20. Magnetic Fields

20.5 Electromagnetic induction

Paper 4

Marking Scheme

Q1.

(a)	(induced) e.m.f. is (directly) proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
(b)(i)	$\Phi = BA$	**C1**
	$= 7.2 \times 10^{-3} \times 3.2 \times 10^{-4}$ $= 2.3 \times 10^{-6}$ Wb	**A1**
(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**
(b)(iii)	$V_0 = 0.82$ V **or** V_0 given as identical numerical answer to the answer in **(b)(ii)**	**A1**
(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**

Q2.

(b)(i)	direction of (induced) e.m.f.	**M1**
	is such as to (produce effects that) oppose the change that caused it	**A1**
(b)(iii)	$\Phi = BA$	**C1**
	$= 0.18 \times \pi \times 0.85^2$	**C1**
	$= 0.41$ Wb	**A1**
(b)(iv)	$E = \Phi / t$	**C1**
	$= 0.41 / 0.045$ $= 9.1$ V	**A1**

Q3.

(a)(i)	product of (magnetic) flux density and area	**M1**
	area perpendicular to the (magnetic) field	**A1**
(a)(ii)	flux $= B \times \pi r^2$ $= 0.17 \times \pi \times 0.36^2$	**C1**
	$= 6.9 \times 10^{-2}$ Wb	**A1**
(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**

Q4.

(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**
(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**

Q5.

(a)	product of (magnetic) flux density and area	**M1**
	where area is perpendicular to the (magnetic) field	**A1**
(b)(i)	$N\Phi = BAN$	**C1**
	$= 400 \times 10^{-3} \times 0.12^2 \times 8$	**C1**
	$= 0.046$ Wb	**A1**
(b)(ii)	(line is a) straight line	**B1**
(b)(iii)	(induced) e.m.f. = rate of change of flux linkage	**C1**
	e.m.f. $= N\Phi/t$ $= 0.046 / 0.60$ $= 0.077$ V	**A1**
(c)	(induced e.m.f. causes) current flow (in the coil)	**B1**
	either	
	current (in magnetic field) causes forces to act on the coil	**B1**
	(opposite sides of) coil forced inwards	**B1**
	or	
	current causes dissipation of energy in the resistance of the coil	**(B1)**
	temperature of the coil rises	**(B1)**

Q6.

(a)	induced e.m.f. is (directly) proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
(b)	V_2 stepped, all at non-zero values, between $t = 0$ and $t = 0.40$ s	**B1**
	V_2 shown with same non-zero magnitude up to $t = 0.15$ s and after $t = 0.25$ s but with a different magnitude between these times	**B1**
	V_2 shown with a magnitude between $t = 0.15$ s and $t = 0.25$ s that is three times the magnitude before $t = 0.15$ s and after $t = 0.25$ s	**B1**
	V_2 shown with same sign up to $t = 0.15$ s and after $t = 0.25$ s, and opposite sign in between	**B1**
(c)(i)	changing current in coil causes changing (magnetic) field **or** changing (magnetic) flux causes induced e.m.f. in ring	**B1**
	induced e.m.f. in ring causes current in ring	**B1**
	(magnetic) field due to (induced) current in ring interacts with (coil's) field to cause upwards force (on ring) **or** (induced) current in ring perpendicular to (coil's magnetic) field causes upwards force (on ring)	**B1**
(c)(ii)	both magnetic fields reverse direction so ring still jumps up **or** current (in ring) and (coil's) field both reverse so ring still jumps up	**B1**

Q7.

(b)(i)	current in wire P gives rise to a magnetic field	**B1**
	as current (in P) changes, wire Q cuts (magnetic) flux (of wire P)	**B1**
	cutting magnetic flux causes induced e.m.f. (across Q)	**B1**
(b)(ii)	sketch shows line with a negative gradient throughout	**B1**

Q8.

