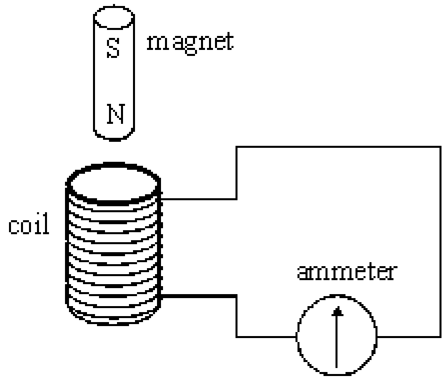
1 A coil is connected to a centre zero ammeter, as shown. A student drops a magnet so that it falls vertically and completely through the coil.



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

____

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(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,

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____

____

(ii) as it left the coil.

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(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.

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(3)

(Total 9 marks)

2 (a) State Lenz's law.

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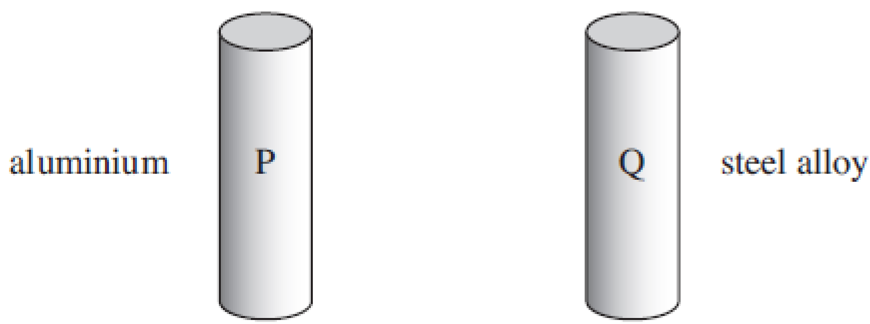
(2)

(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.

____

____

____

(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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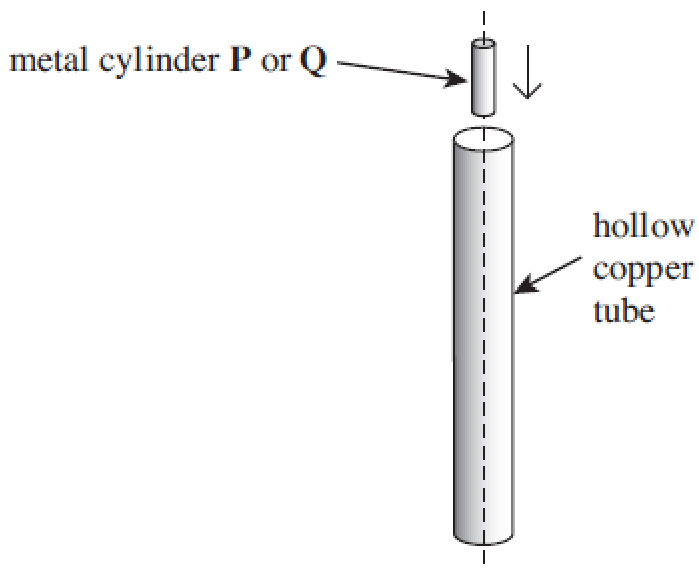
(2)

(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.

(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:

Q:

(3)

(Total 13 marks)

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

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

(1)

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

F ______________________________

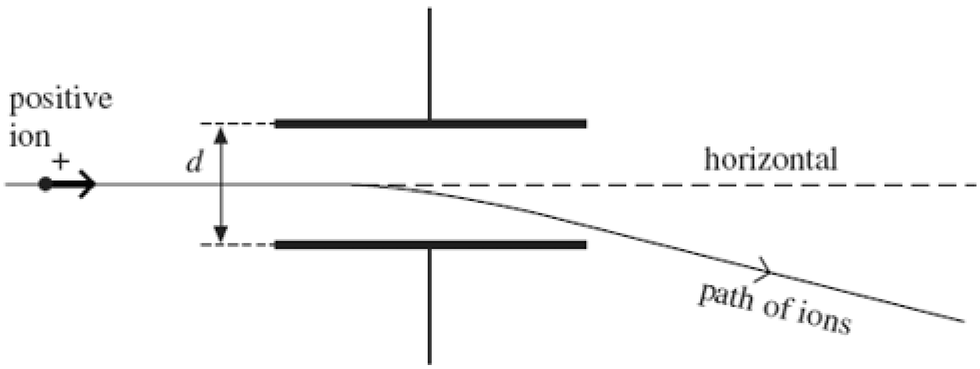
B ______________________________

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.

____

(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 $1.7 \times 10^5 ms^{-1}$. 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 $1.7 \times 10^5 ms^{-1}$ when they pass between the plates at a time when the conditions in part (b)(iii) have been established.

