Magnetic Fields - 1

Exercise A

1 The table below relates the force on a current-carrying wire which is at right angles to the lines of force of a magnetic field and the current. Complete the table below by working out the missing data in each column.

▼ Table 1

	(a)	(b)	(c)	(d)
B / T	0.20 T vertically down	0.20 T vertically down	?	0.1 T horizontal due?
I / A	3.0 A horizontal due north	?	3.0 A horizontal due north	2.0 A vertically up
l / m	0.040 m	0.040 m	0.040 m	0.040 m
F / N	?	0.036 N horizontal due south	0.024 N horizontal due west	? horizontal due east

2 a A straight vertical wire of length 0.10 m carries a downward current of 4.0 A in a uniform horizontal magnetic field of flux density 55 mT that acts due north. Determine the magnitude and direction of the force on the wire.

b A straight horizontal wire of length 50 mm carrying a constant current is in a uniform magnetic field of flux density 140 mT which acts vertically downwards. The wire experiences a force of 28 mN in a direction which is due north. Determine the magnitude and the direction of the current in the wire.

3 A rectangular coil of width 60 mm and of length 80 mm has 50 turns. The coil was placed horizontally in a uniform horizontal magnetic field of flux density 85 mT with its shorter side parallel to the field lines. A current of 8.0 A was passed through the coil. Sketch the arrangement and determine the force on each side of the coil.

4 The Earth's magnetic field at a certain position on the Earth's surface has a horizontal component of 18 μT due north and a downwards vertical component of 55 μT. Calculate:

a the magnitude of the Earth's magnetic field at this position,

b the magnitude and direction of the force on a vertical wire of length 0.80 m carrying a current of 4.5 A downwards.

Exercise B

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

1 **a** In Figure 1, how would the force on the electrons in the magnetic field differ if:

i the magnetic field was reversed in direction,

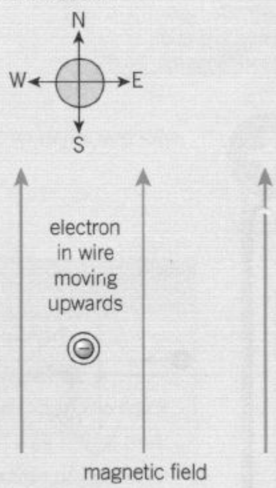
ii the magnetic field was reduced in strength,

iii the speed of the electrons was increased.

b Calculate the force on an electron that enters a uniform magnetic field of flux density 150 mT at a velocity of 8.0×10^6 m s^{-1} at an angle of

i 90°, **ii** 0° to the field.

2 Electrons in a vertical wire move upwards at a speed of 2.5×10^{-3} m s^{-1} into a uniform horizontal magnetic field of magnetic flux density 95 mT. The field is directed along a line from south to north as shown in Figure 6. Calculate the force on each electron and determine its direction.



▲ **Figure 6**

3 A beam of protons and π^+ mesons moving at the same speed is directed into a uniform magnetic field in the same direction as the field.

a Explain why the beam is not deflected by the field.

b If the particles had been directed into the field in a direction at right angles to the field lines at the same speed, state and explain what effect this would have had on the beam.

4 In a Hall probe, electrons passing through the semiconductor experience a force due to a magnetic field.

a Explain why a potential difference is created across the semiconductor as a result of the application of the magnetic field.

b When the magnetic flux density was 90 mT, each electron moving through the slice experiences a force of 6.4×10^{-20} N due to the magnetic field. Calculate:

i the mean speed of the electrons passing through the slice,

ii the magnetic force on each electron if the magnetic flux density is increased to 120 mT.

Exercise C

$e = 1.6 \times 10^{-19}$ C, $\frac{e}{m}$ for the electron $= 1.76 \times 10^{11}$ C kg^{-1}

1 A beam of electrons at a speed of 3.2×10^{7} m s^{-1} is directed into a uniform magnetic field of flux density 8.5 mT in a direction perpendicular to the field lines. The electrons move on a circular orbit in the field.

- **a** i Explain why the electrons move on a circular orbit.
  - ii Calculate the radius of the orbit.
- **b** The flux density is adjusted until the radius of orbit is 65 mm. Calculate the flux density for this new radius.

2 A narrow beam of electrons was directed at a speed of 2.9×10^{7} m s^{-1} into a uniform magnetic field.

- **a** The beam followed a circular path of radius 35 mm in the magnetic field. Calculate the flux density of the magnetic field.
- **b** The speed of the electrons in the beam was halved by reducing the anode voltage. Calculate the new radius of curvature of the beam in the field.

3 The first cyclotron, used to accelerate protons, was 0.28 m in diameter and was in a magnetic field of flux density 1.1 T.

- **a** Show that protons emerged from this cyclotron at a maximum speed of 1.5×10^{7} m s^{-1}.
- **b** Calculate the maximum kinetic energy, in MeV, of a proton from this accelerator.

