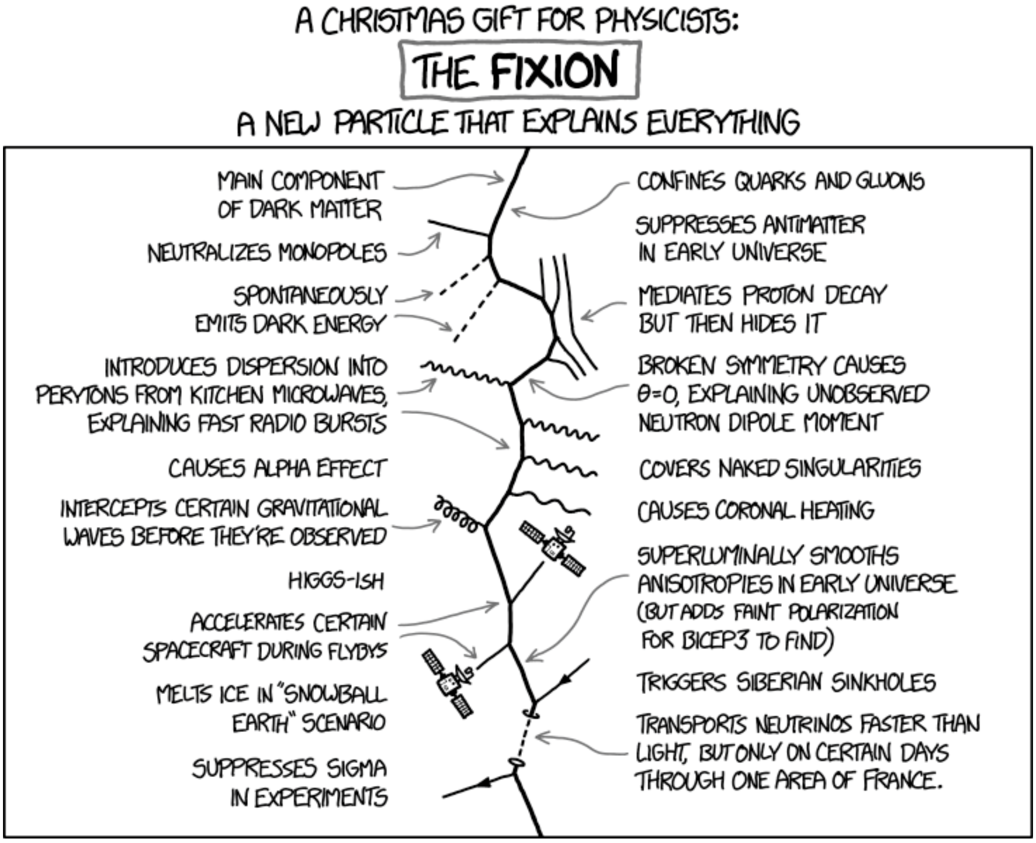
Advanced Higher Physics
Past Paper Questions

2.2 Particles from Space



9. A particle with charge q and mass m is travelling with constant speed v. The particle enters a uniform magnetic field at 90° and is forced to move in a circle of radius r as shown in Figure 9.

The magnetic induction of the field is B.

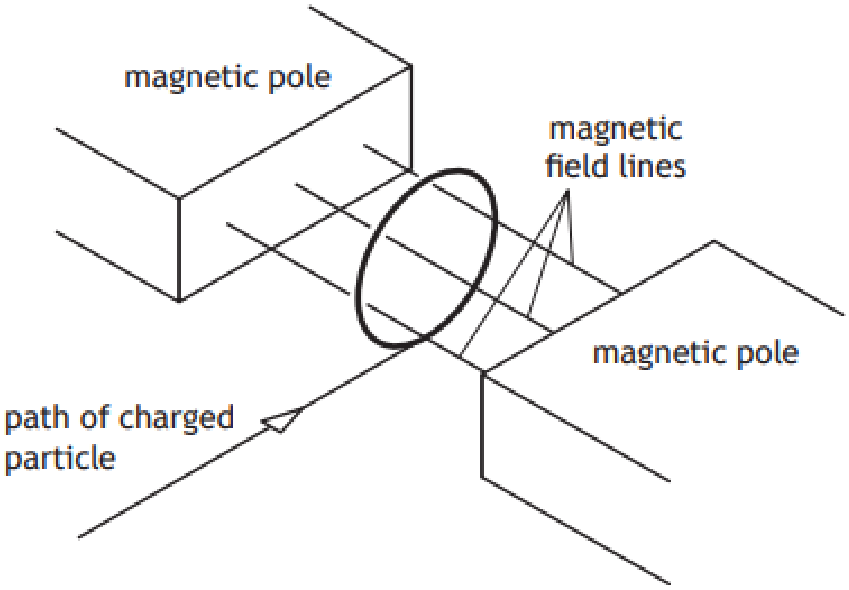


Figure 9

(a) Show that the radius of the circular path of the particle is given by

$$r = \frac{mv}{Bq}$$

2

(b) In an experimental nuclear reactor, charged particles are contained in a magnetic field. One such particle is a deuteron consisting of one proton and one neutron.

