7(a)	direction of induced e.m.f.	**M1**
	such as to (produce effects that) oppose the change that caused it	**A1**

7(b)(i)	$\Phi = BA$	**C1**
	$= 0.047 \times 10^{-3} \times \pi \times 12^2$	**C1**
	$= 0.021$ Wb	**A1**

7(b)(ii)	e.m.f. = flux cut / time	**C1**
	= 0.021 / (1 / 85) = 1.8 V	**A1**

7(b)(iii)	force (due to current) cause anticlockwise moment (to oppose rotation)	**B1**
	(from the LH rule) current is from O to X, so X is at the higher potential	**B1**

Question 7

(a) The majority of the candidates gained full credit, but some candidates specified a particular change causing the induced e.m.f. (e.g. a force or a flux change).

(b) (i) Most candidates identified the correct starting equation for flux, but then a significant number used an incorrect method to calculate the area. Some candidates did not give a correct unit.

(ii) The majority of the candidates gained full credit. Many candidates inappropriately included the number of blades in their calculations and so their answers were incorrect by a factor of 4.

(iii) Lenz's law was often not used to explain that a force or moment was needed to oppose the rotation of the rotor. When this was mentioned, the direction of that force or moment was often not stated. The answer X and reference to current in the rotor blade was required. Those who used Fleming's left-hand rule to correctly determine the current direction often forgot that the rotor is an e.m.f. source with current flowing from lower to higher potential within the source.

7(a)	(induced) e.m.f. is (directly) proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**

7(b)(i)	flux = e.m.f. × time	**C1**
	flux = 0.54 × 15 = 8.1 Wb	**A1**

7(b)(ii)	$\Phi = BA$	**C1**
	area = 8.1 / (38 × 10^{-6}) = 2.1 × 10^5 m^2	**A1**

7(b)(iii)	area = speed × time × width	**C1**
	v = (2.1 × 10^5) / (15 × 68) = 210 m s^{-1}	**A1**

7(b)(iv)	opposing force (due to current in wings) must be backwards	**B1**
	from Fleming's left-hand rule, current (in wings) must be from Q to P	**B1**
	current is from – to + inside an e.m.f. source so P is at higher potential	**B1**

Question 7

(a) Faraday's law was generally recalled accurately. Occasional confusion was seen between the terms flux linkage and flux density.

(b) (i) Leading on from the statement in **(a)**, the relationship between e.m.f. and magnetic flux was generally applied successfully in this question. Weaker candidates found difficulty in identifying an appropriate unit for their numerical answer.

(ii) This question was well answered by most candidates.

(iii) The involvement of the width of the aircraft's wings led to some confusion over the application of two basic equations: speed = distance travelled × time and area = width × distance travelled for a significant number of weaker candidates.

(iv) Candidates found this question difficult. Better answers were written in stages, first considering the direction of the force to oppose the motion of the aircraft, then describing the application of Fleming's left-hand rule to identify the direction of current flow from wingtip Q to P. The strongest candidates appreciated that this current was inside an e.m.f. source and then gave the correct answer.

6(a)(i)	$F = BIL$	**C1**
	force on QR = $5.2 \times 10^{-3} \times 1.2 \times 0.054 \times 190$	**C1**
	= 0.064 N	**A1**

6(a)(ii)	torque = force × perpendicular distance between forces	**C1**
	= $0.064 \times 0.025 \cos\theta = (1.6 \times 10^{-3}) \cos\theta$ N m	**A1**

6(a)(iii)	one complete cycle of a sinusoidal curve between 0 and 360°	**B1**
	τ axis labelled to show maximum and minimum torques at $\pm 1.6 \times 10^{-3}$ N m	**B1**
	maximum at 0 and 360° and minimum at 180° (or vice versa), with torque shown as zero at 90° and 270°	**B1**

6(b)	(ferrous core) increases magnetic flux density	**B1**
	amplitude of torque increases	**B1**

Question 6

(a) (i) The equation $F = BIL$ was stated and used by the majority of the candidates, although there was often some confusion as to the need to include the number of turns, resulting in a reduced force. Weaker candidates found more difficulty in identifying which side of the coil was being referred to as L in their equation.

(ii) The torque was often described as $F \times d$ with no explanation or clarification of the symbols used. Stronger candidates identified the requirement for a perpendicular distance to be identified, and hence the inclusion of a cosine term. Some weaker candidates took the symbol τ as being a time constant, despite it being defined as torque in the question.

(iii) Only the strongest candidates were able to sketch the sinusoidal curve without error, despite some allowance being given for a freehand drawing. Stronger candidates marked intermediate points on their graph to aid their drawing of the curves. The most common errors involved an excessively sharp start and finish to the curve at $\theta = 0°$ or at $\theta = 360°$, and a line that was wrongly or insufficiently curved between the peaks and troughs. The skill of accurately drawing a correct sinusoidal shape is one that would have been of significant benefit in this question. The labelling of the y-axis with values regularly showed number positioning that was imprecise. Few candidates marked the exact position of their values on the grid line, and it was not uncommon to see the negative labels missing a minus sign. Repetition of the power of ten on the axis numbers was also a common error. These two errors appeared across the full range of overall candidate performance.