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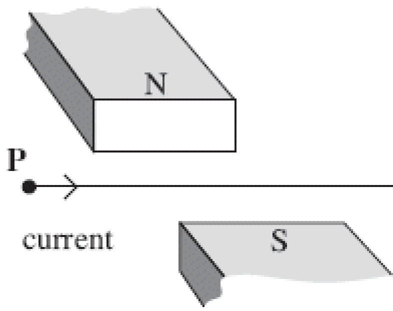
(2)

(Total 11 marks)

4 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.

____

(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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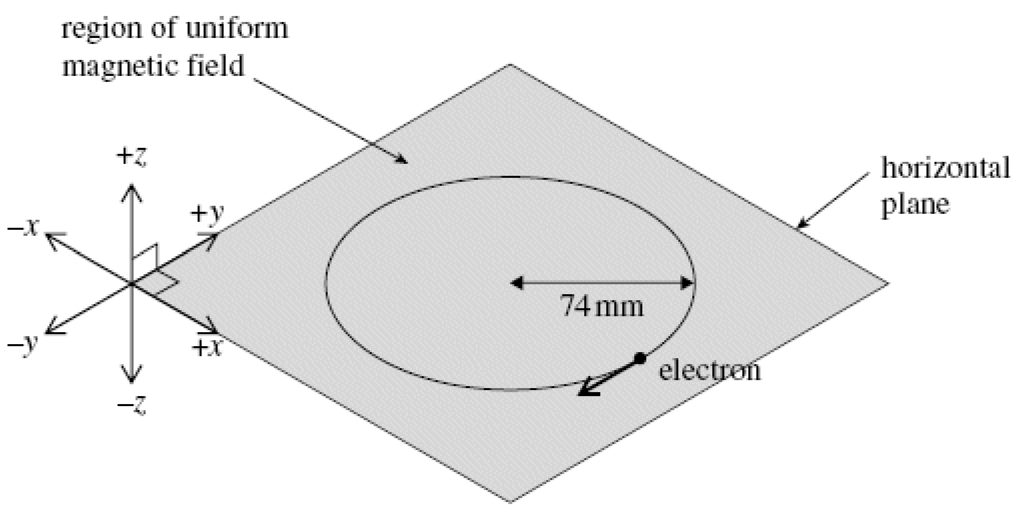
(3)

(Total 10 marks)

5 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)

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

____

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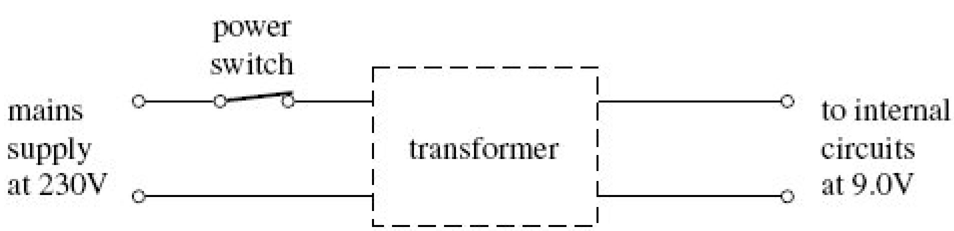
(2)

(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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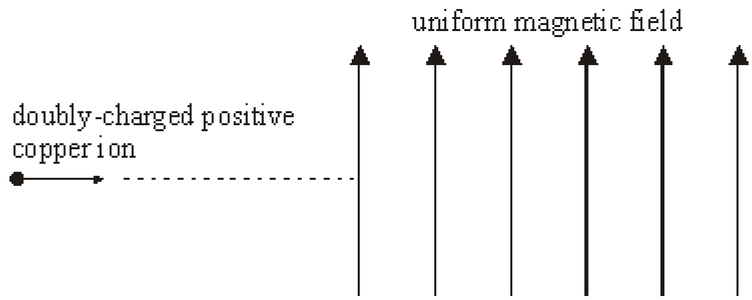
(2)

(Total 16 marks)

7 (a)



The diagram above shows a doubly-charged positive ion of the copper isotope $^{63}_{29}\text{Cu}$ 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 $^{63}_{29}\text{Cu}$ ion = 1.05×10^{-25} kg

____

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(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)

8

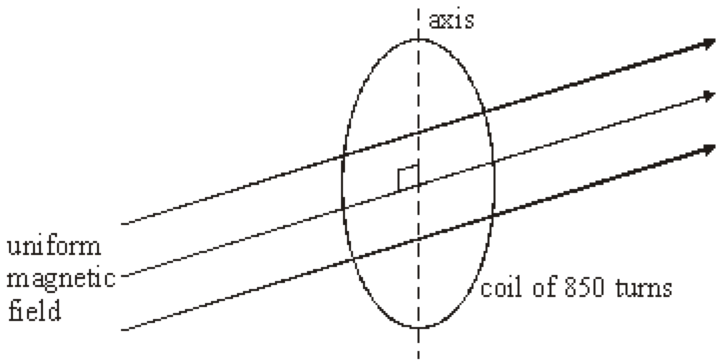


Figure 1

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.

