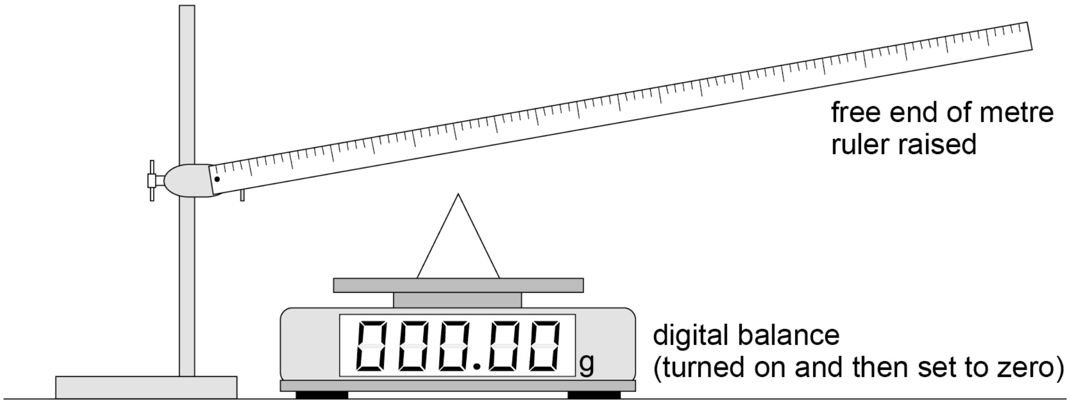
0 1 This question is about using a digital balance to investigate the force on a wire placed in a magnetic field when there is an electric current in the wire.

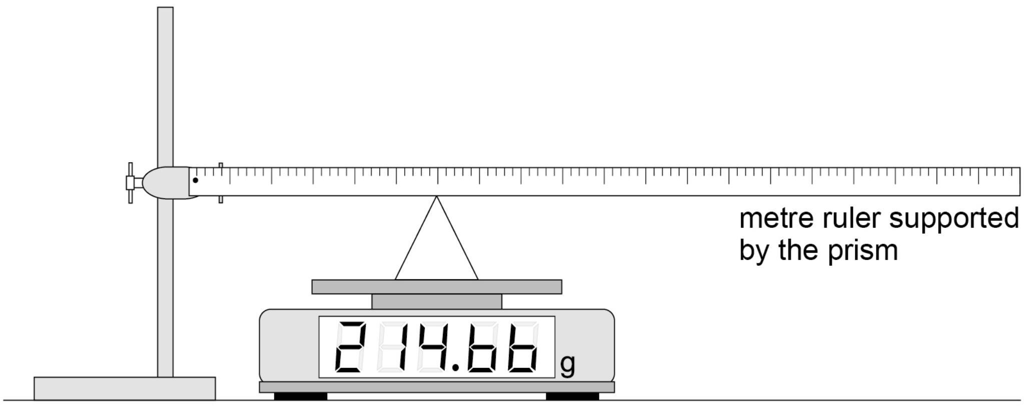
A student carries out the procedure shown in **Figure 1** and **Figure 2**.
A metre ruler is pivoted at the 1.0 cm mark and a prism is placed on a digital balance.
The free end of the ruler is raised and the balance is turned on and then set to zero, as shown in **Figure 1**.

Figure 1



The ruler is then supported by the prism with the apex of the prism at the 30.0 cm mark as shown in **Figure 2**. The height of the pivot is adjusted so that the ruler is horizontal.

Figure 2



0 1 . 1 Deduce the mass of the ruler.
State **one** assumption you make.

[3 marks]