(b) Only the strongest candidates realised that adding a ferrous core would increase the magnetic flux density.

7(a)(i)	loss of energy (of oscillations)	**B1**
	due to resistive forces	**B1**

7(a)(ii)	amplitude (of oscillations) decreases gradually **or** oscillations continue (for several periods)	**B1**

7(a)(iii)	cutting of (magnetic) flux causes induced e.m.f. (in coil) **or** induced e.m.f. causes current (in resistor / circuit)	**B1**
	current causes dissipation of thermal energy in resistor **or** current in resistor causes dissipation of thermal energy	**B1**
	thermal energy comes from energy of oscillations	**B1**

7(b)	(for any given e.m.f.) current is lower so thermal energy dissipated at a lower rate **or** (for any given e.m.f.) current is lower so the resistive force is lower	**B1**
	oscillations are less damped **or** *s*maller decrease in amplitude of oscillations (in each period) **or** oscillations continue for longer	**B1**

Question 7

(a) (i) Stronger candidates identified both the change to the oscillations and the cause of that change. Weaker candidates confused the resistive force on the bar magnet with the resistance in the circuit.

(ii) The words 'oscillation', 'displacement', 'amplitude', 'time' and 'period' were often confused with each other by weaker candidates when describing the gradual reduction in amplitude over time. 'Maximum amplitude' was also an incorrect phrase seen.

(iii) This was one of the more difficult questions on the paper. Candidates were expressly required to focus on conservation of energy, and needed to link two parts of the process in their description, such as magnetic flux change and induced e.m.f., or current and thermal energy dissipation in the resistor. Only the strongest candidates were able to do so, with many candidates focusing instead on the impact of Lenz's law and opposing forces. Whilst many candidates described a change of magnetic flux inducing an e.m.f., there was significant confusion over the process.

(b) Most candidates understood the effect of the increase in resistance, and correctly described the reduction in damping or the increase in the number of oscillations. Few candidates identified the lower thermal energy dissipation or lower resistive force caused by the reduction in the current.

7(a)	• force per unit length • force per unit current • length / current perpendicular to field *1 mark for any two points, 2 marks for all three points.*	**B2**

7(b)(i)	$F = BQv$	**B1**

7(b)(ii)	arrow at Y pointing vertically upwards	**B1**

7(b)(iii)	upwards deflection showing circular path	**B1**

7(c)(i)	electric field applied vertically downwards (may be shown on a labelled diagram)	**B1**
	electric force on particle in opposite direction to magnetic force (may be shown on a labelled diagram)	**B1**
	particle undeflected when magnitudes of electric and magnetic forces are equal	**B1**

7(c)(ii)	$EQ = BQv$	**B1**
	$v = E / B$	**A1**

Question 7

(a) The definition of magnetic flux density was generally well known, so full credit was common. Some candidates' answers were ambiguous with regard to what needed to be perpendicular to the field (whether the force or the length/current). Some also referred to specific units for length and/or current as part of their definition.

(b) (i) Most candidates gave the correct answer.

(ii) Most candidates gave the correct answer. Some weaker candidates drew arrows far from point Y and in some cases well outside the region of the magnetic field.

(iii) Most candidates gave the correct answer, although some curves were carelessly drawn with changes in curvature or discontinuities.

(c) (i) Some candidates' responses relied upon a diagram for some of the credit. This was acceptable, but candidates should be reminded the diagrams are only ever likely to be given credit when they are labelled. Many diagrams were not labelled sufficiently for it to be clear what was being shown. Written descriptions of the required direction of the electric field were frequently insufficiently precise.

(ii) Most candidates gave a correct derivation and the correct answer.

6(a)	$F_B = F_E$	**B1**
	either: $Bqu = qE$ and $E = V / d$ <u>leading to</u> $u = V / Bd$ *or*: $Bqu = qV / d$ <u>leading to</u> $u = V / Bd$	**B1**

6(b)	$E_K = ½mu^2$	**C1**
	$u = \sqrt{[(2 \times 4.1 \times 10^{-17}) / (3.2 \times 10^{-27})]}$ $= 1.6 \times 10^5 \text{ m s}^{-1}$	**C1**
	$B = 980 / (3.6 \times 10^{-2} \times 1.6 \times 10^5)$ $= 0.17 \text{ T}$	**A1**

6(c)	expression is independent of mass and charge	**A1**

6(d)	*either*: electric <u>force</u> is downwards so magnetic force is upwards *or*: no resultant <u>force</u> so magnetic force is upwards	**B1**
	(positive ions so) current is from left to right	**B1**
	from (Fleming's) left-hand rule, magnetic field is into the page	**B1**

6(e)	curved path inside plates with consistent direction of curvature and with no discontinuity at entry or in curvature	**B1**
	direction of deflection is upwards	**B1**

Question 6

(a) Many candidates reproduced the algebra involved in this syllabus derivation correctly. However, only a minority established the core physics behind the derivation as a starting point, the equality between the magnitudes of the electric and magnetic forces.