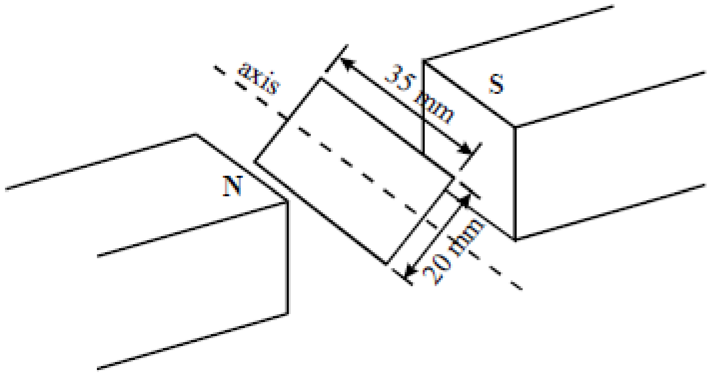
Calculate

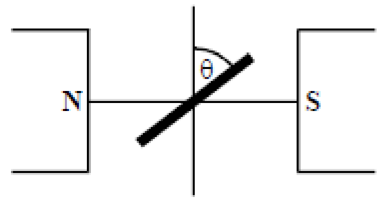
(i) the change of magnetic flux linkage produced by this rotation,

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

(4)
(Total 6 marks)

9 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?

____

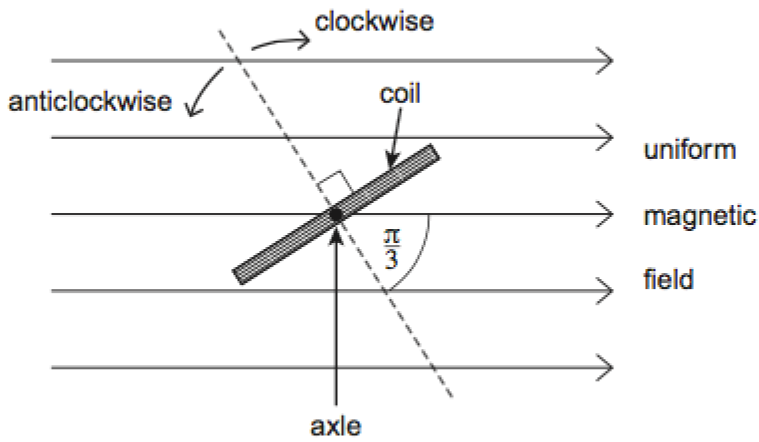
____

____

(2)

(Total 5 marks)

10 The diagram shows a coil placed in a uniform magnetic field. In the position shown, the angle between the normal to the plane of the coil and the magnetic field is $\frac{\pi}{3}$ is rad.

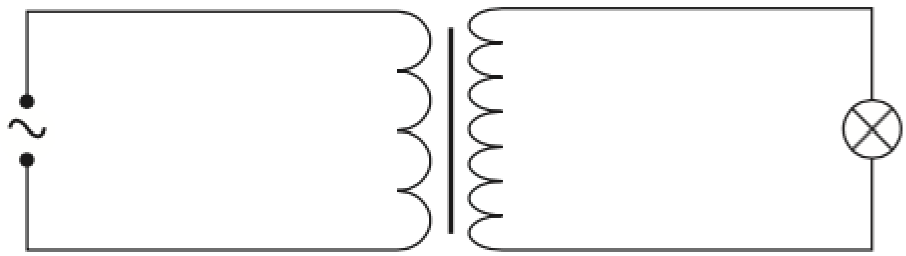


Which line, **A** to **D**, in the table shows the angles through which the coil should be rotated, and the direction of rotation, so that the flux linkage becomes (i) a maximum, and (ii) a minimum?

Angle of rotation / rad		
	(i) for maximum flux linkage	**(ii) for minimum flux linkage**
A	$\frac{\pi}{6}$ clockwise	$\frac{\pi}{3}$ anticlockwise
B	$\frac{\pi}{6}$ anticlockwise	$\frac{\pi}{3}$ clockwise
C	$\frac{\pi}{3}$ clockwise	$\frac{\pi}{6}$ anticlockwise
D	$\frac{\pi}{3}$ anticlockwise	$\frac{\pi}{6}$ clockwise

(Total 1 mark)

11 The primary coil of a step-up transformer is connected to a source of alternating pd.
The secondary coil is connected to a lamp.



Which line, **A** to **D**, in the table correctly describes the ratios of flux linkages and currents through the secondary coil in relation to the primary coil?

