic field of flux density B and describes a circular path of radius r. Which one of the following statements is correct?

The radius r of the circular path is

A unaffected by m.
B inversely proportional to m.
C inversely proportional to v.
D directly proportional to q.
E inversely proportional to B.

J78/II/21

5 In a mass-spectrometer, an ion of mass m and charge q enters a region of uniform magnetic field acting perpendicularly to the original line of flight. The resulting path is

A circular and of radius proportional to m/q.
B circular and of radius proportional to q/m.
C helical and of radius proportional to q/m.
D parabolic with a displacement from the original path proportional to m/q.
E linear and perpendicular to the original path.

J79/II/35

6 The particles Y and Z emitted by a radioactive source at P made tracks in a cloud chamber as illustrated in the diagram (Fig. 1). A magnetic field acted downwards into the paper. Careful measurements showed that both tracks were circular, the radius of the Y track being half that of the Z track.

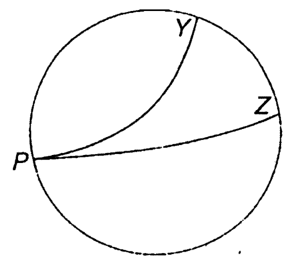


Fig. 1

Which one of the following statements is certainly true?

A The speed of the Z particle was one half that of the Y particle.
B The mass of the Z particle was one half that of the Y particle.
C The mass of the Z particle was twice that of the Y particle.
D The charge of the Z particle was twice that of the Y particle.
E Both the Y and Z particles carried a positive charge.

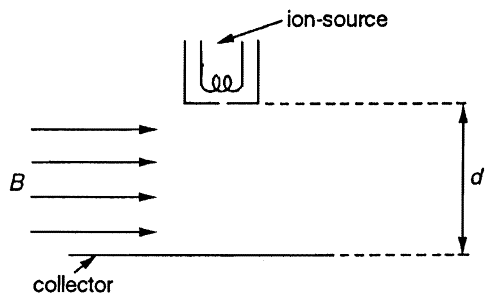
N80/II/35

***7** An electron moving in a vacuum in a uniform magnetic field of flux density 1 mT moves in a circular path. If an α-particle of the same speed is to follow an identical path, what magnetic flux density is required? (Mass of α-particle = 7200 × mass of electron.)

A 3600 mT in the opposite direction
B 1800 mT in the opposite direction
C 1 mT in the opposite direction
D 1800 mT in the same direction
E 2 mT in the same direction

N85/I/26

8

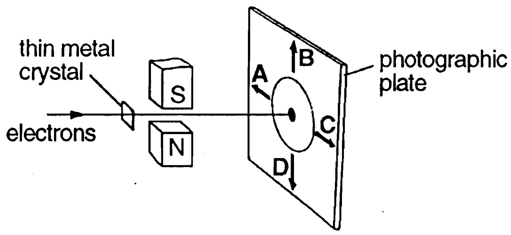


An ion-source is at distance d from a flat, horizontal collector at the same potential as the source. A magnetic field of flux density B acts horizontally as shown in the diagram. The field is uniform throughout the region between the source and the collector.

An ion of charge q and mass m is emitted vertically downwards at speed v. Under what conditions will the ion reach the collector?

A $v > \sqrt{(2Bq/m)}$
B $v < \sqrt{(2Bq/m)}$
C $v > dBq/m$
D $v < dBq/m$
E $v = \sqrt{(dBq/m)}$ J88/I/27

9 G P Thomson's early experiments on the diffraction of electrons by crystals were criticised on the grounds that the beams affecting the photographic plate might be X-rays. He proved that this was not so by placing bar magnets on each side of the beam as shown in the diagram.



How would the magnetic field due to the magnets affect the diffraction ring?

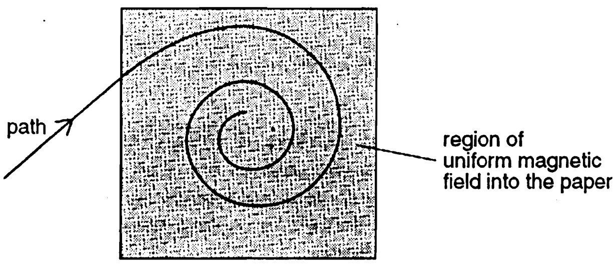
A The ring would be deflected in the direction **A**.
B The ring would be deflected in the direction **B**.
C The ring would be deflected in the direction **C**.
D The ring would be deflected in the direction **D**.
E The diameter of the ring would decrease.

N90/I/19

10 An ion of mass m and charge q enters a region of uniform magnetic field acting perpendicularly to the original line of flight. The resulting path is

A circular and of radius proportional to m/q.
B circular and of radius proportional to q/m.
C curved with a displacement from the original line of flight proportional to m/q.
D linear and perpendicular to the original path.
E spiralling along the original line of flight with a radius proportional to q/m. N91/I/19

11 A common way of investigating charged particles is to observe how they move in a plane at right angles to a uniform magnetic field. The diagram shows the path of a certain particle.



Which of the following gives a satisfactory explanation for the path?

A The momentum of the particle is increasing steadily.
B The charge on the particle is decreasing steadily.
C The magnetic flux density is decreasing steadily.
D The mass of the particle is increasing steadily.
E The speed of the particle is decreasing steadily.

N93/I/26

12 Four particles independently move at the same speed in a direction perpendicular to the same magnetic field.

Which particle is deflected the most?

A a copper ion
B a helium nucleus
C an electron
D a proton J98/I/27

13 An electron moves in a circular path in a vacuum, under the influence of a magnetic field. The radius of the path is 10^{-2} m and the flux density is 10^{-2} T. Given that the specific charge of the electron is -1.76×10^{11} C kg^{-1}, calculate

(a) the period of its orbit,

(b) the period if the electron had only half as much energy.

N76/I/6

14 An electron is projected in vacuum along the axis of a current-carrying solenoid. Describe and explain its motion.

N81/I/8

15 In a proton synchrotron a beam of protons of speed 1.5×10^7 m s^{-1} is caused to follow a circular path of diameter 120 m by the application of a uniform magnetic field. Find the flux density required, and show by means of a labelled sketch the direction of this field relative to the circular path of the protons. J85/II/5

16 A particle of mass M and charge $+Q$ moves with speed v at right angles to a magnetic field of flux density B.

(a) Derive an expression, in terms of B, Q, v and M, for the radius of curvature of the path followed by the particle. [3]

N92/II/3 (part)

Long Questions

17 In a cathode-ray tube with magnetic deflection, a deflecting field of 1×10^{-3} T is applied uniformly over a cylindrical volume of radius 5 cm in a direction parallel to the axis of the cylinder; elsewhere, the field is zero. The electron beam enters the field along a radius of the cylinder.

Describe, with the aid of a diagram, the subsequent path of the electrons. Calculate their speed if the beam suffers a total deflection of 20°.

[Specific charge for the electron, $e/m_e = 1.8 \times 10^{11}$ C kg^{-1}.]

J74/II/8 (part)

18 An electron describes a circular path of radius 4.0 cm in a uniform magnetic field of flux density 3.0×10^{-3} T. Find the speed of the electron. [8 marks]

[Charge of electron, $e = -1.6 \times 10^{-19}$ C; mass of electron, $m_e = 9.1 \times 10^{-31}$ kg.] N74/I/10 (part)

19 How would you produce a beam of positive helium ions? Would it contain ions travelling with different speeds? How would you separate out ions travelling with a particular speed by means of a magnetic field? [6 marks]
N74/II/9 (part)

20 Describe the shapes of the paths followed by electrons injected (i) at right angles into a uniform magnetic field, (ii) at right angles into a uniform electrostatic field.