(b) This question was generally well-answered, with many candidates successfully calculating the correct answer.

(c) Many candidates explained why the particles pass through the field region undeviated, rather than addressing the question asked, which focussed on the expression in part **(a)** and how this expression shows that the speed for undeviated path is independent of the mass and charge of the particle. Many other candidates, who did address the question asked, gave only one of the factors of mass and charge as not appearing in the equation, forgetting that both quantities differ between protons and alpha particles.

(d) Weaker candidates were confused between the current direction and the direction of the electric force on the particles. Many candidates, however, gave a correct analysis of the three terms involved in the left-hand rule, and full credit was common for the more able candidates.

(e) Many candidates were unable to draw the required curve with consistent curvature, and many paths were seen that involved a discontinuity in the path at the point of entry into the field region. Most candidates had the direction of deflection incorrect, with only the strongest candidates able to deduce that with an unchanged electric force but a larger magnetic force, the faster particles will deflect upwards.

7(a)	(induced) e.m.f. is (directly) proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**

7(b)(i)	(uniform acceleration so) velocity is (directly) proportional to time	**M1**
	(Fig. 7.2 shows) e.m.f. is (directly) proportional to time so E is proportional to v.	**A1**

7(b)(ii)	($v = at$ so) distance moved in time $\Delta t = at\Delta t$	**C1**
	$\Phi = BA$	**C1**
	$E = (\Delta\Phi / \Delta \mathrm{t}) = B \times L \times (at\Delta t) / \Delta t = BLat$	**A1**

7(b)(iii)	$B = (0.30 \times 10^{-3}) / (0.45 \times 7.8 \times 2.0)$	**C1**
	$= 4.3 \times 10^{-5}$ T	**A1**

Question 7

(a) Faraday's law of electromagnetic induction was generally well-known, and full credit was common.

(b) (i) A large proportion of the weaker candidates missed the point of this question and focussed solely on the trend of Figure 7.2. The candidates who were successful in answering this question spotted that, whilst Figure 7.2 concerns the relationship between E and t, the question was about the relationship between E and v. The starting point for answering correctly required the direct proportionality between v and t to be established from the information that the acceleration of the rod is uniform from rest. A significant minority of weaker candidates thought that v was inversely proportional to t.

(ii) This challenging derivation required candidates to think of the scenario of the rod moving a short distance Δx in a short time Δt. Many candidates conflated t with Δt and were thus unable to produce a derivation based on correct physics.

(iii) Generally well-answered, with many candidates obtaining the correct answer. A common mistake was for candidates to miss the power-of-ten conversion required in the value of E.

1(a)(i)	$v = r\omega$	**C1**
	$= 0.85 \times 140$ $= 120\ \text{m s}^{-1}$	**A1**

1(a)(ii)	$a = r\omega^2$ **or** $a = v^2 / r$	**C1**
	$a = 0.85 \times 140^2$ **or** $120^2 / 0.85$ $= 1.7 \times 10^4\ \text{m s}^{-2}$	**A1**

1(b)(i)	direction of (induced) e.m.f.	**M1**
	is such as to (produce effects that) oppose the <u>change</u> that caused it	**A1**

1(b)(ii)	$T = 2\pi / \omega$ $= 2\pi / 140 = 0.045\ \text{s} = 45\ \text{ms}$	**A1**

1(b)(iii)	$\Phi = BA$	**C1**
	$= 0.18 \times \pi \times 0.85^2$	**C1**
	$= 0.41\ \text{Wb}$	**A1**

1(b)(iv)	$E = \Phi / t$	**C1**
	$= 0.41 / 0.045$ $= 9.1\ \text{V}$	**A1**

1(b)(v)	force (on spoke) must be anticlockwise, so current is from A to X (by Fleming's left hand rule), so X is at the higher potential	**B1**

Question 1

(a) (i) This question and **(ii)** were generally well answered by candidates that knew the basic equations for centripetal acceleration.

(ii) Some candidates who calculated the correct acceleration made an arithmetic error in rounding, to get a final answer of 1.6×10^4 m s^{-2}.

(b) (i) Lenz's law was only well known by the strongest candidates. To be awarded credit, candidates first needed to make it clear that Lenz's law is to do with the direction of the induced e.m.f. Confusion with Faraday's law was common, with many candidates giving responses in terms of the magnitude of the induced e.m.f.

(ii) This question was generally well answered, with most candidates able to show successfully that the period is 45 ms.