	$\frac{\textbf{Secondary magnetic flux linkage}}{\textbf{Primary magnetic flux linkage}}$	$\frac{\textbf{Secondary current}}{\textbf{Primary current}}$
A	< 1	< 1
B	> 1	< 1
C	> 1	> 1
D	< 1	> 1

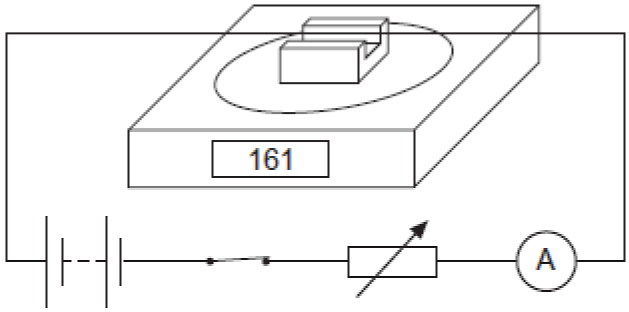
(Total 1 mark)

12 Which one of the following statements is the main reason for operating power lines at high voltage?

A Transformers are never perfectly efficient.
B High voltages are required by many industrial users of electricity.
C Electrical generators produce alternating current.
D For a given amount of transmitted power, increasing the voltage decreases the current.

(Total 1 mark)

13 The diagram shows a rigidly-clamped straight horizontal current-carrying wire held mid-way between the poles of a magnet on a top-pan balance. The wire is perpendicular to the magnetic field direction.



The balance, which was zeroed before the switch was closed, read 161 g after the switch was closed. When the current is reversed and doubled, what would be the new reading on the balance?

A −322 g

B −161 g

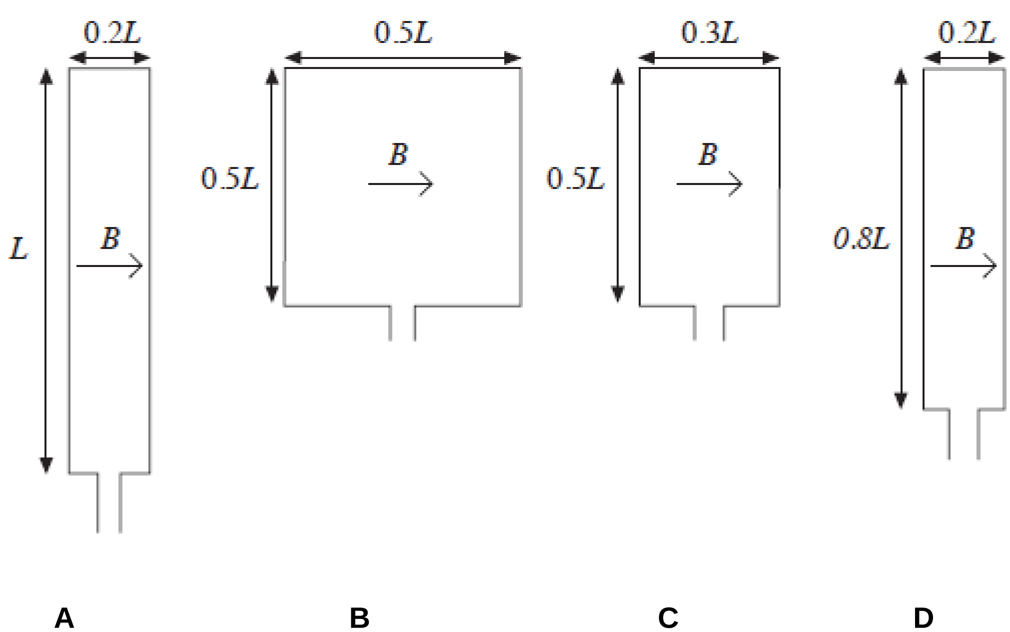
C zero

D 322 g

(Total 1 mark)

14 Four rectangular loops of wire **A**, **B**, **C** and **D** are each placed in a uniform magnetic field of the same flux density B. The direction of the magnetic field is parallel to the plane of the loops as shown.

When a current of 1 A is passed through each of the loops, magnetic forces act on them. The lengths of the sides of the loops are as shown.
Which loop experiences the largest couple?



(Total 1 mark)

15 Which one of the following statements is correct?

An electron follows a circular path when it is moving at right angles to

A a uniform magnetic field.

B a uniform electric field.

C uniform electric and magnetic fields which are perpendicular.

D uniform electric and magnetic fields which are in opposite directions.

(Total 1 mark)

16 Two electrons, X and Y, travel at right angles to a uniform magnetic field.
X experiences a magnetic force, F_{X}, and Y experiences a magnetic force, F_{Y}.

What is the ratio $\frac{F_X}{F_Y}$ if the kinetic energy of X is half that of Y?

A $\frac{1}{4}$

B $\frac{1}{2}$

C $\frac{1}{\sqrt{2}}$

D 1

(Total 1 mark)

17 A lamp rated at 12 V 60 W is connected to the secondary coil of a step-down transformer and is at full brightness. The primary coil is connected to a supply of 230 V. The transformer is 75% efficient.
What is the current in the primary coil?

A 0.25 A

B 0.35 A

C 3.75 A

D 5.0 A

18 The path followed by an electron of momentum p, carrying charge $-e$, which enters a magnetic field at right angles, is a circular arc of radius r.

What would be the radius of the circular arc followed by an α particle of momentum $2p$, carrying charge $+2e$, which entered the same field at right angles?