(a)	direction of induced e.m.f.	**M1**
	such as to (produce effects that) oppose the change that caused it	**A1**
(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**
(b)(iii)	(magnitude of) V_2 is proportional to rate of change of (magnetic) flux	**B1**
	• V_2 is proportional to gradient 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**

Q9.

(a)	direction of (induced) e.m.f.	**M1**
	is such as to oppose the change causing it	**A1**
(b)	ring cuts (magnetic) flux and causes induced e.m.f. in ring	**B1**
	(induced) e.m.f. causes (eddy/induced) currents (in ring)	**B1**
	currents (in ring) cause magnetic field (around ring)	**M1**
	two fields interact to cause resistive/opposing force	**A1**
	or	
	current (in ring) is in a magnetic field	**(M1)**
	which causes resistive force	**(A1)**
	or	
	currents (in ring) dissipate thermal energy	**(M1)**
	(thermal) energy comes from energy of oscillations	**(A1)**
(c)	current cannot pass all the way around the ring	**B1**
	(induced) currents smaller	**B1**
	smaller resistive force (so more oscillations) **or** smaller rate of dissipation of energy (so more oscillations)	**B1**

Q10.

(c)	(oscillating) coils cut magnetic flux **or** as separation of coils changes, magnetic flux changes	**B1**
	cutting flux causes induced e.m.f. in coils	**B1**
	changing (induced) e.m.f. causes changing current (in coil)	**B1**

Q11.

(b)(i)	(maximum) rate of cutting of (magnetic) flux doubles	**B1**
	(peak and hence) r.m.s. induced e.m.f. doubles	**B1**
(c)	current in the coil results in forces that oppose its rotation **or** current in the resistor dissipates the energy of rotation	**B1**
	coil stops rotating	**B1**

Q12.

(a)(i)	e.m.f. $= (\Delta)B \times AN / t$	**C1**
	$= 45 \times 10^{-3} \times \pi \times (1.8 \times 10^{-2})^2 \times 350 / 0.20 = 0.080$ V	**A1**
(a)(ii)	0 to 0.2 s: straight horizontal line at 0.080 V or –0.080 V	**B1**
	0.2 s to 0.4 s: zero	**B1**
	0.4 s to 0.8 s: straight horizontal line at 0.040 V or –0.040 V	**B1**
	opposite polarity to 0 to 0.2 s line	**B1**
(b)	either disc cuts flux lines (of the magnet) **or** there is a changing flux in the disc	**B1**
	(by Faraday's law) e.m.f. is induced in the disc	**B1**
	e.m.f. causes (eddy) currents in the disc	**B1**
	current in the magnetic field (of the magnet) causes force on disc	**B1**

Q13.

(a)	(induced) electromotive force is proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
(b)(ii)	magnitude of e.m.f. varies as rate of change of flux changes	**B1**
	direction of e.m.f. changes when direction of change of flux reverses/when flux changes from increasing to decreasing	**B1**
	flux is continuously increasing and decreasing, so polarity of e.m.f. is continuously switching	**B1**

Q14.

(a)	flux density $\times$ area	**M1**
	where flux is normal to area	**A1**
	or	
	flux density $\times$ area $\times \sin\theta$	**(M1)**
	where θ is angle between flux direction and (plane of) area	**(A1)**
(b)(i)	(alternating) current creates changing (magnetic) flux	**B1**
	core links (magnetic) flux with secondary coil	**B1**
	changing flux (in secondary) causes induced e.m.f.	**B1**
(b)(ii)	rate of change of flux is not constant	**B1**
	(induced) e.m.f. is proportional to rate of change of flux	**B1**

Q15.

(a)(i)	(induced) e.m.f. (directly) proportional to rate	**M1**
	of change of magnetic flux (linkage)	**A1**
(a)(ii)	e.m.f. = 0 apart from thin pulses at t_1 and t_2	**B1**
	rectangular pulses centred on t_1 and t_2, of widths 2 small squares and 1 small square respectively	**B1**
	e.m.fs. at t_1 and t_2 have opposite polarities	**B1**
	magnitude of e.m.f. at t_2 double the magnitude of e.m.f. at t_1	**B1**

Q16.