(iii) Many candidates knew the defining equation for magnetic flux. Some candidates did not know the correct formula for the area of a circle. Other candidates incorrectly included a factor of $\times$ 8 in the calculation.

(iv) Many candidates were awarded credit for realising that the magnitude of the e.m.f. is given by Faraday's law, but $\times$ 8 factors were common here too. Candidates should realise that the spokes are effectively in parallel, not in series, and so the $\times$ 8 factor is not applicable. Some candidates made a mistake with the unit conversion in the value of the time.

(v) This was a difficult question, with only the very strongest candidates demonstrating an ability to use Lenz's law correctly. The application of Lenz's law lay in realising that the cause of the induced e.m.f. is the rotation of the wheel. If current flows in the spokes, then it will cause a force on the wheel in the opposite direction to the rotation. Applying the left-hand rule then leads to a deduction that any current that flows will be from A to X. Finally, because current flows from low potential to high potential inside an e.m.f. source (and high to low potential around any external circuit), end X must be at the higher potential. A common misconception was that X is at the higher potential because it cuts more flux.

7(a)	• force per unit length • force per unit current • length / current perpendicular to field *1 mark for any two points, 2 marks for all three points*	**B2**
7(b)	concentric circles around the wire (at least two circles needed)	**B1**
	spacing between circles increases with distance from wire (at least four circles needed)	**B1**
	arrows showing direction of field is clockwise	**B1**
7(c)(i)	(each) wire sits in the (magnetic) field created by the other	**B1**
	current (in one wire) is perpendicular to (magnetic) field (due to other wire) so (magnetic) force acts (on wire)	**B1**
7(c)(ii)	arrow drawn, starting from X and pointing towards Y, labelled F	**B1**
7(c)(iii)	(forces have) equal magnitudes	**B1**
	(forces are in) opposite directions	**B1**
7(c)(iv)	no change (in the direction of the force) since both the current in X and the field due to Y have reversed	**B1**

NOT FOUND:

9702_w24_qp_41 EXAMINER REPORT (Qu 7)

7(a)	(induced) e.m.f. is (directly) proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**

7(b)(i)	$\Phi = BA$	**C1**
	$= 7.2 \times 10^{-3} \times 3.2 \times 10^{-4}$ $= 2.3 \times 10^{-6}$ Wb	**A1**

7(b)(ii)	tangent drawn at steepest point on Fig. 7.2	**C1**
	evidence of multiplication by 340	**C1**
	maximum rate of change of flux = 0.82 Wb s^{-1}	**A1**

7(b)(iii)	$V_0 = 0.82$ V **or** V_0 given as identical numerical answer to the answer in **(b)(ii)**	**A1**

7(b)(iv)	sinusoidal curve of period 2.0 ms from $t = 0$ to $t = 6.0$ ms	**B1**
	all peaks at $+V_0$ and all troughs at $-V_0$	**B1**
	line showing $V = 0$ at (and only at) $t = 0$, 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 ms	**B1**

7(b)(v)	*A* = 0.82 V **or** *A* has same numerical value as answer in **(b)(iii)**, with unit V	**A1**
	B = $2\pi / (2.0 \times 10^{-3})$	**C1**
	= 3100 rad s^{-1}	**A1**

Question 7

(a) Faraday's law was generally well known, and well stated by many candidates.

(b) (i) Whilst most candidates knew that they need to use the equation for magnetic flux in terms of flux density, many did not appreciate that the flux density they needed was the one corresponding to the maximum value on the graph. Other, generally weaker, candidates confused the flux in one turn with the flux linkage through the whole coil.

(ii) Most candidates found this question difficult. A common mistake was to find the average change of flux linkage over a part of a cycle, rather than to find the instantaneous rate of change of flux at the steepest part of the graph.

(iii) Most candidates appreciated that a consequence of Faraday's law is that the maximum e.m.f. induced across the coil is numerically equal to the maximum rate of change of flux linkage.

(iv) Candidates generally appreciated that the variation of V with t is a sinusoidal curve of period 2.0 ms and amplitude V_0. More challenging, though, was turning that appreciation into an accurate sketch. It was common for credit not awarded because a line was insufficiently sinusoidal in its shape. The more difficult aspect of the question was determining the correct phase for the variation, and appreciating that the times at which V has its maximum magnitude are when the flux density is changing at the greatest rate.

(v) Many candidates realised that A represents the maximum e.m.f., and gave A as the numerical answer from **(b)(iii)** with the unit V. Common mistakes with the calculation of the angular frequency B were to miss the power of ten conversion, to leave the answer in terms of π rather than calculating it to the appropriate precision, or to give an incorrect unit. Most of the stronger candidates were able to achieve full credit.

