25 Electromagnetic induction
Answers to practice questions

Question	Answer	Marks	Guidance
1 (a)	Ammeter deflects in one direction and then in the opposite direction.	1 1	The magnetic flux through the coil increases and in one direction, and then decreases, as the N-pole passes through. This process is then repeated in the opposite direction as the S-pole passes through. The ammeter deflects only when there is relative movement between the magnet and coil.
1 (b) (i)	The acceleration of the magnet would be reduced... because the magnetic field produced by the current induced in the coil gives an upwards force on the N-pole of the magnet that opposes the movement of the N-pole towards the coil.	1 1	According to **Lenz's law**, the direction of an induced emf is always such as to **oppose** the **change of flux** that produces it. In this example the change of flux can be opposed by trying to prevent the magnet from dropping into the coil.
1 (b) (ii)	The acceleration of the magnet would again be reduced... because the magnetic field produced by the current induced in the coil gives an upwards force on the S-pole of the magnet that opposes the movement of the S-pole away from the coil.	1 1	As the magnet leaves, the change of flux can be opposed by trying to keep the magnet in the coil. The induced magnetic field therefore causes a force of attraction on the S-pole of the magnet.
1 (c)	*Relevant points include*: · The magnet would now fall with an acceleration of *g* · An emf would still be induced in the coil · No current could be produced by the induced emf · No induced magnetic field would be produced · There would be no opposing forces on the magnet due to an induced current.	Any 3	There can be a current only if a circuit is complete. With the meter disconnected, the emf cannot give a current, and the coil will therefore not produce an opposing magnetic field. *An alternative explanation* would be in terms of energy: no energy could be dissipated from the circuit if there were no current, and the magnet would lose none of its kinetic energy.
2 (a) (i)	Φ represents magnetic flux	1	Do not confuse this with **flux linkage**, which is (number of turns on coil) × Φ.
2 (a) (ii)	The unit of Φ is weber (Wb), or tesla metre^2 (T m^2).	1	Φ = (flux density) × (area at right angles to flux) $= BA$ The unit of B is tesla, so the unit of Φ is T m^2. 1 T m^2 = 1 Wb
2 (b) (i)	The maximum emf occurs when $\frac{\Delta B}{\Delta t}$ is a maximum i.e. where the gradient of the B–t graph is greatest, ∴ draw tangent to line at $t = 0.5$ or 1.0 s ($t = 0$ is also acceptable). From tangent, $\frac{\Delta B}{\Delta t} \approx 6 \times 10^{-3}$ T s^{-1} ∴ maximum emf $= NA\frac{\Delta B}{\Delta t}$ $= 240 \times 2.5 \times 10^{-4} \times 6 \times 10^{-3}$ $= 3.6 \times 10^{-4}$ V	1 1 1	The magnitude of the induced emf is given by $\varepsilon = N\frac{\Delta\phi}{\Delta t} = N\frac{\Delta(BA)}{\Delta t}$. In this example N and A are constant, hence $\varepsilon \propto \frac{\Delta B}{\Delta t}$. Use a ruler to draw the longest straight line you can that is a tangent to the graph line at its maximum slope. Take readings from the ends of your line. Some tolerance (say 20%) would have to be allowed in the answer: perhaps (2.9 to 4.3) × 10^{-4} V

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2 (b) (ii)	*Graph drawn to show*: · Both + and − values, with zero emf at 0.25 and 0.75 s. · Peak emf at 0.5 and 1.0 s on a graph of the correct (cosine) shape.	2	According to Lenz's law, a positive rate of change of flux (gradient) will produce a negative emf. Technically, your graph should be a −(cosine) curve.
2 (b) (iii)	Pendulum would have to be shorter; $\frac{1}{4}$ of the original length.	1 1	For a pendulum $T \propto \sqrt{\text{length}}$, and frequency $f = \frac{1}{T}$.
2 (b) (iv)	The maximum speed of the magnet is increased ∴ the coil cuts the flux at a higher rate or rate of change of flux increases.	1 1	In simple harmonic motion, v_{max} $2\pi fA$, implying $v_{max} \propto f$ when A is unchanged.
2 (b) (v)	Possible alternative ways: • use a stronger magnet • use a coil with more turns • use a coil of greater area • place a soft iron core in the coil • use a larger amplitude of oscillation of the magnet.	Any 2	There are plenty of other ways of increasing the maximum emf. Anything that increases the rate of change of flux will suffice. Take care with your words, however: **not** a *bigger* magnet, and **not** a *magnet* of greater area.
