1)

i	(vertically) downwards on diagram ✓ reference to Fleming's LH rule **or** equivalent statement ✓	2	Mark sequentially. 1st point: allow "into the page".

ii	number of free electrons in wire = $A \times l \times$ number density $= 5.1 \times 10^{-6} \times 95 \times 10^{-3} \times 8.4 \times 10^{28} = 4.1\ (4.07) \times 10^{22}$ ✓	1	Provided it is shown correctly to at least 2SF, final answer alone is sufficient for the mark. (Otherwise working is mandatory).

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

2

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	

a	ii	$BQv = \frac{mv^2}{r}$ ✓ (gives $BQr = mv$) B and Q are constant so $r \propto$ momentum (mv) ✓	2	Acceptable answers must include correct force equation (1st point). Insist on a reference to B and Q constant for 2nd mark.
b	i	upwards (perpendicular to plane of diagram) ✓	1	Accept "out of the page" etc.

b	ii	$v\left(=\frac{BQr}{m}\right)=\frac{0.48\times1.60\times10^{-19}\times0.19}{1.67\times10^{-27}}$ ✓ $= 8.7(4) \times 10^{6}$ (m s^{-1}) ✓	2	

b	iii	length of path followed (= length of semi-circle) $= \pi r$ ✓ time taken $t\left(=\frac{\pi r}{v}\right)=\frac{\pi\times0.19}{8.74\times10^{6}}$ $= 6.8(3) \times 10^{-8}$ (s) ✓ [or $\frac{v}{r}=\frac{BQ}{m}$ gives $t=\frac{\pi r}{v}=\frac{\pi m}{BQ}$ ✓ $=\frac{\pi\times1.67\times10^{-27}}{0.48\times1.60\times10^{19}}$ $= 6.8(3) \times 10^{-8}$ (s) ✓]	2	Allow ECF from incorrect v from (b)(ii). Max 1 if path length is taken to be $2\pi r$ (gives 1.37×10^{-7}s).

b	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		$v_{max} = 8.74\times10^6\times\left(\frac{0.47}{0.19}\right) = 2.16\times10^7$ (m s^{-1}) ✓ 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) (MeV) ✓	3	1st mark can be achieved by full substitution, as in (b)(ii), or by use of data from (b)(i) and/or (b)(ii). Allow ECF from incorrect v from (b)(ii), or from incorrect t from (b)(iii).

3)

a	i	60 (degrees) ✓	1	

a	ii	angle required is 150° ✓ which is 5π/6 [**or** 2.6(2)] (radians) ✓	2	Correct answer in radians scores both marks.

b	i	(magnitude of the induced) emf ✓	1	Accept "induced voltage" or "rate of change of flux linkage", but not "voltage" alone.

b	ii	frequency $\left(=\frac{1}{T}\right)=\frac{1}{40\times10^{-3}}$ ✓ (= 25 Hz) no of revolutions per minute = 25 × 60 = 1500 ✓	2	1500 scores both marks. Award 1 mark for 40s → 1.5 rev min^{-1}.

b	iii	maximum flux linkage (=BAN) = 0.55 (Wb turns) ✓ angular speed $\omega\left(=\frac{2\pi}{T}\right)=\frac{2\pi}{40\times10^{-3}}$ ✓ (= 157 rad s^{-1}) peak emf (= $BAN\omega$) = 0.55 × 157 = 86(.4) (V) ✓ [**or**, less accurately, use of gradient method ✓ {e.g. $\varepsilon\left(=\frac{\Delta(N\Phi)}{\Delta t}\right)=\frac{0.5-(-0.5)}{(16-4)\times10^{-3}}=\frac{1.0}{12\times10^{-3}}$ } = 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 ✓ correct phase (i.e. starts as a minus sin curve) ✓	2	**Mark sequentially.** Graph must cover at least 80ms. For 2nd mark, accept + sin curve. Perfect sin curves are not expected.

d		BAN = 0.55 ∴ flux density $B = \frac{0.55}{4.0\times10^{-3}\times550}$ ✓ = 0.25(0) (T) ✓	2	**OR** by use of ε from (b)(iii) and f from (b)(ii) substituted in $\varepsilon = BAN(2\pi f)$.