  The mass of a proton $= 1.67 \times 10^{-27}$ kg,
  1 MeV $= 1.6 \times 10^{-13}$ J

4 In a mass spectrometer, a beam of ions at a speed of 7.6×10^{4} m s^{-1} was directed into a uniform magnetic field of flux density 680 mT.

- **a** An ion was deflected in a semi-circular path of diameter 28 mm on to the detector. Calculate the specific charge of the ion.
- **b** A different type of ion was deflected onto the same detector when the magnetic flux density was changed to 400 mT. Calculate the specific charge of this ion.

Exercise D

1.

Show that the units of magnetic flux density, usually T (tesla), can be written as N s C^{-1} m^{-1}.

2.

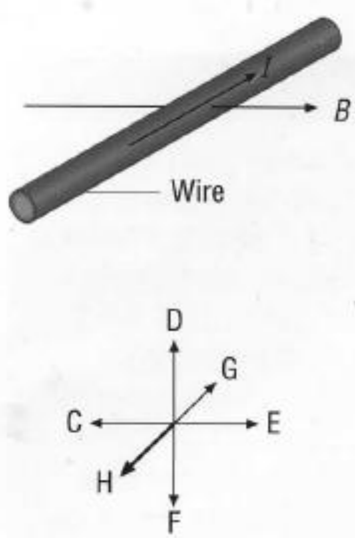


Figure 4

Figure 4 shows the directions of the current I in a short section of wire and the magnetic flux density B at the wire.

(a) The current is in the direction H–G. In which direction is the force on the wire?

(b) The free electrons are drifting in the direction G–H. In which direction is the average force on them?

(c) The wire carries a current of 0.24 A. The length of wire in the magnetic field is 60 mm. The magnetic flux density B is 30 mT. Calculate the force on the wire.

(d) Through what angle must the wire be rotated and in which plane to reduce the force on the wire to **(i)** half the value in (c) and **(ii)** zero?

3.

In a particle accelerator, protons are accelerated from rest in a vacuum by a potential difference (p.d.) V and then directed at right angles into a magnetic field of flux density 0.039 T. They travel in a semicircle that must have a radius less than 0.63 m if they are to remain within the magnetic field.

(a) What is the maximum value of V that can be used to satisfy this condition?

(b) How long does a proton take to complete a semicircle of the maximum allowed radius?

Exercise E

travelling through a velocity selector

1 Here are three possible paths of an electron in a vacuum: A straight line, B circular path, C parabolic path. Which path best describes the motion of an electron initially moving:

(a) at right angles to a magnetic field, **(b)** at right angles to an electric field and **(c)** parallel to a magnetic field?

2 (a) Calculate the magnitude of the force on an electron moving at 2.0×10^7 m s^{-1} as it enters a region of uniform magnetic field of flux density 5.0×10^{-3} T perpendicular to its path.

(b) Calculate the acceleration of the electron and hence the radius of its orbit in the field.

3 Figure 5 shows a beam of protons passing through a hole into a region where there is a uniform electric field of strength E.

(a) Copy the diagram and sketch on it a possible path for the protons.

(b) A uniform magnetic field of flux density B is now applied at right angles (into the plane of the diagram), and the electric field is switched off. Sketch a possible path for the protons.

(c) The electric field is switched on again. Explain why it is now possible for some of the protons to pass undeflected to the detector.

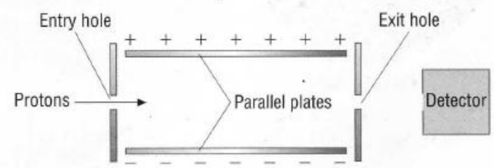


Figure 5

4 The fuel in nuclear fission reactors to generate electricity is $^{235}_{92}U$. In natural uranium over 99% is $^{238}_{92}U$ and only 0.7% is $^{235}_{92}U$. In one 'separation process', each atom of natural uranium is combined with six atoms of fluorine to make the molecule UF_6. The molecules are ionised and, using a velocity selector, made into a beam of particles each with the same velocity.

(a) Explain why the UF_6 ions of $^{238}_{92}U$ have more momentum than those of $^{235}_{92}U$.

(b) The ion beam passes through a region of uniform magnetic field directed at right angles to their velocity as shown in Figure 6 before being collected in a trap.
The figure shows the path of the UF_6 ions of $^{235}_{92}U$. Copy the diagram and add the path of the UF_6 ions of $^{238}_{92}U$.

(c) Hence explain how this device works as a separator. Why would UF_6 ions of $^{238}_{92}U$ reach the collector if the apparatus was not kept under a good vacuum?

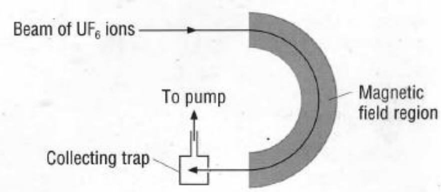


Figure 6

Exercise F

1 A large ion of mass 5.8×10^9 u and charge $+18e$ is accelerated constantly towards a detector by a potential difference of 870 V. Assuming the ion starts from rest, calculate the time taken for the ion to travel 47 cm to the detector.