mass of ruler = ______________________ g

assumption ______________________

____

Question 1 continues on the next page

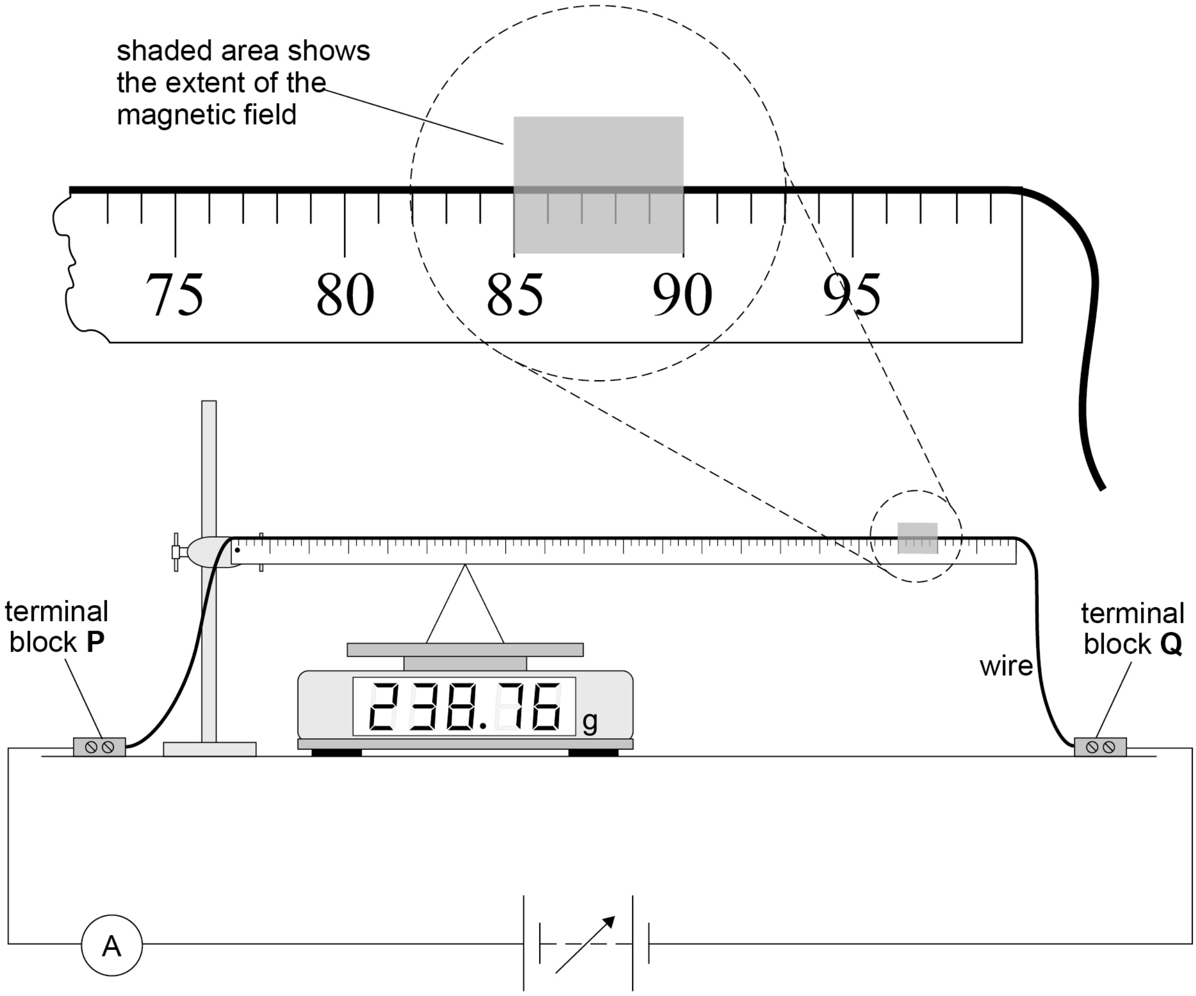
0 1 . 2 The student attaches a uniform wire to the upper edge of the ruler, as shown in **Figure 3**.

The ends of the wire are connected to terminal blocks **P** and **Q** which are fixed firmly to the bench. A power supply and an ammeter are connected between **P** and **Q**.

These modifications cause the balance reading to increase slightly.

A horizontal uniform magnetic field is applied, perpendicular to the wire, between the 85 cm and 90 cm marks, as shown in the close-up diagram in **Figure 3**.