3 (a)	Distance between pulses = 7.2 cm ∴time between pulses = 72 ms Time for 1 revolution of axle = 4 × 72 = 288 ms Number of revolutions per minute $= \left(\frac{1}{288\times10^{-3}}\right) \times 60 = 208$ or 205–211 with an extended range of values of the time between pulses.	1 1 1	Each square in Fig. 5 should have a side of 1 cm; the diagram is not to scale. Some tolerance would have to be allowed in the answer, say between 71 and 73 ms. There is a + and − voltage pulse every time one of the magnets passes the coil. This happens four times per revolution of the axle. The oscilloscope time base is set on 10 ms cm^{-1}, from which the time between pulses can be found.
3 (b) (i)	*Relevant points are*: · Movement of a magnet changes the magnetic flux through the coil (or changes the flux linked with the coil) · The induced emf is proportional to the rate of change of flux linked with the coil (or an emf is produced because the magnetic flux cuts through the coil).	2	As the N-pole of a magnet approaches the coil, the increase of magnetic flux produces a voltage pulse; as it leaves the decrease in flux produces a pulse with opposite polarity. Faraday's law relates induced emf to the rate of change of flux linking the coil.
3 (b) (ii)	Peak induced emf = 1.5 × 5 = 7.5 mV induced emf $= N\frac{\Delta\phi}{\Delta t}$ $\therefore \frac{\Delta\phi}{\Delta t} = \frac{\text{induced emf}}{N} = \frac{7.5\times10^{-3}}{350}$ $= 2.14 \times 10^{-5}$ Wb s^{-1} or 2.1×10^{-5} Wb s^{-1} or T m^2 s^{-1}	1 1 1 1	Readings have to be taken from the coarse scale on the screen in Figure 2, so there would have to be some tolerance in the accepted answers. Reading the peak emf as 7.6 mV would give 2.17 Wb s^{-1} as the final answer here.

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3 (c)	*Relevant points include*: · Direction of induced emf (or current) opposes the change that produces it. · A pulse is produced as a magnet approaches **and leaves** a coil. · Forces on a magnet repel it as it approaches **and** attract it as it leaves. · Current therefore flows one way as the magnet approaches and the opposite way as it leaves.	Any 3	The emf induced in a coil causes a current in it. This current produces a magnetic field that opposes the movement of the magnet, repelling an approaching magnet and attracting a magnet that is moving away. The current flows in opposite directions to provide reversal of the field direction.
3 (d)	Waveform drawn on Figure 2 to show: · larger peak voltages · + and − peaks closer together · narrower (sharper) peaks · sets of peaks closer together.	Any 3	Faster rotation would produce a greater rate of change of flux (therefore larger voltages), and quicker events that occur more frequently.
4 (a)	Diagram completed to show a workable arrangement, with: · a horizontal current-carrying conductor at right angles to the flux lines, a pivot and a balancing weight · magnetic force shown by a labelled arrow directed, for example, downwards · current direction labelled consistent with direction of force: for example, into the plane of the page (towards the back of the arrangement of mounted magnets).	3	A current balance is an apparatus which gives the possibility of measuring a magnetic field by ‘weighing’ the force that acts on a current-carrying conductor in a magnetic field. A simple arrangement consists of a wire frame that is pivoted, with weights on one side to balance the magnetic force on the other side. The force and current directions shown in your diagram must be consistent with Fleming’s left-hand rule.
4 (b) (i)	Force on one wire in the coil $=BIl = 40 \times 10^{-3} \times 0.55 \times 0.15$ $= 3.3 \times 10^{-3}$ N Force on one side of the coil $= 20 \times 3.3 \times 10^{-3} = 6.6 \times 10^{-2}$ N	1 1	Part **(b)** revises work covered in Chapter 7. The coil is square, so its length is indistinguishable from its width. Each side is of length 0.15m. Do not overlook the fact that the coil has 20 turns.
4 (b) (ii)	An emf is induced once the coil is rotating, because the coil cuts the magnetic flux continuously. This induced emf opposes the emf that is causing the coil to rotate, thereby reducing the current.	1 1	The induced emf generated in a rotating motor coil is known as a back emf and is an example of Lenz’s law. It seems strange that a motor carries maximum current when it first starts and minimum current when it rotates fastest.
