Level 3 Physics: Demonstrate understanding of electrical systems –Inductors - Answers

In 2013, AS 91526 replaced AS 90523.

The Mess that is NCEA Assessment Schedules….

In AS 90523 there was an Evidence column with the correct answer and Achieved, Merit and Excellence columns explaining the required level of performance to get that grade. Each part of the question (row in the Assessment Schedule) contributed a single grade in either Criteria 1 (Explain stuff) or Criteria 2 (Solve stuff).

From 2003 to 2008, the NCEA shaded columns that were not relevant to that question.

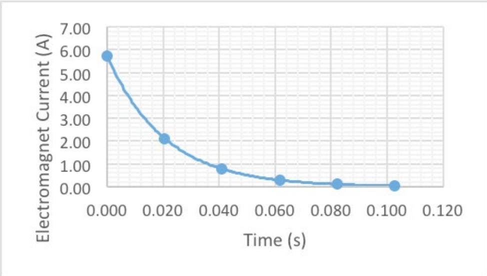
In 91526, from **2013 onwards**, each part of a question contributes to the overall Grade Score Marking of the question and there are no longer separate criteria. There is no shading anymore. There is no spoon. At least their equation editor has stopped displaying random characters over the units.

In **2018**, the Assessment Schedule states that the Marking convention is "a = 1, m = 2, e = 3 and for E at least one e is required and for M at least one m is required"

In **2019**, the Assessment Schedule states that the Marking convention is "a = 1, m = 2, e = 3 and for E at least one e is required"

Question	Evidence	Achievement	Merit	Excellence
2019(2) (a)	$V_{peak} = \sqrt{2} \times 24.0\ V_{RMS} = 33.9$ V	• 33.9 V		
(b)	Area = 1.60 m x 0.600 m = 0.960 m^2 Max B flux = $B \times A$ = 0.0413 T x 0.960 m^2 = 0.0396 Wb	• Correct method of calculating magnetic flux, but incorrect values used.	• 0.0396 Wb	
(c)	Reducing the inductance of the inductive loop would reduce the reactance of the circuit. The resistance remains unchanged, thus the overall impedance would be reduced, and so current would rise.	• ↓ *L* therefore ↑ *I* • ↓ *L*, ↓ *X*L / Z • Idea of changing magnetic flux inducing an **opposing** voltage.	• ↓ *L* results in ↓ *X*L and ↓ *Z* & *I* ↑ • Links changing magnetic flux with induced voltage and current, which in turn produces an opposing magnetic field, reducing the overall magnetic field, which then reduces the inductance.	

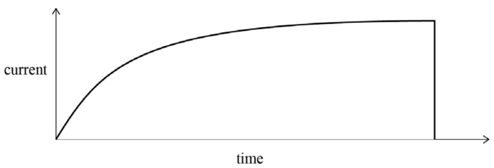
(d)	$f = 1.20\times10^2$ Hz, $L = 5.00\times10^{-3}$ H $X_L = 2\pi\times120\text{ Hz}\times0.005 = 3.77\ \Omega$ $R = 4.00\ \Omega$ $Z = \sqrt{R^2 + X_L^2}$ $= \sqrt{4.00^2 + 3.77^2}$ $Z = 5.496626\ \Omega$ $I = \frac{24.0\text{ V}}{4.496626\ \Omega} = 4.36631\text{ A} = 4.37\text{ A}$	• $X_L = 3.77\ \Omega$ • Z calculated with incorrect X_L value.	• $Z = 5.5\ \Omega$ • I calculation with incorrect Z value.	• $I = 4.37$ A
2018(2) (a)	$I = \frac{EMF}{\text{total } R}$ $= \frac{12.0\text{ V}}{(2.00\ \Omega + 0.09\ \Omega)}$ $= 5.74$ A	• $I = 5.74$ A		
(b)	When the switch is opened, the current / magnetic field collapse quickly creating a large rate of change of current / magnetic flux. Time constant = L/R and the opening of the switch creates a very large *R* (theoretically infinite) so the rate of change becomes very high (theoretically infinite). And so, since EMF = L dI/dt, this produces very large EMF (theoretically infinite).	• Change of current / magnetic flux creates an EMF in coil. • Large R small τ • Not restricted to Kirchhoff's Law *na: if mention of an induced CURRENT produced by the inductor*	• The RAPID change in current / magnetic flux creates and EXTREMELY LARGE EMF in the coil.	
(c)	Kirchhoff Voltage loop around outside of circuit: $+V_{battery} - V_{0.9\ \Omega} - V_{2.0\ \Omega} - V_{coil} = 0$ $+12\text{ V} - 2.0\text{ A} \times 0.09\ \Omega - I_{coil} \times 2.00\ \Omega - 9.00\text{ V} = 0$ $I = 1.41$ A	• Decent attempt at a KVL equation (allow mistakes) • $V_{2.00\ \Omega} = 2.82$ V • Calculates I in left loop = 0.597A (SHOW question)	• Correct working and answer $I = 1.41$ A (SHOW question)	