The kinetic energy of each deuteron is 1·50 MeV.

The mass of the deuteron is $3{\cdot}34 \times 10^{-27}$ kg.

Relativistic effects can be ignored.

(i) Calculate the speed of the deuteron. **4**

(ii) Calculate the magnetic induction required to keep the deuteron moving in a circular path of radius 2·50 m. **2**

(iii) Deuterons are fused together in the reactor to produce isotopes of helium.

$^{3}_{2}He$ nuclei, each comprising 2 protons and 1 neutron, are present in the reactor.

A $^{3}_{2}He$ nucleus also moves in a circular path in the same magnetic field.

The $^{3}_{2}He$ nucleus moves at the same speed as the deuteron.

State whether the radius of the circular path of the $^{3}_{2}He$ nucleus is greater than, equal to or less than 2·50 m.

You must justify your answer. **2**

9. (*a*) A proton moving at constant speed v enters a uniform magnetic field of induction B as shown in Figure 9A.

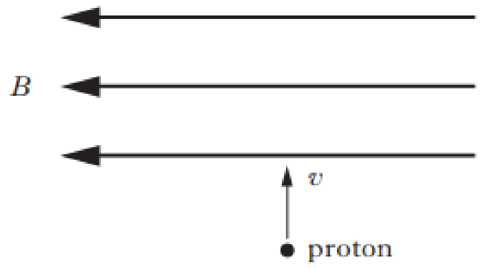


Figure 9A

Within the field the proton follows a circular path of radius r.

(i) Explain why the proton follows a circular path. **1**

(ii) Show that the radius of the path r is given by

$$r = \frac{1 \cdot 05 \times 10^{-8} v}{B}.$$ **2**

(*b*) Another proton moving at the same speed v enters the magnetic field at an angle θ to the magnetic field lines as shown in Figure 9B.

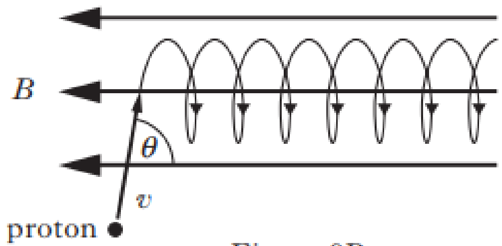


Figure 9B

Explain the shape of the path followed by this proton in the magnetic field. **2** (*c*) The solar wind is a stream of charged particles, mainly protons and electrons, released from the atmosphere of the Sun. Many of these particles become trapped by the magnetic field of the Earth.

Some of the trapped particles move back and forth in helical paths between two ***magnetic mirror points***. The path followed by one particular proton is shown in Figure 9C.

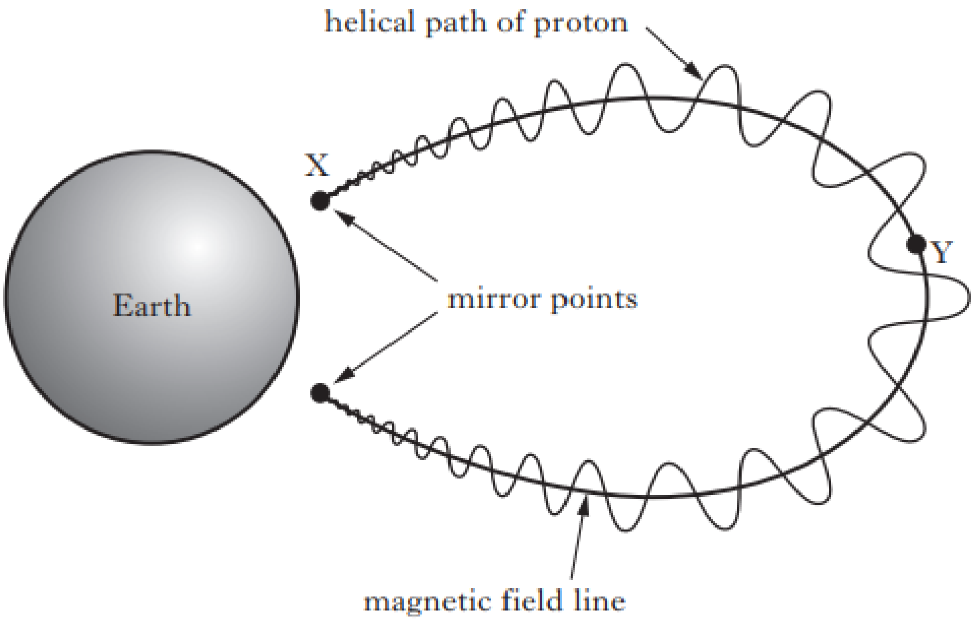


Figure 9C

The speed of the proton remains constant at $1{\cdot}2 \times 10^7\,\mathrm{m\,s^{-1}}$ as it travels along its helical path from one magnetic mirror point to the other.