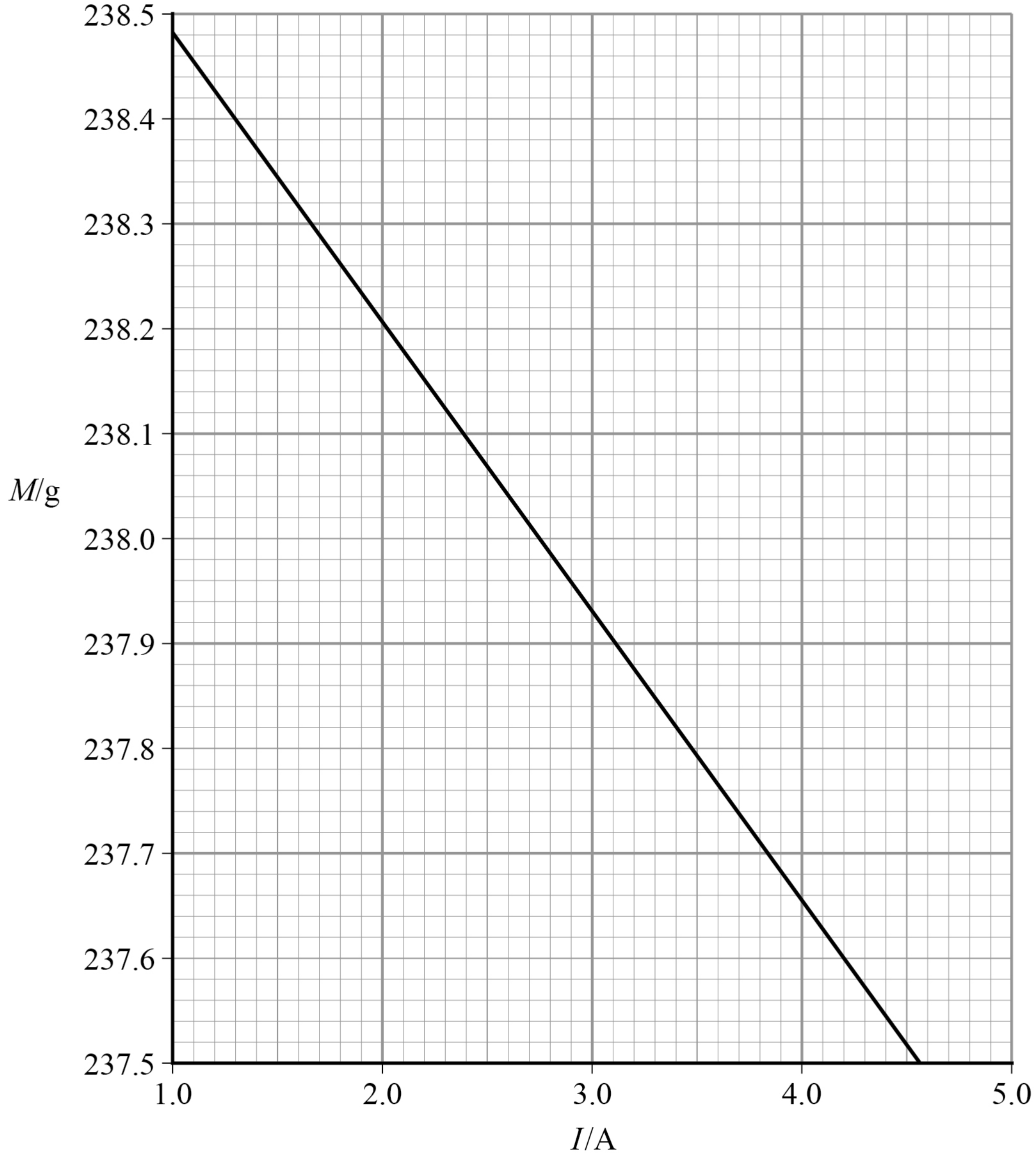
Figure 3



The balance reading M is recorded for increasing values of current I.
A graph of these data is shown in **Figure 4**.

Do not write outside the box

Figure 4



State and explain the direction of the horizontal uniform magnetic field.

[3 marks]

Question 1 continues on the next page

Do not write outside the box

0 1 . 3 It can be shown that B, the magnitude of the magnetic flux density of the horizontal uniform magnetic field, is given by

$$B = \frac{\sigma}{3L}$$

where σ = change in force acting on the prism per unit current in the wire
L = length of the region where the magnetic field cuts through the wire.

Determine B.

[3 marks]