(d)(i)	[Accept with 20 Ω also t = 0.225]. $I_{\text{after }1\tau r}$ = 0.37 (5.72 A) = 2.12 A $I_{\text{after }2\tau r}$ = 0.37 (2.1164 A) = 0.783 A $I_{\text{after }3\tau r}$ = 0.37 (0.783068 A) = 0.290 A $I_{\text{after }4\tau r}$ = 0.37 (0.2897 A) = 0.107 A $I_{\text{after }5\tau r}$ = 0.37 (0.107 A) = 0.0397 A 	• τ = 0.0205 or 0.225 s • I after 1 time constant = 2.12 A • Draws roughly correct shape of graph (exponential decay). • Small R slows the change in current. • Small R, therefore, τ increases. • Provides alternate route for the current.	• TWO points calculated and plotted correctly. • Explains resistor's role in slowing the rate of change of current / reducing size of EMF induced.	• Correct graph AND • Explanation about R.
(ii)	The 20 Ω resistor provides a low resistance pathway for current to travel through. Low resistance means a large Time constant / slows the decrease in current. Since the rate of change of current is less, the EMF induced is smaller.			

2017(2) (a)	The voltage across the inductor will be zero once the current has reached a steady value.	Correct answer.		
(b)	When there is an inductor in a DC circuit, it takes a while for the current to reach the maximum because when the switch is switched on, the changing current results in changing flux. The changing flux creates an induced voltage across the inductor that opposes the source voltage and prevents the current from increasing rapidly.	One aspect correct.	Correct answer including reasoning and links.	
(c)	From the tangent line: $\frac{\Delta I}{\Delta t} = \frac{6}{0.10} = 60 \text{ A s}^{-1}$ $\varepsilon = L\frac{\Delta I}{\Delta t}$ $12 = L \times 60$ $L = \frac{12}{60} = 0.2 \text{ H}$	Correct rate of change of current. OR Correct use of EMF equation, but incorrect rate of change of current.	Correct answer with working.	

(d)	When the switch opens, the current in the first coil (primary) drops to zero very quickly. This causes a very rapid flux change in the primary. This flux change passes through the second coil (secondary). The rapid flux change causes a large induced EMF in the secondary. Because of the turns ratio, the secondary voltage is much greater than the primary voltage. This large secondary voltage is enough to cause a spark.	The current in the first coil (primary) drops to zero very quickly. This causes a very rapid flux change in the primary. This flux change passes through the second coil (secondary). The rapid flux change causes a large induced EMF in the secondary. Because of the turns ratio, the secondary voltage is much greater than the primary voltage.	Describes effect of opening switch affecting flux. AND Explains how this produces secondary voltage. (Voltage proportional to rate of change of current.)	Merit plus Large number of turns on secondary magnifies the voltage Large R results in small τ, so rate of change of current large therefore large voltage

2016(2) (a)	$\frac{N_P}{N_S} = \frac{V_P}{V_S}$ $N_P = \frac{V_P}{V_S} \times N_S = \frac{240}{12} \times 40 = 800 \text{ turns}$	Correct answer.		
(b)	An alternating voltage across the primary causes… An alternating current in the primary, which causes… An alternating magnetic flux in the core, which causes… An alternating voltage in the secondary, which causes… A current in the lamp.	Change in *B* / flux in primary. Induced *V* in secondary.	Links the two points.	