A $\frac{r}{2}$

B r

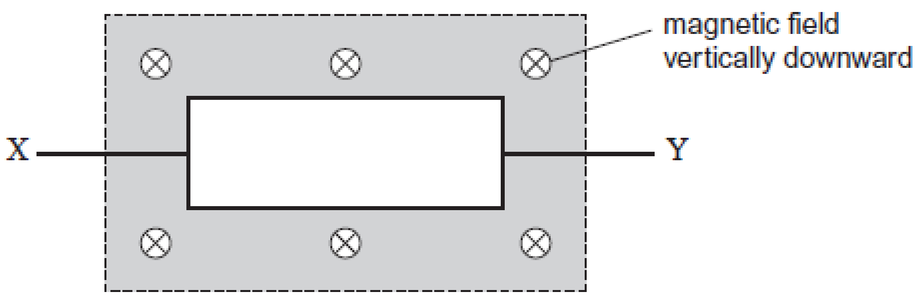
C $2r$

D $4r$

(Total 1 mark)

19 A rectangular coil of area A has N turns of wire. The coil is in a uniform magnetic field, as shown in the diagram.

When the coil is rotated at a constant frequency f about its axis XY, an alternating emf of peak value ε_0 is induced in it.



What is the maximum value of the magnetic flux linkage through the coil?

A $\frac{\varepsilon_0}{2\pi f}$

B $\frac{\varepsilon_0}{\pi f}$

C $\pi f \varepsilon_0$

D $2\pi f \varepsilon_0$

(Total 1 mark)

Mark schemes

1 (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]

2 (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 $t^2 = \dfrac{2 \times 1.0}{9.81}$ (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]

3 (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]

4 (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 $\lambda/2$ 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]

5 (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 $\omega \left(= \frac{v}{r}\right) = \frac{5.59 \times 10^{6}}{74 \times 10^{-3}}$ = 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)**

($= 1.20 \times 10^7$ 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** $\left(= \frac{2\pi}{\omega}\right) = \frac{2\pi}{7.55 \times 10^{-7}}$]

($= 8.32 \times 10^{-8}$ s)

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

2

[9]

6 (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

QWC	descriptor	mark range
good-excellent	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	**5-6**

	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 (= $I\ V$) = 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 (= $P\ t$) = $3.0 \times 0.80 \times 3.15 \times 10^{7}$
= $7.5(6) \times 10^{7}$ (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]

7 (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]

8 (a) Φ (= BA) = $45 \times 10^{-3} \times \pi \times (70 \times 10^{-3})^2$ **(1)**
= 6.9×10^{-4} Wb **(1)** (6.93×10^{-4} Wb)

2

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

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

(if $\Phi = 6.9 \times 10^{-4}$, 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]

9

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

1

(b) $\Phi = BA\cos\theta$ **(1)**
$= 2.5 \times 10^{-3} \times 35 \times 10^{-3} \times 20 \times 10^{-3} \times \cos 30° = 1.5 \times 10^{-6}$ Wb **(1)**

2

(c) $\Phi_{max} = 2.5 \times 10^{-3} \times 35 \times 10^{-3} \times 20 \times 10^{-3}$ (Wb) **(1)** (= 1.75×10^{-6})
flux linkage = $650 \times 1.75 \times 10^{-6} = 1.1(4) \times 10^{-3}$ (Wb turns) **(1)**

2

[5]

10 **D**

[1]

11 **B**

[1]

12 **D**

[1]

13 A

[1]

14 B

[1]

15 A

[1]

16 C

[1]

17 B

[1]

18 B

[1]

19 A

[1]

Examiner reports

1 This question was intended as a straightforward test of the “simple experimental phenomena” of electromagnetic induction and Lenz’s law, as required by Section 13.4.4 of the Specification. It is recognised that most A level candidates have difficulty with these topics and examiners were not very surprised by the many relatively weak answers that were written. Partial (or superficial) understanding of the phenomena appeared to be the main obstacle to progress. For example, in part (a) almost all candidates appreciated that the ammeter needle would deflect, but relatively few saw that it would move one way, and then the other way, before returning to zero. In this part, examiners sometimes wondered what was going through the minds of candidates who wrote things such as “the current through the ammeter would increase, and then return to its normal value”. Perhaps this suggests that these students had never previously encountered a centre zero instrument. Inappropriate use of English also handicapped some candidates in part (a) – typical of which were answers that began with “the ammeter moves to the right”.

Failure to address the question was the main difficulty encountered in most answers to part (b). Instead of stating clearly that the acceleration of the magnet decreased, candidates usually preferred to resort to woolly descriptions of the effect on the motion of the magnet. Responses such as “the magnet slows down” and “it decelerates” were rejected. “The acceleration slows down” was not a preferred response but it was accepted. The major problem in part (b)(ii) was the failure of candidates to read the question properly: this was about the effect on the acceleration of the magnet *as it left* the coil, not *after it had left* the coil. Consequently a large number of candidates followed a broadly correct deduction in (i) by an incorrect one in (ii): they thought that the acceleration would increase. The two explanation marks in part (b) escaped all but the most knowledgeable candidates. Some understanding of what was induced and why, was almost a prerequisite to progress here. Bald reference to Lenz’s law was not considered to be adequate.

