Magnetic Fields and EM Induction Revision Pack

Name: ____________________

Class: ____________________

Date: ____________________

Time:	**352 minutes**
Marks:	**289 marks**
Comments:	

1 (a) State, in words, the two laws of electromagnetic induction.

Law 1 ____

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Law 2 ____

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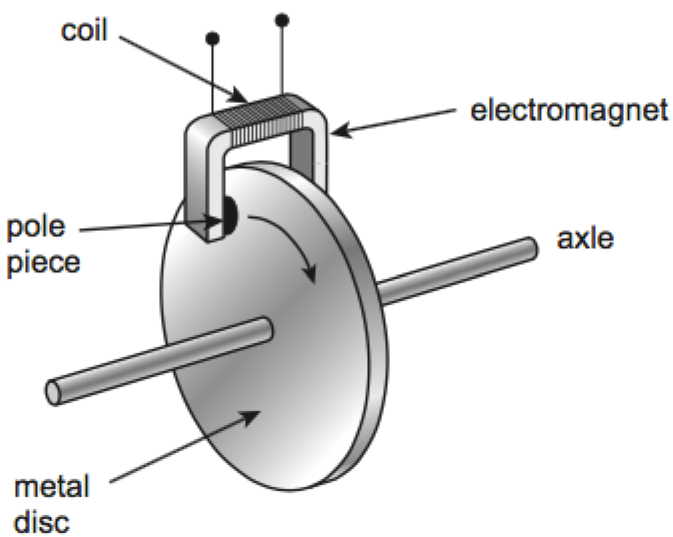
(3)

(b) The diagram below illustrates the main components of one type of electromagnetic braking system. A metal disc is attached to the rotating axle of a vehicle. An electromagnet is mounted with its pole pieces placed either side of the rotating disc, but not touching it. When the brakes are applied, a direct current is passed through the coil of the electromagnet and the disc slows down.



(i) Explain, using the laws of electromagnetic induction, how the device in the diagram acts as an electromagnetic brake.

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(3)

(ii) A conventional braking system has friction pads that are brought into contact with a moving metal surface when the vehicle is to be slowed down.
State **one** advantage and **one** disadvantage of an electromagnetic brake compared to a conventional brake.

Advantage ____

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Disadvantage ____

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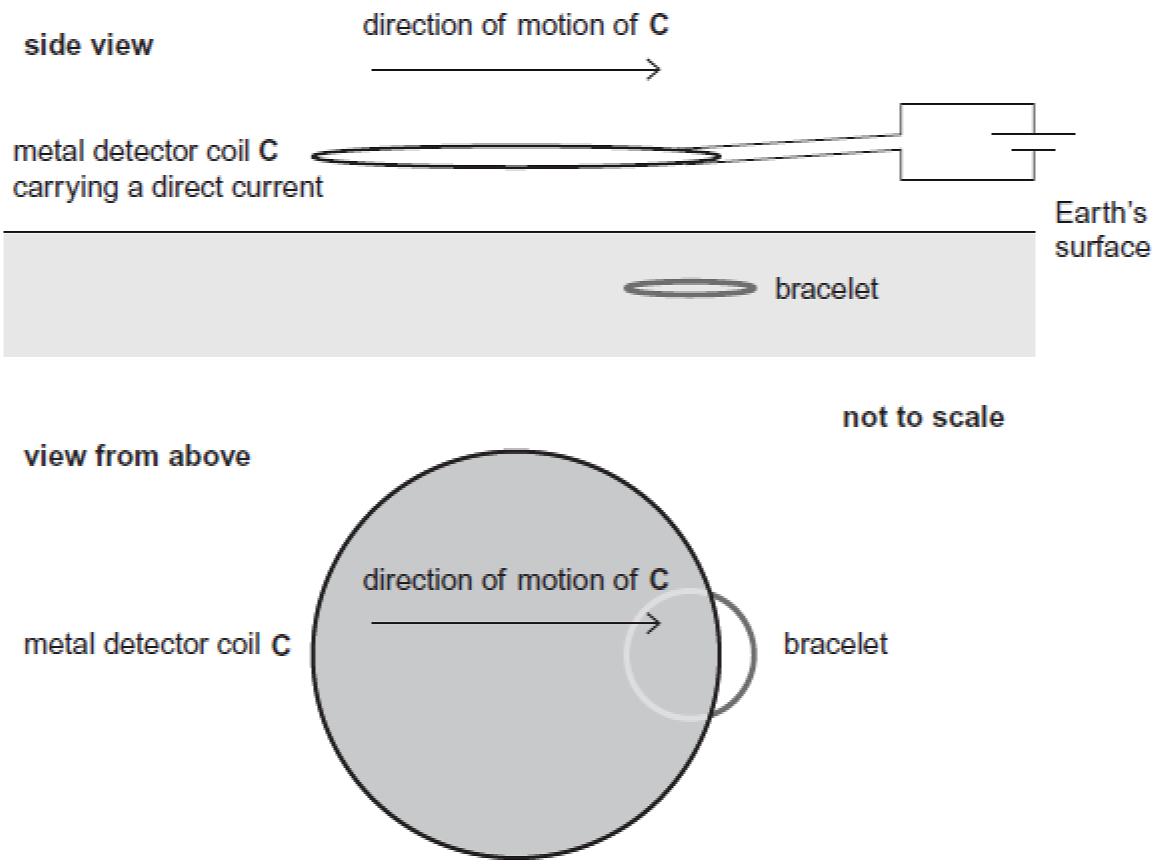
(2)

(Total 8 marks)

2 A metal detector is moved horizontally at a constant speed just above the Earth's surface to search for buried metal objects

Figure 1 shows the coil **C** of a metal detector moving over a circular bracelet made from a single band of metal. The planes of the coil and the bracelet are both horizontal.

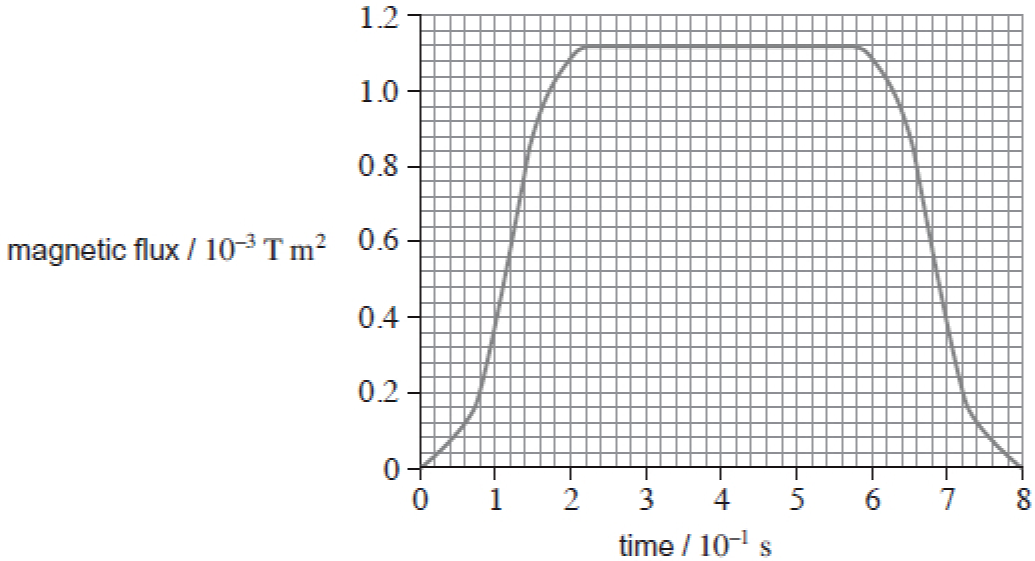
Figure 1



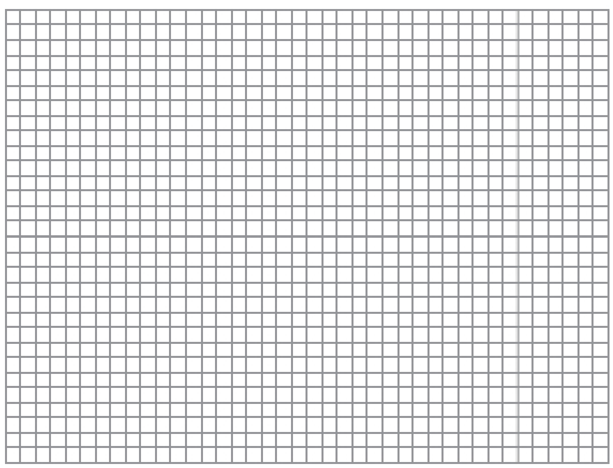
In this metal detector, **C** carries a direct current so that the magnetic flux produced by **C** does not vary. The bracelet is just below the surface, so the flux is perpendicular to the plane of the bracelet. The field is negligible outside the shaded region of **C**.

Figure 2 shows how the magnetic flux through the bracelet varies with time when **C** is moving at a constant velocity.

Figure 2



(a) (i) Sketch a graph on the grid to show how the emf induced in the bracelet varies with time as **C** moves across the bracelet. Use the same scale on the time axis as in **Figure 2**.



(3)

(ii) Use the laws of Faraday and Lenz to explain the shape of your graph.

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(4)

(b) The velocity at which **C** is moved is 0.28 m s^{-1}.

Show that the diameter of the bracelet is about 6 cm.

(1)

(c) Determine the magnetic flux density of the field produced by **C** at the position of the bracelet.

magnetic flux density ____________________ T

(2)

(d) Determine the maximum emf induced in the bracelet.

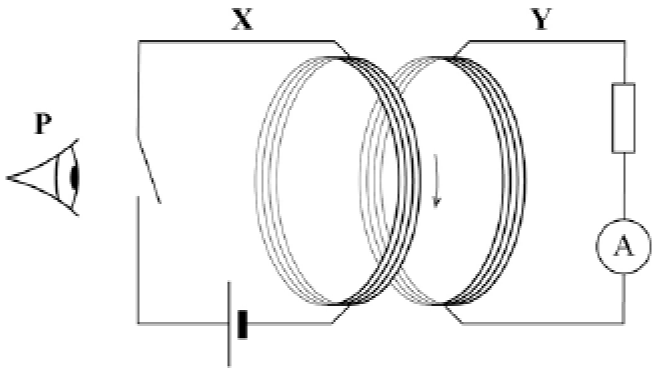
maximum emf ____________________ V

(3)

(Total 13 marks)

3 **Figure 1** shows an arrangement for investigating electromagnetic induction.

Figure 1



When the switch is closed there is a current in the coil in circuit **X**. The current is in a clockwise direction as viewed from position **P**.

Circuit **Y** is viewed from position **P**.

(a) Explain how Lenz's law predicts the direction of the induced current when the switch is opened and again when it is closed.

(4)

An ‘Earth inductor’ consists of a 500 turn coil.   **Figure 2** and **Figure 3** shows it set up to measure the horizontal component of the Earth’s magnetic field. When the coil is rotated an induced emf is produced.

Figure 2

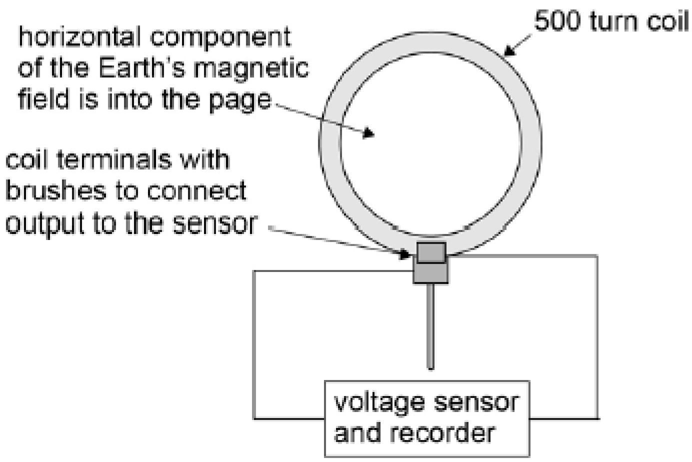
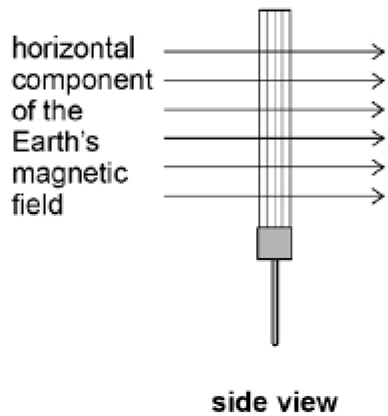
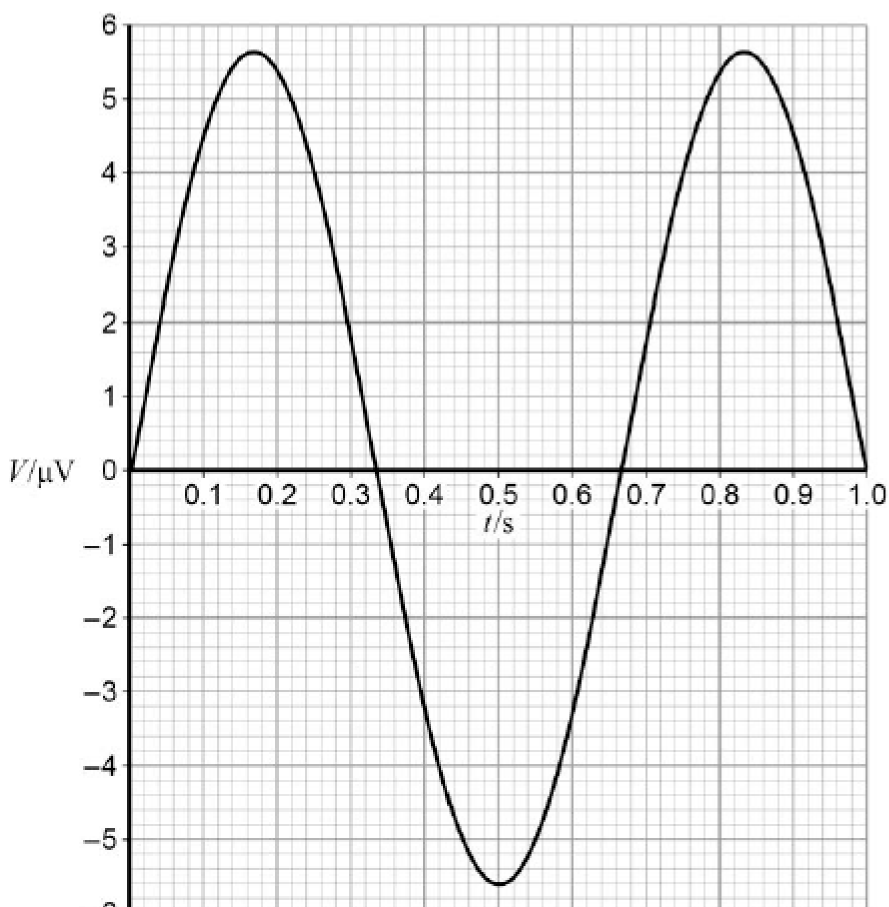


Figure 3



The mean diameter of the turns on the coil is 35 cm. **Figure 4** shows the output recorded for the variation of potential difference V with time t when the coil is rotated at 1.5 revolutions per second.