5(a)	force per unit charge	**B1**
	force on positive charge	**B1**

5(b)(i)	four straight vertical parallel lines, approximately evenly spaced	**B1**
	arrows downwards	**B1**

5(b)(ii)	$E = V / d$	**C1**
	$E = 430 / 0.067$ $= 6.4 \times 10^3$ N C^{-1}	**A1**

5(b)(iii)	smooth curve within plates and straight lines outside plates	**B1**
	direction of deflection shown as upwards	**B1**

5(c)(i)	into the page	**B1**

5(c)(ii)	forces are in opposite directions	**B1**
	(undeviated) when (magnitudes of) forces are equal	**B1**

5(c)(iii)	$Eq = Bqv$	**C1**
	$B = E / v = (6.4 \times 10^3) / (2.6 \times 10^7)$ $= 2.5 \times 10^{-4}$ T	**A1**

Question 5

(a) Definitions were often incomplete because of the omission of the ratio of force to (positive) charge, indicated by words such as ‘per unit charge’.

(b) (i) Carefully drawn sketches of the electric field lines using a ruler made it more likely that they were evenly spaced and started and finished on the plates, as was required. In most cases the field direction was given correctly.

(ii) Where the correct starting equation was stated, most candidates were able to go on to calculate the electric field strength. A common incorrect starting point was to use the equation for the field around a point charge.

(iii) Most candidates correctly sketched a path deviating in the correct direction. Common errors seen included an electron path that remained undeviated for too long within the plates, a curved path once the electron was beyond the plates, and the electron hitting a plate. The last error could have been avoided with a more careful reading of the question.

(c) (i) Stronger candidates were able to identify both the correct plane and correct direction of the magnetic field for an electron. Although not required or assessed, Fleming’s left-hand rule was sometimes quoted indicating its use to answer the question. Weaker candidates had the magnetic field direction opposite to that of the electric field. This error was then generally repeated in **(ii)**.

(ii) Most candidates were able to explain the equality and opposite direction of the two forces. Weaker candidates equated opposite fields rather than forces.

(iii) Where the starting equation was correctly shown, candidates were usually able to progress to a correct final answer for full credit. Many candidates tried to apply the equation for the force on a current in a wire. Whilst it is then possible to derive the correct equation from that starting point, it was rarely done successfully.

5(a)	*any 2 points from*: • (angular) displacement • velocity • momentum • (centripetal) acceleration • (resultant) force	**B2**

5(b)(i)	$Bqv = mv^2 / r$	**M1**
	$v = 2\pi r / T$	**M1**
	completion of algebra leading to $B = 2\pi m / qT$	**A1**

5(b)(ii)	$B = (2\pi \times 4 \times 1.66 \times 10^{-27}) / (2 \times 1.60 \times 10^{-19} \times 2.5 \times 10^{-6})$	**C1**
	$= 0.052$ T	**A1**

5(b)(iii)	**either** the same because T is independent of r **or** the same because B, q and m are unchanged **or** the same because both radius and speed have doubled	**B1**

5(b)(iv)	$qE = Bqv$	**C1**
	$E = Bv = 0.052 \times 1.1 \times 10^6$ $= 5.7 \times 10^4$ N C^{-1}	**A1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 5)

6(a)(i)	non-zero horizontal straight line from X to Y	**B1**

6(a)(ii)	constant flux density (inside coil)	**B1**
	either (magnetic) flux linkage proportional to flux density **or** $\Phi = BAN$ and B, A and N are all constant	**B1**

6(a)(iii)	$\Phi = BAN$	**C1**
	$= 0.080 \times 0.71 \times 10^{-4} \times 64$ $= 3.6 \times 10^{-4}$ Wb	**A1**

6(a)(iv)	*sketch showing*: E is zero from time 0 to time t and non-zero after time t	**B1**
	E has constant non-zero magnitude between time t and time $4t$	**B1**
	E has non-zero value of one sign between time t and time $2t$, and non-zero value of the opposite sign between time $2t$ and time $4t$	**B1**

6(b)	current in spring creates a magnetic field around the spring	**B1**
	either (magnetic) fields around adjacent turns interact to cause a force to be exerted (between the turns) **or** current in one turn interacts with (magnetic) field due to adjacent turns to cause force to be exerted (between the turns)	**B1**
	(magnetic force) is attractive so distance (between turns) decreases	**B1**

NOT FOUND:

9702_m24_qp_42 EXAMINER REPORT (Qu 6)

7(a)(i)	$V_H = BI / ntq$ $= (4.0 \times 10^{-6} \times 5.4) / (1.5 \times 10^{16} \times 1.8 \times 10^{-3} \times 1.60 \times 10^{-19}) = 5.0\ \text{V}$	**A1**

7(a)(ii)	sketch: straight diagonal line from (0, 0) to $t = 0.020$ s **and** straight diagonal line between two non-zero V_H values of same sign from $t = 0.040$ to 0.050 s	**B1**
	horizontal straight line at $V_H = 5.0$ V from $t = 0.020$ to 0.040 s	**B1**
	horizontal straight line at $V_H = 2.5$ V from $t = 0.050$ to 0.080 s	**B1**