4 (b) (iii)	Applied pd/voltage from supply = I_0R $= 0.55 \times 0.50 = 0.275$ V net pd/voltage when coil rotates = IR $= 0.14 \times 0.50 = 0.070$ V $\therefore$ back emf $= 0.275 - 0.070 = 0.205$ V Induced back emf $= N\dfrac{\Delta\phi}{\Delta t}$ gives $\dfrac{\Delta\phi}{\Delta t} = \dfrac{\text{inducedemf}}{N} = \dfrac{0.205}{20}$ $\therefore$ maximum rate at which flux is cut by coil = 1.03 (or 1.02) $\times 10^{-2}$ Wb s^{-1}	1 1 1 1	The voltage from the supply connected to the motor can be found using $V = IR$ when the coil is not turning since there is no back emf. When the coil starts to turn there is a smaller voltage across the resistance of the coil – the differences in these two voltages is the induced emf in the coil. This induced emf is equal to the rate of change of **flux linkage**, not the rate of change of flux. Once again, do not forget that the coil has **20 turns**.

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5 (a)	Magnetic flux linkage is the product of magnetic flux and the number of turns that cut the flux **or** = $N\Phi$ (= NBA, where B is normal to A), with terms defined. The unit of $N\Phi$ is weber turn (Wb turn)	1 1	Magnetic flux linkage is a useful idea because an induced emf is proportional to the rate of change of flux linkage. Its unit is written by convention as Wb turn, even though the number of turns is just a number. $N\Phi$ is not usually expressed in Wb, although that is dimensionally correct.
5 (b)	*Relevant points include*: • The alternating voltage, V_{in}, supplied to the input causes an alternating current in the primary coil • The ac in the primary coil produces an alternating magnetic flux in the core • This alternating flux passes through the secondary coil • The induced emf, V_{out}, in the secondary coil is proportional to the rate of change of flux linkage • There are fewer turns on the secondary than on the primary, so $V_{out} < V_{in}$	Any 4	A **step-down** transformer is one that is used to reduce the voltage of an alternating supply. The magnetic field produced by the current in the primary is concentrated in the magnetically soft core. An emf is induced in the secondary coil because it is in a continuously changing, alternating magnetic field. An ideal transformer with equal numbers of turns on the two coils would give $V_{out} = V_{in}$. Fewer turns on the secondary reduces the flux linkage with the secondary, reducing Vout.
5 (c) (i)	Use of $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ gives $\frac{V_s}{230} = \frac{1}{15}$ from which output voltage $V_{out} = V_s = 15.3$ V	1 1	The ‘turns ratio’, which is given in the question as 15:1, is N_p:N_s, i.e. primary turns:secondary turns. The output voltage is the voltage across the secondary coil.
5 (c) (ii)	*Reasons for imperfect efficiency*: • Thermal energy losses caused by the currents in the coils, which have resistance • Energy is required to magnetise, demagnetise and re-magnetise the core • Eddy currents induced in the core cause thermal energy losses in the core • Imperfect flux linkage: not all the magnetic flux produced by the primary coil passes through the secondary coil.	Any 2	No real transformer can ever be 100% efficient, but practical transformers do have very high efficiencies (approaching, and sometimes exceeding, 99%). Do **not** just write “heating” or “heat loss” – try to give some detail of where and how the heat loss occurs.
6 (a) (i)	Use of $\frac{N_s}{N_p} = \frac{V_s}{V_p}$ gives $\frac{N_s}{3000} = \frac{12}{230}$ from which number of turns on secondary N_s = 157 or 156	1 1	Correct use of the turns ratio equation (which is given in the Data Booklet) should lead to two easy marks. The answer works out to be 156.52, but you must state it as a **whole number**. Transformers cannot have fractional numbers of turns!