(i) The proton oscillates between the two mirror points with a frequency of 4·0 Hz. Calculate the distance that the proton travels in moving from one mirror point to the other. **3**

(ii) Explain why the radius of the helical path followed by the proton increases as it moves from point X to point Y as shown in Figure 9C. **1**

(iii) At point X the radius of curvature of the helix for this proton is $1{\cdot}0 \times 10^4\,\mathrm{m}$. Calculate the strength of the Earth's magnetic field at this point. **2**

(11)

9. (*a*) A proton moving at constant speed v enters a uniform magnetic field of induction B as shown in Figure 9A.

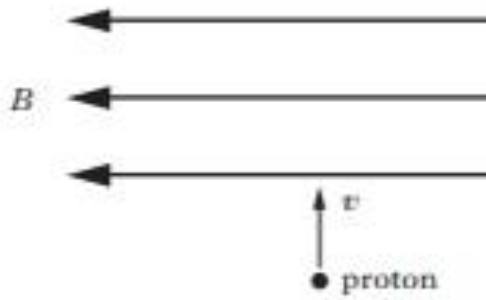


Figure 9A

Within the field the proton follows a circular path of radius r.

(i) Explain why the proton follows a circular path. 1

(ii) Show that the radius of the path r is given by

$$r = \frac{1{\cdot}05 \times 10^{-8} v}{B}.$$ 2

(*b*) Another proton moving at the same speed v enters the magnetic field at an angle θ to the magnetic field lines as shown in Figure 9B.

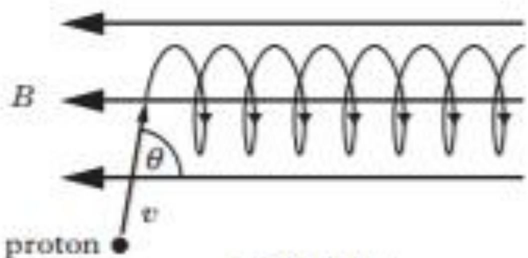


Figure 9B

Explain the shape of the path followed by this proton in the magnetic field. 2

(*c*) The solar wind is a stream of charged particles, mainly protons and electrons, released from the atmosphere of the Sun. Many of these particles become trapped by the magnetic field of the Earth.

Some of the trapped particles move back and forth in helical paths between two ***magnetic mirror points***. The path followed by one particular proton is shown in Figure 9C.

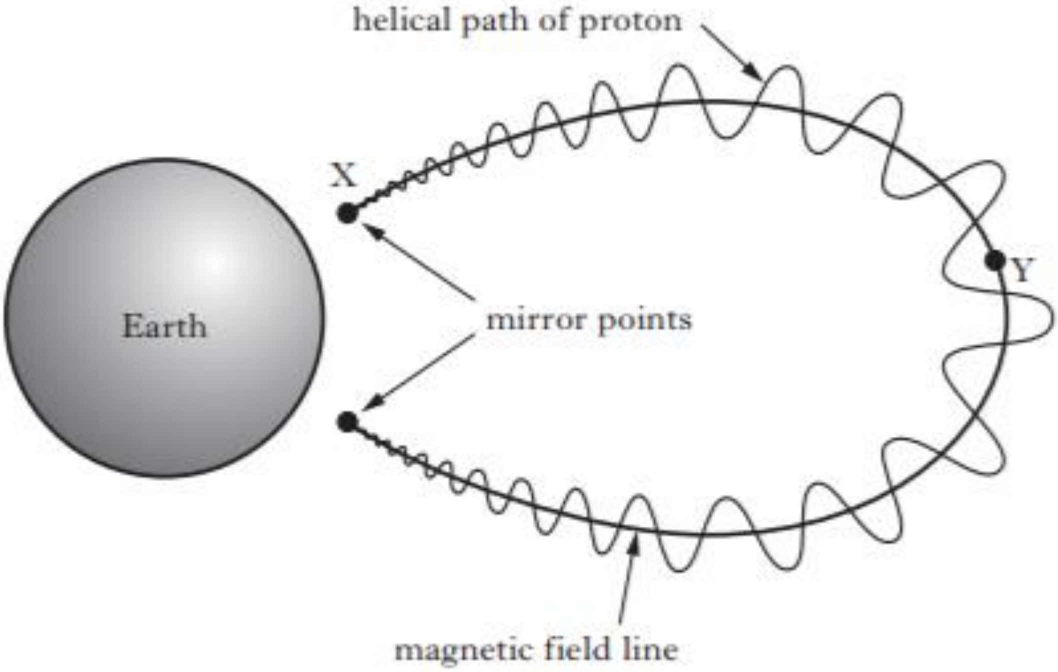


Figure 9C

The speed of the proton remains constant at $1{\cdot}2 \times 10^7\,\mathrm{m\,s^{-1}}$ as it travels along its helical path from one magnetic mirror point to the other.