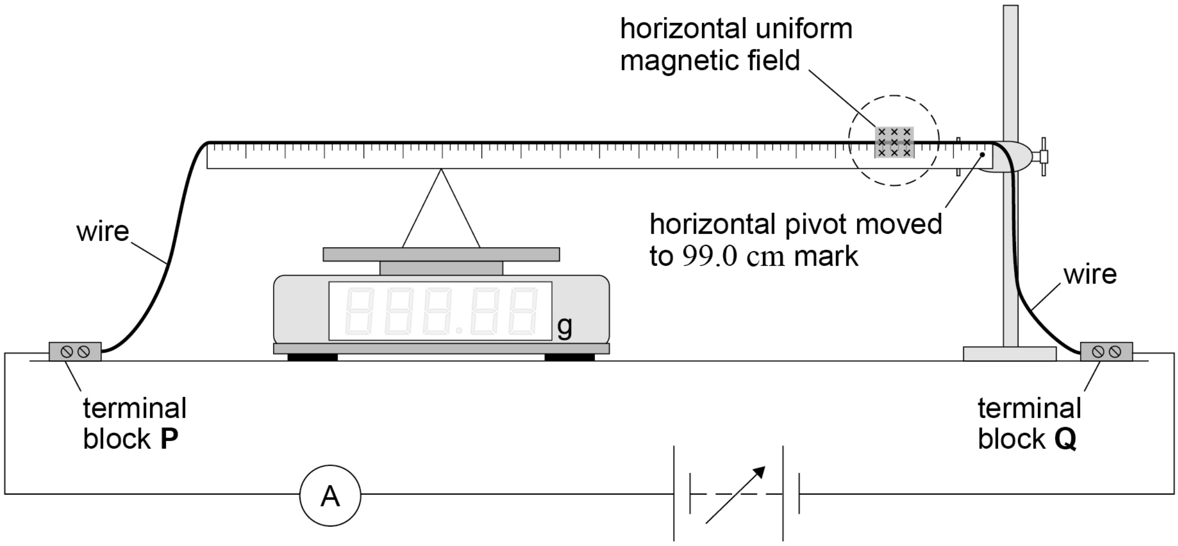
B = ____________________ T

Do not write outside the box

0 1 . 4 The experiment is repeated with the ruler pivoted at the 99.0 cm mark. Nothing else is changed from **Figure 3**.

This arrangement is shown in **Figure 5**.

Figure 5



Tick (✓) **one** box in row 1 and **one** box in row 2 of **Table 1** to identify the effect, if any, on the magnitude of the forces acting on the apparatus as a certain current is passed through the wire.

Tick (✓) **one** box in row 3 and **one** box in row 4 of **Table 1** to identify the effect, if any, on the graph produced for this modified experiment compared with the graph in **Figure 4**.

[3 marks]

Table 1

		Reduced	**No effect**	**Increased**
1	Force acting on the current-carrying wire due to the horizontal uniform magnetic field			
2	Force acting on the prism due to the pivoted ruler			
3	Gradient of the graph			
4	Vertical intercept of the graph			

Question 1 continues on the next page

Do not write outside the box

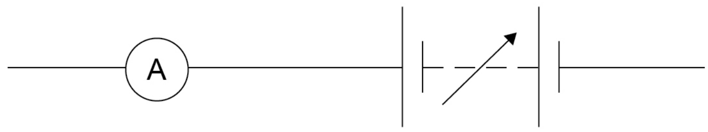
0 1 . 5 **Figure 6** shows the balance being used to measure the forces between two wires. The connections joining these wires to the power supply are not shown.

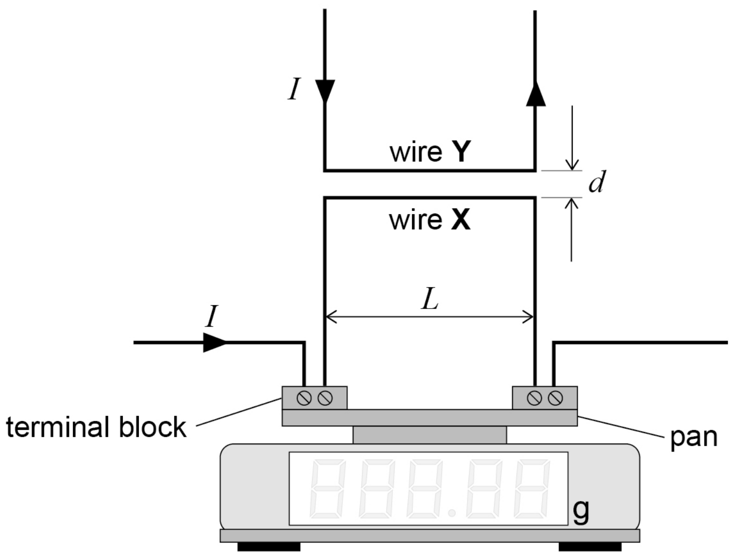
The pan of the balance moves a negligible amount during use and it supports a straight conducting wire **X** of horizontal length L.
Terminal blocks are used to connect **X** into the circuit. The weight of these does not affect the balance reading.
A second conducting wire **Y** is firmly supported a distance d above **X**.

Show, by adding detail to **Figure 6**, the wire connections that complete the circuit. The currents in **X** and **Y** must have the same magnitude and be in the directions indicated.

[2 marks]

Figure 6





Do not write outside the box

0 1 . 6 The vertical force F on wire **X** due to the magnetic field produced by wire **Y** is given by

$$F = \frac{kI^2L}{d}$$

where k is a constant
d is the perpendicular distance between **X** and **Y**
I is the current in the wires
and L is the horizontal length of wire **X**.

A student wants to measure k using the arrangement in **Figure 6**.

The student is told that the following restrictions must apply:

- L is fixed
- I must not exceed $5.0\ \text{A}$
- the result for k must be obtained using a **graphical method**
- the experimental procedure must involve **only one** independent variable.