Even after presenting indifferent answers to the earlier parts of this question, many candidates salvaged most of the three marks in part (c). Most appreciated that an incomplete circuit meant that no current could flow, but many candidates wrongly thought that the missing ammeter would also prevent the induction of an emf.

2 Acceptable statements really needed to refer to both the direction of the induced emf (or current) and to the change (in magnetic flux) that produces the effect. In part (b)(i) an explanation of the greater mass of Q was required, so a simple statement that density was involved was inadequate; candidates had to state that steel (or Q) has a greater density than aluminium (or P). In part (b)(ii) the time of 0.45s was usually justified through the application of $s = ut + ½ at^2$, although some candidates made no attempt to justify this value. Backwards working, such as showing that the distance fallen is approximately 1.0m when the time of fall is 0.45s, was accepted. Explanations of why the two times are equal were expected to refer to acceleration due to gravity being independent of the mass of a falling body.

There was widespread misunderstanding in candidates' attempts to answer part (c). In part (i), clearly Q is a moving magnet passing through a conducting tube and so the magnet's flux lines are cut by the tube – hence an emf is induced. A significant number of responses stated that Q would be cutting through the flux lines of the tube. The tube was regularly referred to as a magnet. A very common misapprehension was that when a current is induced in the tube, it is the current that causes the emf. In part (c)(ii) many answers were too trivial, such as ones which referred to the repulsion of poles, or were simply wrong, such as attributing the effect to induced *charges*. Some responses even suggested that the induced electromotive force acts as a mechanical force to oppose the falling magnet. Examiners were pleased to encounter logical answers stating that the induced emf caused a current to flow in the copper, which then produced a magnetic field to oppose the movement of the falling magnet Q by opposing the magnet's own field. Relatively few answers made any reference as to why cylinder P would fall without opposition.

Full marks were regularly awarded in part (d), where it was usually seen that the time for P would be unaffected (an explanation was needed for the mark) but that for Q would be shorter. Some candidates thought that the increased resistance of the tube would cause a reduced emf; these answers were subjected to a two mark maximum.

3 In part (a)(i) many candidates were unaware of the condition under which $F = BQv$ applies, which is given clearly in the specification. A common incorrect answer was to state that the force has to be perpendicular to B, without any reference to v. In part (a)(ii) the main difficulty proved to be the meaning of B; magnetic flux density was correct and the loose 'magnetic field strength' was not accepted. Some candidates thought that v represents voltage.

Part (b)(i) was a test of Fleming' left hand rule when applied to a stream of positive ions. Together with the figure, the first paragraph of part (b) defines 'downwards' as the direction towards the lower (negative) plate. The correct answer in (b)(i) is 'into the plane of the diagram', not downwards.

In part (b)(ii) candidates were expected to consider the force conditions applying to the undeflected ions. A common misconception was that the magnetic field is equal to the electric field. The main errors in part (b)(iii), where the numerical value obtained was often correct, were the omission of clear working and not knowing that the unit of B is T. Some candidates could only quote $F = BQv$ and were at a loss to make further progress without $F = EQ$ and $E = V/d$.

Many candidates were totally lost in part (c). Others correctly explained that the ions would now be the magnetic force (which is proportional to v) increases whilst the electrostatic force (which is independent of v) remains constant.

4 Most candidates were able to use Fleming's left hand rule in order to give the correct force direction in part (a) (i). Sometimes a candidate's answer was contradictory and went unrewarded, for example 'downwards towards the S pole'. Most answers to part (a) (ii) were reasonably good when explaining why the wire would vibrate, but rarely explained why these vibrations are vertical. An explanation by reference to the mutually perpendicular field, current and force directions was required in a complete answer. The reversal of force direction with change of current direction was well understood.

Fewer candidates made reference to the continuous current reversals brought about by ac causing the process to repeat, or to the fact that the size of the current affects the magnitude of the magnetic force.

It was evident that a large number of candidates had made a second, more enlightened, attempt at part (b) once they had realised that direct substitution of $I = 2.4$ A into $F = BIL$ did not lead to the value of force (about 40 mN) they had been asked to show. Once they realised that the maximum force is caused by the peak current, it became a straightforward matter to secure three marks.

The final part of the question, part (c), involved the resonance effect observed when the wire is supplied with ac current at the frequency of its fundamental vibration. Resonance was usually mentioned, but fewer candidates used the values provided in the question together with $c = f\lambda$ to give a wholly convincing account of why the wire would vibrate in its fundamental mode at 80 Hz.