(i) The proton oscillates between the two mirror points with a frequency of 4·0 Hz. Calculate the distance that the proton travels in moving from one mirror point to the other. **3**

(ii) Explain why the radius of the helical path followed by the proton increases as it moves from point X to point Y as shown in Figure 9C. **1**

(iii) At point X the radius of curvature of the helix for this proton is $1{\cdot}0 \times 10^4\,\mathrm{m}$. Calculate the strength of the Earth's magnetic field at this point. **2**

(11)

Revised 2014

7. The Sun is constantly losing mass through nuclear fusion. Particles also escape from the corona as shown in Figure 7A. This stream of particles radiating from the Sun is known as the Solar wind and its main constituent, by mass, is protons.

Figure 7A

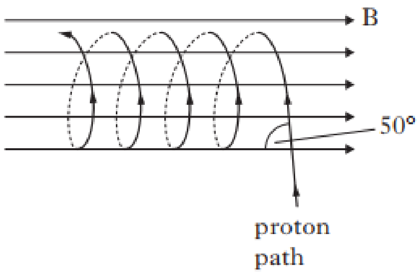
(*a*) Astronomers estimate that the Sun loses mass at a rate of $1{\cdot}0 \times 10^{9}\,\text{kg s}^{-1}$. This rate has been approximately constant through the Sun's lifetime of $4{\cdot}6 \times 10^{9}$ years.

Estimate the mass lost by the Sun in its lifetime as a percentage of its current mass. **2**

(*b*) A proton in the solar wind has energy of 3·6 MeV.

(i) Calculate the velocity of this proton. **3**

(ii) The proton enters the magnetic field around the Earth at an angle of 50° as shown in Figure 7B. The magnetic field strength is 58 μT.



(A) Explain the shape of the path followed by the proton in the magnetic field. **2**

(B) Calculate the radius of curvature of this path. **3**

(iii) An antiproton of energy 3·6 MeV enters the same region of the Earth's magnetic field at an angle of 30° to the field.

Describe **two** differences in the paths taken by the antiproton and the original proton. **2**

(12)

Revised & Traditional 2013

6. Detailed observations of sunspots have been obtained by the Royal Greenwich Observatory since 1874. These observations include information on the sizes and positions of sunspots as well as their numbers. The number of sunspots is an indication of solar activity. A graph of the average number of sunspots since 1950 is shown in Figure 6.

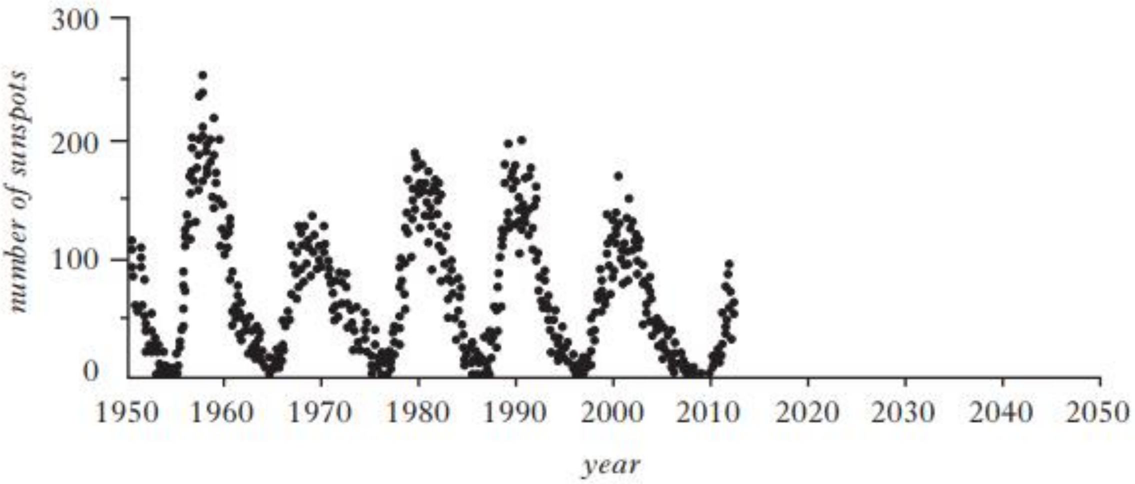


Figure 6

Coronal mass ejections (CME) are one type of solar activity. CMEs are huge magnetic bubbles of plasma that expand away from the Sun at speeds as high as 2000 km s^{-1}. A single CME can carry up to ten million tonnes (10^{10} kg) of plasma away from the Sun.