Figure 4



(b) Determine the flux density, B_H, of the horizontal component of the Earth's magnetic field.

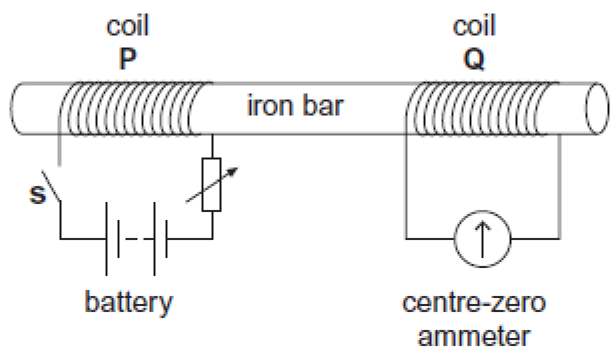
horizontal component of flux density = ______________ T

(3)

(Total 7 marks)

4 (a) **Figure 1** 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 1



(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.

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(3)

(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 (i). Explain why this differs from what was observed in part (i).

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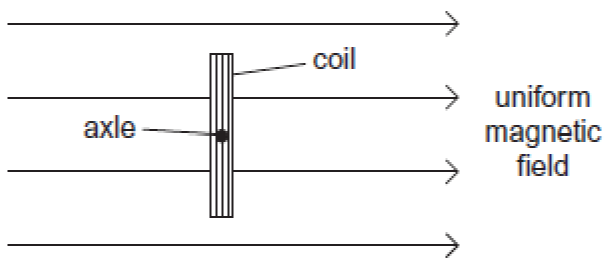
(2)

(b) **Figure 2** 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 2



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

flux linkage ____________________ unit ___________

(2)

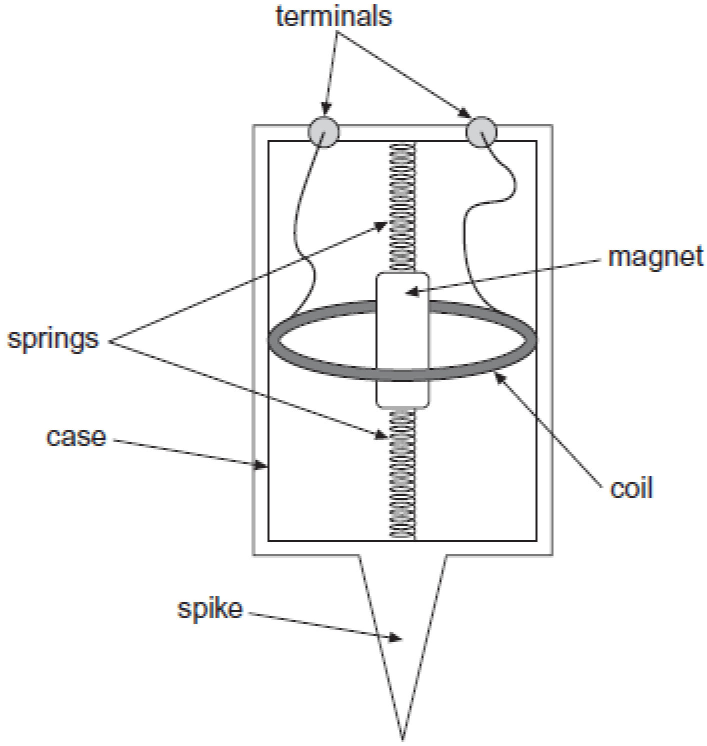
(ii) The coil is rotated through 90° in a time of 0.50 s.
Determine the mean emf in the coil.

mean emf ____________________ V

(2)

(Total 9 marks)

5 The diagram below shows the main parts of a geophone.



The spike attaches the geophone firmly to the ground. At the instant an earthquake occurs, the case and coil move upwards due to the Earth's movement. The magnet remains stationary due to its inertia. In 3.5 ms, the coil moves from a position where the flux density is 9.0 mT to a position where the flux density is 23.0 mT.

(a) The geophone coil has 250 turns and an area of 12 cm^2.

Calculate the average emf induced in the coil during the first 3.5 ms after the start of the earthquake.

emf ____________________ V

(3)

(b) Explain how the initial emf induced in the coil of the geophone would be affected:

if the stiffness of the springs were to be increased

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if the number of turns on the coil were to be increased.

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(2)

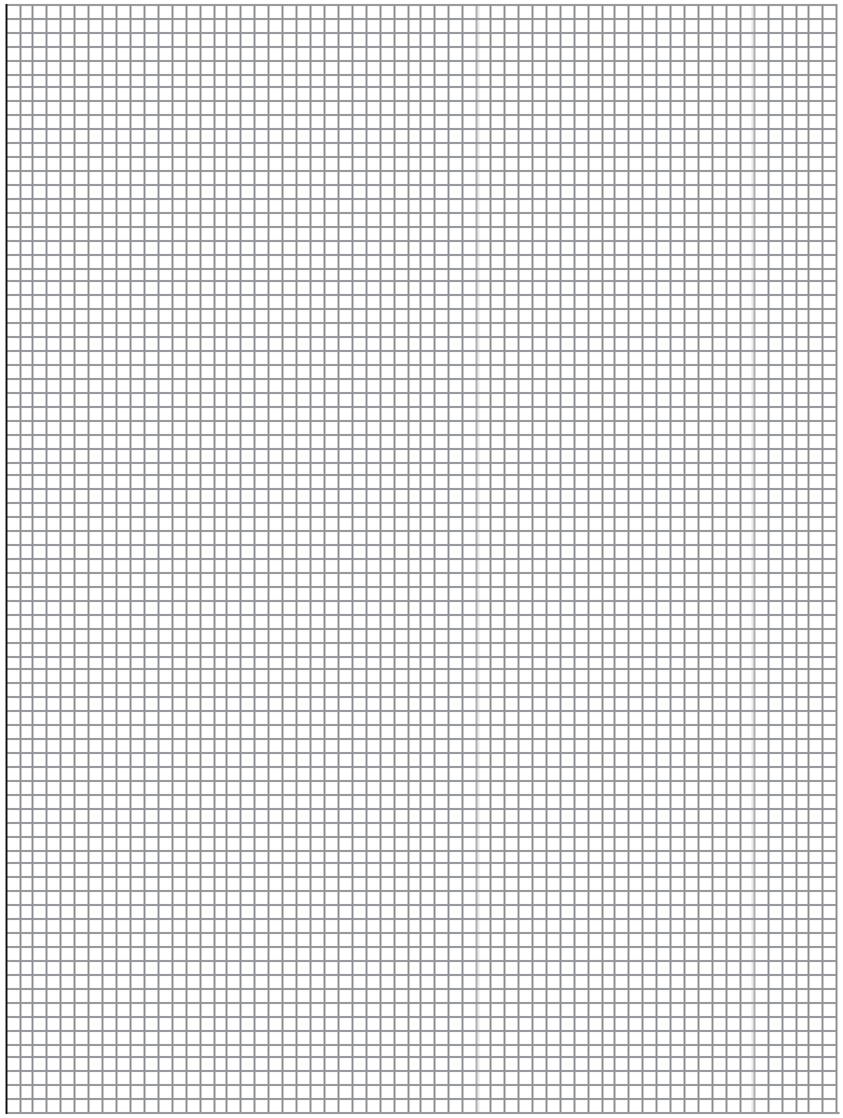
(c) (i) The geophone's magnet has a mass of 8.0×10^{-3} kg and the spring stiffness of the system is 2.6 N m^{-1}.

Show that the natural period of oscillation of the mass−spring system is approximately 0.35 s.

(2)

(ii) At the instant that the Earth stops moving after one earthquake, the emf in the coil is at its maximum value of +8 V. The magnet continues to oscillate.

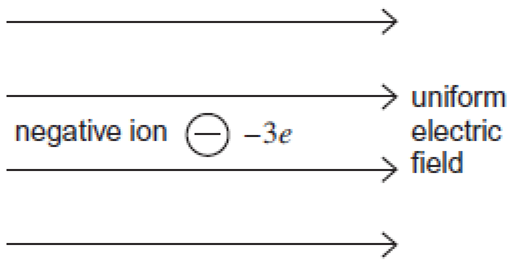
On the grid below, sketch a graph showing the variation of emf with time as the magnet's oscillation decays.
Show at least **three** oscillations.



(3)
(Total 10 marks)

6 (a) **Figure 1** shows a negative ion which has a charge of $-3e$ and is free to move in a uniform electric field. When the ion is accelerated by the field through a distance of 63 mm parallel to the field lines its kinetic energy increases by 4.0×10^{-16} J.

Figure 1



(i) State and explain the direction of the electrostatic force on the ion.

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(2)

(ii) Calculate the magnitude of the electrostatic force acting on the ion.

magnitude of electrostatic force ____________________ N

(2)

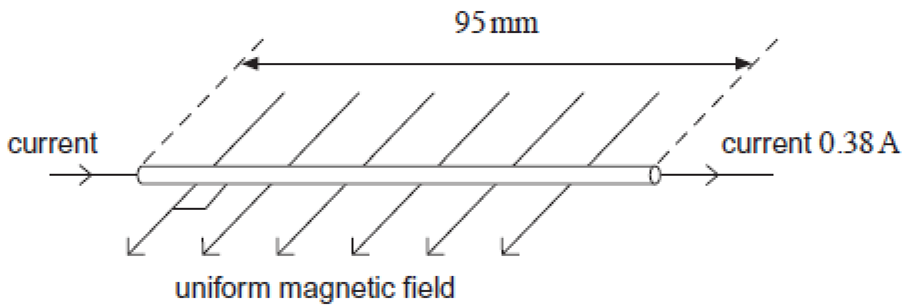
(iii) Calculate the electric field strength.

electric field strength ____________________ NC^{-1}

(1)

(b) **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.

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(2)

(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 5.1×10^{-6} m^2.
Show that there are about 4×10^{22} free electrons in this section of wire.

(1)

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

flux density ____________________ T

(2)

(Total 10 marks)

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

first situation ____

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second situation ____

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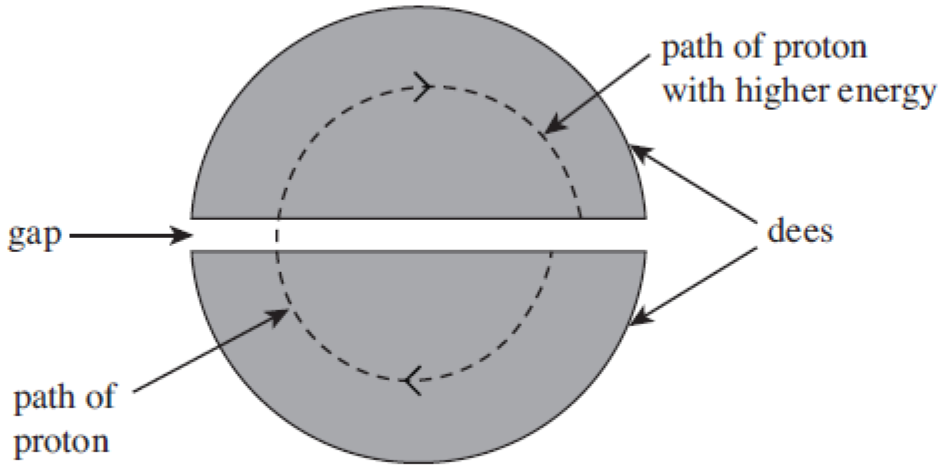
(2)

(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)

(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. The diagram below shows a plan view of this arrangement.



(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 the diagram above.

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(1)

(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 ____________________ ms^{-1}

(2)

(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)

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

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(2)

(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 Me V, of the protons accelerated by the cyclotron if the outer radius of the dees is 470 mm.

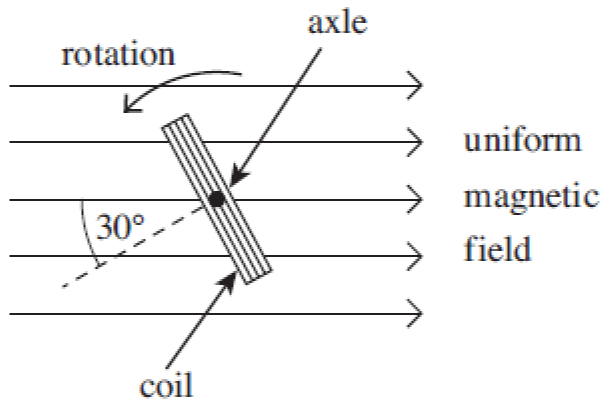
maximum kinetic energy ____________________ Me V

(3)

(Total 14 marks)

8 A rectangular coil is rotating anticlockwise at constant angular speed with its axle at right angles to a uniform magnetic field. **Figure 1** shows an end-on view of the coil at a particular instant.

