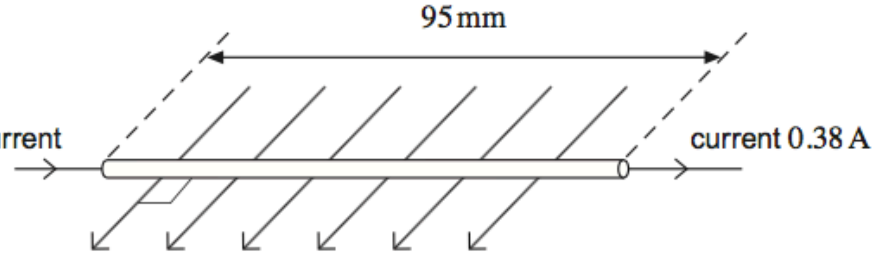
1)

Figure 2 shows a section of a horizontal copper wire carrying a current of 0.38 A. A horizontal uniform magnetic field of flux density B is applied at right angles to the wire in the direction shown in the figure.

Figure 2



(i) State the direction of the magnetic force that acts on the moving electrons in the wire as a consequence of the current and explain how you arrive at your answer.

[2 marks]

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(ii) Copper contains 8.4×10^{28} free electrons per cubic metre. The section of wire in **Figure 2** is 95 mm long and its cross-sectional area is $5.1 \times 10^{-6}\,\text{m}^2$. Show that there are about 4×10^{22} free electrons in this section of wire.

[1 mark]

(iii) With a current of 0.38 A, the average velocity of an electron in the wire is $5.5 \times 10^{-6}\,\text{m s}^{-1}$ and the average magnetic force on one electron is $1.4 \times 10^{-25}\,\text{N}$. Calculate the flux density B of the magnetic field.

[2 marks]

flux density .... T

2)

(a) (i) State **two** situations in which a charged particle will experience no magnetic force when placed in a magnetic field.

first situation ....

....

....

second situation ....

....

....

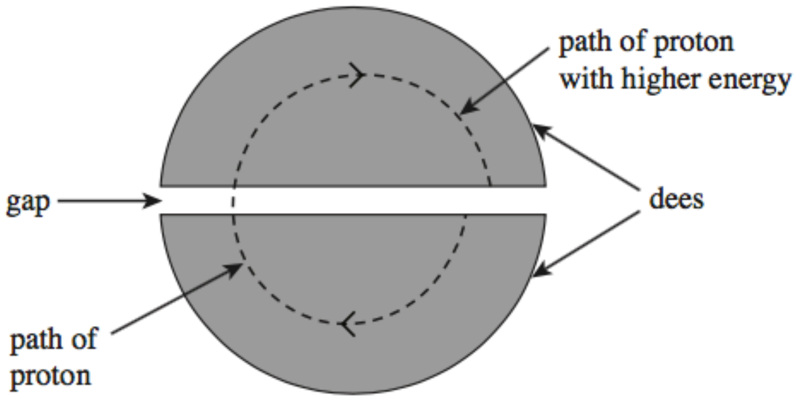
(2 marks)

(a) (ii) A charged particle moves in a circular path when travelling perpendicular to a uniform magnetic field. By considering the force acting on the charged particle, show that the radius of the path is proportional to the momentum of the particle.

(2 marks)

(b) In a cyclotron designed to produce high energy protons, the protons pass repeatedly between two hollow D-shaped containers called 'dees'. The protons are acted on by a uniform magnetic field over the whole area of the dees. Each proton therefore moves in a semi-circular path at constant speed when inside a dee. Every time a proton crosses the gap between the dees it is accelerated by an alternating electric field applied between the dees. **Figure 2** shows a plan view of this arrangement.

Figure 2



(b) (i) State the direction in which the magnetic field should be applied in order for the protons to travel along the semicircular paths inside each of the dees as shown in **Figure 2**.

....

(1 mark)

(b) (ii) In a particular cyclotron the flux density of the uniform magnetic field is 0.48 T. Calculate the speed of a proton when the radius of its path inside the dee is 190 mm.

speed .... $m\,s^{-1}$

(2 marks)

(b) (iii) Calculate the time taken for this proton to travel at constant speed in a semicircular path of radius 190 mm inside the dee.

time .... s

(2 marks)

(b) (iv) As the protons gain energy, the radius of the path they follow increases steadily, as shown in **Figure 2**. Show that your answer to part (b)(iii) does not depend on the radius of the proton's path.