Use your knowledge of physics to discuss the potential effects that solar activity could have on Earth over the next few years. **(3)**

6. A positively charged particle travelling at $2{\cdot}29 \times 10^6\,\text{m}\,\text{s}^{-1}$ enters a magnetic field of uniform magnetic induction 2·50 T as shown in Figure 6A.

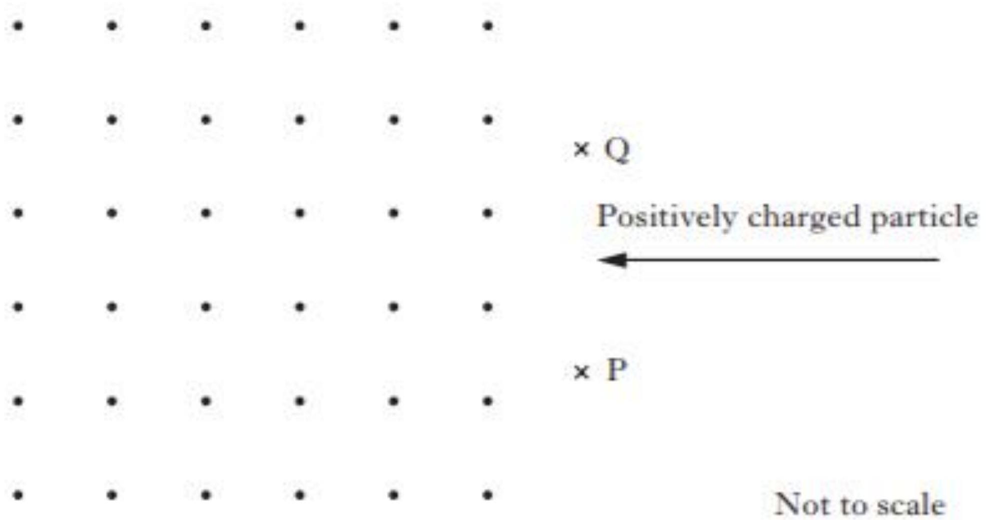


Figure 6A

The direction of the magnetic field is out of the page. The particle follows a semicircular path before exiting the field.

(*a*) (i) State whether the particle will exit the field at point P or point Q. **1**

(ii) Show that the charge to mass ratio of the particle is given by

$$\frac{q}{m} = \frac{v}{rB}$$

where the symbols have their usual meaning. **1**

(iii) The radius of the path taken by the particle is 19·0 mm.

Use information from the data sheet to identify the charged particle. You must justify your answer by calculation. **3**

(iv) Calculate the time between the particle entering and leaving the magnetic field. **2**

(v) An identical particle travelling at twice the speed of the original particle enters the field at the same point.

How does the time spent in the magnetic field by this particle compare with the original? Justify your answer. **2** (*b*) An unknown particle also travelling at $2{\cdot}29 \times 10^6\ \mathrm{m\,s^{-1}}$ enters the field as shown in Figure 6B. The path taken by this particle is shown.

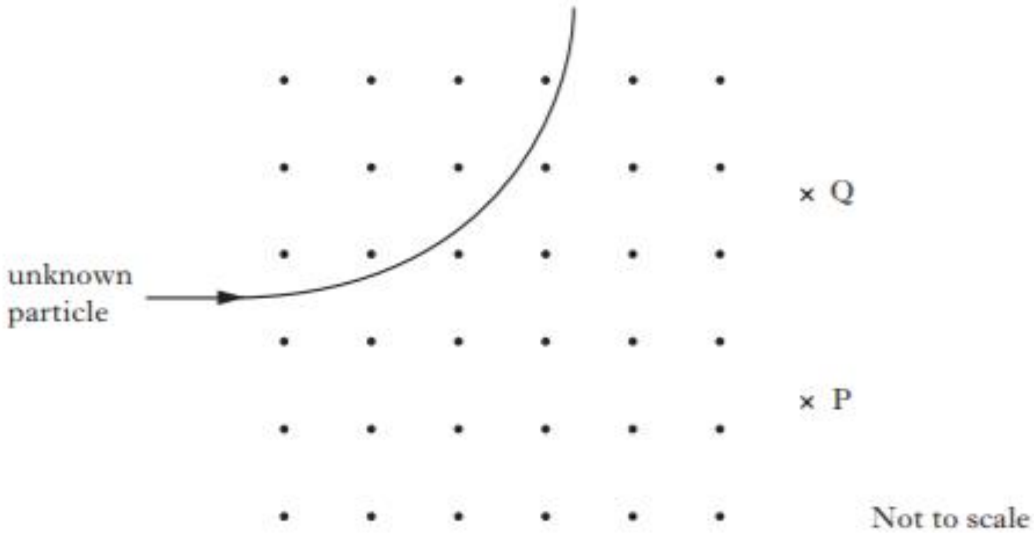


Figure 6B

What can you conclude about:

(i) the charge of the unknown particle; **1**

(ii) the charge to mass ratio of the unknown particle? **1**

(11)

Marks

8. (*a*) Figure 8A shows a current carrying wire of length l, perpendicular to a magnetic field B. A single charge $-q$ moves with constant velocity v in the wire. Using the relationship for the force on a current carrying conductor placed in a magnetic field, derive the relationship $F = qvB$ for the magnitude of the force acting on charge q. **2**

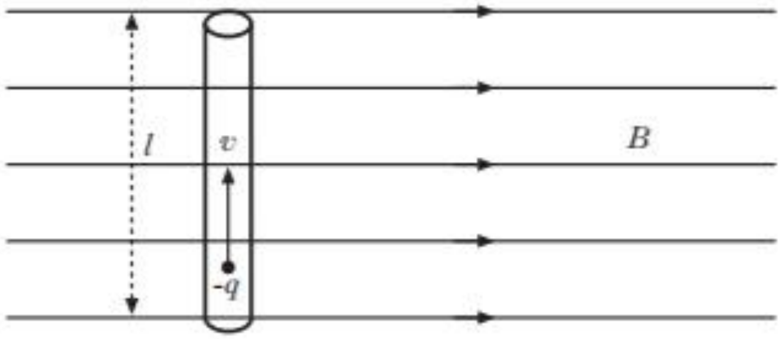


Figure 8A

(*b*) An electron with a speed of $2 \cdot 0 \times 10^6\,\text{m s}^{-1}$ enters a uniform magnetic field at an angle θ. The electron follows a helical path as shown in Figure 8B.

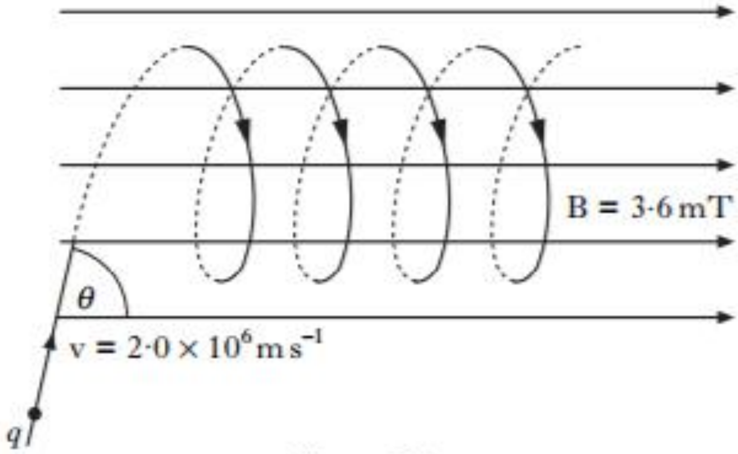


Figure 8B

The uniform magnetic induction is $3 \cdot 6\,\text{mT}$ and the radius of the helical path is $2 \cdot 8\,\text{mm}$. Calculate the value of angle θ. **3**

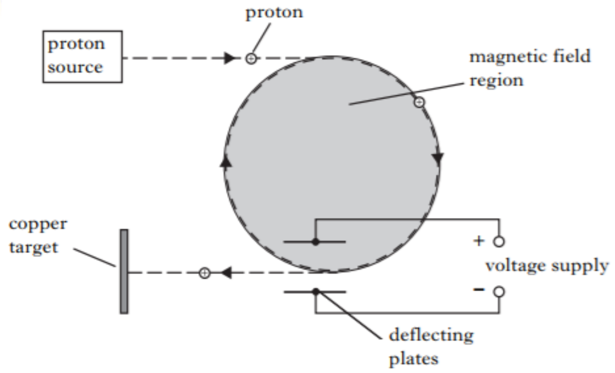
(*c*) A second electron travelling at the same speed enters the field at a smaller angle θ.

Describe how the path of the second electron differs from the first. **2**

(7)

7. A beam of protons enters a region of uniform magnetic field, at right angles to the field.

The protons follow a circular path in the magnetic field until a potential difference is applied across the deflecting plates. The deflected protons hit a copper target. The protons travel through a vacuum. A simplified diagram is shown in Figure 7A.



(*a*) State the direction of the magnetic field, B. **1**

(*b*) The speed of the protons is $6{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$ and the magnetic induction is $0{\cdot}75\,\mathrm{T}$. Calculate the radius of the circular path followed by the protons. **3**

(*c*) Calculate the electric field strength required to make the protons move off at a tangent to the circle. **2**

(*d*) A proton of charge q initially travels at speed v directly towards a copper nucleus as shown in Figure 7B. The copper nucleus has charge Q.