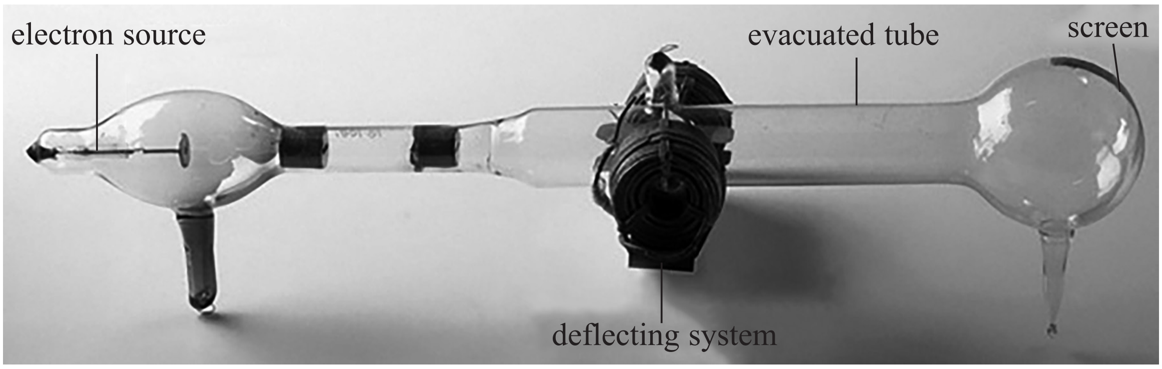
Explain what the student could do to find k.

[5 marks]

19

Turn over ►

2 At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown.



Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

(a) Explain how electrons from the source become a beam of high-energy electrons.

(2)

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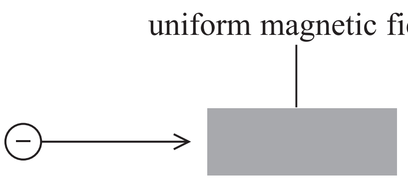
(b) An electron is travelling left to right and enters a region of uniform magnetic field as shown below. The direction of the magnetic field is perpendicular to the direction of travel of the electron.



(i) The magnetic field deflects the electron in the direction up the page.

Explain the direction of the magnetic field that would produce this deflection.

(2)

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(ii) Explain why the electron would travel in a circular path if no other forces acted on it.

(2)

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(c) In a modern version of Thompson's experiment, a uniform electric field of electric field strength E is applied so that the electric and magnetic forces on the electrons are equal and in opposite directions.

(i) Show that for electrons to be undeflected their velocity must be given by

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

where B is the magnetic flux density of the magnetic field.

(2)

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(ii) The beam is produced by accelerating electrons through a potential difference of 250 V. The electric field strength is $1.4 \times 10^4\ \mathrm{V\,m^{-1}}$. The magnetic flux density is 1.5×10^{-3} T.

Calculate the value of the specific charge e/m for the electron using this data.

(3)

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....

e/m = ...

(d) In his original experiments, Thompson determined the specific charge of a range of particles. His results indicated that the specific charge of an electron is about 2000 times bigger than that for a hydrogen ion.

Deduce what conclusion can be made from this information.

(1)

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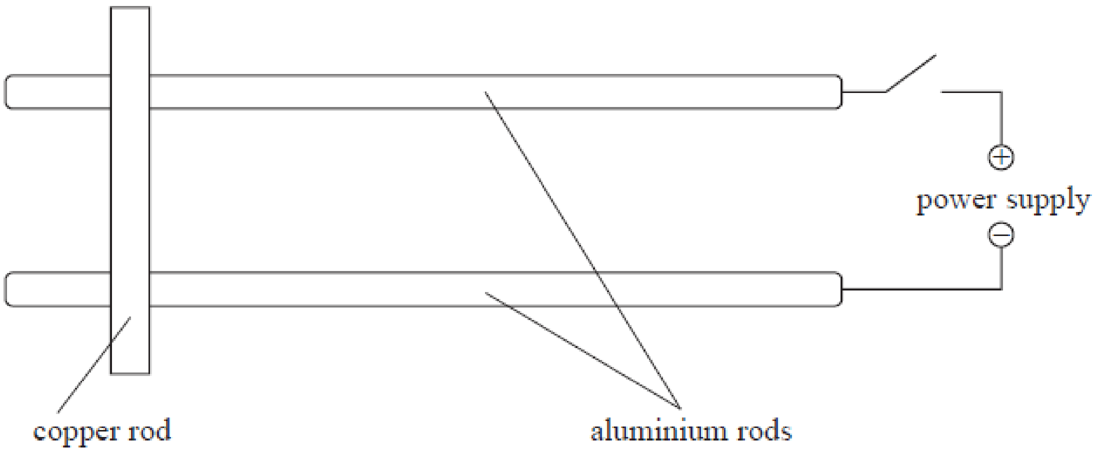
(Total for Question 7 = 12 marks)

Section B

Q1.