Explain clearly why the paths are so different. [5]

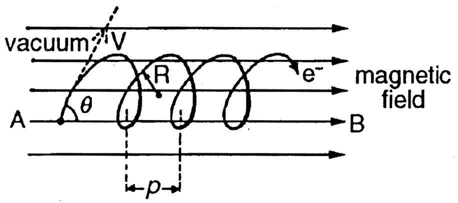


Fig. 2

An electron is injected at a speed v of 7.0×10^6 m s^{-1} at an angle θ into a uniform magnetic field of flux density 3.14×10^{-5} T. It describes a helical path as shown in Fig. 2.

Assuming that $\sin \theta = 3/5$ and $\cos \theta = 4/5$, show that the velocity component of the electron perpendicular to the field is 4.2×10^6 m s^{-1}. Hence, calculate

(a) the radius R of the helical path,

(b) the time for the electron to complete one revolution in the helix,

(c) the velocity component of the electron parallel to the field,

(d) the pitch, p, of the helix.

If the angle θ were very small, what would be the pitch of the helix? [11]

A stream of electrons, all of the same speed but making various small angles with the field, is now injected at the same point. A fluorescent screen at right angles to the field is moved along AB. Describe what is seen. [4]

[The specific charge of the electron, $e/m_e = -1.75 \times 10^{11}$ C kg^{-1}.]
N75/II/9

21 Summarise the evidence which suggests that electrons *(a)* have the same charge, *(b)* have the same mass.

In the apparatus shown in Fig. 3, electrons are emitted from a cathode C and accelerated by a potential difference V between C and a narrow slit S_1. A magnetic field of flux density B causes the electrons to pass through slits S_2 and S_3 following a semi-circular path of radius R with centre 0. A detector D records the electron beam current, which is

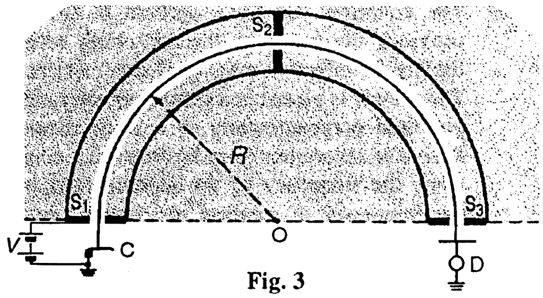


Fig. 3

adjusted to its maximum value by altering V. The whole apparatus is evacuated and a uniform magnetic field acts over the shaded region – the path of the electron is left unshaded for clarity.

(a) Explain why the electron path is circular.

(b) Deduce the direction of the magnetic flux.

(c) Find an expression for the speed of the electrons at S_1 in terms of V and e/m_e, where e and m_e are the charge and the mass of the electron, respectively.

(d) Derive an expression for e/m_e in terms of R, B and V.

The cathode is replaced by a source producing protons and the magnetic flux is reversed. What changes in the p.d. V will be needed to measure e/m_p, the specific charge of a proton?
J82/III/4

22 Particles of mass m and charge e^- are projected with speed v into a uniform magnetic field of flux density B. The initial direction of the particles is at right angles to the field.

(i) Show that each particle moves in a circular path.

(ii) Derive an expression for the radius of the path.

(iii) Show that the time for one revolution is independent of the initial speed.

Describe the paths of particles which enter a magnetic field at angles other than 90°.

When following circular paths, charged particles may emit electromagnetic waves of frequency equal to the frequency of revolution. Calculate the ratio of the wavelength emitted by protons to that emitted by electrons when so moving in the Earth's magnetic field. N82/III/4 (part)

23 *(a)* An electron of mass m, and change e moves in a vacuum with uniform speed v. A uniform magnetic field of flux density B acts perpendicular to the direction of v.

(i) Explain why the electron moves in a circular orbit and show by means of a careful sketch the direction of its rotation relative to the direction of B.

(ii) Find an expression for the radius of its orbit in terms of v, B, e and m_e.

(iii) Hence show that the time t taken to complete one revolution in the orbit is given by $t = 2\pi m_e/Be$.

(b) The equation you have derived in (a) (iii) above provides the basis of the following technique for finding the effective mass of charge carriers in a solid. The sample is placed in a radio-frequency electric field, polarised perpendicularly to a static magnetic field. Resonant absorption of radio-frequency energy occurs when the frequency of the electric field is equal to the frequency of rotation of charge carriers in the magnetic field. In such an experiment in silicon carried out at 4 K, resonant absorption was detected at a frequency of 2.4×10^{10} Hz at a magnetic flux density of 0.20 T.

(i) Find the ratio m^*/m_e, where m^* is the effective mass of charge carriers in silicon and m_e is the free electron mass.

(ii) Suggest why the experiment had to be performed at a very low temperature. J83/I/14 (part)

24 (b) Ions having charge $+Q$ and mass M are accelerated from rest through a potential difference V. They then move into a region of space where there is a uniform magnetic field of flux density B, acting at right angles to the direction of travel of the ions, as shown in Fig. 4.

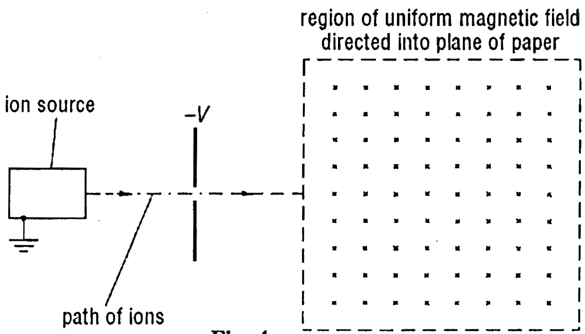


Fig. 4

(i) Show that v, the speed with which the ions enter the magnetic field, is given by

$$v = \sqrt{\frac{2QV}{M}}.$$ [3]

(ii) Hence derive an expression, in terms of M, Q, B and V, for the radius of the path of the ion in the magnetic field. [4]

(iii) Briefly describe and explain any change in the path in the magnetic field of an ion of twice the specific charge (i.e. for which the ratio Q/M is doubled). [4] J92/III/5 (part)

In E Field

25 In a certain particle accelerator, doubly-ionised helium atoms (He^{2+}) pass between points which differ in potential by 1.0×10^6 V. The charge on an electron is -1.6×10^{-19} C. The change of energy of each ion is

A 0.4×10^{-13} J
B 0.8×10^{-13} J
C 1.6×10^{-13} J
D 3.2×10^{-13} J
E 6.4×10^{-13} J

N77/II/23

26 Starting from rest, a proton and an α-particle are accelerated through the same potential difference. The ratio of their final speeds, v_p/v_α is

A $1/2$
B $1/\sqrt{2}$
C 1
D $\sqrt{2}$
E 2

N79/II/37

27 In an evacuated enclosure, a metal plate PQ is maintained at a negative potential V relative to a second plate MN. Electrons of velocity v enter the space between the plates as shown (Fig. 5).