Figure 1



(a) At the instant shown in **Figure 1**, the angle between the normal to the plane of the coil and the direction of the magnetic field is 30°.

(i) State the minimum angle, in degrees, through which the coil must rotate from its position in **Figure 1** for the emf to reach its maximum value.

angle ____________________ degrees

(1)

(ii) Calculate the minimum angle, in radians, through which the coil must rotate from its position in **Figure 1** for the flux linkage to reach its maximum value.

angle ____________________ radians

(2)

(b) **Figure 2** shows how, starting in a different position, the flux linkage through the coil varies with time.

(i) What physical quantity is represented by the gradient of the graph shown in **Figure 2**?

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(1)

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

revolutions per minute ____________________

(2)

Figure 2

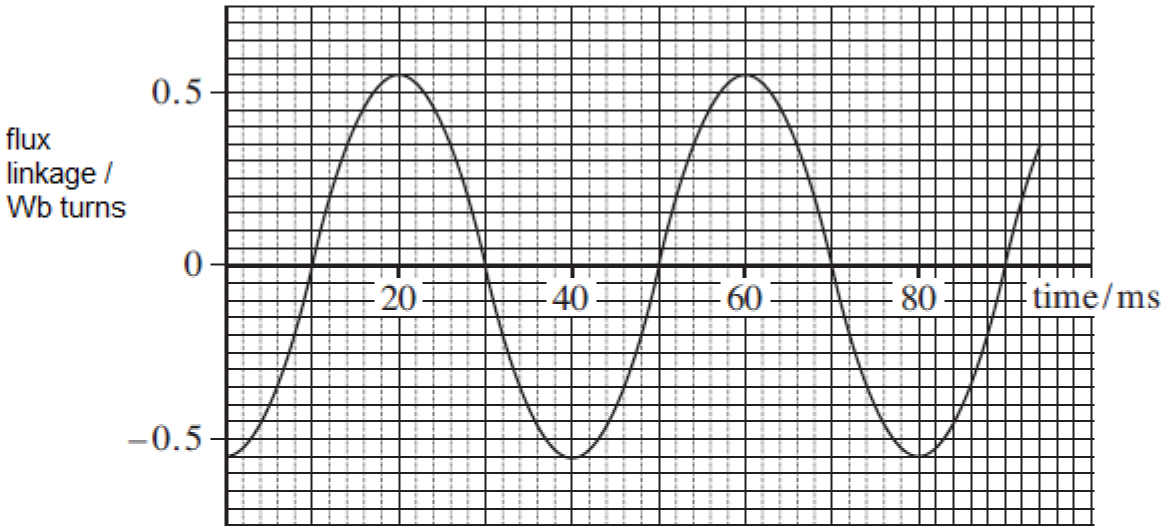
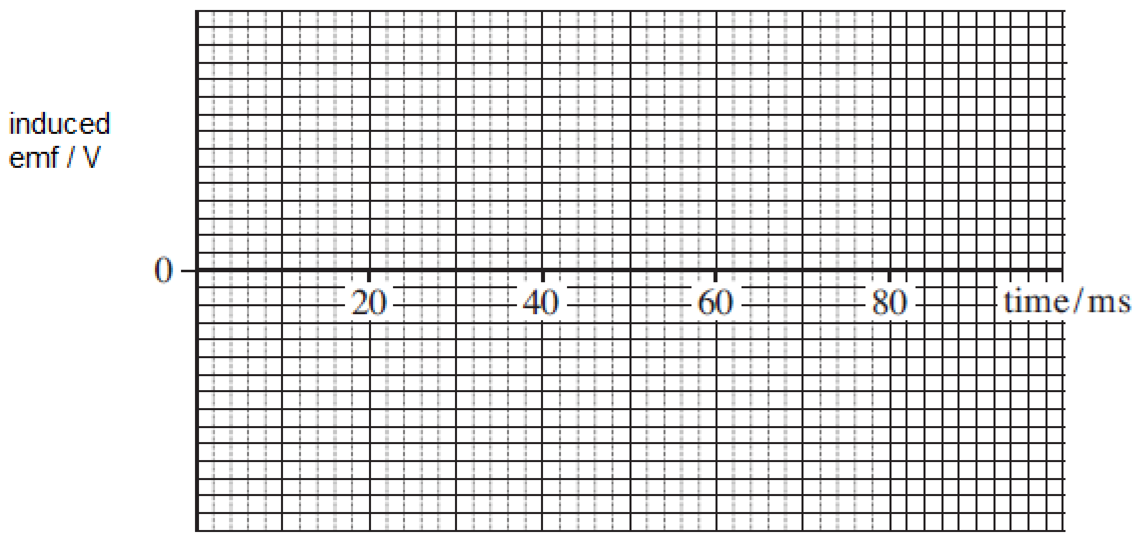


Figure 3



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

peak emf ____________________ V

(3)

(c) Sketch a graph on the axes shown in **Figure 3** above to show how the induced emf varies with time over the time interval shown in **Figure 2**.

(2)

(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)

(Total 13 marks)

9 (a) State Lenz's law.

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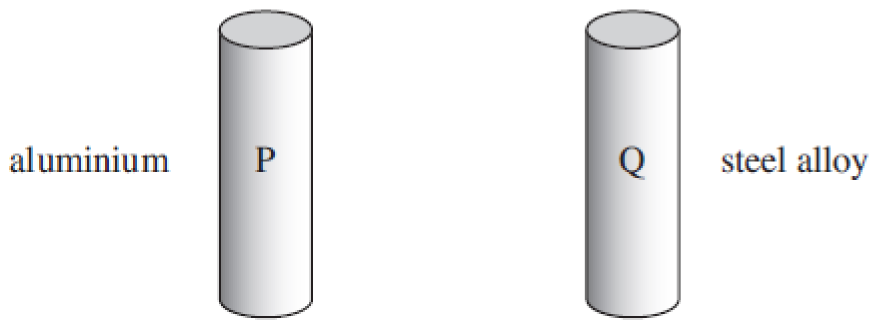
(2)

(b) **Figure 1** shows two small, solid metal cylinders, **P** and **Q**. **P** is made from aluminium. **Q** is made from a steel alloy.

Figure 1



(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.

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(1)

(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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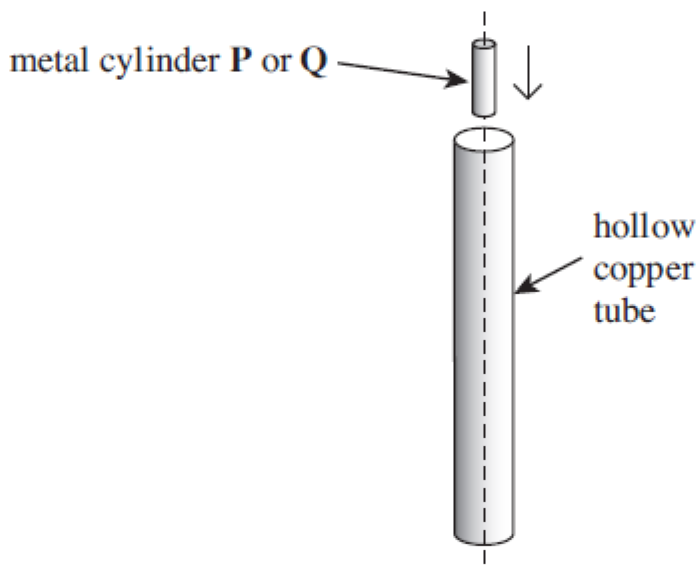
(2)

(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 2**.

Figure 2



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

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

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(2)

(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)

(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: ____

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Q: ____

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(3)

(Total 13 marks)

10 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)

(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)

(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)

(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)

(Total 12 marks)

11 (a) The equation $F = BQv$ may be used to calculate magnetic forces.

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

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(1)

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

F ____

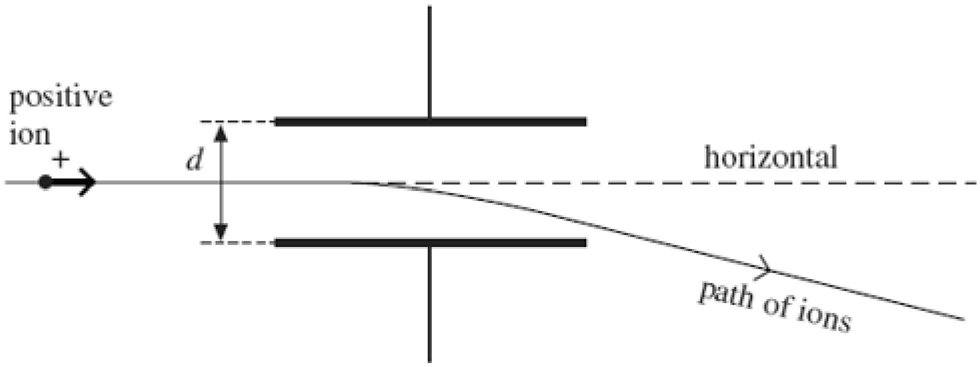
B ____

Q ____

v ____

(1)

(b) The figure below 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.



While 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.

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

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(1)

(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)

(iii) A stream of ions passes between the plates at a velocity of 1.7 x 10^5 ms^{-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)

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

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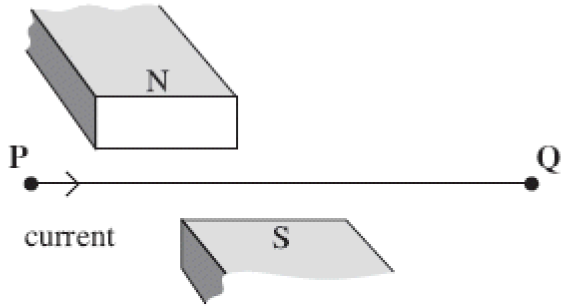
(2)

(Total 11 marks)

12 The figure below 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.



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

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(1)

(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)

(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)

(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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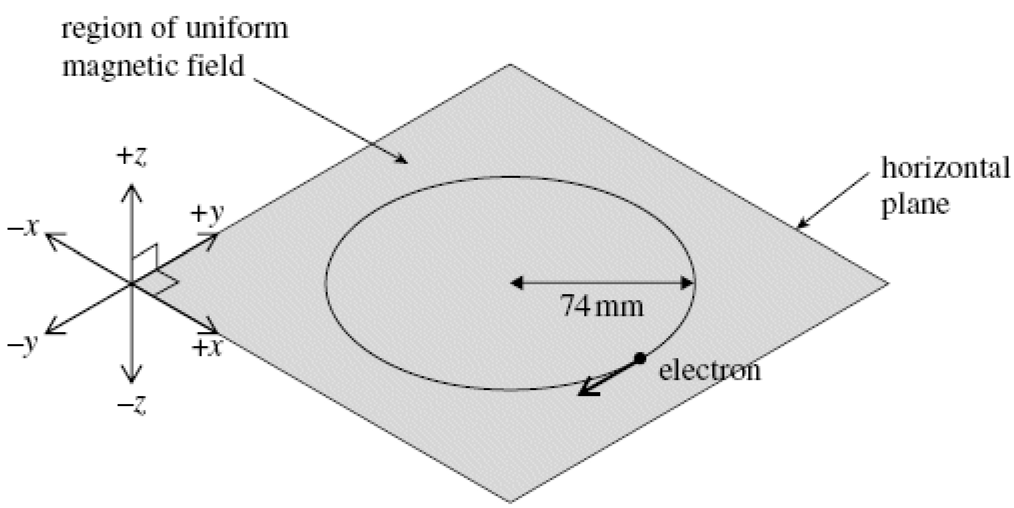
(3)

(Total 10 marks)

13 When travelling in a vacuum through a uniform magnetic field of flux density 0.43 m T, an electron moves at constant speed in a horizontal circle of radius 74 mm, as shown in the figure below.



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

direction of magnetic field ________________________

(1)

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

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(2)

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

(2)

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

answer = ______________________

(2)

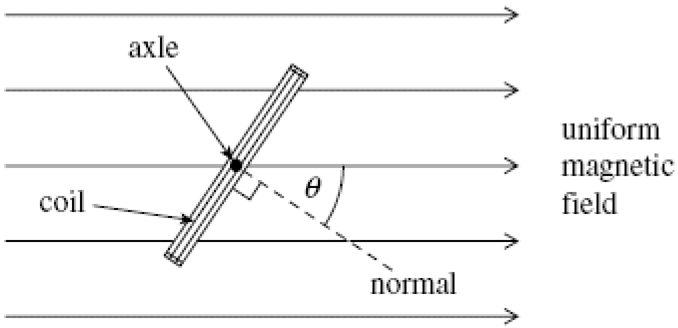
(iii) How many times does the electron travel around the circle in one minute?

answer = ______________________

(2)

(Total 9 marks)

14 The figure below 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 the figure below the angle between the direction of the magnetic field and the normal to the plane of the coil is θ.