Figure 7B

(i) Show that the distance of closest approach, r, to the copper nucleus is given by

$$\frac{qQ}{2\pi\varepsilon_0 mv^2}.$$ **1**

(ii) Calculate the distance of closest approach for a proton initially travelling at $6{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$. **3**

(iii) Name the force that holds the protons together in the copper nucleus. **1**

(*e*) The beam of protons in Figure 7A is replaced by a beam of electrons. The speed of the electrons is the same as the speed of the protons.

State **two** changes that must be made to the magnetic field to allow the electrons to follow the same circular path as the protons. **2**

(13)

Marks

8. An electron travelling at $9{\cdot}5 \times 10^7\,\mathrm{m\,s^{-1}}$ enters a uniform magnetic field B at an angle of 60° as shown in Figure 13.

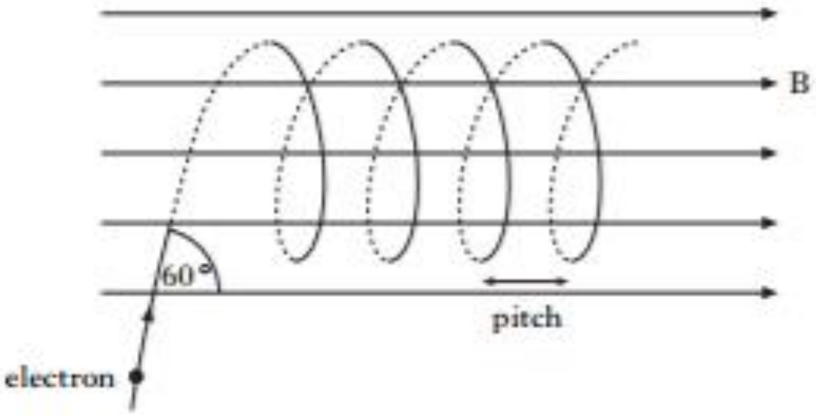


Figure 13

The electron moves in a helical path in the magnetic field.

(*a*) (i) Calculate the component of the electron's initial velocity:

(A) parallel to the magnetic field; **1**

(B) perpendicular to the magnetic field. **1**

(ii) By making reference to **both** components, explain why the electron moves in a helical path. **2**

(*b*) (i) The magnetic field has a magnetic induction of 0·22 T.

Show that the radius of the helix is $2{\cdot}1 \times 10^{-3}\,\mathrm{m}$. **2**

(ii) Calculate the time taken for the electron to make one complete revolution. **2**

(iii) The distance between adjacent loops in the helix is called the pitch as shown in Figure 13.

Calculate the pitch of the helix. **2**

(*c*) A proton enters the magnetic field with the same initial speed and direction as the electron shown in Figure 13. The magnetic field remains unchanged.

State **two** ways that the path of the proton in the magnetic field is different from the path of the electron. **2**

(12)

Marks

7. A charged particle moves with a speed of $2{\cdot}0 \times 10^6\,\text{m s}^{-1}$ in a circular orbit in a uniform magnetic field, shown in Figure 11.

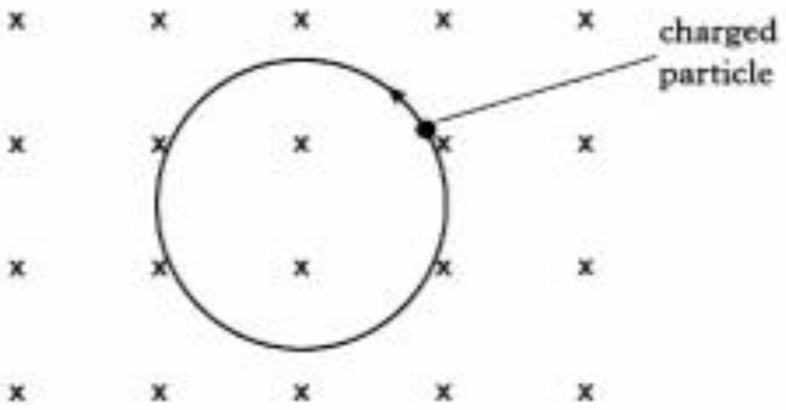


Figure 11

The magnetic induction is 1·5 T and is directed into the page. The circular orbit has a radius of 13·9 mm.

(*a*) (i) State whether the charge on the particle is positive or negative. **1**

(ii) Calculate the charge to mass ratio of the particle. **3**

(iii) Identify the charged particle. You must justify your answer using information from the data sheet. **2**

(*b*) An electron enters a uniform magnetic field at an angle to the magnetic field lines as shown in Figure 12.