4)

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 induces current in Q" is just ✓ from the last two marking points.	max 3	
4(a)(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	
4(b)(i)	flux linkage $(= n\Phi = nBA) = 40\times0.42\times3.6\times10^{-3}$ $= 6.0(5)\times10^{-2}$ ✓ Wb turns ✓	Unit mark is independent. Allow 6×10^{-2} Accept 60 mWb turns if this unit is made clear. Unit: allow Wb	2	
4(b)(ii)	change in flux linkage = $\Delta(n\Phi) = 6.05\times10^{-2}$ (Wb turns) ✓ induced emf $\left(=\frac{\Delta(n\Phi)}{\Delta t}\right) = \frac{6.05\times10^{-2}}{0.50}$ = 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	
Total			9	

5)

a		(magnetic) <u>field</u> is applied perpendicular to path **or** direction **or** velocity of charged particles ✓ (magnetic) <u>force</u> 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 ✓	max 4
b	i	radius r of path = $\frac{\text{circumference}}{2\pi} = \frac{27\times10^3}{2\pi}$ = 4.30×10^3 (m) (allow 4.3 km) ✓	3

		centripetal force $\left(=\frac{mv^2}{r}\right)=\frac{1.67\times10^{-27}\times(3.00\times10^7)^2}{4.30\times10^3}$ ✓ $= 3.50 \times 10^{-16}$ (N) ✓	

b	ii	magnetic flux density $B\left(=\frac{F}{Qv}\right)=\frac{3.50\times10^{-16}}{1.60\times10^{-19}\times3.00\times10^7}$ ✓ $= 7.29\times10^{-5}$ ✓ 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

6)

a	i	magnetic field (or *B*) must be at right angles to velocity (or *v*) ✓	**1**
a	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**
b	ii	magnetic **force** = electric **force** [or *BQv* = *EQ*] ✓ these forces act in opposite directions [**or** are balanced **or resultant** vertical force is zero] ✓	**2**

b	iii	*BQv* = *EQ* gives flux density $B=\frac{E}{v}$ ✓ $E\left(=\frac{V}{d}\right)=\frac{45}{65\times10^{-3}}$ ✓ (= 738 V m^{-1}) $B\left(=\frac{738}{1.7\times10^5}\right)=4.3\times10^{-3}$ ✓ T ✓	**4**
c		ions would be deflected upwards ✓ magnetic force increases but electrostatic force is unchanged [**or** magnetic force now exceeds electrostatic force] ✓	**2**
		Total	**11**

7)

(a)		magnetic field direction: $-z$ ✓	1
(b)		direction changes meaning that velocity is not constant ✓ acceleration involves change in velocity (or acceleration is rate of change of velocity) ✓ [**alternatively** magnetic force on electron acts perpendicular to its velocity ✓ ∴force changes direction of movement causing acceleration ✓]	2
(c)	(i)	$BQv = \frac{mv^2}{r}$ ✓ gives $v\left(=\frac{BQr}{m}\right)$ $= \frac{0.43 \times 10^{-3} \times 1.60 \times 10^{-19} \times 74 \times 10^{-3}}{9.11 \times 10^{-31}}$ ✓ (= 5.59×10^{6} m s^{-1})	2
(c)	(ii)	angular speed $\omega\left(=\frac{v}{r}\right) = \frac{5.59 \times 10^{6}}{74 \times 10^{-3}} = 7.5(5) \times 10^{7}$ ✓ *unit*: rad s^{-1} ✓ (accept s^{-1})	2
(c)	(iii)	frequency of electron's orbit $f\left(=\frac{\omega}{2\pi}\right) = \frac{7.55 \times 10^{7}}{2\pi}$ ✓ (= 1.20×10^{7} s^{-1}) number of transits min^{-1} = $1.20 \times 10^{7} \times 60 = 7.2 \times 10^{8}$ ✓ [**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} = $\frac{60}{8.32 \times 10^{-8}} = 7.2 \times 10^{8}$ ✓]	2
		Total	9

8)