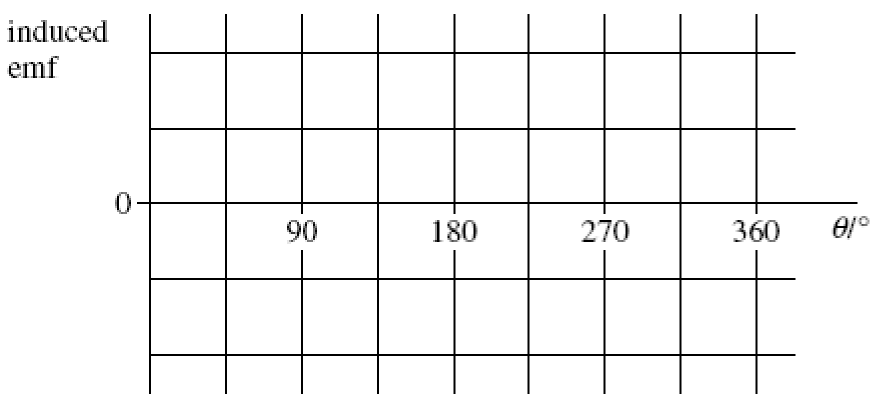
(a) The coil has 50 turns and an area of 1.9×10^{-3} m^2. The flux density of the magnetic field is 2.8×10^{-2} T. Calculate the flux linkage for the coil when θ is 35°, expressing your answer to an appropriate number of significant figures.

answer = ______________________ Wb turns

(3)

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

(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)

(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)

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

(3)

(Total 8 marks)

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

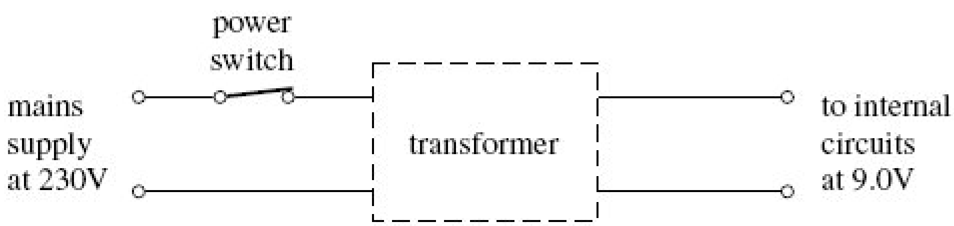
(2)

(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.

(Allow one lined page).

(6)

(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 the diagram below.



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

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

answer = ____________________ W

(1)

(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)

(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 year = 3.15×10^7 s

answer = ____________________ J

(1)

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

(2)

(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)

(Total 16 marks)

16

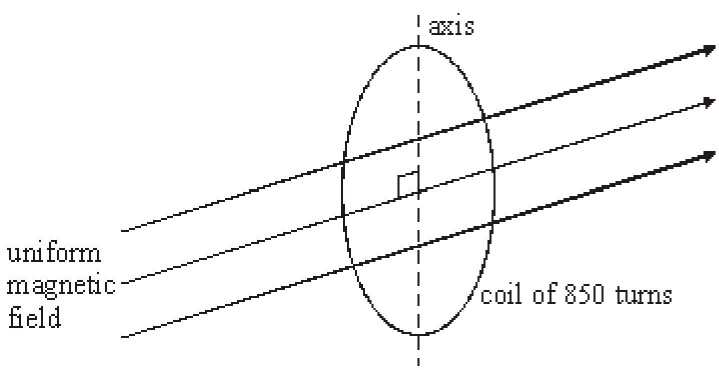


Figure 1

A circular coil of diameter 140 mm has 850 turns. It is placed so that its plane is perpendicular to a horizontal magnetic field of uniform flux density 45 mT, as shown in **Figure 1**.

(a) Calculate the magnetic flux passing through the coil when in this position.

____

____

(2)

(b) The coil is rotated through 90° about a vertical axis in a time of 120 ms.

Calculate

(i) the change of magnetic flux linkage produced by this rotation,

____

____

(ii) the average emf induced in the coil when it is rotated.

____

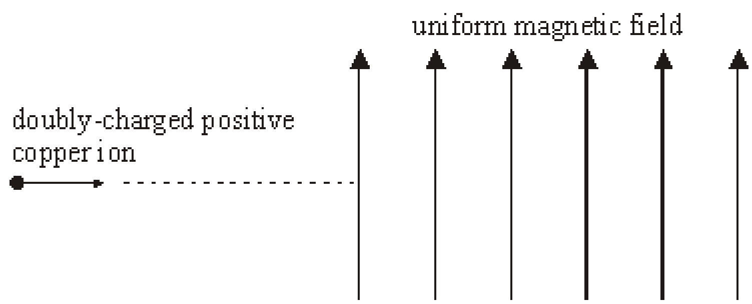
____

____

(4)

(Total 6 marks)

17 (a)



The diagram above shows a doubly-charged positive ion of the copper isotope $^{63}_{29}Cu$ that is projected into a vertical magnetic field of flux density 0.28 T, with the field directed upwards. The ion enters the field at a speed of 7.8×10^5 m s^{-1}.

(i) State the initial direction of the magnetic force that acts on the ion.

____

(ii) Describe the subsequent path of the ion as fully as you can.
Your answer should include both a qualitative description and a calculation.

mass of $^{63}_{29}Cu$ ion = 1.05×10^{-25} kg

(5)

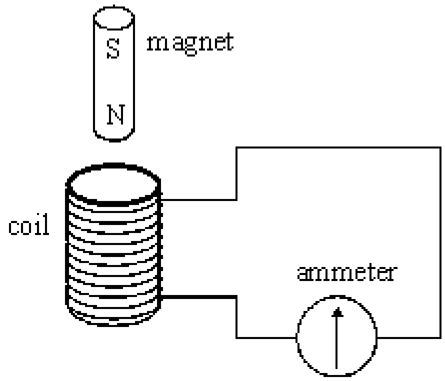
(b) State the effect on the path in part (a) if the following changes are made separately.

(i) The strength of the magnetic field is doubled.

(ii) A singly-charged positive $^{63}_{29}Cu$ ion replaces the original one.

(3)
(Total 8 marks)

18 A coil is connected to a centre zero ammeter, as shown. A student drops a magnet so that it falls vertically and completely through the coil.



(a) Describe what the student would observe on the ammeter as the magnet falls through the coil.

____

____

____

____

(2)

(b) If the coil were not present the magnet would accelerate downwards at the acceleration due to gravity. State and explain how its acceleration in the student's experiment would be affected, if at all,

(i) as it entered the coil,

____

____

____

(ii) as it left the coil.

____

____

____

(4)

(c) Suppose the student forgot to connect the ammeter to the coil, therefore leaving the circuit incomplete, before carrying out the experiment. Describe and explain what difference this would make to your conclusions in part (b).

You may be awarded marks for the quality of written communication provided in your answer.

___

___

___

___

___

(3)

(Total 9 marks)

19 (a) The equation $F = BIl$, where the symbols have their usual meanings, gives the magnetic force that acts on a conductor in a magnetic field.

Given the unit of each of the quantities in the equation.

F ___ *B* ___

I ___ l ___

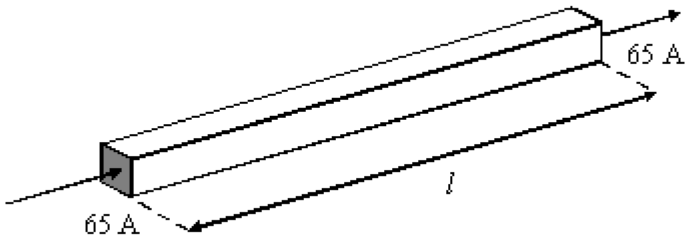
State the condition under which the equation applies.

___

___

(2)

(b) The diagram shows a horizontal copper bar of 25 mm × 25 mm square cross-section and length l carrying a current of 65 A.



(i) Calculate the minimum value of the flux density of the magnetic field in which it should be placed if its weight is to be supported by the magnetic force that acts upon it.

density of copper = 8.9×10^3 kg m^{-3}

____

____

____

____

____

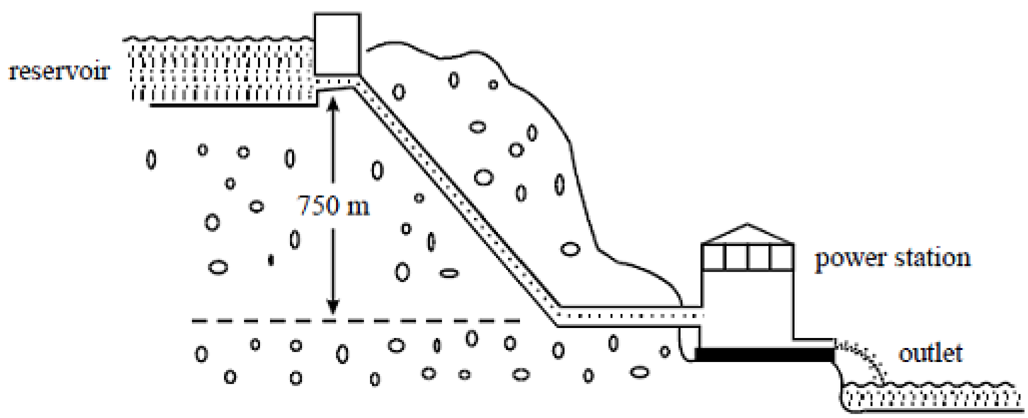
(ii) Draw an arrow on the diagram above to show the direction in which the magnetic field should be applied if your calculation in part (i) is to be valid. Label this arrow M.

(5)

(Total 7 marks)

20 A hydroelectric power station has a power output of 2.0 MW when water passes through its turbines at a rate of 1.4 m^3 s^{-1} . The water is supplied from a reservoir which is 750 m above the power station turbines, as shown in the diagram below.

density of water = 1000 kg m^{-3}



(a) Calculate

(i) the mass of water passing through the turbines each second,

(ii) the loss of potential energy per second of the water flowing between the reservoir and the power station turbines,

(iii) the efficiency of the power station.

(6)

(b) The turbines drive generators that produce alternating current at an rms potential difference of 25 kV which is then stepped up to an rms potential difference of 275 kV by means of a transformer.

(i) Calculate the rms current supplied by the generators to the transformer when the power output of the generators is 2.0 MW.

(ii) The transformer has an efficiency of 95%. Calculate the output current of the transformer.

____

____

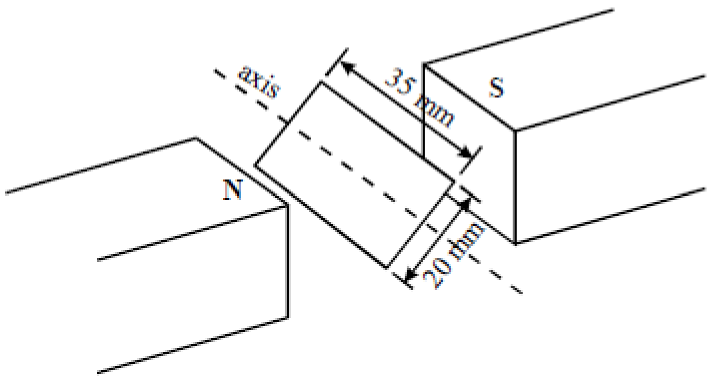
____

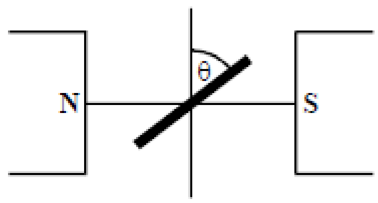
____

(4)

(Total 10 marks)

21 A rectangular coil measuring 20 mm by 35 mm and having 650 turns is rotating about a horizontal axis which is at right angles to a uniform magnetic field of flux density 2.5×10^{-3} T. The plane of the coil makes an angle θ with the vertical, as shown in the diagrams.





front view

(a) State the value of θ when the magnetic flux through the coil is a minimum.

____

(1)

(b) Calculate the magnetic flux passing through the coil when θ is 30°.

____

____

(2)

(c) What is the maximum *flux linkage* through the coil as it rotates?

____

____

____

(2)

(Total 5 marks)

22 Protons and pions are produced in a beam from a target in an accelerator. The two types of particles can be separated using a magnetic field.

(a) State the quark composition of

(i) a proton,

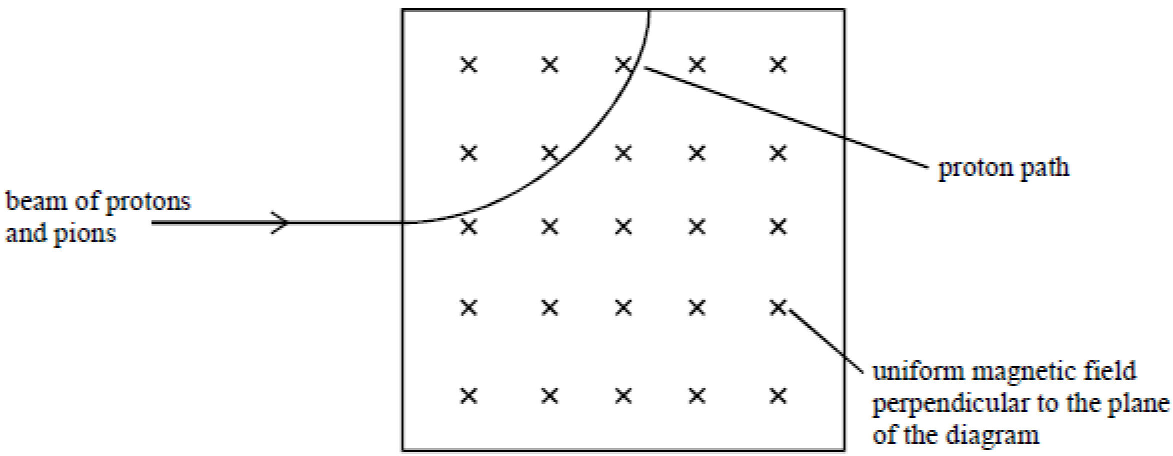
___

(ii) a positive pion, π^+

___

(2)

(b) A narrow beam consisting of protons and positive pions, all travelling at a speed of 1.5×10^7 m s^{-1} , is directed into a uniform magnetic field of flux density 0.16 T, as shown in the diagram.



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

___

___

___

___

___

___

___

(ii) Sketch, on the diagram above, the path of the pions from the point of entry into the field to the point of exit from the field.