A large number of candidates had forgotten that the fundamental condition would be $L = \lambda/2$ (this should be studied in unit 2). After using c = $f\lambda$ with $\lambda = 0.40$ m, they concluded that the frequency of waves on the wire would be 160 Hz. These candidates then attempted to argue that resonance would occur at 80 Hz because 80 is one half of 160, not understanding that if 160 Hz was the fundamental frequency, no frequency lower than 160 Hz could possibly set the wire into resonance.

5 In part (a) the correct application of Fleming's left hand rule to moving electrons was a much sterner test than it ought to have been for A2 candidates. It seemed that responses were distributed almost randomly between the six alternative directions. Part (b) was the familiar test of whether candidates understood the significance of the directional nature of velocity for a particle moving in a circle. The expected approach was to point out that a change in direction shows that velocity is changing, and that acceleration involves a change in velocity.

Alternatively, it could be argued that the force on the electron always acts at right angles to its velocity, thus changing the electron's direction of travel and causing it to accelerate.

Candidates with a superficial acquaintance with this situation tended to refer to centripetal force in their answers, without conveying any proper understanding of the directional nature of velocity.

As suggested by the question, the starting point for successful answers to part (c) (i) was the equation $BQv = mv^2/r$. Most candidates arrived at a correct result for the speed of the electron, by substituting either the separate values for e and me, or for the specific charge e/me, from the *Data and Formulae Booklet*. Calculation of the angular speed in part (c) (ii) usually caused little difficulty, but its unit was not always known: m s^{-1} was often written down. Those who had quoted m s^{-1} usually then got into difficulty in part (c) (iii), because they tried to find the orbital period by dividing the circumference of the circle by their value for $\omega/m\ s^{-1}$. A particularly worrying error by many candidates in this part was a calculator error when trying to divide ω (= 7.55×10^7 rad s^{-1}) by 2π. This led to a final incorrect answer of 7.1×10^9 revolutions per minute, which appeared in a large number of scripts. The error appears to have been caused by an incorrect sequence of division and multiplication operations on calculators.

6

In part (a) (i), the requirement that $N_p > N_s$ was regarded as fundamental for the first mark; the second mark was awarded for either a core linking the coils or an ac supply. Some candidates missed the point of the question completely by writing about how transformers change voltages rather than concentrating on their essential features.

Most attempts to answer part (a) (ii) fell well short of examiners' expectations. In many cases the principal cause of this was a lack of detailed knowledge or confused understanding. When this kind of question is employed to assess the quality of candidates' written communication, it will be expected that a good answer will be structured: well organised, and coherent. This was another general error, because candidates often presented answers that rambled on without general direction.

Successful answers were primarily expected to address **two** (and only two) causes of energy loss; four causes are commonly identified by the standard sources that deal with this topic, so asking for two was not unduly demanding. For each cause that was identified, there was a requirement to discuss how the loss could be reduced by suitable features and materials.

Answers that could be placed in the 'good to excellent' category (five or six marks) should have backed up this factual knowledge with some physical reasoning. Very few answers addressed these requirements sufficiently successfully to deserve the award of full marks. It seemed that most of the candidates had heard about eddy currents, but not all of them knew exactly what they are or where they occur. Many answers showed considerable confusion; 'eddy currents caused by the coils can be stopped by using a soft iron core', 'heat losses from the currents can be reduced by using smaller currents', and 'energy losses from re-magnetising the core can be cut down by laminating it' were typical of the confused responses seen.

A proportion of the candidates evidently mixed up the principles of energy loss reduction in transformers with the principles involved in reducing power losses from transmission cables, because there were frequent references to using higher voltages in the transformers in order to reduce the currents causing the heating.

The calculations in parts (b) (i) and (ii) were usually correct, with $P = I\,V$ and the transformer efficiency equation being successfully applied. Almost all of the answers to part (b) (iii) were incorrect, because candidates did not realise that when on standby the transformer, as well as the load, continues to waste energy. Consequently, the power wasted on standby was 3.0 W, not 2.7 W.

This error did not prevent candidates from accessing both available marks in part (b) (iv), provided they correctly applied the physical principles there. In this part, relatively few completely correct answers were seen, largely because the candidates were unable to convert an energy value from J to kWh.

In part (c) it was usual to award both marks; most candidates knew that it takes an appreciable time for a computer to boot up and this would therefore be a disadvantage of switching off. For the advantage, a more specific point than 'saves energy' was being looked for, because this response does little more than re-state the question.

7 Students are much more accustomed to diagrams which show magnetic fields acting at right angles to the plane of a diagram, than magnetic fields acting in the plane of a diagram. Consequently the seeds of confusion were sown at the start of part (a) for a large proportion of the candidates, many evidently treating the question as though it referred to an electric field. Therefore the path of the ion in part (ii) was stated to be parabolic, and not circular, in a large number of the scripts. Perhaps the aim of the required calculation was a little obscure, but a question about a circular path ought to have triggered 'radius' in the minds of the candidates. Many calculated this radius very successfully, the principal error being a wrong value for the charge of the doubly-charged ion.