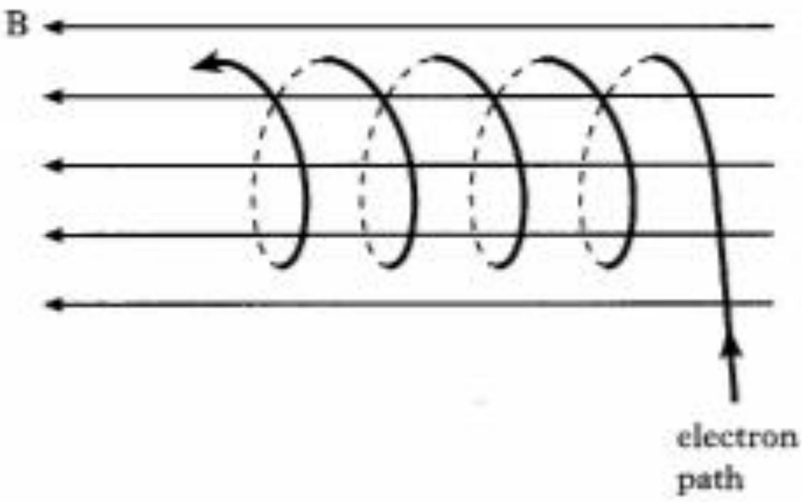


Figure 12

Explain the shape of the electron path in the magnetic field. **2** (*c*) Charged particles which enter the Earth's atmosphere near the North pole collide with air molecules. The light emitted in this process is called the Aurora Borealis.

In Figure 13, the Earth's magnetic field is indicated by continuous lines which show the magnetic field direction in the region surrounding the Earth.

The extent of the Earth's atmosphere is also shown.

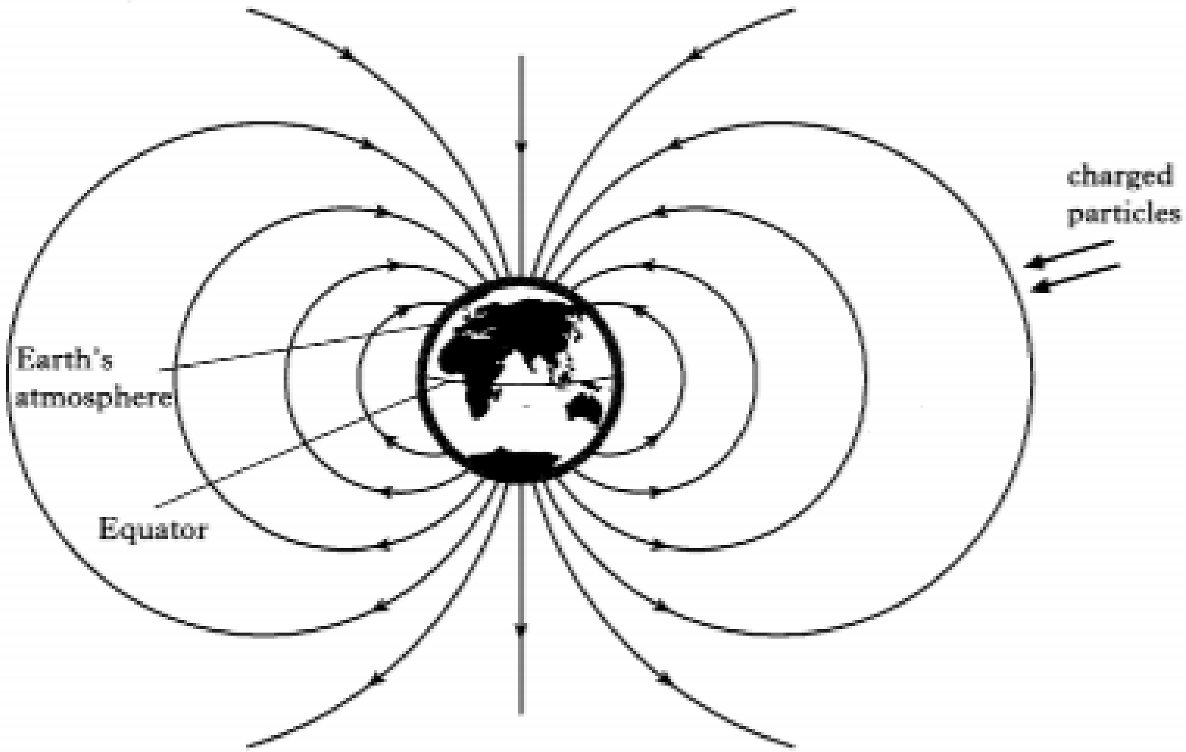


Figure 13

Charged particles approach the Earth in the direction shown in Figure 13.
Explain why these particles do **not** cause an aurora above the Equator. 2

(10)