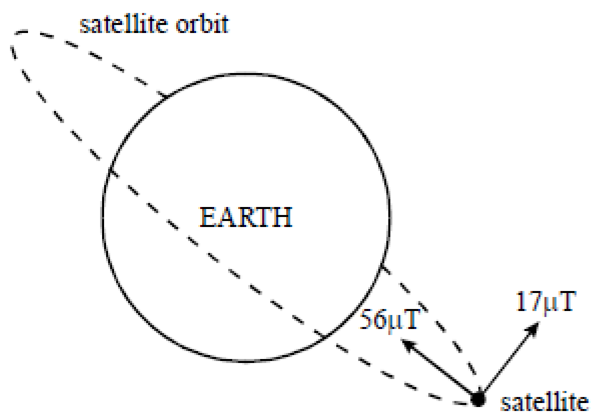
(iii) If the magnetic field were increased, how would this affect the paths of the particles?

(7)
(Total 9 marks)

23 (a) A satellite moves in a circular orbit at constant speed. Explain why its speed does not change even though it is acted on by a force.

(3)

(b) At a certain point along the orbit of a satellite in uniform circular motion, the Earth's magnetic flux density has a component of 56 μT towards the centre of the Earth and a component of 17 μT in a direction perpendicular to the plane of the orbit.



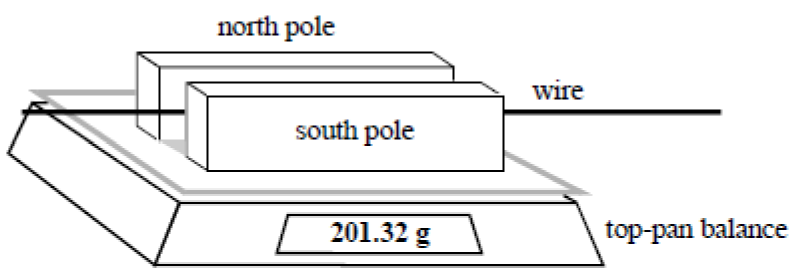
(i) Calculate the magnitude of the resultant magnetic flux density at this point.

(ii) The satellite has an external metal rod pointing towards the centre of the Earth. Calculate the angle between the direction of the resultant magnetic field and the rod.

(iii) Explain why an emf is induced in the rod in this position.

(4)
(Total 7 marks)

24 The diagram shows a magnet placed on a top-pan balance. A fixed horizontal wire, through which a current can flow, passes centrally through the magnetic field parallel to the pole-pieces. With no current flowing, the balance records a mass of 201.32 g. When a current of 5.0 A flows, the reading on the balance is 202.86 g.



(a) (i) Explain why the reading on the balance increased when the current was switched on.

(ii) State the direction of current flow and explain your answer.

(iii) If the length of the wire in the magnetic field is 60 mm, estimate the flux density of the magnetic field.

___

___

___

(6)

(b) Sketch a graph to show how you would expect the balance reading to change if the current through the wire was changed.

(2)
(Total 8 marks)

25 A metal aircraft with a wing span of 42 m flies horizontally with a speed of 1000 km h^{-1} in a direction due east in a region where the vertical component of the flux density of the Earth's magnetic field is 4.5×10^{-5} T.

(a) Calculate the flux cut per second by the wings of the aircraft.

___

___

___

___

(b) Determine the magnitude of the potential difference between the wing tips, stating the law which you are applying in this calculation.

___

___

___

(c) What would be the change in the potential difference, if any, if the aircraft flew due west?

____

____

(Total 6 marks)

26 (a) (i) State **two** differences between a proton and a positron.

difference 1 ____

____

difference 2 ____

____

(ii) A narrow beam of protons and positrons travelling at the same speed enters a uniform magnetic field. The path of the positrons through the field is shown in **Figure 1**.

Sketch on **Figure 1** the path you would expect the protons to take.

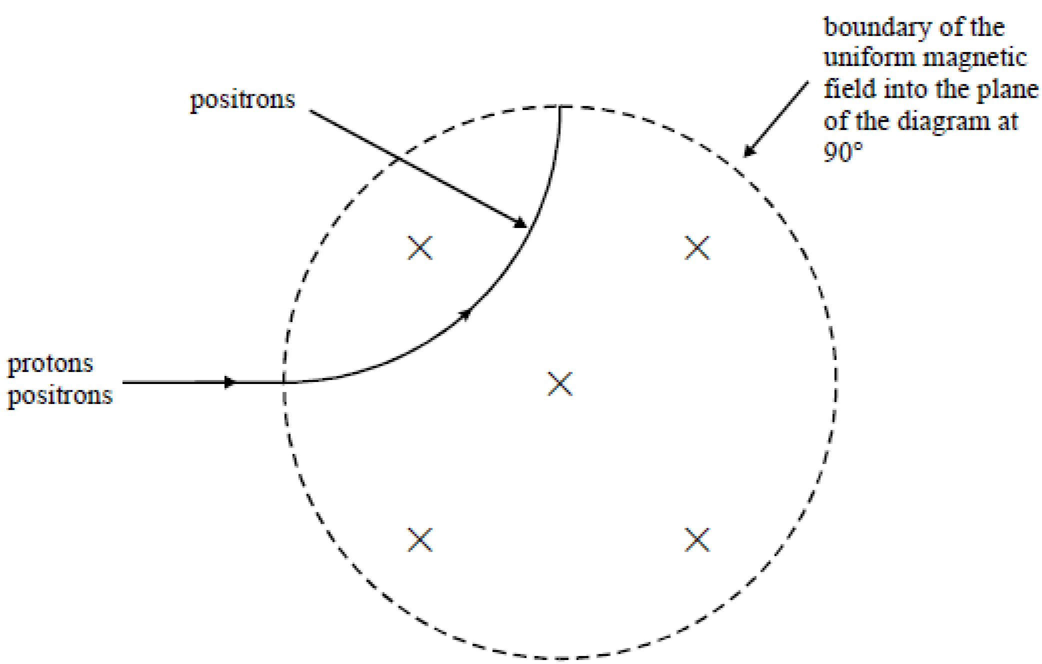


Figure 1

(iii) Explain why protons take a different path to that of the positrons.

____

____

____

____

____

____

(5)

(b) **Figure 2** shows five isotopes of carbon plotted on a grid in which the vertical axis represents the neutron number N and the horizontal axis represents the proton number Z. Two of the isotopes are stable, one is a beta minus emitter and two are positron emitters.

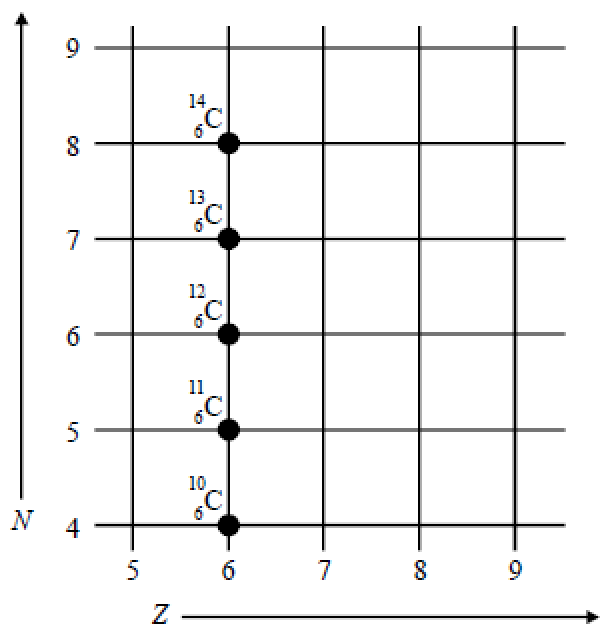


Figure 2

(i) Which isotope is a beta minus emitter?

____

(ii) Which of the two positron emitters has the shorter half-life? Give a reason for your choice.

____

____

____

(3)

(c) A positron with kinetic energy 2.2 MeV and an electron at rest annihilate each other. Calculate the average energy of each of the two gamma photons produced as a result of this annihilation.

___

___

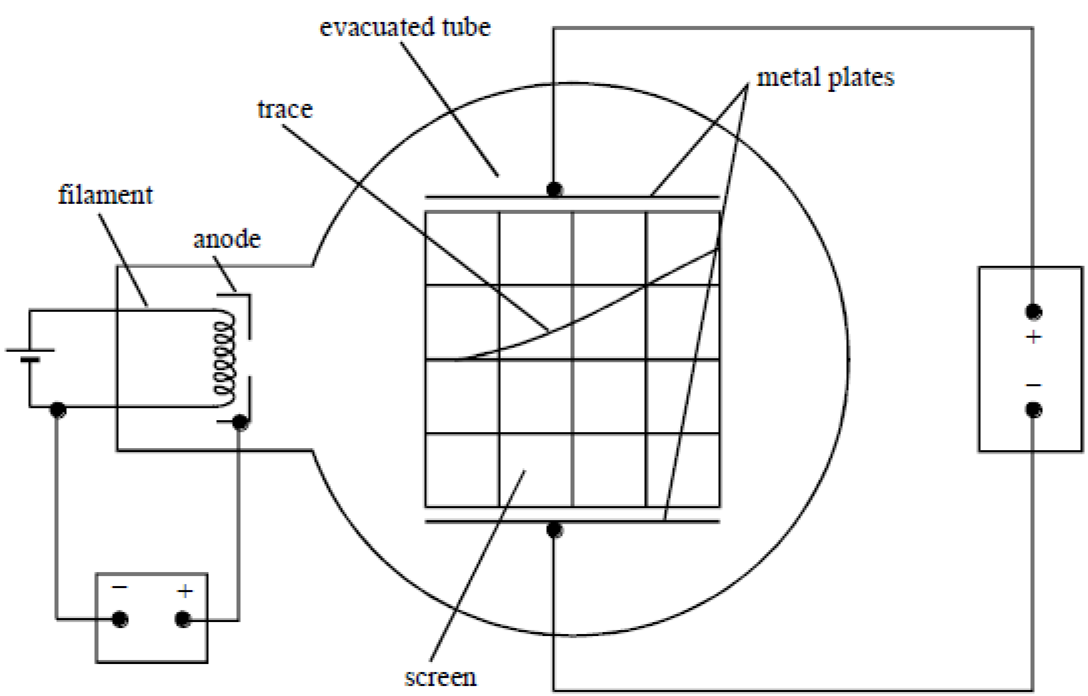
___

___

(2)

(Total 10 marks)

27 A narrow beam of electrons is directed into a uniform electric field created by two oppositely-charged parallel metal plates at right angles to the field lines. A fluorescent screen is used to make the beam give a visible trace.



(a) (i) Explain why the beam curves towards the positive plate.

___

___

(ii) How does the trace show that, on entry to the electric field, all the electrons have the same speed?

___

___

___

(3)

(b) The beam is produced as a result of accelerating electrons between the filament and a metal anode.

(i) Explain why the wire filament must be hot.

____

____

____

(ii) Write down an equation relating the speed of the electrons, v, to the potential difference, V_A, between the anode and the filament.

____

____

(2)

(c) The deflection of the beam due to the electric field can be cancelled by applying a suitable uniform magnetic field *in* the same region as the electric field.

(i) What direction should the magnetic field be in to do this?

____

____

(ii) Write down an equation relating the speed of the electrons v to the plate voltage V_p, the plate separation d, and the magnetic flux density B necessary to make the beam pass undeflected between the plates.

____

____

(iii) The following measurements were made when the beam was undeflected.

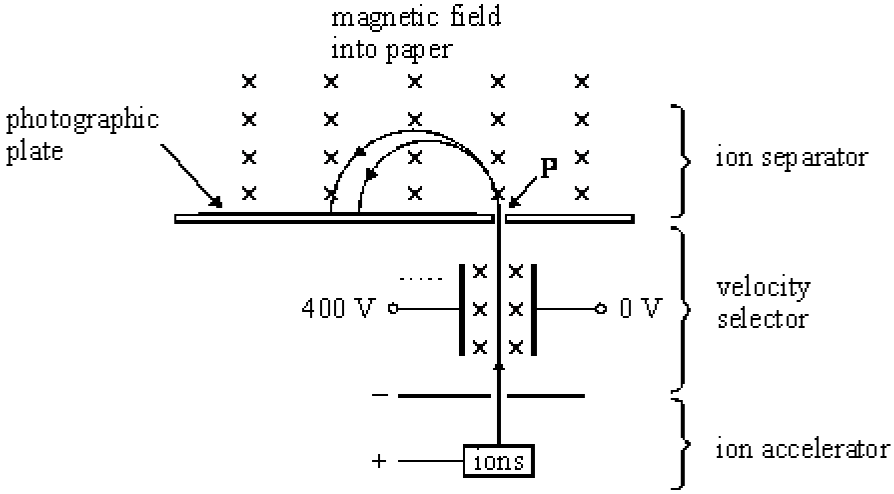
V_A = 3700 V V_p = 4500 V d = 50 mm B = 2.5 mT

Use the two equations you have written down and the given data to calculate the specific charge, e/m, of the electron.

(5)

(Total 10 marks)

28 The diagram below shows a diagram of a mass spectrometer.



(a) The magnetic field strength in the velocity selector is 0.14 T and the electric field strength is 20 000 V m^{-1}.

(i) Define the unit for magnetic flux density, the tesla.

____

____

(2)

(ii) Show that the velocity selected is independent of the charge on an ion.

(2)

(iii) Show that the velocity selected is about 140 km s^{-1}.

(1)

(b) A sample of nickel is analysed in the spectrometer. The two most abundant isotopes of nickel are $^{58}_{28}Ni$ and $^{60}_{28}Ni$. Each ion carries a single charge of $+1.6 \times 10^{-19}$ C.

mass of a proton or neutron = 1.7×10^{-27} kg

The $^{58}_{28}Ni$ ion strikes the photographic plate 0.28 m from the point **P** at which the ion beam enters the ion separator.