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(2 marks)

(c) The protons leave the cyclotron when the radius of their path is equal to the outer radius of the dees. Calculate the maximum kinetic energy, in MeV, of the protons accelerated by the cyclotron if the outer radius of the dees is 470 mm.

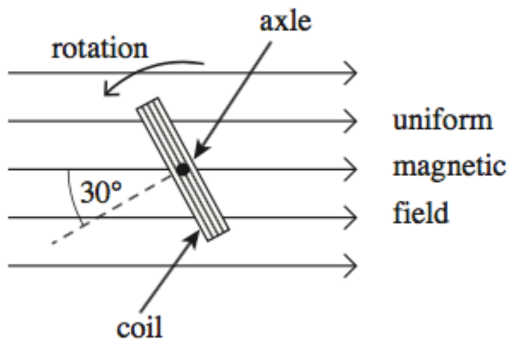
maximum kinetic energy .... MeV

(3 marks)

3)

A rectangular coil is rotating anticlockwise at constant angular speed with its axle at right angles to a uniform magnetic field. **Figure 3** shows an end-on view of the coil at a particular instant.

Figure 3



(a) At the instant shown in **Figure 3**, the angle between the normal to the plane of the coil and the direction of the magnetic field is 30°.

(a) (i) State the minimum angle, in degrees, through which the coil must rotate from its position in **Figure 3** for the emf to reach its maximum value.

angle .... degrees
(1 mark)

(a) (ii) Calculate the minimum angle, in radians, through which the coil must rotate from its position in **Figure 3** for the flux linkage to reach its maximum value.

angle .... radians
(2 marks)

(b) **Figure 4** shows how, starting in a different position, the flux linkage through the coil varies with time.

(b) (i) What physical quantity is represented by the gradient of the graph shown in **Figure 4**?

....
(1 mark)

(b) (ii) Calculate the number of revolutions per minute made by the coil.

revolutions per minute ....
(2 marks)

Figure 4

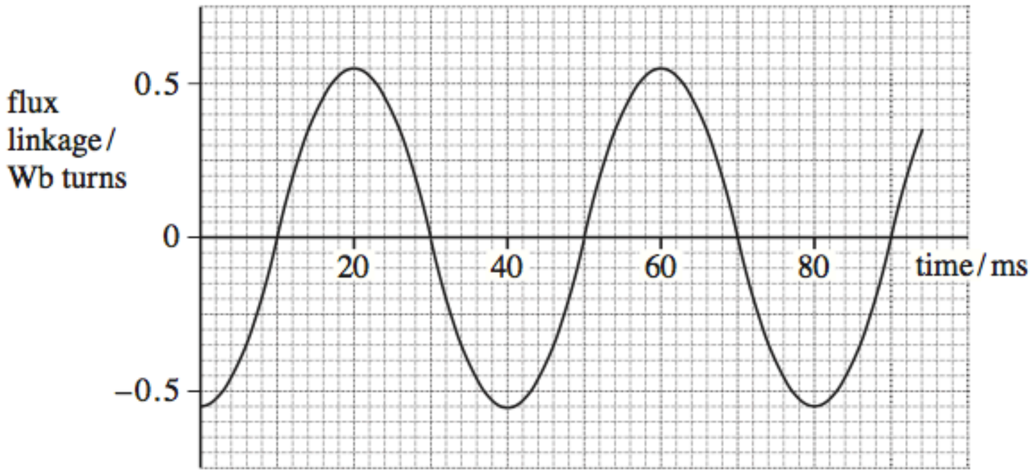
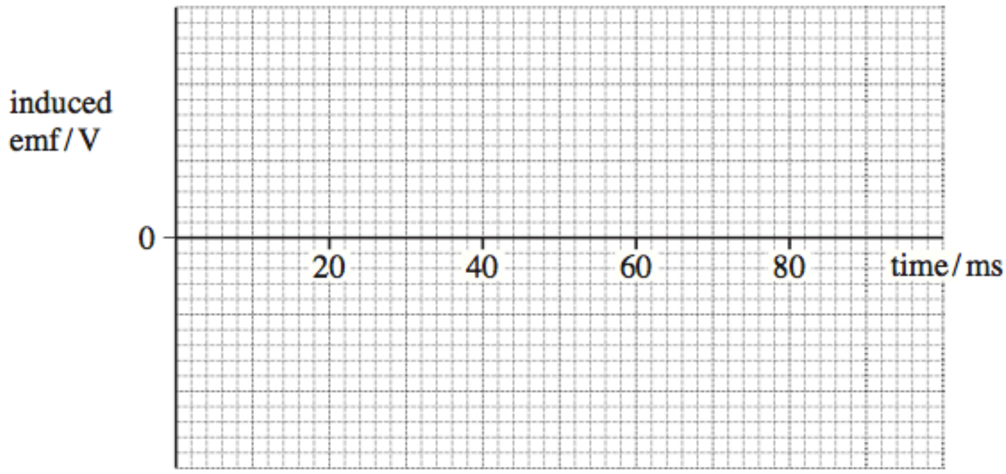