6 (a) (ii)	Applying $P = IV$ for one lamp gives current in each lamp $I = \frac{P}{V} = \frac{30}{12} = 2.5$ A Total current supplied by transformer $I_{tot} = 8 \times 2.5 = 20$ A ∴ Total resistance of the lamps $R = \frac{V}{I_{tot}} = \frac{12}{20} = 0.60\ \Omega$	1 1 1	Part **(a)(ii)** depends on your familiarity with current electricity, covered in AS Physics. *Alternative solutions are possible* For example total power supplied = 8 × 30 = 240 W and using $P = \frac{V^2}{R}$ gives $R = \frac{V^2}{P} = \frac{12^2}{240} = 0.60\ \Omega$

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6 (a) (iii)	If transformer is perfectly efficient, primary power = secondary power (or $I_pV_p = I_sV_s$) Power input = primary power = secondary power = power output = 8 × 30 = 240 W	1 1 1	If a device is perfectly efficient, the energy supplied to it per second is equal to the energy it supplies per second. *Alternative solution*: $P_{out} = I_sV_s = 20 \times 12 = 240$ W Since the transformer is perfectly efficient, $P_{in} = P_{out} = 240$ W
6 (b)	*Relevant points include*: • The pendulum bob cuts through the magnetic flux of the field of the magnet • There is an induced emf in the bob • This emf causes circulating currents (eddy currents) in the brass bob • These currents cause thermal energy losses in the bob • The energy converted in this way comes from the kinetic energy of the bob, causing it to slow down rapidly that is, heavy damping	Any 4	Electromagnetic damping can be applied very successfully in practical devices, such as the electromagnetic retarders that are fitted to buses and coaches to enhance their braking systems. All rely on Lenz's law: the induced emfs act so as to oppose the change of flux producing them. *Alternative approach* instead of the last two points: · the currents in the bob produce magnetic fields . . . · which interact with the existing magnetic field to oppose the motion of the bob
7 (a) (i)	Power $P = I_{rms}V_{rms}$ gives $I_{rms} = \frac{P}{V_{rms}} = \frac{960\times10^3}{11\times10^3}$ = 87.3 A Peak current $I_0 = I_{rms}\sqrt{2}$ $87.3\sqrt{2}$ = 123 A or 120 A	1 1 1	Electrical power distribution relies on basic current electricity theory, which was covered in AS Physics. $P = IV$ applies to ac, just as it does to dc, provided rms values are used. The peak current is the instantaneous value of ac, whereas the rms current is a more meaningful average value.
7 (a) (ii)	Power lost from cables = $I_{rms}^2 R$ = $87.3^2 \times 1.8$ = 13.7×10^3 W ∴ power available at output end = 960 − 14 = 946 kW Percentage of input power available at output = $\frac{946}{960} \times 100$ = 98.5% or 98.6% or 99%.	1 1 1 1	Note that the mean power dissipated is proportional to I_{rms}^2, and not to I_0^2. (Part **(a)(i)** of this question could mislead you!) 11 kV is a standard distribution voltage used on local distribution networks. At 11 kV the power loss is slight. If you repeat this calculation for the same power line operated in the same way but at 3 kV, you will find that the output power is only 81% of the input power. The power loss increases as the operating voltage decreases, because the current increases.

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7 (b)	*Relevant points include*: · Power is lost from the cables (or pd is dropped along them) · Longer cables have greater resistance · Power lost from cables = $I_{rms}^2 r$ · Less power is wasted if a high voltage is used · Because at high voltage the current needed is less (for the same power) · ac voltages can be changed using transformers · Transformers cannot be operated by steady dc.	Any 5	The main object of modern power distribution networks, like the National Grid, is to minimise the power wasted as a result of the heating of the cables. This involves taking the power for as much of the distance as possible at the highest acceptable voltage. At the same time, the system must be safe – and high voltage electricity is inherently dangerous. The reduction in voltage is therefore carried out in stages by transformers at the consumers' end of the system: from the National Grid at 450 kV → 132 kV → 33 kV → 11 kV → 230 V at the consumer.
8 (a)	4 complete waves occur in 6cm, so the time period of 1 wave is $\frac{6 \times 20 \times 10^{-3}}{4}$ = 0.03 s So frequency = $\frac{1}{0.03}$ = 33 Hz or 33.3 Hz	1 1	Each large square represents 1 cm, so the wavelength can be found by simply multiplying the width of a wave by the time base setting. It's divided by 4 as there are 4 complete waves.
8 (b) (i)	Peak value = 2.6 × 0.1 = 0.26 V rms value = $\frac{0.26}{\sqrt{2}}$ = 0.18 V or 0.184 V	1 1	As with part (a), simply multiply the peak value (0.26) by the Y-gain (0.10).
8 (b) (ii)	$P = \frac{(V_{rms})^2}{R} = \frac{0.184^2}{470}$ = 720 μW or 719 μW	1	You may get a slightly different answer if you used a rounded value in the calculation.