Calculate:

(i) the magnetic flux density of the field in the ion separator;

(3)

(ii) the separation of the positions where the two isotopes hit the photographic plate.

(2)
(Total 10 marks)

29 **Figure 1** shows the plan view of a cyclotron in which protons are emitted in between the dees. The protons are deflected into a circular path by the application of a magnetic field. **Figure 2** shows a view from in front of the cyclotron.

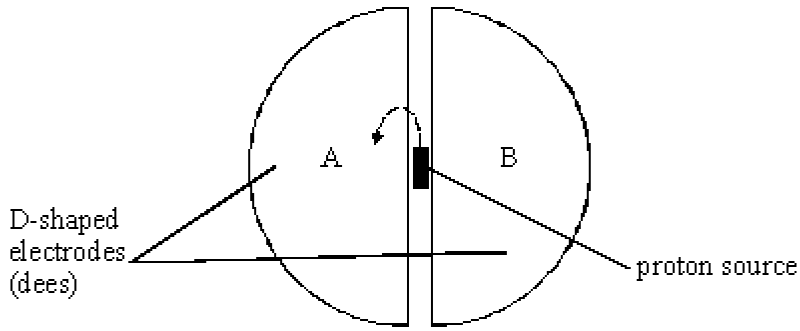


Figure 1

Figure 2

(a) (i) Mark on **Figure 2** the direction of the magnetic field in the region of the dees such that it will deflect the proton beam in the direction shown in **Figure 1**.

(2)

(ii) Show that the velocity of the proton, v, at some instant is given by:

$$v = \frac{Ber}{m}$$

where m is the proton mass, r the radius of its circular path, B the magnetic flux density acting on the proton and $+e$ the proton charge.

(2)

(iii) Write down an equation for the time T for a proton to make a complete circular path in this magnetic field.

(2)

(iv) Explain how your equation leads to the conclusion that T is independent of the speed with which the proton is moving.

____

____

____

(1)

(b) In addition to this magnetic field there is an electric field provided between the dees. This accelerates the proton towards whichever dee is negatively charged. An alternating potential difference causes each dee to become alternately negative and then positive. This causes the proton to accelerate each time it crosses the gap between the dees.

(i) Describe and explain the effect the acceleration has on the path in which the proton moves.

____

____

____

(2)

(ii) In terms of T, write down the frequency with which the p.d. must alternate to match the period of motion of the proton.

(1)

(c) (i) Calculate the velocity of a proton of energy 0.12 keV.

the proton mass, $m = 1.7 \times 10^{-27}$ kg
the magnitude of the electronic charge, $e = 1.6 \times 10^{-19}$ C

(3)

(ii) Calculate the de Broglie wavelength of the 0.12 keV proton.

the Planck constant, $h = 6.6 \times 10^{-34}$ J s

(3)

(iii) Name the region of the electromagnetic spectrum which has an equivalent wavelength to that of the proton.

____

(1)
(Total 17 marks)

30 A transformer is required to produce an r.m.s. output of 2.0×10^{3} V when it is connected to the 230 V r.m.s. mains supply. The primary coil has 800 turns.

(a) Calculate the number of turns required on the secondary coil, assuming the transformer is ideal.

(2)

(b) The transformer suffers from *eddy current* losses.

(i) Explain how *eddy currents* arise.

____

____

____

____

____

(4)

(ii) State the feature of transformers designed to minimise eddy currents.

____

(1)

(Total 7 marks)

Mark schemes

1 (a) *(Faraday's law)*

(induced) emf ∞ rate of change of flux (linkage) ✓

(Lenz's law)

<u>direction of</u> induced emf (or current) ✓

is such as to oppose the change (in flux) producing it ✓

In either order.

Allow "(induced) emf = rate of change of flux linkage".

Ignore incorrect reference to names of laws.

3

(b) (i) current in coil produces magnetic field or flux (that passes through disc) ✓

rotating disc cuts flux inducing / producing emf **or** current (in disc) ✓

induced (eddy) currents (in disc) interact with magnetic field ✓

force on (eddy) currents slows (or opposes) rotation (of disc) ✓

Alternative *for last two points:*

(eddy) currents in disc cause heating of disc ✓

energy for heating comes from ke of disc or vehicle (which is slowed) ✓

max 3

(ii) *Advantage*: any one ✓

- no material (eg pads or discs or drums) to wear out
- no pads needing replacement
- no additional (or fewer) moving parts

Disadvantage: any one ✓

- ineffective at low speed **or** when stationary
- dependent on vehicle's electrical system remaining in working order
- requires an electrical circuit (or source of electrical energy) to operate whereas pads do not

Answers must refer to advantages and disadvantages of the <u>electromagnetic</u> brake.

Only accept points from these lists.

2

[8]

2 (a) (i) graph showing two pulses one at start and the other at the end with no emf between the pulses

Positive and negative pulses shown

Similar shaped 'curved' pulses : negative between 0 and 0.22 ± 0.02 s and positive pulse 0.58 ± 0.02 and 0.8

3

(ii) emf induced when the flux is changing or induced emf depends on the rate of change of flux

emf induced when flux changes between 0 and 0.2(2) s and / or between 0.6(0.58)s and 0.8 s
OR
no change in flux between 0.2 and 0.6 so no induced emf

Induced emf / current produces a field to oppose the change producing it.

Flux linking bracelet increases as the bracelet enters the field produced by C and decreases as it leaves so opposite emfs

4

(b) (Takes 0.21 s or 0.22 s for flux to change from 0 to maximum so)
diameter = 0.28 × 0.21 = 0.059 (0.588) (m)
or 0.28 × 0.22 = 0.062 (0.616) (m)

must be to at least 2sf

1

(c) Area of bracelet = 3.14×0.031^2

$B = 1120 \times 10^{-6} / (3.14 \times 0.031^2) = 0.38$ (T)
B = 0.40 T if 3 cm used for radius

Condone incorrect power of 10

Allow answers in range 0.38T to 0.41 T (depends on value used for r)

2

(d) Use of steepest gradient of graph or tangent drawn on Figure 2
Correct data from tangent or points on the steepest part of the graph
10 to 11 mV

3

[13]

3 (a) Induced current such as to opposes the change producing it✓

Switch on current increases the flux through Y✓

Current opposite direction / anticlockwise to create opposing flux✓

Switch off flux thorough Y due to X decreases so current travels clockwise to create flux to oppose the decrease✓

one marks for Lenz's law statement

two for explaining what happens at switch on ***OR*** *switch off adequately*

one for completing the argument for switch on and off adequately

4

(b) Determines correctly in the calculation two of V_{pk}(5.6±1 μV) , A (0.096 m^2) and ω(9.4 rad s^{-1})β✓

Substitutes all three in $v = BAn\omega$ ignoring powers of 10 and calculation errors for A and / or ω provided they have been attempted with working shown✓

B_H = 12.4 nT✓

Allow 2 or 3 sf

3

[7]

4 (a) (i) meter deflects then returns to zero ✓
current produces (magnetic) field / flux ✓
change in field / flux through Q induces emf ✓
induced emf causes current in Q (and meter) ✓

Deflection to right (condone left) then zero is equivalent to 1st mark.

Accept momentary deflection for 1st point.

"Change in field / flux <u>induces</u> current in Q" is just ✓ from the last two marking points.

max 3

(ii) meter deflects in opposite direction (or to left, or ecf) ✓
field / flux through P is reduced ✓
induces emf / current in opposite direction ✓

Ignore references to magnitude of deflection.

max 2

(b) (i) flux linkage ($= n\Phi = nBA$) = 40 × 0.42 × 3.6 × 10^{-3}
= 6.0(5) × 10^{-2} ✓

Unit mark is independent.

Allow 6 × 10^{-2}.

Wb turns ✓

Accept 60 mWb turns if this unit is made clear.

Unit: allow Wb.

2

(ii) change in flux linkage = $\Delta(n\Phi)$= 6.05 × 10^{-2} (Wb turns) ✓

induced emf $\left(= \frac{\Delta(n\phi)}{\Delta t}\right) = \frac{6.05 \times 10^{-2}}{0.50}$ = 0.12(1) (V) ✓

Essential to appreciate that 6.05 × 10^{-2} is change in flux linkage for 1st mark. Otherwise mark to max 1.

2

[9]

5

(a) emf = $\Delta(BAN) / t$

Change in flux = $A \times \Delta B$ or 12 × (23 − 9) seen

C1

Substitution ignoring powers of 10

C1

1.2 V

A1

3

(b) Reduced

M0

Magnet will move (with the case)

A1

Increased

M0

Flux <u>linkage increases</u> or emf is proportional to N

A1

2

(c) (i) Formula used

$2\pi\sqrt{\frac{8\times10^{-3}}{2.6}}$ seen

B1

0.348 / 0.349 seen to at least 3 sf

B1

2

(ii) Period consistent at 0.35 s or V_0 = 8 V

B1

Shape shows decreasing amplitude

M1

At least 3 cycles starting at 8 V

A1

3

[10]

6 (a) (i) force acts towards left or in opposite direction to field lines ✓
because ion (or electron) has negative charge
(∴ experiences force in opposite direction to field) ✓

Mark sequentially.
Essential to refer to negative charge (or force on + charge is to right) for 2nd mark.

2

(ii) (use of $W = F s$ gives) force $F = \frac{4.0 \times 10^{-16}}{63 \times 10^{-3}}$ ✓

$= 6.3(5) \times 10^{-15}$ (N) ✓

If mass of ion m is used correctly ***using algebra*** *with F = ma, allow both marks (since m will cancel). If numerical value for m is used, max 1.*

2

(iii) electric field strength $E\left(=\frac{F}{Q}\right)=\frac{6.35\times10^{-15}}{3\times1.6\times10^{-19}}$ = 1.3(2) ✓ 10^4 (N C^{-1}) ✓

[**or** $\Delta V\left(=\frac{\Delta W}{Q}\right)=\frac{4.0\times10^{-16}}{3\times1.60\times10^{-19}}$ (833 V)

$E\left(=\frac{\Delta V}{d}\right)=\frac{833}{63\times10^{-3}}$ = 1.3(2) ✓ 10^4 (V m^{-1}) ✓]

Allow ECF from wrong F value in (ii).

1

(b) (i) (vertically) downwards on diagram ✓
reference to Fleming's LH rule **or** equivalent statement ✓

Mark sequentially.
1st point: allow "into the page".

2

(ii) number of free electrons in wire = $A \times l \times$ number density
$= 5.1 \times 10^{-6} \times 95 \times 10^{-3} \times 8.4 \times 10^{28} = 4.1\ (4.07) \times 10^{22}$ ✓

Provided it is shown correctly to at least 2SF, final answer alone is sufficient for the mark. (Otherwise working is mandatory).

1

(iii) $B\left(=\frac{F}{Qv}\right)=\frac{1.4\times10^{-25}}{1.60\times10^{-19}\times5.5\times10^{-6}}$ ✓ = 0.16 (0.159) (T) ✓

[**or** $B\left(=\frac{F}{Il}\right)=\frac{1.4\times10^{-25}\times4.07\times10^{22}}{0.38\times95\times10^{-3}}$ ✓ = 0.16 (0.158) (T) ✓]

In 2nd method allow ECF from wrong number value in (ii).

2

[10]

7 (a) (i) *Two examples (any order)*:

- when charged particle is at rest **or** not moving relative to field ✓
- when charged particle moves parallel to magnetic field ✓

2

(ii) $BQv=\frac{mv^2}{r}$ ✓ (gives $BQr=mv$)

Acceptable answers must include correct force equation (1st point).

B and *Q* are constant so $r \propto$ momentum (mv) ✓

Insist on a reference to B and Q constant for 2nd mark.

2

(b) (i) upwards (perpendicular to plane of diagram) ✓

Accept "out of the page" etc.

1

(ii) $v\left(=\frac{BQr}{m}\right)=\frac{0.48\times1.60\times10^{-19}\times0.19}{1.67\times10^{-27}}$ ✓ $=8.7(4)\times10^{6}$ (m s^{-1})

2

(iii) length of path followed (= length of semi-circle) = πr ✓

time taken $t\left(=\frac{\pi r}{v}\right)=\frac{\pi\times0.19}{8.74\times10^{6}}=6.8(3)\times10^{-8}$ (s) ✓

Allow ECF from incorrect v from (b)(ii).

[**or** $\frac{v}{r}=\frac{BQ}{m}$ gives $t=\frac{\pi r}{v}=\frac{\pi m}{BQ}$ ✓

$=\frac{\pi\times1.67\times10^{-27}}{0.48\times1.60\times10^{-19}}=6.8(3)\times10^{-8}$ (s) ✓]

Max 1 if path length is taken to be $2\pi r$ (gives 1.37×10^{-7}s).

2

(iv) $v \propto r$ (and path length $\propto r$) ✓

t = (path length / v) **or** (πr / v)

so r cancels (∴time doesn't depend on r) ✓

[**or** $t\left(=\frac{\pi r}{v}\right)=\frac{\pi rm}{BQr}$ ✓ $=\frac{\pi m}{BQ}$ (because r cancels) ✓]

[**or** $BQv = m\omega^2 r$ gives $BQ\omega r = m\omega^2 r$ and $BQ = m\omega = 2\pi fm$ ✓

∴ frequency is independent of r ✓]

2

(c) $v_{max} = 8.74 \times 10^6 \times \left(\frac{0.47}{0.19}\right) = 2.16 \times 10^7$ (m s^{-1}) ✓

1st mark can be achieved by full substitution, as in (b)(ii), or by use of data from (b)(i) and / or (b)(ii).