Figure 5



(b) (iii) Calculate the peak value of the emf generated.

peak emf V
(3 marks)

(c) Sketch a graph on the axes shown in **Figure 5** above to show how the induced emf varies with time over the time interval shown in **Figure 4**.
(2 marks)

(d) The coil has 550 turns and a cross-sectional area of $4.0 \times 10^{-3}\,m^2$.

Calculate the flux density of the uniform magnetic field.

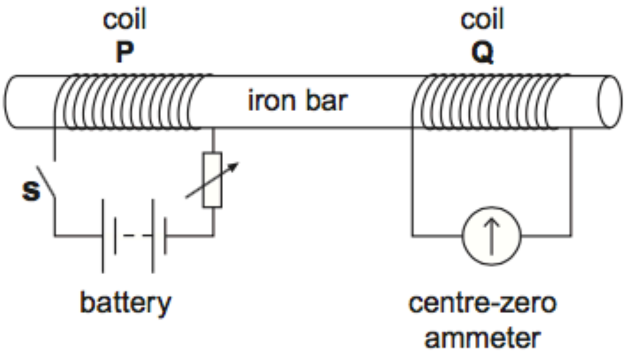
flux density .... T

(2 marks)

4)

(a) **Figure 5** shows two coils, **P** and **Q**, linked by an iron bar. Coil **P** is connected to a battery through a variable resistor and a switch **S**. Coil **Q** is connected to a centre-zero ammeter.

Figure 5



(a) (i) Initially the variable resistor is set to its minimum resistance and **S** is open. Describe and explain what is observed on the ammeter when **S** is closed.

[3 marks]

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(a) (ii) With **S** still closed, the resistance of the variable resistor is suddenly increased. Compare what is now observed on the ammeter with what was observed in part (a)(i). Explain why this differs from what was observed in part (a)(i).

[2 marks]

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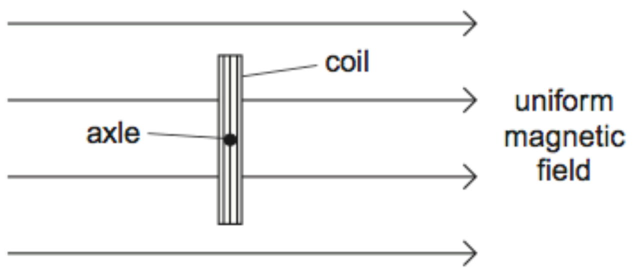
(b) **Figure 6** shows a 40-turn coil of cross-sectional area 3.6×10^{-3} m^2 with its plane set at right angles to a uniform magnetic field of flux density 0.42 T.

Figure 6



(b) (i) Calculate the magnitude of the magnetic flux linkage for the coil.
State an appropriate unit for your answer.

[2 marks]

flux linkage .... unit ....

(b) (ii) The coil is rotated through 90° in a time of 0.50 s.
Determine the mean emf in the coil.

[2 marks]

mean emf V

5)

The Large Hadron Collider (LHC) uses magnetic fields to confine fast-moving charged particles travelling repeatedly around a circular path. The LHC is installed in an underground circular tunnel of circumference 27 km.