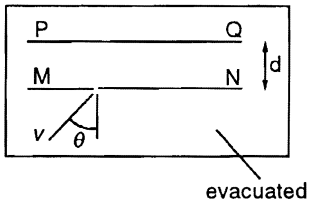


Fig. 5

Given that the electron charge is e and that the electron mass is m_e, electrons just reach the plate PQ if

A $\frac{1}{2} m_e v^2 = eV/d$
B $\frac{1}{2} m_e (v \cos \theta)^2 = eV$
C $\frac{1}{2} m_e (v \sin \theta)^2 = eV/d$
D $\frac{1}{2} m_e (v \sin \theta)^2 = eV$
E $\frac{1}{2} m_e (v \cos \theta)^2 = eV/d$

N81/II/7

28 Fig. 6 below shows an arrangement of two metallic half-cylinders with a common axis with a number of slits S that define a semicircular path of radius r, the whole being enclosed in a vacuum vessel. The outer half-cylinder is at a positive potential with respect to the inner one so that a constant radial electric field is maintained between them. A collimated beam of singly charged positive ions is injected at S_1.

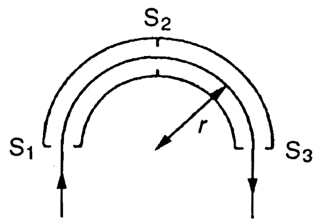


Fig. 6

Given that the incident beam contains ions of different masses and speeds, the beam which emerges at S_3 contains only ions that have the same

A mass.
B specific charge.
C speed.
D kinetic energy.
E momentum.

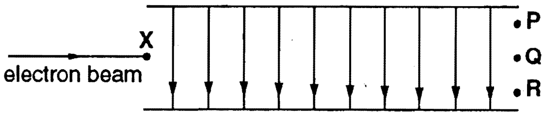
N83/II/17

29 Starting from rest, a proton and an α-particle are accelerated through the same potential difference. If the final speed of the proton is v, what is the final speed of the α-particle?

A $2v$
B $\sqrt{2}\,v$
C v
D $v/\sqrt{2}$
E $v/2$

N84/II/35

30 An electron beam enters a region in an evacuated tube in which there is a uniform electric field directed as shown in the diagram.



Which of the following is a possible path for the beam?

A a curved line from **X** to **P**
B a curved line from **X** to **R**
C the straight line **XQ**
D a line curving out of the plane of the diagram
E a line curving into the plane of the diagram

N88/I/27

31 When an electron, travelling in a vacuum, enters a uniform electric field **E** arranged at right angles to its path, it is deflected

A in the direction of **E** into a parabolic path.
B in the direction opposite to **E** into a parabolic path.
C in the direction of **E** into a circular path.
D in the direction opposite to **E** into a circular path.
E in a direction perpendicular to **E** into a circular path.

N89/I/28

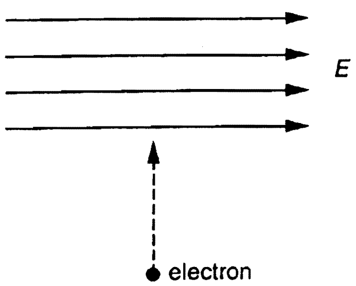
32 The electrons in a cathode-ray tube are accelerated from cathode to anode by a potential difference of 2000 V.

If this p.d. is increased to 8000 V, the electrons will arrive at the anode with

A twice the kinetic energy and four times the velocity.
B four times the kinetic energy and twice the velocity.
C four times the kinetic energy and sixteen times the velocity.
D sixteen times the kinetic energy and four times the velocity.

N94/I/27

33 An electron is projected at right angles to a uniform electric field E.



In the absence of other fields, in which direction is the electron deflected?

A into the plane of the paper
B out of the plane of the paper
C to the left
D to the right

N98/I/17

34 Electrons are emitted with negligible speed from a cathode mounted in an evacuated tube. They are accelerated towards a plane collecting electrode, parallel to the cathode and 10 mm away from it, by a potential difference of 800 V between collector and cathode. Find the time taken for an electron to pass from cathode to collector. (Neglect edge-effects.)

[Specific charge of electron, $e/m_e = 1.8 \times 10^{11}$ C kg^{-1}.]

N79/I/8

35 A particle of mass m and charge q is accelerated from rest through a potential difference V. Write down an expression for its final speed v in terms of m, q and V.

Find the ratio of the final speeds of a proton and an alpha-particle if both are accelerated from rest through the same potential difference.

J83/I/11

36 A proton ($^1_1$H) and a helium nucleus ($^4_2$He) are both accelerated from rest through a potential difference which gives the proton a speed v. Find the speed of the helium nucleus in terms of v.

J86/II/4

37 Two parallel plates are set a distance of 12 mm apart in a vacuum as illustrated in Fig. 7. The top plate is at a potential of +300 V and the bottom plate is at a potential of −300 V.

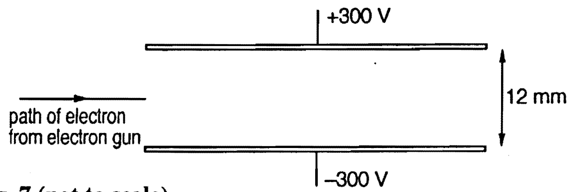


Fig. 7 (not to scale)

(a) On Fig. 7 draw lines to show the electric field between the plates. [3]

(b) At a point mid-way between the plates the field is uniform. Calculate the magnitudes of

(i) the electric field strength at this point,

field strength....................................

(ii) the force on an electron at this point.

force................................ N [5]

(c) A high speed electron from an electron gun is projected towards the pair of plates as shown.

Show a possible path of the electron as it passes between the plates. [2] N97/II/4

38 *(a)* Electrons in a cathode-ray tube leave the cathode with negligible speed at a potential of −9000 V and are accelerated to an anode at a potential of −200 V. For an electron in this tube calculate

(i) the gain in electrical potential,

electrical potential gain = ...

(ii) the loss in potential energy,

potential energy loss = ... J

(iii) the gain in kinetic energy,

kinetic energy gain = ... J

(iv) the speed on reaching the anode.

speed = ... m s^{-1}[6]

(b) Explain why *(a)*(i) is a gain but *(a)*(ii) is a loss. [2]

J99/II/6 (part)

Long Questions

39 Fig. 8 shows two plane, parallel metal plates *PQ* and *RS* in an evacuated enclosure. The separation of the plates is 15 mm and *PQ* is maintained at a potential of +100 V relative to *RS*. *A* and *B* are two slits in the plate *PQ*, separated by 25 mm. A collimated beam containing electrons of different kinetic energies is directed at *A* at an angle of 60° to the plate, as shown.

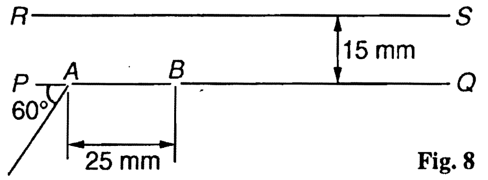


Fig. 8

(a) Find the kinetic energy of the electrons that *just* reach the plate *RS*.

(b) Find the velocity of the electrons that emerge from *B*.

[Electron charge, $e = -1.6 \times 10^{-19}$ C; electron mass, $m_e = 9.1 \times 10^{-31}$ kg.]

J78/I/13 (part)

40 The electrons in a certain cathode-ray tube reach 10% of the speed of light. Calculate the potential difference through which the electrons are accelerated. (Neglect relativistic effects.)

According to relativity theory, the energy of an electron moving at a high speed v is greater than $m_e v^2/2$. To allow for this increase, must the potential difference through which the electrons are accelerated be greater or less than your calculated value if they are still to have 10% of the speed of light?

[The specific charge of the electron, $e/m_e = 1.8 \times 10^{11}$ C kg^{-1}. The speed of light *in vacuo*, $c = 3.0 \times 10^8$ m s^{-1}.]