(b)(i)	direction of induced e.m.f./current	**M1**
	(tends to) oppose the change causing it	**A1**
(b)(ii)	magnetic field in solenoid is increasing	**B1**
	field in coil in opposite direction to oppose increase	**B1**
	arrow inside or just above small coil pointing in opposite direction to P	**B1**
(c)	e.m.f. $= N\Delta\phi / \Delta t$	**C1**
	$= (75 \times 1.4 \times 10^{-3} \times 2 \times 7.0 \times 10^{-4}) / 0.12$	**C1**
	$= 1.2 \times 10^{-3}$ V	**A1**

Q17.

(a)	(induced) e.m.f. proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
(b)	current in primary coil gives rise to magnetic flux	**B1**
	changing (magnetic) flux in core links with secondary coil	**B1**
	induced e.m.f. (in secondary coil) causes current in load/resistor	**B1**

Q18.

(a)	(induced) e.m.f. proportional to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
(b)(i)	any two from t_1, t_3, t_5, t_7	**A1**
(b)(ii)	t_2 **and** t_4 **or** t_4 **and** t_6	**A1**
(c)	e.m.f. $= N\Delta\Phi / \Delta t$	**C1**
	$= (2 \times 9.4 \times 10^{-4} \times 5.0 \times \pi \times (1.8 \times 10^{-2})^2 \times 63) / (6.0 \times 10^{-3})$	**C1**
	$= 0.10$ V	**A1**

Q19.

(a)	induced e.m.f. proportional to rate	**M1**
	of change of (magnetic) flux (linkage) **or** of cutting (magnetic) flux	**A1**
(b)	current in coil produces flux	**B1**
	(by Faraday's law) changing flux induces e.m.f. in ring	**B1**
	current in ring causes field (around ring)	**B1**
	(by Lenz's law) field around ring opposes field around coil	**B1**

Q20.

(a)	(magnetic) flux density × area	**B1**
	magnetic flux density normal to area **or** reference to cross-sectional area **or** × sin (angle between *B* and *A*)	**B1**
	× number of turns on coil	**B1**
(b)	e.m.f. = BAN/t **or** e.m.f = rate of change of flux linkage	**C1**
	= $(7.5 \times 10^{-3} \times \pi \times \{1.2 \times 10^{-2}\}^2 \times 160) / 0.15$ = 3.6×10^{-3} V	**A1**
(c)	sketch: zero for 0–0.10 s, 0.25–0.35 s, and 0.425–0.55 s, and non-zero outside these ranges	**B1**
	two horizontal steps, with zero voltage either side	**B1**
	with same polarity	**B1**
	correct values (1st step 3.6 mV and 2nd step 7.2 mV)	**B1**

Q21.

(a)	(induced) e.m.f. proportional/equal to rate	**M1**
	of change of (magnetic) flux (linkage)	**A1**
(b)(i)	induced e.m.f. = $(\Delta B)AN/\Delta t$ = $(2 \times 0.19 \times 1.5 \times 10^{-4} \times 120) / 0.13$	**C1**
	= 0.053 V	**A1**
(b)(ii)	reading on voltmeter connected to coil C / V: 0 0.053 0 (*all three values required*)	**A1**
	reading on voltmeter connected to Hall probe / V: zero in middle column	**B1**
	final column correct sign (negative)	**B1**
	final column correct magnitude (0.20)	**B1**

Q22.

(b)	$E = 0$ for $0 \rightarrow t_1$ **and** $t_3 \rightarrow t_4$	**B1**
	E is non-zero at all points between $t_1 \rightarrow t_3$	**M1**
	E has constant magnitude between $t_1 \rightarrow t_3$	**A1**