7(b)(i)	e.m.f. = rate of change of (magnetic) flux (linkage)	**C1**
	$E = NA\,\Delta B / \Delta t$ **or** $E = NA \times$ gradient (at $t = 0.010$ s)	**C1**
	$E = 3000 \times 3.4 \times 10^{-4} \times (4.0 \times 10^{-6}) / (0.020) = 2.0 \times 10^{-4}$ V	**A1**

7(b)(ii)	sketch: line showing non-zero E from $t = 0$ to $t = 0.020$ s and from $t = 0.040$ s to $t = 0.050$ s, and $E = 0$ at all other times	**B1**
	'top hats' showing constant non-zero E from $t = 0$ to $t = 0.020$ s and from $t = 0.040$ s to $t = 0.050$ s	**B1**
	magnitude of E shown as 2.0×10^{-4} V in both non-zero sections	**B1**
	sign of E in the $t = 0$ to $t = 0.020$ s region opposite to the sign of E in the $t = 0.040$ s to $t = 0.050$ s region	**B1**

Question 7

(a) (i) This question was generally well answered. A significant number of weaker candidates thought that the *t* in the equation for the Hall voltage is a time rather than the thickness of the slice. It is important to note that candidates were asked to show that the Hall voltage is 5.0 V, which required a calculation using the data supplied. Some candidates assumed a Hall voltage of 5.0 V and reverse-calculated a value for magnetic flux density, which is not what was asked.

(ii) Many candidates were able to achieve at least partial credit for this question. A common misunderstanding was that the Hall voltage decreased to zero at t = 0.050 s, rather than to 2.5 V. Some candidates did calculate the 2.5 V figure, but found it difficult to locate that value correctly on the V_H-axis.

(b) (i) This question was well answered, with many candidates achieving full credit.

(ii) A significant minority of candidates thought that the variation with time of the induced e.m.f. was proportional to the magnetic flux rather than to its rate of change. Candidates that did understand the laws of electromagnetic induction were usually able to achieve at least some of the credit available, and the mark scheme was structured in such a way as to enable a variety of ways of obtaining partial credit. Many of the stronger candidates obtained full credit.

6(a)	• force per unit length • force per unit current • length / current perpendicular to field *1 mark for any two points, 2 marks for all three points*	**B2**

6(b)(i)	into the page	**B1**

6(b)(ii)	$F = Bqv$	**C1**
	$= 4.8 \times 10^{-3} \times 1.6 \times 10^{-19} \times 1.7 \times 10^{7} = 1.3 \times 10^{-14}$ N	**A1**

6(b)(iii)	arrow at point X pointing down the page	**B1**

6(b)(iv)	$F = mv^2 / r$	**C1**
	$1.3 \times 10^{-14} = (9.11 \times 10^{-31}) \times (1.7 \times 10^{7})^2 / r$	**C1**
	($r = 0.020$ m) $d = 2r$ $d = 0.040$ m	**A1**

6(c)	path shows upwards deflection such that the curvature is always anticlockwise within the field	**B1**
	circular path with larger radius	**B1**
	line enters field at X and leaves field at distance 2*d* vertically from X	**B1**

NOT FOUND:

9702_w23_qp_41 EXAMINER REPORT (Qu 6)

6(a)(i)	product of (magnetic) flux density and area	**M1**
	area perpendicular to the (magnetic) field	**A1**

6(a)(ii)	flux $= B \times \pi r^2$ $= 0.17 \times \pi \times 0.36^2$	**C1**
	$= 6.9 \times 10^{-2}$ Wb	**A1**

6(b)	time for one revolution = 1 / 25 s	**C1**
	e.m.f. = rate of cutting flux **or** $\Delta\Phi / \Delta t$	**C1**
	$= 0.069 \times 25$ = 1.7 V	**A1**

6(c)	current (in disc) is perpendicular to magnetic field **or** current causes force to act on disc	**B1**
	force opposes rotation of disc	**B1**
	left-hand rule indicates current is from rim to axle	**B1**

Question 6

(a) (i) This question was generally well answered, with most candidates knowing the definition of magnetic flux. A small number of candidates spoilt what would otherwise have been a creditworthy response by adding a second, contradictory, definition. Some gave the definition of flux density, and others defined magnetic flux as a number of lines (which would make it a dimensionless quantity).

(ii) This question was generally well answered, although there were some candidates who, whilst successfully calculating the numerical value, did not know the unit of magnetic flux. It was also common for weaker candidates here to consider that one significant figure was sufficient in the answer.

(b) This question was generally well answered, with full credit being common.

(c) This question is a good example of the need to answer the question that was asked, and not attempt to reproduce the mark scheme for a question from a previous paper. This question did not ask candidates to explain why there is an induced current, and it did not ask for a statement of Lenz's law. The question asked candidates to use Lenz's law to determine the direction of the current in the disc.