N80/III/5 (part)

41

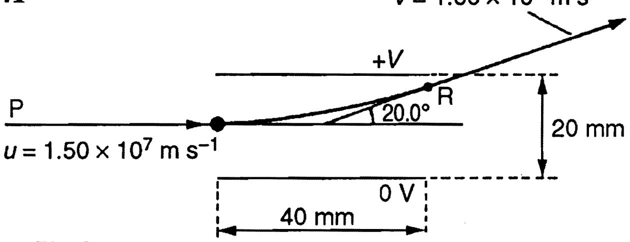


Fig. 9

A beam of electrons travelling at a uniform speed of 1.50×10^7 m s^{-1} in vacuum enters the gap between two plane, parallel deflection plates along the line PQ, midway between the plates (Fig. 9). The plates are 40 mm long and 20 mm apart; the upper plate is at a positive potential *V* with respect to the lower. The beam emerges from the plates at R with a velocity of 1.60×10^7 m s^{-1} at an angle of 20.0° to the original direction.

(a) Draw, to scale, a labelled vector diagram to show the change of velocity Δv of an electron during its path between the points Q and R. Use your diagram to find the magnitude and direction of Δv.

(b) How long does the electron take to go from Q to R? Hence find its acceleration during the deflection.

(c) Neglecting gravitational effects, find the value of *V* that caused this deflection.

(d) You were told to neglect gravity in this calculation. Show that this simplification is justified.

J83/I/13 (part)

42 Summarise, by means of diagrams and mathematical expressions, the nature and magnitude of the forces which act on electrons.

(a) when at rest,

(b) when in motion,

in gravitational, electric and magnetic fields.

An ion beam containing a mixture of singly charged sodium ions and potassium ions is accelerated from rest in a vacuum by a potential difference of 5 kV. If the beam current is 20 μA, what is the total number of ions passing any fixed point in the beam each second?

The accelerating p.d. is now applied only for a short time, so as to produce a "bunch" of accelerated ions which then travel along a 20 m field-free vacuum space to a detector. Pulses due to the arrival of the sodium and potassium ions occur at slightly different times. Calculate this time difference.

[Ionic masses: sodium, Na^+, 3.81×10^{-26} kg, potassium, K^+, 6.49×10^{-26} kg.]

Suggest a method by which such a time difference might be measured, and hence describe how such a device can be used as a mass spectrometer. N84/III/4

43 *(b)*

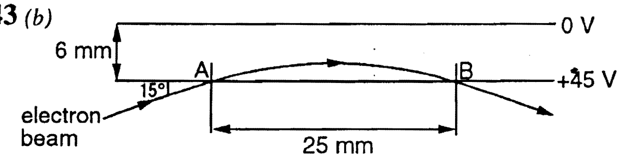


Fig. 10

Fig. 10 shows the principle of a type of velocity selector for electrons. Two parallel metal plates are arranged 6.0 mm apart in a vacuum. The lower plate is at a potential of +45 V relative to the upper, and has two parallel slits A and B in it, 25 mm apart.

A collimated beam containing electrons of different speeds is directed towards slit A at an angle of 15° with the plate. Electrons emerging from B all have the same velocity.

(i) What is the magnitude and direction of the acceleration of an electron while it is between the plates? (Neglect the effect of gravity.)

(ii) Find the speed of the electrons while come out of slit B. N85/II/8 (part)

44 Fig. 11 shows part of the deflection system of a cathode-ray tube. An electron moving with a speed of 1.5×10^7 m s^{-1} approaches the region between two parallel metal plates, which are 20 mm apart and 60 mm long. The upper plate is at a steady positive potential of 80 V with respect to the lower.

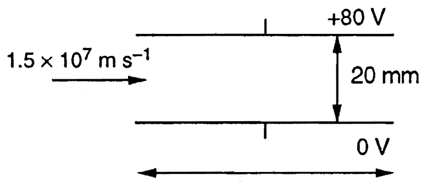


Fig. 11

(a) Copy Fig. 11 on to your answer paper and sketch the path of the electron as it passes between and beyond the plates. [1]

(b) Find the magnitude and direction of the acceleration of the electron in the region between the plates. [3]

(c) Hence find the vertical and horizontal components of the velocity of the electron when it emerges from the plates. [3]

(d) Use your answer to *(c)* above to find the angle through which the electron beam has been deflected as a result of passing between the plates. [3] N87/II/11 (part)

45 *(c)* In a cathode-ray tube, the accelerating potential for the electrons is 10.0 kV and the distance within which the acceleration takes place is 0.100 m.

(i) Find the time it takes for an electron to pass along the cathode-ray tube if, after the acceleration, it has a further 0.400 m to travel at a constant potential. [5] N88/III/11 (part)

46 *(b)* In one type of c.r.o., the electrostatic deflection system consists of two parallel metal plates, each of length 2.0 cm, with a separation of 0.50 cm, as shown in Fig. 12.

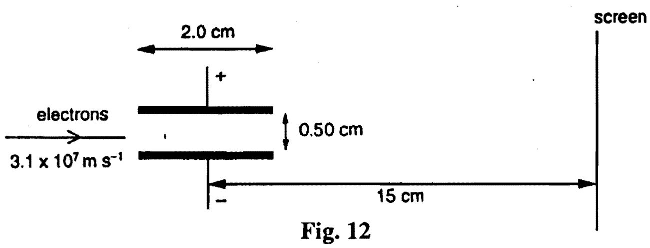


Fig. 12

The centre of the plates is situated 15 cm from a screen. A potential difference of 80 V between the plates provides a uniform electric field in the region between the plates. Electrons of speed 3.1×10^7 m s^{-1} enter this region at right angles to the field. Calculate

(i) the time taken for an electron to pass between the plates,

(ii) the electric field strength between the plates,

(iii) the force on an electron due to the electric field,

(iv) the acceleration of the electron along the direction of the electric field,

(v) the speed of the electron at right angles to its original direction of motion as it leaves the region between the plates. [9]

(c) Hence, by considering your answer to *(b)*(v) and the original speed of the electron, estimate the deflection of the electron beam on the screen. [2]

(d) (i) Figure 13 represents the front of the screen of the c.r.o.

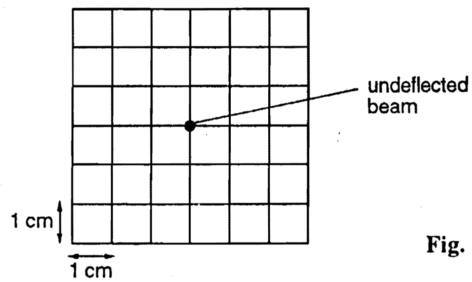


Fig. 13

Copy Fig. 13 on to your paper and mark on your diagram the position of the deflected beam of electrons.

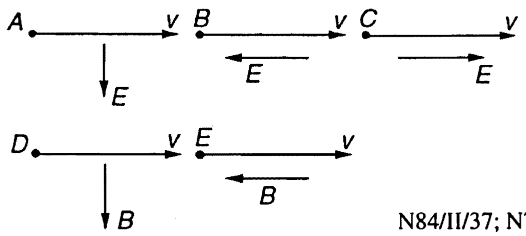
(ii) Draw similar sketch diagrams to show the trace on the screen if the p.d. across the plates is

(1) varying sinusoidally with r.m.s. value 80 V,

(2) a half-wave rectified sinusoidal voltage of r.m.s. value 80 V. [5] J94/III/4 (part)

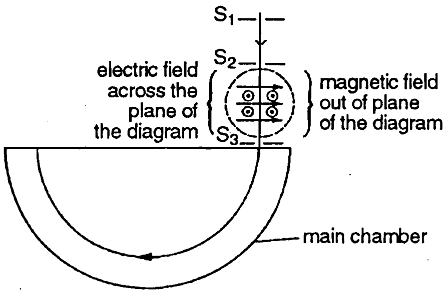
In B & E Fields

47 An electron moving with velocity v in a vacuum enters either a region of uniform electric field E or a region of uniform magnetic field B. The following diagrams show the orientation of the field with respect to the initial velocity. Which one of the arrangements causes the electron to move in a parabolic path?