(a) In the presence of a suitably directed uniform magnetic field, charged particles move at constant speed in a circular path of constant radius. By reference to the force acting on the particles, explain how this is achieved and why it happens.

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(4 marks)

(b) (i) The charged particles travelling around the LHC may be protons. Calculate the centripetal force acting on a proton when travelling in a circular path of circumference 27 km at one-tenth of the speed of light. Ignore relativistic effects.

answer = ... N

(3 marks)

(b) (ii) Calculate the flux density of the uniform magnetic field that would be required to produce this force. State an appropriate unit.

answer = ... unit ....

(3 marks)

(c) The speed of the protons gradually increases as their energy is increased by the LHC. State and explain how the magnetic field in the LHC must change as the speed of the protons is increased.

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(2 marks)

6)

(a) The equation $F = B\,Q\,v$ may be used to calculate magnetic forces.

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

....

....
(1 mark)

(a) (ii) Identify the physical quantities that are represented by the four symbols in the equation.

F ....

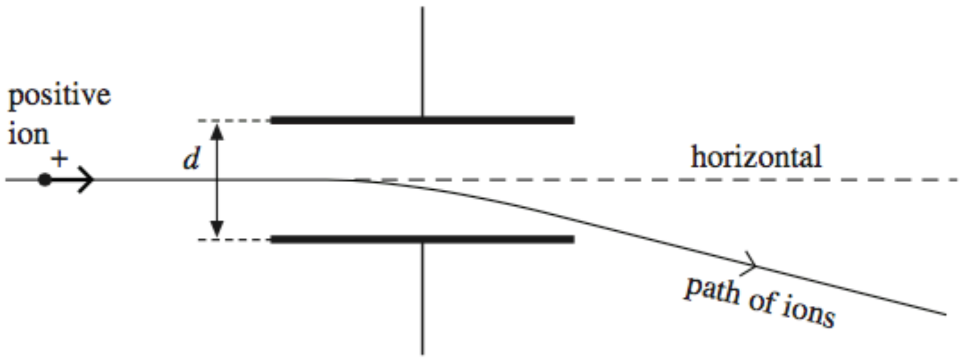
B ....

Q ....

v ....
(1 mark)

(b) **Figure 5** shows the path followed by a stream of identical positively-charged ions, of the same kinetic energy, as they pass through the region between two charged plates. Initially the ions are travelling horizontally and they are then deflected downwards by the electric field between the plates.

Figure 5



Whilst the electric field is still applied, the path of the ions may be restored to the horizontal, so that they have no overall deflection, by applying a magnetic field over the same region as the electric field. The magnetic field must be of suitable strength and has to be applied in a particular direction.

(b) (i) State the direction in which the magnetic field should be applied.

....
(1 mark)

(b) (ii) Explain why the ions have no overall deflection when a magnetic field of the required strength has been applied.

....

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....

(2 marks)

(b) (iii) A stream of ions passes between the plates at a velocity of $1.7 \times 10^5\,\text{m}\,\text{s}^{-1}$. The separation *d* of the plates is 65 mm and the pd across them is 48 V. Calculate the value of *B* required so that there is no overall deflection of the ions, stating an appropriate unit.

answer = ...

(4 marks)

(c) Explain what would happen to ions with a velocity higher than $1.7 \times 10^5\,\text{m}\,\text{s}^{-1}$ when they pass between the plates at a time when the conditions in part (b)(iii) have been established.