The apparatus shown in the diagram can be used to demonstrate that a force acts on a current-carrying conductor when the conductor is in a magnetic field.



The apparatus is placed in a magnetic field. When the switch is closed, the copper rod rolls along the aluminium rods.

(a) Add to the diagram to indicate the direction of the current in the copper rod.

(1)

(b) State the direction of the magnetic field that will make the copper rod move to the right.

(2)

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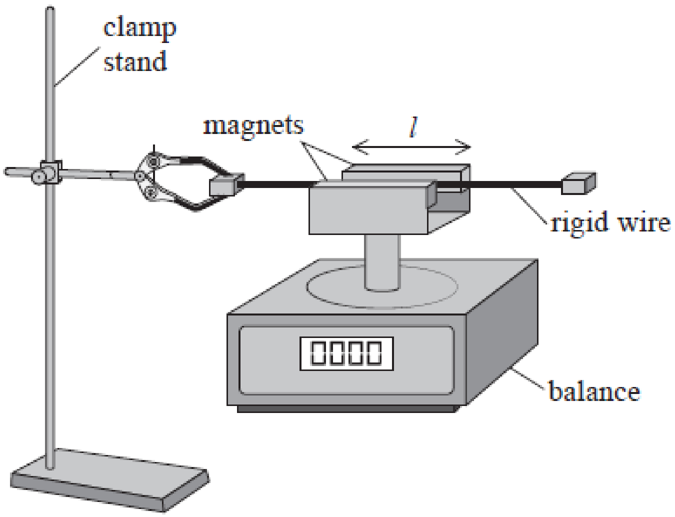
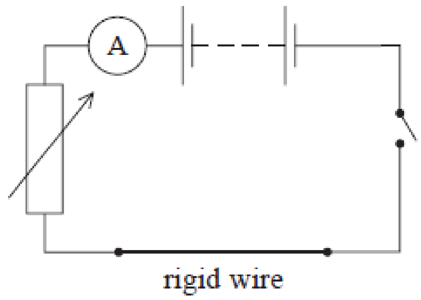
(Total for question = 3 marks)

Q2.

A student set up the apparatus shown. A length of rigid wire was held horizontally by a clamp in a uniform magnetic field of flux density *B*.
The circuit connected to the rigid wire is also shown.





With the switch open, the balance was set to zero. When the switch was closed a current *I* in the circuit was recorded by the ammeter and the reading on the balance increased.

The length *l* of wire in the magnetic field was 15.5 cm. When the current in the circuit was 4.55 A, the reading on the balance increased by 5.65 g.

Calculate the magnetic flux density *B* in the region of the rigid wire.

(3)

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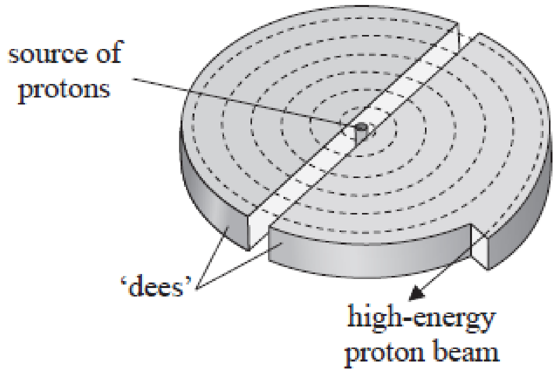
B = ...

(Total for question = 3 marks)

Q3.

Proton beam therapy is being introduced in the UK as a new cancer treatment.

A beam of protons is accelerated by a cyclotron to an energy of 23 MeV and is then focused onto a tumour.



* Explain how the cyclotron produces the high-energy proton beam.

(6)