N84/II/37; N78/II/33

48 The diagram shows a mass spectrometer in which positive ions pass through slits S_1, S_2 and S_3 before entering the main chamber. Between S_2 and S_3 they pass through mutually perpendicular magnetic and electric fields, the intensities of which may be varied.



What is the purpose of the mutually perpendicular fields between S_2 and S_3?

A to accelerate the ions to high velocity
B to eliminate stray electrons from the beam
C to select ions of a particular charge
D to select ions of a particular mass
E to select ions of a particular velocity

N81/II/39; N90/I/27

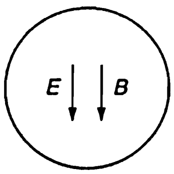
49 Considering only alpha particles, electrons and protons, which one of the following correctly names the particles for which the magnitude of the specific charge (Q/m) is greatest and least?

	greatest Q/m	*least Q/m*
A	electron	alpha particle
B	alpha particle	electron
C	electron	proton
D	proton	electron
E	proton	alpha particle

J83/II/38

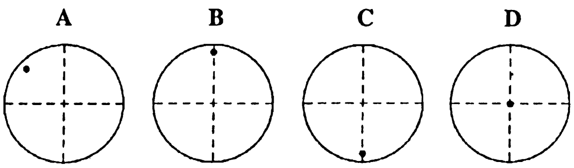
50 In a cathode-ray oscilloscope tube, the electron beam passes through a region where there are electric and magnetic fields directed vertically downwards as shown.

front view of screen



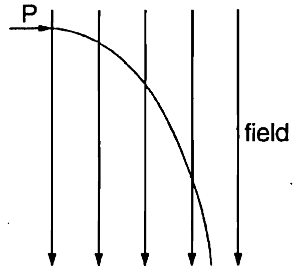
The deflections of the spot from the centre of the screen produced by the electric field E and the magnetic field B acting separately are equal in magnitude.

Which diagram shows a possible position of the spot on the screen when both fields are operating together?



J84/II/18; N91/I/27; J97/I/27

51 A charged particle is projected horizontally at P into a uniform vertical field. The particle follows the path shown.



Ignoring gravitational effects, what describes a possible state of charge of the particle and the nature of the field?

	charge	field
A	negative	electric
B	negative	magnetic
C	positive	electric
D	positive	magnetic

N86/I/26; N92/I/26; J2000/I/27

52 A charged particle is situated in a region of space and it experiences a force only when it is in motion. It can be deduced that the region encloses

A both an electric field and a gravitational field.
B both a magnetic field and an electric field.
C both a magnetic field and a gravitational field.
D a magnetic field only.
E an electric field only.

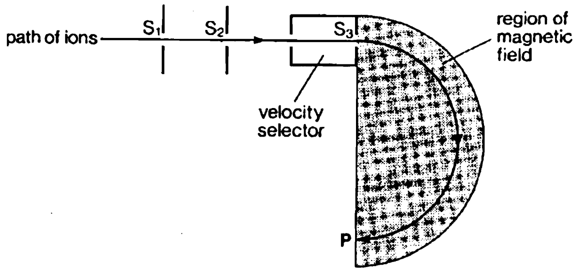
J89/I/26

53 An electron is projected with velocity v into a region where there exists a uniform electric field of strength E perpendicular to a uniform magnetic field of flux density B. If the electron velocity is to remain constant, v must be

A of magnitude B/E and parallel to B.
B of magnitude E/B and parallel to E.
C of any magnitude but at 45° to both E and B.
D of magnitude B/E and perpendicular to both E and B.
E of magnitude E/B and perpendicular to both E and B.

J90/I/28

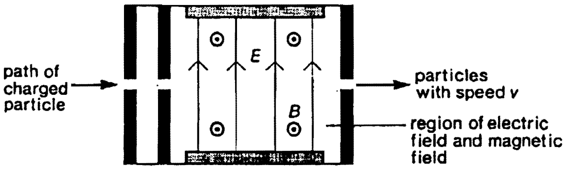
54 The diagram shows the principle of a simple form of mass spectrometer. Ions are passed through narrow slits S_1 and S_2 and into a velocity selector. The selected ions, after passage through the slit S_3, are deviated by the uniform magnetic field.



Which quantity must be the same for all ions arriving at point **P**?

A charge
B $\frac{\text{charge}}{\text{mass}}$
C mass
D momentum J91/I/29; N95/I/29

55 The diagram shows a velocity selector used in a mass spectrometer.



The charged plates give a uniform electric field of strength E. In the same region there is a uniform magnetic field of strength B, at right angles to the electric field.

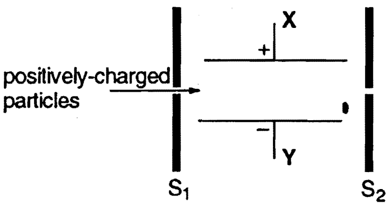
Particles carrying charge Q and having speed v pass through undeviated, because the forces on them due to the electric and magnetic fields are equal in magnitude but opposite in direction.

What is the speed v of particles leaving the selector?

A $\frac{B}{E}$ **B** $\frac{E}{B}$ **C** $\frac{BQ}{E}$ **D** $\frac{EQ}{B}$

J95/I/27

56 The diagram shows part of a velocity selector.



A beam of positively-charged particles, with a range of velocities, enters through the slit in S_1. An electric field is provided by two parallel plates **X** and **Y** with a p.d. between them of polarity as shown. The velocity selector is completed by the addition of an electromagnet to produce a magnetic field of a suitable strength and direction so that particles of only a particular velocity emerge from the slit in S_2.

What should be the direction of the magnetic field?

A from **X** to **Y**
B from **Y** to **X**
C perpendicular to and into the plane of the diagram
D perpendicular to and out of the plane of the diagram

J96/I/27

57 An electron beam enters a region in which there is an electric field perpendicular to the beam. A similar electron beam enters a magnetic field, also perpendicular to the beam direction.

Does the magnitude of the force on the electrons depend on their speeds in these two fields?

	electric field	*magnetic field*
A	no	no
B	no	yes
C	yes	no
D	yes	yes

N97/I/5

58 A small plastic sphere carrying a negative charge is maintained at a constant height by the action of a downward vertical electric field.

A uniform magnetic field is applied in the same direction as the electric field.

What does the sphere do?

A move downwards in a spiral path
B move in a horizontal circle
C move upwards in a spiral path
D remain stationary N99/I/27

59 A beam of electrons of speed v passes undeflected through superimposed uniform magnetic and electric fields of magnitudes B and E respectively. How must the fields be related in both magnitude and direction?

J77/I/6

60 *(b)* To find the mass m of an atom of an element, it is necessary to determine the specific charge q/m_1 of an ion of that element, to find the number n of elementary charges on the ion and to know the values of the electron charge e and mass m_e. Give the principle of an experiment to measure the specific charge of an ion and write down an equation from which q/m_1 can be calculated. Show how m is then determined.

N82/I/17 (part)

61 In a mass-spectrometer, negatively charged particles enter a region in which the uniform magnetic flux density is 0.087 T and the uniform electric field strength is 3.04×10^6 V m^{-1}, as shown in Fig. 15. The particles are not deflected.