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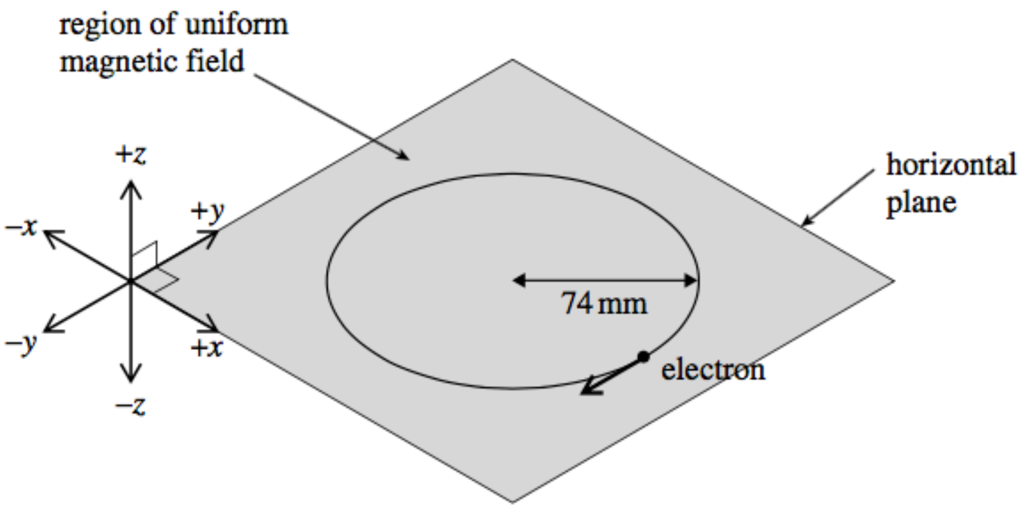
....

(2 marks)

7)

When travelling in a vacuum through a uniform magnetic field of flux density 0.43 mT, an electron moves at constant speed in a horizontal circle of radius 74 mm, as shown in **Figure 3**.

Figure 3



(a) When viewed from vertically above, the electron moves clockwise around the horizontal circle. In which one of the six directions shown on **Figure 3**, +*x*, –*x*, +*y*, –*y*, +*z* or –*z*, is the magnetic field directed?

direction of magnetic field ....

(1 mark)

(b) Explain why the electron is accelerating even though it is travelling at constant speed.

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....

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(2 marks)

(c) (i) By considering the centripetal force acting on the electron, show that its speed is $5.6 \times 10^6\ \mathrm{m\,s^{-1}}$.

(2 marks)

(c) (ii) Calculate the angular speed of the electron, giving an appropriate unit.

answer = ...

(2 marks)

(c) (iii) How many times does the electron travel around the circle in one minute?

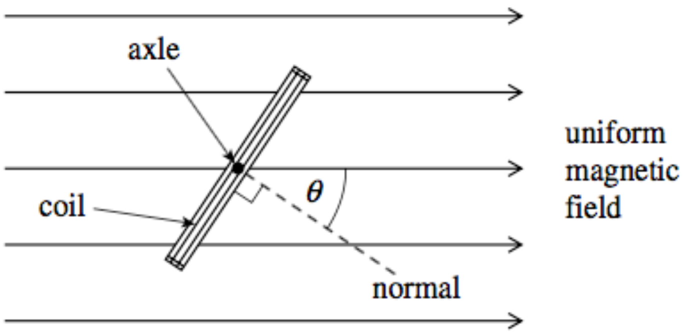
answer = ...

(2 marks)

8)

Figure 4 shows an end view of a simple electrical generator. A rectangular coil is rotated in a uniform magnetic field with the axle at right angles to the field direction. When in the position shown in **Figure 4** the angle between the direction of the magnetic field and the normal to the plane of the coil is θ.

Figure 4



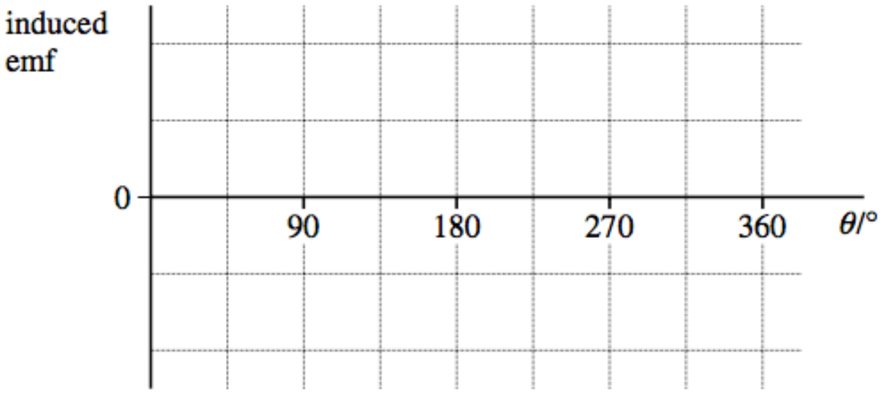
(a) The coil has 50 turns and an area of $1.9 \times 10^{-3}\,\text{m}^2$. The flux density of the magnetic field is $2.8 \times 10^{-2}\,\text{T}$. Calculate the flux linkage for the coil when θ is 35°, expressing your answer to an appropriate number of significant figures.

answer = ... Wb turns
(3 marks)

(b) The coil is rotated at constant speed, causing an emf to be induced.