E_k (= ½ $mv_{max}{}^2$) = ½ × 1.67 × 10^{-27} × (2.16 × 10^7)^2 ✓

.   (= 3.90 × 10^{-13} J)

$= \frac{3.90 \times 10^{-13}}{1.60 \times 10^{-13}} = 2.4(4)$ (Me V) ✓

Allow ECF from incorrect v from (b)(ii), or from incorrect t from (b)(iii).

3

(Total 14 marks)

8 (a) (i) 60 (degrees) ✓

1

(ii) angle required is 150° ✓

which is 5π / 6 [**or** 2.6(2)] (radians) ✓

Correct answer in radians scores both marks.

2

(b) (i) (magnitude of the induced) emf ✓

Accept “induced voltage” or “rate of change of flux linkage”, but not “voltage” alone.

1

(ii) frequency $\left(=\frac{1}{T}\right) = \frac{1}{40 \times 10^{-3}}$ ✓ (= 25 Hz)

no of revolutions per minute = 25 × 60 = 1500 ✓

1500 scores both marks.

Award 1 mark for 40s → 1.5 rev min^{-1}.

2

(iii) maximum flux linkage *(=BAN)* = 0.55 (Wb turns) ✓

angular speed $\omega\left(=\frac{2\pi}{T}\right) = \frac{2\pi}{40 \times 10^{-3}}$ ✓ (= 157 rad s^{-1})

peak emf (= $BAN\omega$) = 0.55 × 157 = 86(.4) (V) ✓

[**or**, less accurately, use of gradient method ✓

{e.g $\varepsilon\left(=\frac{\Delta(N\Phi)}{\Delta t}\right) = \frac{0.5 - (-0.5)}{(16 - 4) \times 10^{-3}} = \frac{1.0}{12 \times 10^{-3}}$ } = 83 (± 10)

(V) ✓ ✓

(max 2 for (iii) for values between 63 and 72 V or 94 and 103V)]

3

(c) sinusoidal shape of constant period 40 ms ✓

Mark sequentially.

Graph must cover at least 80ms.

correct phase (i.e. starts as a minus sin curve) ✓

For 2nd mark, accept + sin curve.

Perfect sin curves are not expected.

2

(d) $BAN = 0.55$ ∴ flux density $B = \frac{0.55}{4.0 \times 10^{-3} \times 550}$ ✓

= 0.25(0) (T) ✓

***OR** by use of ε from (b)(iii) and f from*

(b)(ii) substituted in ε = $BAN(2\pi f)$.

2

(Total 13 marks)

9 (a) direction of induced emf (or current) ✓

opposes change (of magnetic flux) that produces it ✓

2

(b) (i) (volumes are equal and mass of Q is greater than that of P) density of steel > density of aluminium ✓

Allow density of Q greater (than density of P).

1

(ii) use of $s = ½ g t^2$ gives $t^2 = \frac{2 \times 1.0}{9.81}$ (from which $t = 0.45$ s) ✓

Backwards working is acceptable for 1st mark

(vertical) acceleration [**or** acceleration due to gravity] is independent of mass of falling object
[**or** correct reference to $F = mg = ma$ with m cancelling] ✓

2 nd mark must refer to mass.
Do not allow "both in free fall" for 2 nd mark.

2

(c) (i) moving magnet [**or** magnetic field] passes through tube ✓ there is a change of flux (linkage)(in the tube)

[**or** flux lines are cut **or** appropriate reference to $\varepsilon = N (\Delta\phi / \Delta t)$] ✓

In this part marks can be awarded for answers which mix and match these schemes.

[**Alternative:**
(conduction) electrons in copper (or tube) acted on by (moving) magnetic field of Q ✓
induced emf (or current) is produced by redistributed electrons ✓]

2

(ii) emf produces current (in copper) ✓
this current [*allow* emf] produces a magnetic field✓
this field opposes magnetic field (or motion) of Q
[**or** acts to reduce relative motion **or** produces upward force] ✓
no emf is induced by P because it is not magnetised (or not magnet)
[**or** movement of P is not opposed by an induced emf or current] ✓

***Alternative** to 3rd mark:*
current gives heating effect in copper and energy for this comes from ke of Q ✓

max 3

(d) time for P is unaffected because there is still no (induced) emf
[**or** because P is not magnetised
or because there is no repulsive force on P]✓
time for Q is shorter (than in (c)) ✓
current induced by Q would be smaller ✓
because resistance of brass ∝ resistivity and is therefore higher
[**or** resistance of brass is higher because resistivity is greater] ✓
giving weaker (opposing) magnetic field
[**or** less opposition to Q's movement] ✓

Condone "will pass through faster" for 2nd mark.
If emf is stated to be smaller for Q, mark (d) to max 2.

max 3

[13]

10 (a) (magnetic) field is applied perpendicular to path

or direction **or** velocity of charged particles ✓

(magnetic) force acts perpendicular to path

or direction **or** velocity of charged particles ✓

force depends on speed of particle **or** on B [or $F \propto v$ or $F = BQv$ explained] ✓

force provides (centripetal) acceleration towards centre of circle

[**or** (magnetic) force is a centripetal force] ✓

$BQv = \frac{mv^2}{r}$ **or** $r = \frac{mv}{BQ}$ shows that r is constant when B and v are constant ✓

4

(b) (i) radius r of path = $\frac{\text{circumference}}{2\pi} = \frac{27 \times 10^3}{2\pi}$ = 4.30×10^3 (m)

(allow 4.3km) ✓

centripetal force $\left(= \frac{mv^2}{r}\right) = \frac{1.67 \times 10^{-27} \times (3.00 \times 10^7)^2}{4.30 \times 10^3}$ ✓ = 3.50×10^{-16}(N) ✓

3

(ii) magnetic flux density $B \left(= \frac{F}{Qv}\right) = \frac{3.50 \times 10^{-16}}{1.60 \times 10^{-19} \times 3.00 \times 10^7}$ ✓

= 7.29×10^{-5} ✓ T ✓

3

(c) magnetic field must be increased ✓

to increase (centripetal) force **or** in order to keep r constant ✓

[**or** otherwise protons would attempt to travel in a path of larger radius]

[**or**, referring to $r = \frac{mv}{BQ}$, B must increase when v increases to keep r constant]

2

[12]

11 (a) (i) magnetic field (or B) must be at right angles to velocity (or *v*) ✓

1

(ii) *F* = (magnetic) force (on a charged particle or ion)

B = **flux density** (of a magnetic field)

Q = charge (of particle or ion)

v = velocity [**or** speed] (of particle or ion)

all four correct ✓

1

(b) (i) into plane of diagram ✓

1

(ii) magnetic **force** = electric **force** [or *BQv* = *EQ*] ✓

these forces act in opposite directions [**or** are balanced **or resultant** vertical force is zero] ✓

2

(iii) *BQv* = *EQ* gives flux density $B = \frac{E}{v}$ ✓

$E\left(=\frac{V}{d}\right) = \frac{45}{65 \times 10^{-3}}$ ✓ (= 738 V m^{-1})

$B\left(=\frac{738}{1.7 \times 10^{5}}\right) = 4.3 \times 10^{-3}$ ✓ T ✓

4

(c) ions would be deflected upwards ✓

magnetic force increases but electrostatic force is unchanged [**or** magnetic force now exceeds electrostatic force] ✓

2

[11]

12 (a) (i) (vertically) downwards **(1)**

1

(ii) force *F* is perpendicular to both *B* and *I* [**or** equivalent correct explanation using Fleming LHR] **(1)**

magnitude of *F* changes as size of current changes **(1)**

force acts in opposite direction when current reverses [**or** ac gives alternating force] **(1)**

continual reversal of ac means process is repeated **(1)**

max 3

(b) appreciation that maximum force corresponds to peak current **(1)**

peak current = 2.4 × $\sqrt{2}$ = 3.39 (A) **(1)**

F_{max} (= $B\,I_{pk}\,L$) = 0.22 × 3.39 × 55 × 10^{-3} **(1)** (= 4.10 × 10^{-2} N)

3

(c) wavelength (λ) of waves = $\left(= \frac{c}{f}\right) = \frac{64}{80}$ = 0.80 (m) **(1)**

length of wire is λ/2 causing fundamental vibration **(1)**

[**or** λ of waves required for fundamental (= 2 × 0.40) = 0.80 m **(1)**
natural frequency of wire $\left(= \frac{c}{\lambda}\right) = \frac{64}{0.80}$ = 80 (Hz) **(1)**]

wire resonates (at frequency of ac supply) [**or** a statement that fundamental frequency (or a natural frequency) of the wire is the same as applied frequency] **(1)**

3

[10]

13 (a) magnetic field direction: $-z$ **(1)**

1

(b) direction changes meaning that velocity is not constant **(1)**

acceleration involves change in velocity
(or acceleration is rate of change of velocity) **(1)**

[**alternatively**

magnetic force on electron acts perpendicular to its velocity **(1)**
∴ force changes direction of movement causing acceleration **(1)**]

2

(c) (i) $BQv = \frac{mv^2}{r}$ **(1)** gives v $\left(= \frac{BQr}{m}\right)$

$= \frac{0.43 \times 10^{-3} \times 1.60 \times 10^{-19} \times 74 \times 10^{-3}}{9.11 \times 10^{-31}}$ **(1)** (= 5.59 × 10^{6} m s^{-1})

2

(ii) angular speed ω $\left(= \frac{v}{r}\right) = \frac{5.59 \times 10^{6}}{74 \times 10^{-3}}$ = 7.5(5) × 10^{7} **(1)**

unit: rad s^{-1} **(1)** (accept s^{-1})

2

(iii) frequency of electron's orbit $f \left(= \frac{\omega}{2\pi}\right) = \frac{7.55 \times 10^7}{2\pi}$ **(1)**

(= 1.20×10^7 s^{-1})

number of transits min^{-1} = $1.20 \times 10^7 \times 60 = 7.2 \times 10^8$ **(1)**

[**alternatively**

orbital period $\left(= \frac{2\pi r}{v}\right) = \frac{2\pi \times 74 \times 10^{-3}}{5.59 \times 10^6}$ [**or** $\left(= \frac{2\pi}{\omega}\right) = \frac{2\pi}{7.55 \times 10^{-7}}$]

(= 8.32×10^{-8} s)

number of transits min^{-1} = $\frac{60}{8.32 \times 10^{-8}} = 7.2 \times 10^8$ **(1)**]

2

[9]

14 (a) flux linkage (= $N\phi = BAN \cos\theta$)

= $2.8 \times 10^{-2} \times 1.9 \times 10^{-3} \times 50 \times \cos 35°$ **(1)**

= 2.2×10^{-3} (Wb turns) **(1)**

answer must be to **2 sf** only **(1)**

3

(b) (i) reasonable sine curve drawn on axes, showing just one cycle, starting at emf = 0 **(1)**

1

(ii) the flux linkage in these positions is **zero** **(1)**

1

(iii) induced emf µ (or =) rate of change of flux (linkage) **(1)**

flux (linkage) through the coil changes as it is rotated **(1)**

from maximum at θ = 0, 180° to zero at 90° and 270° **(1)**

rate of change is greatest when plane of coil is parallel to B [**or** reference to $\varepsilon = BAN\omega \sin \omega t$, **or** $\varepsilon = BAN\omega \sin\theta$] **(1)**

because coil then cuts flux lines perpendicularly [**or** $\varepsilon = BAN\omega \sin \omega t$ shows ε is greatest when ωt = 90° or 270°] **(1)**

max 3

[8]

15 (a) (i) primary coil with more turns than secondary coil **(1)**

(wound around) a core **or** input is ac **(1)**

2

(ii) the mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication

<table>
<tr><th>QWC</th><th>descriptor</th><th>mark range</th></tr>
<tr><td>good-excellent</td><td>Two causes of energy losses are clearly identified, correct measures to indicate how these two losses may be reduced are stated and a detailed physical explanation of why these measures are effective is given.

eg any two from the following four

1 When a transformer is in operation, there are ac currents in the primary and secondary coils. The coils have some resistance and the currents cause heating of the coils, causing some energy to be lost. This loss may be reduced by using low resistance wire for the coils. This is most important for the high current winding (the secondary coil of a step-down transformer). Thick copper wire is used for this winding, because thick wire of low resistivity has a low resistance.

2 The ac current in the primary coil magnetises, demagnetises and re-magnetises the core continuously in opposite directions. Energy is required both to magnetise and to demagnetise the core and this energy is wasted because it simply heats the core. The energy wasted may be reduced by choosing a material for the core which is easily magnetised and demagnetised, ie a magnetically soft material such as iron, or a special alloy, rather than steel.

3 The magnetic flux passing through the core is changing continuously. The metallic core is being cut by this flux and the continuous change of flux induces emfs in the core. In a continuous core these induced emfs cause currents known as eddy currents, which heat the core and cause energy to be wasted. The eddy current effect may be reduced by laminating the core instead of having a continuous solid core; the laminations are separated by very thin layers of insulator. Currents cannot flow in a conductor which is discontinuous (or which has a very high resistance).

4 If a transformer is to be efficient, as much as possible of the magnetic flux created by the primary current must pass through the secondary coil. This will not happen if these coils are widely separated from each other on the core. Magnetic losses may be reduced by adopting a design which has the two</td><td>5-6</td></tr>
</table>

	coils close together, eg by **better core design**, such as winding them on top of each other around the same part of a common core which also surrounds them.		

modest-adequate	Up to two sources of energy losses are stated and there is an indication of how these may be minimised by suitable features or materials. There is no clear appreciation of an understanding of the physical principles to explain why these measures are effective.	**3-4**
poor-limited	Up to two sources of energy losses are given, but the answer shows no clear understanding of the measures required to minimise them.	**1-2**
incorrect, inappropriate or no response	There is no answer or the answer presented is irrelevant or incorrect.	**0**

Answers which address only **one** acceptable energy loss should be marked using the same principles, but to max 3.