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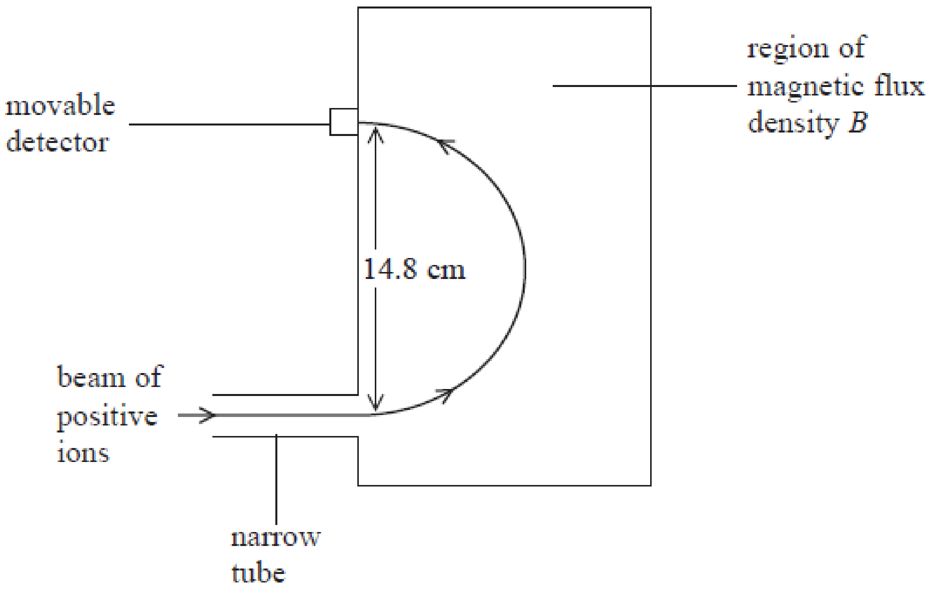
(Total for question = 6 marks)

Q4.

A mass-spectrometer is an instrument that is used to measure the masses of molecules. Molecules of a gas are ionised and travel through a vacuum in a narrow tube. The ions enter a region of uniform magnetic flux density *B* where they are deflected in a semicircular path as shown.



(a) State why it is necessary for the molecules to be ionised.

(1)

....

(b) State the direction of the magnetic field.

(1)

....

(c) The ions have a charge of +*e* and a speed of 1.20×10^5 m s^{-1}. When *B* has a value of 0.673 T, the ions are detected at a point where the diameter of the arc is 14.8 cm.

Calculate the mass of an ion.

(3)

....

Mass of an ion = ...

(d) Ions with a smaller mass but the same charge and speed are also present in the beam. On the diagram sketch the path of these ions.

(Total for question = 6 marks)

Q5.

At the end of the 19th century, J.J. Thompson used electric and magnetic fields to deflect beams of charged particles. A photograph of his apparatus is shown. (1

Electrons were accelerated through a potential difference to produce a beam of high-energy electrons. The beam was then deflected in perpendicular directions by the magnetic and electric fields. The final position of the beam on the screen was determined by the charge and mass of the electrons.

In a modern version of Thompson's experiment, a uniform electric field of electric field strength *E* is applied so that the electric and magnetic forces on the electrons are equal and in opposite directions.

(i) Show that for electrons to be undeflected their velocity must be given by

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

where *B* is the magnetic flux density of the magnetic field.

(2)

....

....

(ii) The beam is produced by accelerating electrons through a potential difference of 250 V.

The electric field strength is 1.4×10^4 V m^{-1}. The magnetic flux density is 1.5×10^{-3} T.

Calculate the value of the specific charge *e*/*m* for the electron using this data.

(3)

....

....

e/*m* = ...

(Total for question = 5 marks)

Q6. The magnetic force F that acts on a current-carrying conductor in a magnetic field is given by the equation

$$F = BIl.$$

(a) State the condition under which this equation applies.

(1)

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....

(b) The unit for magnetic flux density B is the tesla.

Express the tesla in base units.

(2)

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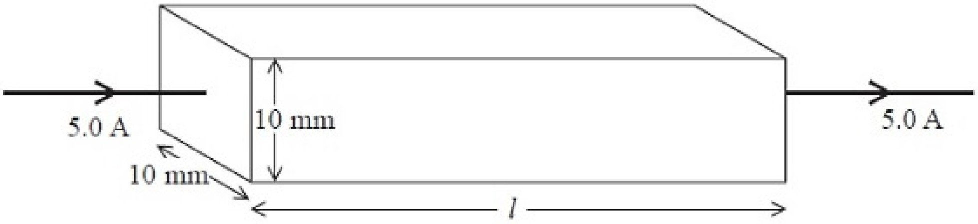
(c) The diagram shows a rectangular bar of aluminium which has a current of 5.0 A through it.



The bar is placed in a magnetic field so that its weight is supported by the magnetic field.

Calculate the minimum value of the magnetic flux density B needed for this to occur.

density of aluminium = 2.7×10^3 kg m^{-3}

(3)

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Minimum B = ...

(d) State the direction of the magnetic field.