(b) (i) Sketch a graph on the outline axes to show how the induced emf varies with angle θ during one complete rotation of the coil, starting when $\theta = 0$. Values are not required on the emf axis of the graph.

(1 mark)



(b) (ii) Give the value of the flux linkage for the coil at the positions where the emf has its greatest values.

answer = ... Wb turns

(1 mark)

(b) (iii) Explain why the magnitude of the emf is greatest at the values of θ shown in your answer to part (b)(i).

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(3 marks)

9)

(a) State Lenz's law.

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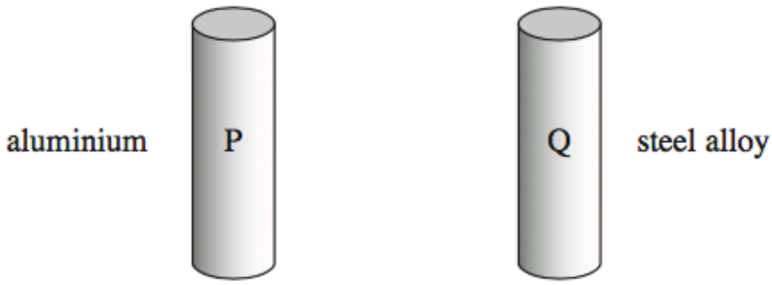
(2 marks)

(b) **Figure 4** shows two small, solid metal cylinders, **P** and **Q**.
P is made from aluminium. **Q** is made from a steel alloy.

Figure 4



(b) (i) The dimensions of **P** and **Q** are identical but **Q** has a greater mass than **P**. Explain what material property is responsible for this difference.

....

....

....
(1 mark)

(b) (ii) When **P** and **Q** are released from rest and allowed to fall freely through a vertical distance of 1.0 m, they each take 0.45 s to do so. Justify this time value and explain why the times are the same.

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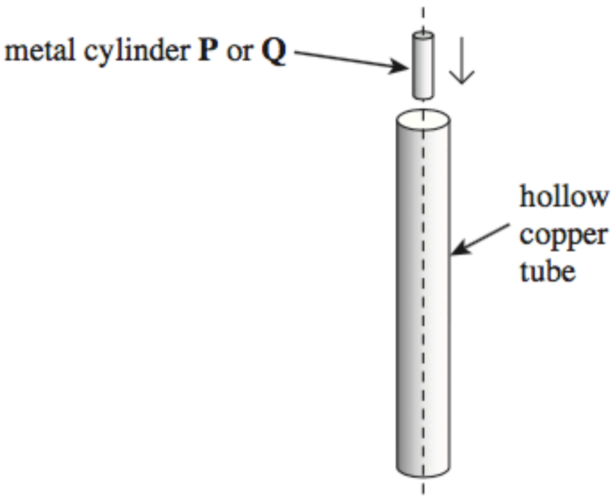
(2 marks)

(c) The steel cylinder **Q** is a strong permanent magnet. **P** and **Q** are released separately from the top of a long, vertical copper tube so that they pass down the centre of the tube, as shown in **Figure 5**.

Figure 5



The time taken for **Q** to pass through the tube is much longer than that taken by **P**.

(c) (i) Explain why you would expect an emf to be induced in the tube as **Q** passes through it.

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(2 marks)

(c) (ii) State the consequences of this induced emf, and hence explain why **Q** takes longer than **P** to pass through the tube.

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(3 marks)

(d) The copper tube is replaced by a tube of the same dimensions made from brass. The resistivity of brass is much greater than that of copper. Describe and explain how, if at all, the times taken by **P** and **Q** to pass through the tube would be affected.

P: ....

....

....

....

Q: ....

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....