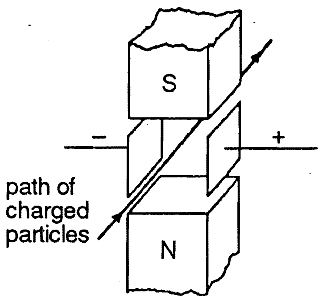


Fig. 15

Draw a sketch showing the direction of the force which each field exerts on the particles and find the velocity of the particles. [5]

J88/II/6

62 A narrow beam of identical positively charged particles passes through two slits, S_1, and S_2, as shown in **Fig. 16**.

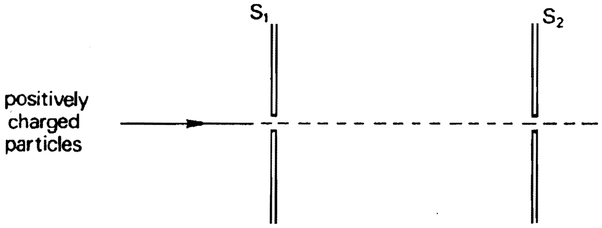


Fig. 16

A uniform magnetic field of flux density B is applied in the region between S_1 and S_2 in a direction *out of* the plane of the paper.

(a) A uniform electric field is applied in the space between the slits such that charged particles of only one speed v can pass through S_2. On **Fig. 16**, mark clearly with an arrow labelled E the direction of this electric field. [2]

(b) Explain how this combination of magnetic and electric fields allows particles of only one speed to pass through S_2. Deduce an expression for v in terms of B and the electric field strength, E. [3]

(c) Sketch on **Fig. 16** a possible path, in the region of the electric and magnetic fields, of particles having a speed greater than v. [2]

J93/II/7

63 *(c)*

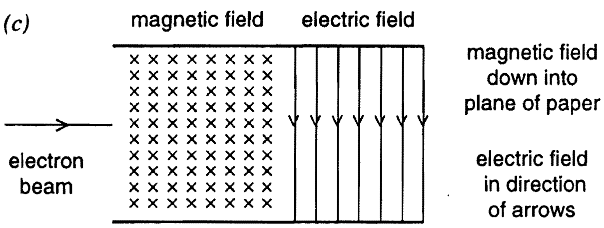


Fig. 17

While travelling between the anode and the screen of a cathode-ray tube, electrons move through adjacent electric and magnetic fields, as illustrated in Fig. 17.

On Fig. 17, sketch a possible path of an electron through both fields. [3] J99/II/6 (part)

Long Questions

64 What do you understand by the terms *ion, the charge on an ion* and *the specific charge of an ion*? [3]

Describe briefly an experiment to measure the specific charge of the electron. [7]

N77/III/5 (part)

65 *(a)* Describe the principles of an experiment which could be performed in a school laboratory to determine the speed of the electrons in a beam travelling through a vacuum. Give the theory which would enable you to calculate the speed. [8]

J89/II/11 (part)

66 *(a)* Describe by means of a diagram and a simple equation the force due to

(i) an electric field,

(ii) a magnetic field,

acting on an electron moving at right angles to each field.

Hence explain how an electric field and a magnetic field may be used in the selection of the velocity of negatively charged particles. [9]

J92/III/5 (part)

67 *(a)* What is meant by a *field of force*? [1]

(b) A particle has mass m and charge $+q$.

(i) State the magnitude and the direction of the force on this particle when it is at rest in

1. a gravitational field,
2. an electric field,
3. a magnetic field.

(ii) State the magnitude and the direction of the force on this particle when it is moving with velocity v in a direction normal to

1. a gravitational field,
2. an electric field,
3. a magnetic field. [9]

J96/III/2 (part)

68 This question concerns three different types of field, namely, gravitational field, electric field and magnetic field.

(a) Explain what is meant by the term *field* in physics and define the following terms:

(i) gravitational field strength g,

(ii) electric field strength E,

(iii) magnetic flux density B. [4]

(b) How is the mass M of a body related to its weight W at the surface of the Earth? [1]

(c) A proton is travelling with velocity 8.6×10^6 m s^{-1} at right angles to

(i) a gravitational field of field strength 9.8 N kg^{-1},

(ii) an electric field of field strength 1.7×10^6 N C^{-1},

(iii) a magnetic field of magnetic flux density 0.089 T.

Calculate the magnitude of the force which each of the fields exerts, separately, on the proton. [5]

(d) How would each of your answers in *(c)* be affected if the proton were stationary instead of moving? [3]

(e) For the moving proton in *(c)*, illustrate on three diagrams, one for each field, the direction in which each force acts. [3]

(f) The three fields in (c) act in the same direction. Calculate for the proton, at the instant when it enters the fields, the magnitude of

(i) the resultant force,

(ii) the acceleration. [4]

N96/III/1

69 (a) Define *electric field strength* and state an SI unit of electric field strength. [2]

(b) State the equation for the force F acting on a charge Q travelling with velocity v in, and at right angles to, a magnetic field of field strength B. [1]

(c) Outline Millikan's experiment and summarise the experimental evidence it provides for the quantisation of charge. [6]

(d) A part of a mass spectrometer is illustrated in Fig. 18. The whole arrangement is in a vacuum. Negative ions of mass 2.84×10^{-26} kg and charge -1.60×10^{-19} C, are generated at S, which is at a potential of –3000 V. The ions are accelerated in a narrow beam towards H, which is a hole in a hollow metal container. The container is kept at zero potential.

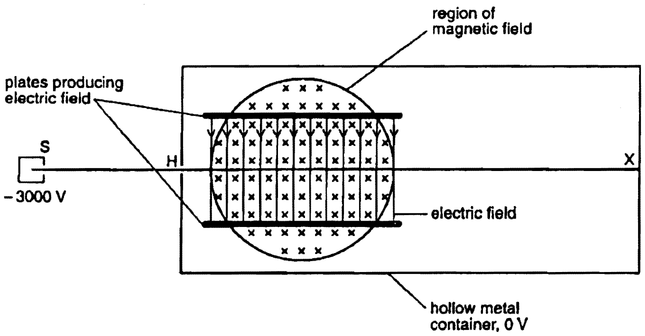


Fig. 18

Once inside the container the negative ions enter a region in which there is an electric field of field strength E, and a magnetic field of flux density 0.83 T. When in these fields the negative ions continue in a straight line with constant velocity.

(i) Calculate the velocity of the ions when they reach H. [4]

(ii) Explain, using a sketch, how it is possible for the ions not to be deflected in the fields. [2]

(iii) Calculate the electric field strength E. [3]

(iv) The electric field is then switched off. State, without calculation, what would happen to the path of the negative ions. [2]

J97/III/6

70 (d) A source of protons is situated inside a similar positively charged sphere and these protons accelerate to earth along an evacuated tube, as illustrated in Fig. 19.

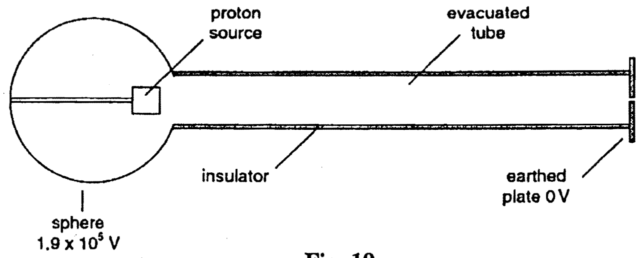


Fig. 19

For a proton accelerated from rest through a potential difference of 1.9×10^5 V,

(i) calculate the change in potential energy,

(ii) show that its speed is 6.0×10^6 m s^{-1}. [4]

(e) The protons emerge from the evacuated tube into a region of uniform magnetic field of flux density 0.18 T. The region is evacuated and the magnetic field is normal to the direction of motion of the protons.