6

(b) (i) power wasted internally (= IV) = 0.30 × 9.0 = 2.7 (W) **(1)**

1

(ii) input power $\left(= \frac{2.7}{0.90}\right)$ = 3.0 (W) **(1)**

mains current $\left(= \frac{3.0}{230}\right)$ **(1)** (= 1.30×10^{-2} A)

2

(iii) energy wasted per year (= Pt) = $3.0 \times 0.80 \times 3.15 \times 10^7$ = $7.5(6) \times 10^7$ (J) **(1)**

1

(iv) energy wasted = $\frac{7.56 \times 10^7}{3.6 \times 10^6}$ = 21.0 (kWh) **(1)**

cost of wasted energy = 21.0 × 20 = 420p (£4.20) **(1)**

2

(c) answers should refer to:

an advantage of switching off **(1)**

- cost saving, saving essential fuel resources, reduced global warming etc

a disadvantage of switching off **(1)**

- inconvenience of waiting, time taken for computer to reboot etc
- risk of computer failure increased by repeated switching on and off
- energy required to reboot may exceed energy saved by switching off

2

[16]

16

(a) Φ (= BA) = 45 × 10^{-3} × π × (70 × 10^{-3})^2 **(1)**
= 6.9 × 10^{-4} Wb **(1)** (6.93 × 10^{-4} Wb)

2

(b) (i) $N\Delta\Phi$ (= NBA – 0) = 850 × 6.93 × 10^{-4} **(1)**

= 0.59 (Wb turns) **(1)** (0.589 (Wb turns))

(if Φ = 6.9 × 10^{-4}, then 0.587 (Wb turns))

(allow C.E. for value of Φ from (a))

(ii) induced emf (= $N\frac{\Delta\Phi}{\Delta t}$) = $\frac{0.589}{0.12}$ **(1)**

= 4.9 V **(1)** (4.91 V)

(allow C.E. for value of Wb turns from (ii)

4

[6]

17

(a) (i) out of plane of diagram **(1)**

(ii) circular path **(1)**
in a horizontal plane [or out of the plane of the diagram] **(1)**

$BQv = \frac{mv^2}{r}$ **(1)**

radius of path, $r\left(\frac{mv}{BQ}\right) = \frac{1.05 \times 10^{-25} \times 7.8 \times 10^5}{0.28 \times 2 \times 1.6 \times 10^{-19}}$ **(1)**

= 0.91(4) m **(1)**

max 5

(b) (i) radius decreased **(1)**
halved **(1)**
[or radius is halved **(1) (1)**]

(ii) radius increased **(1)**
doubled **(1)**
[or radius is doubled **(1) (1)**]

max 3

[8]

18 (a) deflects one way **(1)**
then the other way **(1)**

2

(b) (i) acceleration is less than *g* [or reduced] **(1)**
suitable argument **(1)** (e.g. correct use of Lenz's law)

(ii) acceleration is less than *g* [or reduced] **(1)**
suitable argument **(1)** (e.g. correct use of Lenz's law)

4

(c) magnet now falls at acceleration *g* **(1)**
emf induced **(1)**
but no current **(1)**
no energy lost from circuit **(1)**
[or no opposing force on magnet, or no force from magnetic field or no magnetic field produced]

3
QWC 2

[9]

19 (a) units: F - newton (N), B - tesla (T) or weber metre^{-2} (Wb m^{-2}),
I - ampere (A), l - metre (m) **(1)**
condition: I must be perpendicular to B **(1)**

2

(b) (i) mass of bar, $m = (25 \times 10^{-3})^2 \times 8900 \times l$ **(1)**
(= $5.56l$) weight of bar (= mg) = $54.6l$ **(1)**
$mg = BIl$ or weight = magnetic force **(1)**
$54.6l = B \times 65 \times l$ gives $B = 0.840$ T **(1)**

(ii) arrow in correct direction (at right angles to I, in plane of bar) **(1)**

5

[7]

20 (a) (i) mass per sec (= density × vol per sec) = 1000 × 1.4 **(1)**

= 1400 kg (s^{-1})

(ii) loss of E_p per sec $(= \frac{mgh}{t})$ = 1400 × 9.8 × 750 **(1)**

= 1.0 × 10^7 J (s^{-1}) **(1)** (1.03 × 10^7 J s^{-1})

(allow C.E. for value of mass per sec from (i))

(iii) efficiency $(= \frac{\text{power output}}{\text{loss of } E_p \text{ per second}}) = \frac{2.0 \times 10^6}{1.0 \times 10^7}$ **(1)**

= 0.2 **(1)**

(allow C.E. for value (ii))

6

(b) (i) (use of $P = IV$ gives) $I_{rms} = \frac{2.0 \times 01^6}{25 \times 10^3}$ **(1)**

= 80 A **(1)**

(ii) power output = (0.95 × power input) = 0.95 × 2.0 (MW) = 1.9 (MW) **(1)**

$I = \frac{1.9(MW)}{275(kV)}$ = 6.9 A **(1)**

[or I for 100% efficiency $\left(= \frac{2 \times 10^6}{275 \times 10^3}\right)$ = 7.3 (A) **(1)**

I for 95% efficiency = 95% of 7.3 = 6.9 A]

4

[10]

21 (a) θ = 90° (or 270° or $\frac{\pi}{2}$ or $\frac{3\pi}{2}$) **(1)**

1

(b) Φ = BA cosθ **(1)**

= 2.5 × 10^{-3} × 35 × 10^{-3} × 20 × 10^{-3} × cos 30° = 1.5 × 10^{-6} Wb **(1)**

2

(c) Φ_{max} = 2.5 × 10^{-3} × 35 × 10^{-3} × 20 × 10^{-3} (Wb) **(1)** (= 1.75 × 10^{-6})

flux linkage = 650 × 1.75 × 10^{-6} = 1.1(4) × 10^{-3} (Wb turns) **(1)**

2

[5]

22 (a) (i) uud **(1)**

(ii) $u\bar{d}$ **(1)**

2

(b) (i) $\frac{mv^2}{r} = Bev$ [or $r = \frac{mv}{Be}$] **(1)**

$m = 1.67 \times 10^{-27}$ **(1)**

$r \left(\frac{mv}{Be}\right) = \frac{1.67 \times 10^{-27} \times 1.5 \times 10^{7}}{0.16 \times 1.6 \times 10^{-19}}$ **(1)**

= 0.98 m **(1)**

(ii) pion path more curved than proton path **(1)**

(iii) path more curved
[or radius (of path) smaller] **(1)**
for both paths **(1)**

7

[9]

23 (a) gravity or force acts towards centre **(1)**
force acts at right angles to velocity or direction of motion
[or velocity is tangential] **(1)**
no movement in direction of force **(1)**
no work done so no change of kinetic energy so no change in speed **(1)**

3

(b) (i) $B = (56^2 + 17^2)^{1/2} = 59\ \mu T$ **(1)**

(ii) $\tan\theta = \frac{17}{56}$ **(1)**

θ = 17° **(1)** (± 1°)

(iii) rod sweeps out or cuts (magnetic) flux
[or rod cuts field] **(1)**

4

[7]

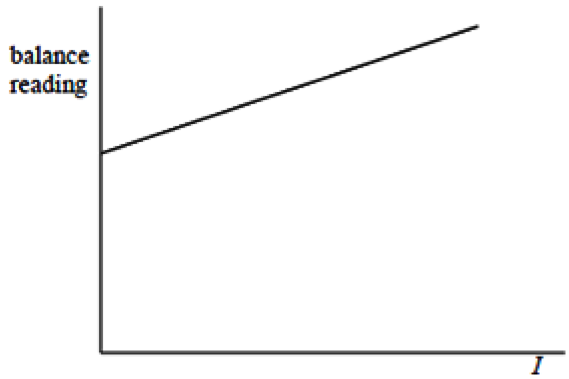
24 (a) (i) interaction between current and B-field gives force on wire **(1)**
equal and opposite force on magnet (down) **(1)**

(ii) force on wire must be up **(1)**
∴ current right to left **(1)**
by left hand rule **(1)**

(iii) (force = $BIl = mg$ = change in mass × 9.8)
$B \times 5.0 \times 0.060 = 1.54 \times 10^{-3} \times 9.8$ **(1)**
B = 0.050 T [50.3 mT] **(1)**

(max 6)

(b)



straight line **(1)**
intercept, upward slope **(1)**

(2)

[8]

25

(a) 1000 km hr^{-1} = $\frac{1000 \times 10^3}{3600}$ m s^{-1}

flux cut per second = B × area swept out per second $\left[\text{or } 4.5 \times 10^{-5} \times 42 \times \frac{10^4}{36}\right]$ **(1)**

= 0.52Wb **(1)**

(b) induced e.m.f. equals flux cut per second [or equation and symbols defined] **(1)**
$\therefore E$ = 0.52V **(1)**

(c) direction of p.d. reversed **(1)**

[6]

26

(a) (i) *including, for example:*
positron is an antimatter particle; proton is a matter particle (*)
positron is a lepton; proton is a hadron (*)
positron has a smaller rest mass than a proton (*)
positron is not composed of other particles; proton is made up of quarks (*)
(*) any two **[1] [1]**

(ii) proton path has greater radius of curvature than positron **(1)**

(iii) radius of curvature $r = \frac{mv}{Be}$ and v, B and e are constants **(1)**

therefore r proportional to m **(1)**
mass of proton is (much) greater than mass
of positron (at same speed) **(1)**

5

(b) (i) C - 14 **(1)**

(ii) C - 10 **(1)**
as this is furthest from stability **(1)**

3

(c) rest mass of electron = 0.51 MeV therefore total energy available
= (2.2 +2 × 0.51)= 3.22 (MeV) **(1)**

gamma photons produced have average energy = $\frac{3.22}{2}$ = 1.6 MeV**(1)**

2

[10]

27 (a) (i) electrons are negatively charged so beam is attracted to positive plate
[or repelled by negative plate or electron experiences force towards positive plate]
(1)

(ii) beam does not spread out **(1)**
if speeds varied, faster electrons would be
deflected less than slower electrons **(1)**

3

(b) (i) to give conduction electrons sufficient
k.e. to leave metal [or to cause thermionic
emission or electrons have insufficient
ke. in a cold filament to leave filament] **(1)**

(ii) $\frac{1}{2}mv^2 = eV_A$ [or $v = \sqrt{\frac{2eV_A}{m}}$] **(1)**

2

(c) (i) into the plane of the diagram **(1)**
perpendicular to the diagram [or the electric field] **(1)**

(ii) $Bev = \frac{eV_p}{d}$ **(1)**

(iii) combine the two equations to give $\frac{e}{m} = \frac{V_p^2}{2V_A B^2 d^2}$ **(1)**

$$\frac{e}{m} = \frac{4500^2}{2 \times 3700 \times (2.5 \times 10^{-3})^2 \times (50 \times 10^{-3})^2}$$ **(1)**

1.75×10^{11} Ckg^{-1} **(1)**

max 5

[10]

28 (a) (i) 1 N per A per m
or 1 Wb m^{-2}
or quotes: $B = F/IL$ with terms defined
or induced $EMF = \Delta BAN/t$ with terms defined
or a slightly flawed attempt at the definition in statement form

C1

It is the flux density (perpendicular to a wire) that produces a force of 1N per m on the wire when the current is 1A
or
$B = F/IL$ **and** 1 T is flux density when F = 1N; I = 1A and L = 1 m
or induced $EMF = \Delta BAN/t$ and 1 T is the flux change when emf = 1V for A=1 N =1 and t =1 or similar

A1

2

(ii) force on charge due to E field , $F_E = Eq$ **or** Vq/d
and
force due to B field, $F_B = Bqv$
or $Eq=Bqv$

B1

$= Bqv$; cancels q **and states explicitly** $v = \frac{E}{B}$

or $v = \frac{V}{dB}$

B1

2

(iii) v = 20000/0.14 (seen) **or** 143 × 10^3 m s^{-1}

B1

1

(b) (i) $Bqv = mv^2/r$ or $r = mv/Bq$ (allow e instead of q)
mass of ion = $1.7 \times 10^{-27} \times 58$ (may be in equation)
or (9.86×10^{-26} kg seen)

C1

or
radius = 0.14 m (may be in equation)

C1

Substitutes and arrives at 0.62 to 0.63 T

A1

3

(ii) Calculates new radius (0.145 m) or diameter (0.288 m) using $r \propto m$ or otherwise **allowing ecf**

C1

0.010 m (condone 0.01 m) or 0.0096 – 0.0097 m
(Allow 0.0079 m or 0.008 m due to use of different sfs for B and v)

A1

2

[10]

29 (a) (i) vertical field line(s)

B1

directed downwards

B1

2

(ii) mv^2/r and Bev seen

M1

equated and correctly rearranged

A1

2

(iii) $v = \frac{2\pi r}{T}$ or equivalent

M1

$T = \frac{2\pi m}{Be}$

A1

2

(iv) no *v* in the equation for *T (m*, *B* and *e* all independent of *v*)

B1

1

(b) (i) proton spirals outwards/suitable diagram B1

as v ↑ *r* ↑

B1

2

(ii) $f = 1/T$

B1

1

(c) (i) conversion of keV to J (1.92×10^{-17})

C1

use of ½ mv^2

1.50×10^5 ms^{-1}

A1

3

(ii) $\lambda = \frac{h}{p}$

$p = mv$ or substituted values

C1

2.6×10^{-12} m

A1

3

(iii) *y*-rays or X-rays or answer consistent with candidate's λ

B1

1

[17]

30

(a) $\frac{N_S}{N_P} = \frac{V_S}{V_P}$

C1

7000 (6960)

A1

(2)

(b) (i) changing magnetic field

B1

emf or changing magnetic field is in the core

B1

e.m.f. induced (due to changing magnetic field) not back emf

B1

current flows as core is made from a conducting material

B1

(4)

(ii) laminated core

B1

(1)

[7]