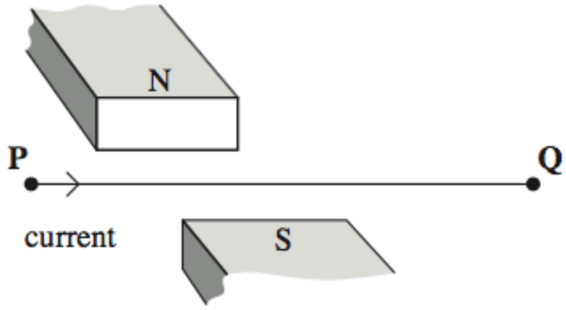
....

(3 marks)

10)

Figure 5 shows a horizontal wire, held in tension between fixed points at **P** and **Q**. A short section of the wire is positioned between the pole pieces of a permanent magnet, which applies a uniform horizontal magnetic field at right angles to the wire. Wires connected to a circuit at **P** and **Q** allow an electric current to be passed through the wire.

Figure 5



(a) (i) State the direction of the force on the wire when there is a direct current from **P** to **Q**, as shown in **Figure 5**.

....

(1 mark)

(a) (ii) In a second experiment, an alternating current is passed through the wire. Explain why the wire will vibrate vertically.

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(3 marks)

(b) The permanent magnet produces a uniform magnetic field of flux density 220 mT over a 55 mm length of the wire. Show that the maximum force on the wire is about 40 mN when there is an alternating current of rms value 2.4 A in it.

(3 marks)

(c) The length of **PQ** is 0.40 m. When the wire is vibrating, transverse waves are propagated along the wire at a speed of $64\,m\,s^{-1}$. Explain why the wire is set into large amplitude vibration when the frequency of the a.c. supply is 80 Hz.

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(3 marks)

11)

(a) (i) Outline the essential features of a step-down transformer when in operation.

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(2 marks)

(a) (ii) Describe **two** causes of the energy losses in a transformer and discuss how these energy losses may be reduced by suitable design and choice of materials.
The quality of your written communication will be assessed in this question.

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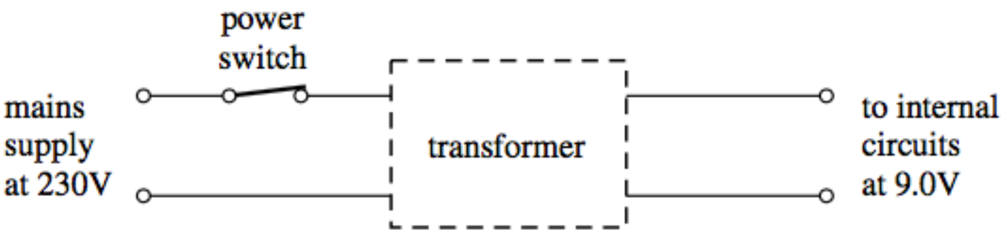
(6 marks)

(b) Electronic equipment, such as a TV set, may usually be left in 'standby' mode so that it is available for instant use when needed. Equipment left in standby mode continues to consume a small amount of power. The internal circuits operate at low voltage, supplied from a transformer. The transformer is disconnected from the mains supply only when the power switch on the equipment is turned off. This arrangement is outlined in **Figure 4**.

Figure 4



When in standby mode, the transformer supplies an output current of 300 mA at 9.0 V to the internal circuits of the TV set.

(b) (i) Calculate the power wasted in the internal circuits when the TV set is left in standby mode.

answer = ... W

(1 mark)

(b) (ii) If the efficiency of the transformer is 0.90, show that the current supplied by the 230 V mains supply under these conditions is 13 mA.

(2 marks)

(b) (iii) The TV set is left in standby mode for 80% of the time. Calculate the amount of energy, in J, that is wasted in one year through the use of the standby mode.

$$1 \text{ year} = 3.15 \times 10^7 \text{ s}$$

answer = ... J

(1 mark)

(b) (iv) Show that the cost of this wasted energy will be about £4, if electrical energy is charged at 20 p per kWh.

(2 marks)

(c) The power consumption of an inactive desktop computer is typically double that of a TV set in standby mode. This waste of energy may be avoided by switching off the computer every time it is not in use. Discuss **one** advantage and **one** disadvantage of doing this.

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(2 marks)