Mark schemes

1 (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* ∝ 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) $v \left(= \frac{BQr}{m} \right) = \frac{0.48 \times 1.60 \times 10^{-19} \times 0.19}{1.67 \times 10^{-27}}$ ✓ $= 8.7(4) \times 10^{6}$ (m s^{-1})

2

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

time taken $t \left(= \frac{\pi r}{v} \right) = \frac{\pi \times 0.19}{8.74 \times 10^{6}} = 6.8(3) \times 10^{-8}$ (s) ✓

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

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

$= \frac{\pi \times 1.67 \times 10^{-27}}{0.48 \times 1.60 \times 10^{-19}} = 6.8(3) \times 10^{-8}$ (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 ($\therefore$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 $BQ = m\omega = 2\pi fm$ ✓

$\therefore$ 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)

$=\frac{3.90\times10^{-13}}{1.60\times10^{-13}}=2.4(4)$ (Me V) ✓

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

3

(Total 14 marks)

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

3 (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]

4 (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 × 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]

5 (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]

6 (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 $\left(=\frac{BQr}{m}\right)$

$$= \frac{0.43\times10^{-3}\times1.60\times10^{-19}\times74\times10^{-3}}{9.11\times10^{-31}}$$ **(1)** (= 5.59 × 10^6 m s^{-1})

2

(ii) angular speed ω $\left(=\frac{v}{r}\right)=\frac{5.59\times10^6}{74\times10^{-3}}$ = 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]

7 D

[1]

8 A

[1]

9 B

[1]

10 A

[1]

Examiner reports

1 The two situations expected to be given in part (a)(i) were when the charge is at rest, or when it is *moving* parallel to the direction of the magnetic field. These answers were given by a high proportion of the candidates. Inexact expressions such as “when the charge is *placed* parallel to the field” were viewed with suspicion and went unrewarded. Also unsuccessful were attempts such as “when it is not moving perpendicular to the field” and “when it does not cut any flux lines”. Some candidates thought they could answer by subjecting the moving charge to an electric field over the same region (as in an ion velocity selector) so that there would be no resultant force on the charge. This was not acceptable because the magnetic force would still be acting.

In part (a)(ii) most candidates gained the first mark by quoting $BQv = mv^2 / r$. Cancelling one v then gives mv = BQr. However, to show that $mv \propto$ r it is necessary to point out that B and Q must be constant. The large number of answers which failed to do this did not receive the second mark.

Examiners were surprised by the large number of incorrect answers to part (b)(i), on a topic that has usually been well understood. Perhaps this was because the question is set in the context of a device being used to accelerate protons (rather than electrons). Consequently many candidates could not see that the magnetic field has to act upwards, out of the plane of the diagram.

Errors in part (b)(ii) included using the wrong mass and/or charge for a proton, but the majority of answers were correct. The frequent slip of using $2\pi r$ instead of πr for the path length incurred a one mark penalty in part (b)(iii); many candidates got around this problem by dividing their answer for time by 2. Part (b)(iv) was often rewarding, but it also defeated many candidates. The expected approaches included using algebraic equations for the time, or an argument based on the proportionality of the speed and radius. Less precise attempts, such as “gwhen the speed increases the radius increases so the time is the same’ were not credited. A few candidates repeated the calculation in part (b)(iii) for a different radius to show that the time was unaltered. In part (c) the candidates who thought that the protons would still be travelling at the speed they had calculated in part (b)(ii) were under a serious misapprehension and gained no marks. Surprisingly few used $v \propto r$ to find the new velocity, most preferring to repeat their earlier calculation in full but using r = 0.47m. The conversion of the kinetic energy unit from J to MeV . which is an AS topic . defeated many.

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 It was rare for all four marks to be awarded in part (a). The essence of this question was well understood, but poor use of English and an inability to write logically limited the mark that could be given. An alarming proportion of answers made no reference at all to the magnetic field; these students appeared to be answering a more general question about circular motion. Many of the students evidently thought that the purpose of the magnetic force (presumably acting outwards) was to balance the centripetal force, rather than to *provide* it. Relatively few correct solutions were seen that used $r = mv / BQ$ to show that r is constant when B and v are constant.

The common error in part (b)(i) was failure to deduce the radius of the path of the protons from the 27 km circumference of the LHC. This only meant the loss of one of the three marks, however, provided the principles of the rest of the calculation were correct. Careless arithmetic such as failure to square v, and/or forgetting to convert km to m, was also a frequent source of loss of marks. $F = BQv$ was usually applied successfully in part (b)(ii), where the unit of magnetic flux density was quite well known. Almost inevitably, there was some confusion between *flux density* and *magnetic flux.*

The fact that had to be appreciated in part (c) was that in the LHC the radius of the path of the charged particles must remain constant as they are accelerated. A large proportion of students thought that it was necessary to maintain a constant centripetal force for this to happen, whereas it ought to have been clear to them that F must increase as v increases if r is to be constant.

4 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.

5 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.

6 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 ω/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.