2 Figure 2 shows a Bainbridge mass spectrometer.
The beam consists of singly ionised neon-20 atoms all travelling at the same speed, 3.0×10^5 m s^{-1}, through a vacuum. As the beam passes through the magnetic field it follows a circular path of radius 0.125 m.

(a) Explain why the path is a semicircle.

(b) Show that the force on each ion of mass 3.32×10^{-26} kg is 2.4×10^{-14} N. In which direction is this force?

(c) Calculate the magnetic field strength or flux density in teslas.

(d) Suggest where the detector should be positioned to detect ions of neon-22 travelling with the same speed. Explain your decision.

(Figure 2 is on the next page.)

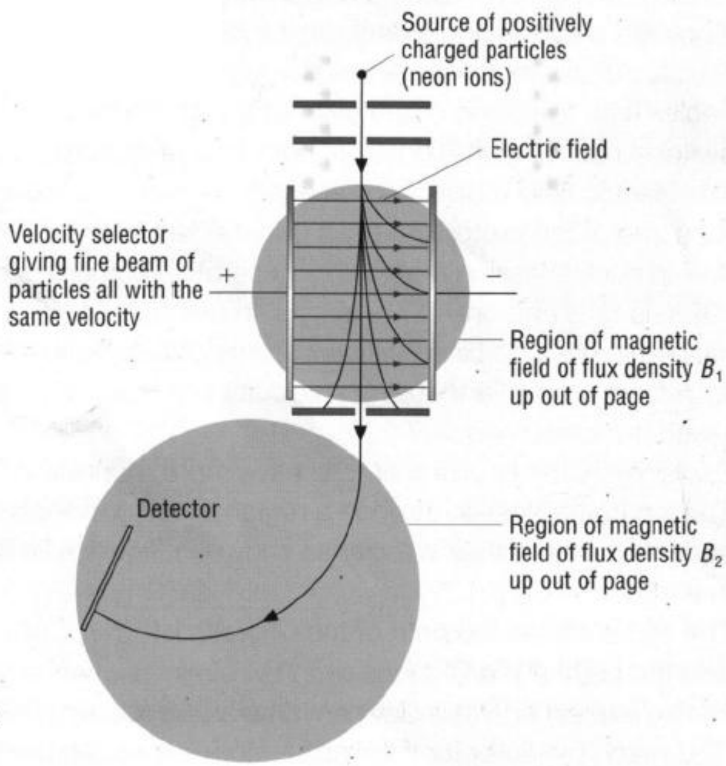


Figure 2 A Bainbridge mass spectrometer

3.

The spectrometer of Figure 4 is used to collect the nuclides $^{238}_{92}U$ and $^{206}_{82}Pb$ from a small sample of rock to date it.

(a) Singly ionised nuclei of the two nuclides from the sample of rock pass through the hole in the 200 V electrode with negligible velocity. They are accelerated towards the electrode at 0 V. Show that the momentum gained by an ion of $^{206}_{82}Pb$, mass 3.5×10^{-25} kg, is about 5×10^{-21} N s.

(b) Calculate the radius of the circular path of the lead ion when within the uniform region of magnetic field of flux density 0.12 T.

(c) The lead and uranium ions have the same charge and kinetic energy when they enter the magnetic field, yet the uranium ions follow a path of greater radius. Explain why this is.

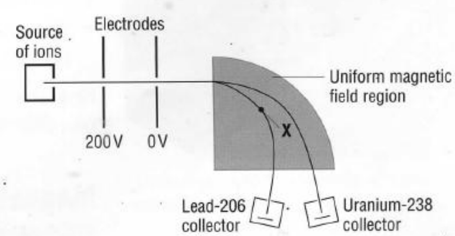
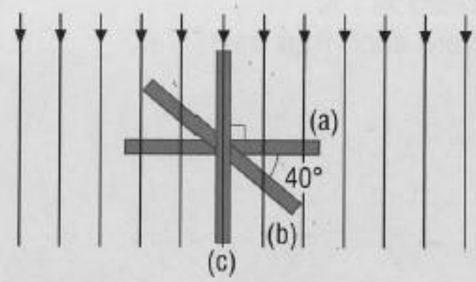


Figure 4

4.

A rectangular coil of 400 turns of wire has length 8.9 cm and width 6.4 cm. It rotates in a magnetic field of flux density 0.045 T. Calculate the flux through the coil and the flux linkage when the plane of the coil is **(a)** at right angles to the field, **(b)** has moved through an angle of 40° and **(c)** has moved through 90° so that it is parallel to the field, as shown in Figure 4.



Coil shown in three positions, (a), (b) and (c)

Figure 4 Rectangular coil

5.

A long coil or solenoid wound on an iron rod has 300 turns of cross-sectional area 4.0×10^{-5} m^2. When it carries a certain current the flux linkage of the coil is 6.0×10^{-4} Wb turns.

(a) Calculate **(i)** the flux linking one turn of the coil and **(ii)** the flux density in the iron rod.

(b) Why is it not possible to answer this question when the coil is wound on a wooden dowel?