(i) Calculate the radius of the path of the protons in the magnetic field.

(ii) Measurement of this radius can be used as a means of determining the kinetic energy of the protons. State and explain what happens to the radius if the kinetic energy of the protons were to be reduced. [4]

J98/III/3 (part)

71 (b) An electron is accelerated from rest between a negative cathode and a positive anode in a vacuum. The potential difference between the anode and cathode is 2000 V and their separation is 0.074 m. Calculate

(i) the electric field between the electrodes (assumed to be uniform),

(ii) the kinetic energy of the electron when it reaches the anode,

(iii) the speed of the electron when it reaches the anode. [6]

(c) In an experiment, an electron travelling with speed 4.3×10^7 ms^{-1} enters a magnetic field of uniform flux density 0.0086 T, in a direction at right angles to the field.

(i) Sketch the path of the electron in the magnetic field and show the direction of the field.

(ii) Calculate the radius of the path of the electron in the field.

(iii) Calculate the electric field strength required to provide an equal force to that provided by the magnetic field.

(iv) Explain how it is possible to select electrons of a particular speed by the use of electric and magnetic fields. [9]

N98/III/6 (part)

72 *(a)* A stationary negatively-charged particle experiences a force in the direction of the field in which it is placed. State, with a reason in each case, whether or not the field is

(i) magnetic,

(ii) electric,

(iii) gravitational. [3]

(b) (i) Calculate the magnitude of the electric field strength required to maintain an electron in a fixed position in the gravitational field of the Earth, near its surface.

(ii) Hence explain why gravitational effects are ignored when considering the motion of electrons in electric fields. [4]

(c) Atoms of Neon-20 are ionised by the removal of one electron from each atom. For a Neon-20 ion,

(i) state the charge on the ion,

*(ii) calculate its mass. [3]

(d) The ions in *(c)* are accelerated from rest in a vacuum through a potential difference of 1400 V. They are then injected into a region of space where there are uniform electric and magnetic fields acting at right angles to the original direction of motion of the ions, as shown in Fig. 20.

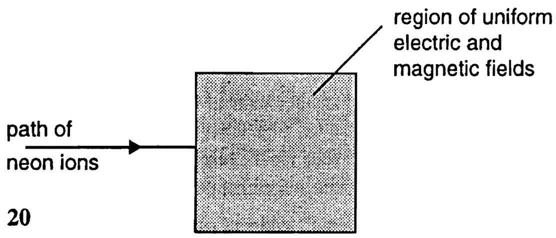


Fig. 20

The electric field has field strength E and the flux density of the magnetic field is B.

(i) Copy Fig. 20 and on your diagram indicate clearly the directions of the electric and magnetic fields so that the ions pass undeflected through the region.

(ii) Calculate the speed of the accelerated ions on entry into the region of the electric and magnetic fields.

(iii) The electric field strength E is 6.2×10^3 V m^{-1}. Calculate the magnitude of the magnetic flux density so that the ions are not deflected in the region of the fields. [7]

(e) The mechanism by which the neon atoms in *(c)* are ionised is changed so that each atom loses two electrons. State what change occurs in

(i) the speed of the ions entering the region of the electric and magnetic fields in *(d)*,

(ii) the path of the ions in the two fields. [3]

J99/III/6

Millikan's Experiment

Questions **73–75** all relate to an experiment in which a small, charged plastic sphere is maintained in a stationary position by the application of a suitable vertical electric field between two large horizontal plates in an evacuated chamber.

73 The mass of the sphere is 3.2×10^{-14} kg and it carries a net charge equal to that of 10 electrons. If the electronic charge e is -1.6×10^{-19} C and the acceleration of free fall g is 10 ms^{-2} the field required to keep the sphere stationary is

A 5×10^{-6} V m^{-1}
B 5×10^{-5} V m^{-1}
C 2×10^{3} V m^{-1}
D 2×10^{4} V m^{-1}
E 2×10^{5} V m^{-1} N78/II/17

74 If, when the sphere is stationary, a uniform vertical magnetic field is applied in the same direction as the electric field, the negatively charged sphere will

A remain stationary.
B move upwards in a helical path.
C move downwards in a helical path.
D move in a horizontal circle.
E move in a vertical circle. N78/II/18

75 If, with no magnetic field, the sphere loses one electron and the electric field is unchanged, the sphere will

A accelerate upwards with an acceleration greater than g.
B accelerate upwards with an acceleration less than g.
C accelerate downwards with an acceleration equal to g.
D accelerate downwards with an acceleration less than g.
E accelerate downwards with an acceleration greater than g. N78/II/19

Questions 76 and 77 refer to the following information.

76 Two similar metal plates, each of area A, are arranged horizontally, one vertically above the other, a distance d apart. They are maintained at a steady potential difference V.

The capacitance between them is C and the charge on the top plate is Q. A small oil-drop of radius r and carrying a charge q is between them.

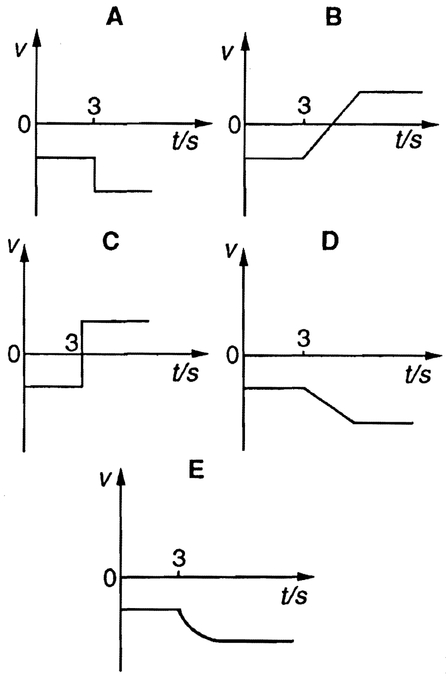
The electric force on the oil-drop may be found from

A d, q and V.
B q, Q and V.
C Q, r and V.
D C, d and Q.
E C, q and Q. N79/II/23

77 If other variables are kept constant, the potential difference needed to hold the drop stationary between the plates is independent of the

A radius of the drop r.
B acceleration of free fall g.
C density of air.
D density of the oil.
E viscosity of the air. N79/II/24

78 In Millikan's apparatus, a negatively-charged oil drop is observed to be falling at uniform speed for a period of 3 s, after which time an electric field is applied vertically downwards. Which one of the following graphs could represent the variation of the velocity, v, of the oil drop with the time, t, from the instant observations commenced?



N81/II/36

79 In a Millikan experiment, a positively charged oil-drop is observed to fall at a uniform speed of $4v$ when the electric field between the plates is zero. On applying an electric field X, the drop *rises* at a uniform speed of $2v$. On changing the electric field, the drop is observed to fall at a uniform speed of v. If the charge on the drop remains unaltered, what are the magnitude and direction of the final field? (Neglect upthrust from the air.)

	magnitude	*direction*
A	$X/4$	vertically downwards
B	$X/2$	vertically downwards
C	X	vertically downwards
D	$X/4$	vertically upwards
E	$X/2$	vertically upwards

N82/II/18

80 An early experimenter, working in other than SI units, obtained the following ten values for the magnitudes of the charges on small oil drops:

9.82	19.64	39.28	39.28	34.37
19.64	19.64	29.46	19.64	39.28

What value do these results suggest for the magnitude of the charge of the electron as measured in these units?