The key to answering the question was to appreciate that the current in the disc, being perpendicular to the external magnetic field, causes a force to act on the disc. The point where Lenz's law is applied is to determine that the direction of this force must be to oppose the rotation of the disc (which is the change that leads to the induced e.m.f.). Once the direction of the force on the disc is known, Fleming's left-hand rule can then be used to determine the current direction.

Many responses were very muddled, with some candidates confusing the external magnetic field with the field created by the induced current, others having two currents in the disc (one in each direction), others having currents opposing fields as if two completely different quantities can be compared and others having e.m.f.s or currents (rather than a force) opposing motion.

As a suggestion of general guidance, when candidates are asked to apply Lenz's law, they should stop to consider: what is the change that is causing the induced e.m.f.? Is it a changing field? It is it a changing current? Is it motion through a field? When the nature of the change has been determined, it is then a simple step to apply Lenz's law to determine how that change must be opposed. If an increasing field, then another field set up in the opposite direction would oppose the change. If a decreasing field, then another field set up in the same direction would oppose the change. If movement through the field, then a force would oppose the motion. Then, to create the response around that analysis, candidates should address the particular scenario presented in the question and not resort to attempting to replicate irrelevant learnt answers.

6(a)	a region where a force acts on	**M1**
	a current-carrying conductor **or** a moving charge **or** a magnetic material / magnetic pole	**A1**

6(b)	concentric circles around the wire	**B1**
	spacing between circles increases with distance from wire	**B1**
	arrows showing direction of field is clockwise	**B1**

6(c)(i)	$F = BIL$	**C1**
	force per unit length $= BI$ $= 2.6 \times 10^{-3} \times 5.0$ $= 0.013\ \text{N m}^{-1}$	**A1**

6(c)(ii)	to the right	**B1**

6(c)(iii)	force (per unit length) has the same magnitude due to Newton's 3rd law	**B1**
	$0.013 = 1.5 \times 10^{-3} \times I$ current = 8.7 A	**A1**

Question 6

(a) Candidates generally knew what is meant by a magnetic field. The most common mistake was to refer to the force acting on a charged particle, rather than a moving charged particle. When candidates referred to more than one object that the force was exerted upon, they all needed to be correct.

(b) Most candidates gained credit for drawing field lines that were concentric circles. Most candidates also gained credit for the direction of the field lines. However, for some candidates, the separation of the field lines did not convincingly increase with distance from the wire and for some the separation was definitely intended to be constant.

(c) (i) Most candidates correctly calculated the force per unit length.

(ii) Many correct directions were stated here. However, many candidates did not either remember that currents in opposite directions would cause a repelling force or could use Fleming's left-hand rule to deduce this from first principles.

(iii) Many candidates determined the correct magnitude of current in wire P. However, a large number did not explain their reasoning or did not do so fully enough.

6(a)	it is zero when (plane of) probe is parallel to the (magnetic) field (lines)	**B1**
	it is maximum when (plane of) probe is perpendicular to (magnetic) field (lines)	**B1**

6(b)(i)	number density of charge carriers	**B1**

6(b)(ii)	smaller value of n so greater Hall voltage / V_H	**B1**

6(c)	(36 mV corresponds to) 48 mT	**C1**
	use of 1.4 s or (8.6 – 7.2) s	**C1**
	$E = \Delta BAN / \Delta t$	**C1**
	$= \dfrac{48 \times 10^{-3} \times 0.018^2 \times \pi \times 780}{1.4}$ $= 0.027\,\text{V}$	**A1**

Question 6

(a) The main difficulty for candidates was thinking that the voltage is due to the principles of electromagnetic induction / cutting flux, rather than the Hall effect. Responses in terms of the Hall voltage being determined by the act of rotation, rather than the orientation of the probe relative to the magnetic field, were common.

(b) (i) There were many incorrect or incomplete responses here. Some responses included quantities such as the number of turns or the number of moles that are not used to find the Hall voltage.

(ii) A good number of candidates were able to explain why copper is not used for the Hall probe. Some did not clear make in their statement a comparison between the two materials. For example, smaller n was needed, not just small n.

(c) Most candidates were able to use the correct equation for Faraday's law. However, many candidates struggled to determine the correct value of flux density to use and to deduce that the relevant time was that relating to the steepest part of the graph. Only the strongest candidates were able to put all these considerations together to determine the correct answer.