(1)

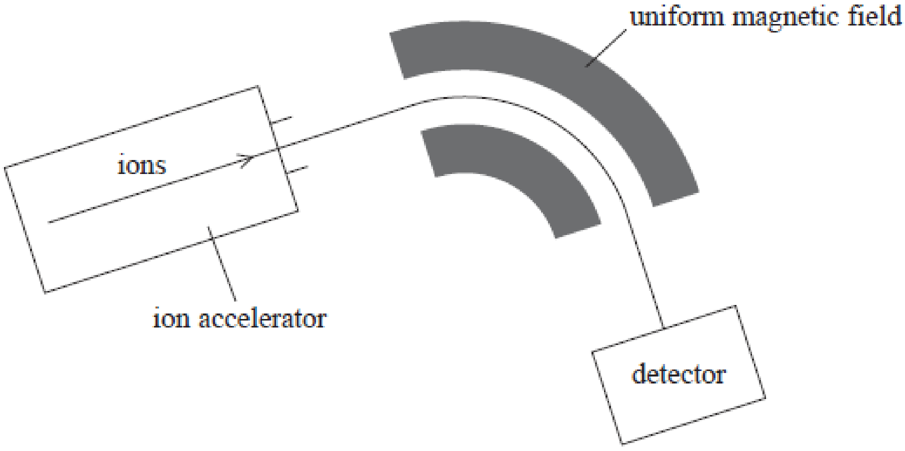
....

(Total for Question = 7 marks)

Q7.

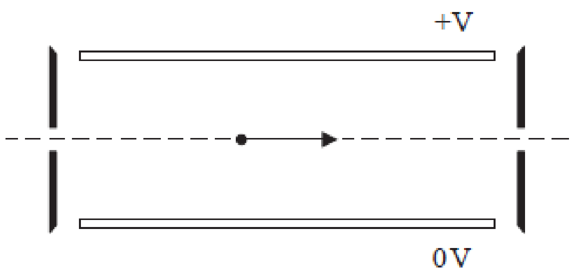
Mass spectrometry is a technique used to separate ions based on their charge to mass ratio.

The atoms in a sample are ionised and then accelerated and formed into a fine beam.
This beam is passed into a region of uniform magnetic field and the ions are deflected by different amounts according to their mass.



Analysis of mass spectrometer data shows that chlorine exists in nature as two isotopes, chlorine-35 and chlorine-37.

In most mass spectrometers the ions are passed through a velocity selector, after being accelerated, to produce a beam of ions of a particular velocity.
The velocity selector consists of a pair of parallel plates, across which a potential difference (p.d.) is applied to create an electric field.



In one mass spectrometer the plates are 2.5 cm apart and a p.d. of 135 V is applied.

A magnetic field is also applied to produce a force on the ions in the opposite direction to the force from the electric field. For one particular speed the ions travel in a straight line and emerge from the selector.

(i) Add to the diagram to indicate the directions of the electric field and the magnetic field.

(2)

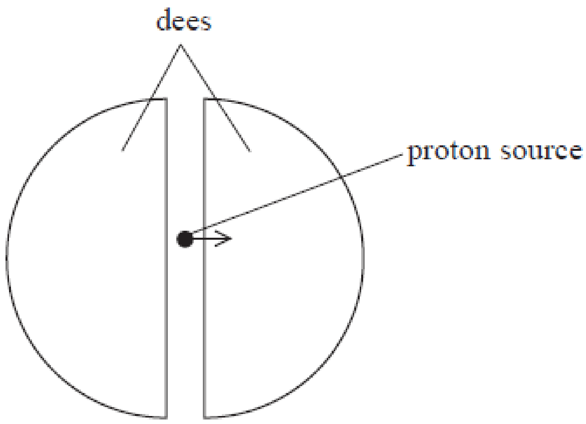
(ii) The magnetic flux density applied to the velocity selector is 24.5 mT.

Deduce whether this magnetic flux density is suitable to produce a beam of chlorine-35 ions of speed 2.2×10^5 m s^{-1}.

(4)

Q8.

A cyclotron is a particle accelerator which can be used to accelerate protons. The cyclotron consists of two semicircular electrodes called 'dees'. An alternating potential difference is applied across the gap between the dees. A uniform magnetic field is applied at right angles to the plane of the dees.



(i) Complete the diagram to show the path of the protons.

(1)

(ii) State the direction of the magnetic field needed in order to produce the path you have sketched.

(1)

....

(iii) Explain how the kinetic energy of the protons is increased as they follow the path you have shown.

(3)

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(iv) Show that the magnetic flux density *B* of the applied magnetic field is given by

$$B = \frac{2\pi f m}{e}$$

where *f* is the frequency of the alternating potential difference, *m* is the mass of the proton and *e* is the charge on the proton.

(3)

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(v) In a particular cyclotron *B* is 1.2 mT.
Calculate the frequency *f* of the alternating potential difference.

(2)

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f = ...