A 2.45
B 4.91
C 9.82
D 19.64

J85/I/26; N95/I/26; N2000/I/27

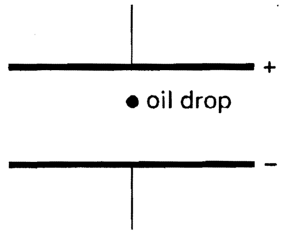
81 Drops **X** and **Y**, of the same oil, remained stationary in air in the same vertical electric field. After the field was switched off, **X** fell more quickly than **Y**.

Which deduction can be made?

A **X** had a greater charge than **Y**.
B **Y** had a greater charge than **X**.
C Both **X** and **Y** were positively charged.
D The charges on **X** and **Y** were identical in sign and magnitude.

J86/I/26; N96/I/27

82 A negatively-charged oil drop is held stationary between horizontal, charged metal plates, the upper plate being positive.



The drop acquires additional negative charge. In order to keep the drop stationary, what change should be made?

A Move the plates closer together.
B Reverse the charges on the plates.
C Give the positive plate more positive charge.
D Move both plates the same distance upwards.
E Decrease the potential difference between the plates.

J87/I/26; J91/I/27

83 In an experiment to measure the electron charge, an oil drop with an excess of two electron charges is held stationary between two parallel horizontal plates when the potential difference between them is 150 V.

A second oil drop, of mass twice that of the first, is held stationary with 200 V between the plates. Neglecting the upthrust of the air, how many excess electron charges does the second drop carry?

A 2 **D** 6
B 3 **E** 8
C 4

N87/I/26

***84** Which one of the following statements about the charge on the electron is **incorrect**?

A It can be measured in coulomb.
B It is equal in magnitude to the charge on the proton.
C It is equal in magnitude to the charge on the beta-particle.
D It can be determined experimentally only if the mass of the electron is known.
E It is the smallest charge which can be found on a charged oil drop.

N89/I/27

85 In Millikan's experiment, oil drops are used to measure the elementary charge e.

Which statement about the behaviour of the oil drops during the experiment is correct?

A When an oil drop becomes charged, the size of the charge must equal e.
B When an oil drop is stationary, it must carry a charge.
C When an oil drop moves upwards, only the electric force is acting on it.
D When no electric field acts, all drops move downwards with the same constant velocity.

J93/I/27; J99/I/27

86 An oil-drop of mass m, carrying a charge q, is in the region between two horizontal plates. When the potential difference between the upper and lower plates is V, the drop is stationary. The potential difference is then increased to 2 V.

What is the initial upward acceleration of the drop?

A g B $2g$ C $\frac{2qV}{m} - g$ D $\frac{2qV}{m}$

N97/I/27

87 Two large horizontal metal plates are arranged one above the other a short distance apart in a vacuum. A small, negatively charged sphere introduced between them may be held stationary if an appropriate potential difference is applied to the plates. Explain how (if at all) the equilibrium of the sphere might be affected if the plates were slowly pulled apart while remaining connected to the source of e.m.f.

J78/I/9

88 An oil drop of mass m carrying charge q is maintained stationary between two plane, horizontal metal plates by the application of a suitable electric field. Write down an expression for the magnitude E of this field, and state its direction.

State what would happen if

(a) the drop acquired additional charge of the same sign,

(b) the plates were moved apart, the potential difference between them remaining constant. J85/II/6

89 A student repeated Millikan's oil-drop experiment and measured the charge on a number of different drops. The results obtained are shown in the table.

Charge on oil-drop / 10^{-19} C								
1.64	3.23	1.61	4.83	1.59	1.63	7.96	1.62	1.64

Use these results to obtain a value for e, the elementary charge. [4] J89/II/6

Long Questions

*90 Describe, giving all relevant equations, how the electron charge may be found from observations of the motion of a charged oil drop moving vertically in a vertical electric field.

An oil drop of mass 2.0×10^{-15} kg falls at its terminal velocity between a pair of *vertical* parallel plates. When a potential gradient of 5.0×10^4 V m^{-1} is maintained between the plates, the direction of fall becomes inclined at an angle of 21° 48' to the vertical. Draw vector diagrams to illustrate the forces acting on the drop *(a)* before, and *(b)* after, the field is applied. Give formulae for the magnitude of the vectors involved. (Stokes' law may be assumed and the Archimedes' upthrust ignored.)

Calculate the charge on the drop.

[$g = 10$ m s^{-2}.] J75/II/9

*91 An oil drop, of radius r and density ρ, carrying a charge q, remains suspended between two large horizontal metal plates separated by a distance x and maintained at a potential difference V. Deduce the condition for the drop to remain stationary, neglecting the upthrust of the air.

The charge on such a drop may be varied by bringing up a radioactive source. Account for such changes.

N76/III/6 (part)

92 A potential difference V is maintained between two large horizontal metal plates separated by a small distance d. Between them is a small oil top of mass m carrying a charge q. Neglecting the upthrust of the air, derive the condition for the drop to remain at rest. Explain why it is reasonable to neglect the upthrust.

The value of q found in one such experiment was 1.15×10^{-18} C, the mass m was determined with an error of +5%, and the distance d with an error of −2%. The other quantities involved were measured with negligible error. Find the consequent absolute error in the calculated value of q. When values of q are determined from many such experiments, they show a certain regularity. Describe this regularity and explain what may be deduced from it.

J80/III/4 (part)

93 Show by means of a labelled sketch the important features of the apparatus used by Millikan to measure the electron charge by observations on charged oil droplets.

State the forces acting on a stationary charged droplet in this experiment, and give the relationship between these forces.

In a certain Millikan experiment the necessary adjustments are made to keep a charged droplet stationary between the plates. Describe and explain what would happen to the droplet if the separation of the plates were then slowly reduced, the potential difference between the plates remaining constant.

The diameters of the droplets used by Millikan were of the order of 10^{-6} m (about two wavelengths of visible light). He deduced their mass by measuring their speed and using data on the viscosity of air. Why did he not measure the diameter, using a microscope, to calculate the mass from the known density of oil?

In one experiment Millikan found that the charge Q on a particular drop had the following values at various times. (The units, e.s.u., are those which were then in use.)

Q/e.s.u.
6.87×10^{-9}
4.44×10^{-9}
8.37×10^{-9}
5.39×10^{-9}
1.97×10^{-9}
2.96×10^{-9}

Use these results to find a value for the electron charge (in e.s.u.). Deduce the conversion factor between the SI unit of charge (the coulomb) and the e.s.u. of charge.

The Millikan experiment is said to provide experimental evidence for *the quantisation of charge*. What is meant by *quantisation*? What is its importance in relation to electric charge? N86/II/11

94 *(a)* (i) An oil droplet between two metal plates across which there is a potential difference, may be observed to be stationary. The arrangement is as shown in Fig. 21.

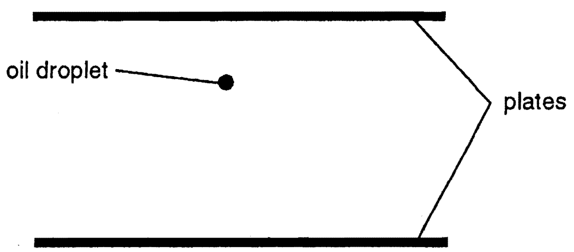


Fig. 21

Show on a similar diagram the forces acting on the oil drop, together with the appropriate charge on the drop and the direction of the electric field. [2]

(ii) 1. State what additional information is required if the value of the charge is to be determined.

2. Write down the equation used to determine the charge. [3]

N98/III/6 (part)