7(a)	force per unit current	**M1**
	force per unit length	**M1**
	current / wire is perpendicular to (magnetic) field (lines)	**A1**

7(b)(i)	current (in coil) is perpendicular to magnetic field (so force on wire)	**B1**
	force (on wire) is perpendicular to current and field (so is vertical) **or** current and field are both horizontal (so force is vertical)	**B1**

7(b)(ii)	$NBIL = mg$	**C1**
	$B = (2.16 \times 10^{-3} \times 9.81) / (40 \times 3.94 \times 0.0300)$	**C1**
	$= 4.48 \times 10^{-3}$ T	**A1**

7(b)(iii)	(magnetic) forces (on balance and newton meter) are (equal and) opposite	**B1**
	reading $= 0.563 - (2.16 \times 10^{-3} \times 9.81)$ $= 0.542$ N	**A1**

Question 7

(a) The definition of magnetic flux density was generally well known, though it was not always clear in candidate responses that it is the current in the wire that has to be perpendicular to the magnetic field for the force per unit current per unit length definition not to require inclusion of a sin θ factor. It was often ambiguous what it was that candidates were describing as 'perpendicular', with many responses appearing to be describing the orientation of the force produced rather than the orientation of the current and the magnetic field.

(b) (i) Candidates needed to explain why there is a force, and then to explain why this force is vertical. Candidates were generally more successful in answering the first point than the second point.

(ii) Many candidates were successful in being awarded partial credit. A common error was the omission of the 40 turns factor. Some candidates ignored the instruction to give their answer to three significant figures. Weaker candidates usually started off on the wrong track with responses that were unable to be awarded credit. The most common incorrect starting approach was to equate the magnetic force with the reading on the newton meter rather than the force exerted on the top-pan balance.

(iii) Candidates were expected to deduce (and explain) that, because the balance reading increased, the force on the magnets was downwards and therefore, by Newton's third law, the magnetic force on the coil is upwards. Many of the more able candidates were able to deduce correctly the new reading of 0.542 N, but only the strongest candidates successfully explained their reasoning.

8(a)	direction of induced e.m.f.	**M1**
	such as to (produce effects that) oppose the change that caused it	**A1**

8(b)(i)	X = 0.85 A	**A1**
	Y = 2π / 0.040	**C1**
	= 160 rad s^{-1}	**A1**

8(b)(ii)	two cycles of a sinusoidal curve with a period of 0.040 s	**B1**
	correct phase (i.e. V_2 max / min at t = 0, 0.02, 0.04, 0.06 and 0.08 s, and V_2 zero at t = 0.01, 0.03, 0.05, 0.07 s)	**B1**
	maximum / minimum V_2 shown (consistently) at ± 6.5 V	**B1**

8(b)(iii)	(magnitude of) V_2 is proportional to rate of change of (magnetic) flux	**B1**
	• V_2 is proportional to <u>gradient</u> of I_1–t curve • V_2 has maximum magnitude when I_1–t curve is steepest • V_2 is zero when I_1–t curve is horizontal / a maximum or minimum • V_2 changes sign when sign of gradient of I_1–t curve changes *Any two points, 1 mark each*	**B2**

Question 8

(a) Candidates who knew their 'bookwork' were generally aware that Lenz's law governs the direction of the induced e.m.f. and were able to articulate the law correctly.

(b) (i) This was generally well answered, with a significant proportion of candidates achieving full credit.

(ii) Most candidates realised that the variation of V_2 with t is sinusoidal with a period of 0.040 s. Many correctly calculated the peak voltage of 6.5 V and represented that consistently in their responses. Candidates found it more difficult to deduce the correct phase for the voltage, with all but the strongest candidates usually giving answers that were either in phase or in antiphase with Fig. 8.2.

(iii) Most creditworthy attempts to explain the variation of V_2 with t got as far as a statement of Faraday's law of electromagnetic induction and then stopped. Candidates needed to articulate how the laws of electromagnetic induction applied to this situation, and only the strongest candidates were successful at doing this.

6(a)(i)	PQRS and WXYZ	**B1**

6(a)(ii)	force on charge carriers is perpendicular to both (magnetic) field and current	**B1**
	as charge carriers are deflected to one side, an electric field is set up	**B1**
	(steady V_H when) electric and magnetic forces on charge carriers are equal (and opposite)	**B1**

6(b)(i)	*n*: number density of charge carriers	**B1**
	t: distance PW (or SZ or QX or RY)	**B1**
	q: charge on each charge carrier	**B1**

6(b)(ii)	V_H inversely proportional to *t*	**B1**
	(so *t* needs to be small for) V_H to be large enough to measure	**B1**

Question 6

(a) (i) Most candidates correctly identified the faces that were perpendicular to the magnetic field.

(ii) Many candidates knew the electrons would experience a force towards one face and hence an electric field was set up. However, only the stronger candidates realised that the force on the charge carriers (electrons) was perpendicular to both the magnetic field and the current. A misconception evident in responses was that the two fields (electric and magnetic) become equal rather that the forces on the charge carriers due to the two fields becoming equal.

(b) (i) Some candidates were not awarded credit here because they were not specific enough in their responses. The detail of number of charge carriers **per unit volume** and the charge of **a charge carrier** was often missing. Some candidates did not seem familiar with this formula at all and number of moles and time were seen as responses.

(ii) This was generally well answered. However, some candidates answered in terms of *n* rather than *t*, perhaps recalling mark schemes from similar questions from previous examination sessions.