(a)		flux linkage ($= N\phi = BAN \cos \theta$) = $2.8 \times 10^{-2} \times 1.9 \times 10^{-3} \times 50 \times \cos 35°$ ✓ = 2.2×10^{-3} (Wb turns) ✓ answer must be to **2 sf** only ✓	3
(b)	(i)	reasonable sine curve drawn on axes, showing just one cycle, starting at emf = 0 ✓	1
(b)	(ii)	the flux linkage in these positions is **zero** ✓	1
(b)	(iii)	induced emf ∝ (or =) rate of change of flux (linkage) ✓ flux (linkage) through the coil changes as it is rotated ✓ from maximum at θ = 0, 180° to zero at 90° and 270° ✓ rate of change is greatest when plane of coil is parallel to *B* [**or** reference to $\varepsilon = BAN\omega \sin \omega t$, **or** $\varepsilon = BAN\omega \sin \theta$] ✓ because coil then cuts flux lines perpendicularly [**or** $\varepsilon = BAN\omega \sin \omega t$ shows ε is greatest when ωt = 90° or 270°] ✓	**max 3**
		Total	8

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 ✓	1	Allow density of Q greater (than density of P).
b	ii	use of $s = ½ g t^2$ gives $t^2 = \frac{2 \times 1.0}{9.81}$ (from which $t = 0.45$ s) ✓ (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	Backwards working is acceptable for 1st mark. 2nd mark must refer to mass. Do not allow "both in free fall" for 2nd mark.
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 $\varepsilon = N(\Delta\Phi/\Delta t)$]✓ [**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	In this part marks can be awarded for answers which mix and match these schemes.
c	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] ✓	max 3	**Alternative** to 3rd mark: current gives heating effect in copper and energy for this comes from ke of Q ✓
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] ✓	max 3	Condone "will pass through faster" for 2nd mark. If emf is stated to be smaller for Q, mark (d) to max 2.

10)

(a)	(i)	(vertically) downwards ✓	**1**
(a)	(ii)	force F is perpendicular to both B and I [**or** equivalent correct explanation using Fleming LHR] ✓ magnitude of F changes as size of current changes ✓ force acts in opposite direction when current reverses [**or** ac gives alternating force] ✓ continual reversal of ac means process is repeated ✓	**max 3**
(b)		appreciation that maximum force corresponds to peak current ✓ peak current = $2.4 \times \sqrt{2} = 3.39$ (A) ✓ F_{max} (= $B\, I_{pk}\, L$) = $0.22 \times 3.39 \times 55 \times 10^{-3}$ ✓ (= 4.10×10^{-2} N)	**3**
(c)		wavelength (λ) of waves = $\left(= \frac{c}{f}\right) = \frac{64}{80} = 0.80$ (m) ✓ length of wire is $\lambda/2$ causing fundamental vibration ✓ [**or** λ of waves required for fundamental (= 2×0.40) = 0.80 m ✓ natural frequency of wire $\left(= \frac{c}{\lambda}\right) = \frac{64}{0.80} = 80$ (Hz) ✓] 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] ✓	**3**
		Total	**10**

11)

(a) (i)	primary coil with more turns than secondary coil ✓ (wound around) a core **or** input is ac ✓	**2**
(a) (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 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.	**5 - 6**
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.	

(b)	(i)	power wasted internally (= IV) = 0.30 × 9.0 = 2.7 (W) ✓	1
(b)	(ii)	input power $\left(=\frac{2.7}{0.90}\right)$ = 3.0 (W) ✓ mains current $\left(=\frac{3.0}{230}\right)$ ✓ (= 1.30 × 10^{-2} A)	2
(b)	(iii)	energy wasted per year (= Pt) = 3.0 × 0.80 × 3.15 × 10^7 = 7.5(6) × 10^7 (J) ✓	1
(b)	(iv)	energy wasted = $\frac{7.56 \times 10^7}{3.6 \times 10^6}$ = 21.0 (kWh) ✓ cost of wasted energy = 21.0 × 20 = 420p (£4.20) ✓	2
(c)		answers should refer to: an advantage of switching off ✓ • cost saving, saving essential fuel resources, reduced global warming etc a disadvantage of switching off ✓ • 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
		Total	**16**