In part (b) it was not possible to award any marks to candidates who were convinced that the path was parabolic; they tended to write about curves that were 'steeper' or 'with a bigger slope', etc.

8 The topic of electromagnetism continues to present greater difficulty than most of the remainder of the Unit 4 content. Candidates who had mastered the distinction between magnetic flux and flux linkage, and who appreciated that induced emf = (rate of change of $N\Phi$), readily gained all six marks. Only a small minority of the candidates came into this category, however. When finding the cross-sectional area presented to the flux, there was evidence of the usual confusion between diameter and radius, leading to the loss of one mark on the question. More worrying were those candidates who wrote the area of a circle as $2\pi r$, or as $2\pi r^2$. In part (b), examiners took the view that candidates should know that an emf is measured in V – final answers expressed in Wb turns s^{-1} were not accepted.

9 Attempts at part (a) revealed huge uncertainty in the minds of many of the candidates, with 0° and 90° repeatedly crossed out before arriving at a considered decision. In the end, more than half of the candidates seemed to get a correct answer.

After the examination it was decided that part (b) should be removed and the answers were not marked by the examiners.

The amplification column of section 13.4.3 of Physics Specification A reads "$\Phi = BA$, B normal to A". This same entry has appeared in the previous two NEAB syllabuses, stretching back over ten years, out of which the current AQA specification was developed. It was intended by the designers of the specification, and the previous syllabuses, as shorthand for "$\Phi = BA$, where B is normal to A". "B normal to A" defines the condition under which the equation applies, rather than implying that the 90° condition is the only case in which magnetic flux may be calculated.

However, it has been pointed out to the examiners that teachers at many centres have interpreted "B normal to A" as defining the only condition under which candidates could be expected to calculate magnetic flux. (This is consistent with the 90° case being a restriction which definitely applies to the equations $F = B11$ and $F = BQ$ v in sections 13.4.1 and 13.4.2 of the specification).

Therefore, in fairness to all candidates taking the test, the two marks for part (b) of Question 3 were discounted from the assessment and the whole paper was marked out of 28 rather than 30.

Part (c) was seldom answered correctly. Very few candidates knew the distinction between flux and flux linkage, and there were considerable difficulties over powers of 10. Many candidates obtained one mark by determining the maximum flux correctly but did not then multiply their result by 650. The correct unit of flux linkage evaded almost all.

10 This question required students to decide through what angle (in rad), and in which direction, a coil should be rotated in order to achieve maximum and minimum values of flux linkage. 66% of them were successful. Distractor A, which was almost the exact opposite of the correct answer, was the most popular incorrect response.

11 This question tested students' knowledge of the flux linkages and currents in the primary and secondary windings of a step-up transformer. The same question had been used in an earlier examination. The facility this time was 54%, up from 46% when used previously.

12 This question, with a facility of 86%, was one of the easiest questions in this test. Students readily appreciated that the real reason that power lines are operated at high voltage is that this reduces the current, hence lowering joule heating losses from the cables.

13 In this question the students needed to know that reversing the current in a wire placed in a magnetic field would reverse the direction of the force on it, and that doubling the current would double the force. 60% of the responses were correct, up from 41% the last time this question appeared in an examination. The most common incorrect answer was distractor D (22%), where the force would be doubled but not reversed.

14 This question gave the most surprising outcome because, although its facility of 54% was satisfactory, it was a very poor discriminator between the strongest and weakest students. The physics of the question is clear enough: the couple on the coil is proportional to its cross-sectional area. The puzzling outcome may have arisen because 39% of the answers were for distractor A. The ratios of the areas are actually 0.20, 0.25, 0.15 and 0.16 respectively, so why so many students selected 0.20 remains a mystery. Maybe they were put off by the greater length of the long side of the rectangle.

15 This question required students to understand the trajectory of an electron moving in electric and / or magnetic fields. 73% gave a correct response.

16 Calculation of the force acting on electrons moving in magnetic fields in relation to their kinetic energies was the basis of this question. Because the kinetic energy of X is half that of Y, it follows that $v_x = v_y / \sqrt{2}$ and that the ratio of the forces is $1 / \sqrt{2}$. The facility of this question was 54%; 18% of the students gave distractor A and 23% gave B.

17 This question was a transformer calculation that caused few problems. Its facility was 78% and it discriminated very well.

18 This question, which had been used in an earlier examination, had a facility of 60% in 2014. On the previous occasion its facility was 55%. It may be readily seen that the radius of the path of a moving charged particle in a magnetic field is proportional to momentum p and inversely proportional to charge Q. When both p and Q are doubled, the charge will continue in a path of the same radius. Incorrect responses were evenly spread between distractors A, C and D. This was the most discriminating question in the test.

19 This question could be answered by knowing that the emf generated in a coil rotating in a magnetic field is given by $\varepsilon = BAN\omega \sin \omega t$, that and that $\omega = 2\pi f$. The maximum emf $\varepsilon_0 = BAN\omega$, which is (maximum flux linkage) × $2\pi f$. 59% of the answers were correct.