(c)	Graph as below. When the switch closes, there is an increase in current. This causes a back emf that opposes the current change. This causes the current to rise gradually. When the current reaches a maximum value, there is no flux change and no induced emf. The current is limited only by the resistance. When the switch opens, there is an open circuit; this means the current must drop to zero (almost) instantaneously. 	Graph correct. Explanation of the current change when the switch closes. Explanation of the constant current. Explanation of the current change when the switch opens.	Any two correct points.	Any three points.
(d)	$V = IR \quad I = \frac{V}{R} = \frac{6.0}{35} = 0.171\text{ A}$ $E = \frac{1}{2}LI^2$ $E = \frac{1}{2} \times 0.10 \times 0.171^2$ $E = 0.00147\text{ J}$	Correct current (0.171 A). Correct working for energy with incorrect current.	Correct answer: (1.47×10^{-3} J) 1.5 J 1.5 mJ	

2015(3) (a)	Inductors store energy as magnetic fields.	Magnetic fields.		
(b)	$V_R = IR = 0.26 \times 12.5 = 3.25\ V$ $V_L = V_S - V_R = 9.00 - 3.25 = 5.75\ V$ $V_L = -L\frac{dI}{dt}$ So $\frac{dI}{dt} = \frac{V_L}{L} = \frac{5.75}{10 \times 10^{-3}} = 575\ A\ s^{-1}$	V_R calculated. AND V_L calculated.	V_R calculated. V_L calculated. $\frac{dI}{dt}$ calculated.	
(c)	When the switch is closed, the change in current, $\frac{dI}{dt}$, is very great so the reactive inductor opposes the change in current (producing a back emf), so most of the current goes through the bulb (as these two components are in parallel). As $\frac{dI}{dt}$ becomes smaller, the opposition of the inductor (its effective resistance) becomes smaller so more current flows through the inductor and less through the bulb.	Explains why initially little current flows through the inductor. Inductor produces a back emf / induced voltage Less current in bulb, less Power	Explains why initially little current flows through the inductor AND Explains why finally most of the current flows through the inductor and not the resistor.	Explains why there is a change in I AND Less current in bulb, less Power

(d)	A changing (alternating) current inducing a changing (fluctuating) magnetic field around the coil of wire. The size of the field is determined by the frequency of the alternating current. Changing / fluctuating magnetic fields cause currents to flow in the bicycle wheels. By Lenz's law, a current creates a magnetic field that opposes the magnetic field that created it – the higher the frequency, the greater the eddy currents. The induced magnetic field always opposes or reduces the field that created it.	Alternating currents have fluctuating magnetic fields/flux. Changing flux will induce a voltage Opposite direction due to Lenz's Law. High frequency results in large induced voltage / (rate of) change in current.	Changing flux results in an induced voltage / current / field (Faraday's Law). AND It will be large because rate of flux change is large due to high frequency. OR Changing flux results in an induced voltage / current / field (Faraday's Law). AND It is in opposite direction to oppose change/ the current (Lenz's Law).	Changing flux results in an induced voltage / current / field (Faraday's Law). AND It will be large because rate of flux change is large due to high frequency. AND It is in opposite direction to oppose change / the current (Lenz's Law).
2014(3) (d)	As soon as current starts to change from its original zero value, current, and hence flux, in the inductor is changing. Changing flux in an inductor induces a voltage, which will act to oppose the change that is making it.	The inductor slows / opposes the change in current. (not "decreases the current"). A voltage is induced to oppose the changing current. Voltage induced due to changing flux/magnetic field.	Changing current linked to changing flux, causing a voltage that opposes the changing current. Takes longer for current to decrease because induced voltage opposes the change. Opposing voltage induced due to rate of change of current.	Changing current linked to changing flux, causing a voltage that opposes the changing current therefore the current takes longer to decrease.

(e)	When the capacitor is fully charged, energy is stored in its electric field ($E = ½QV$). When the capacitor is fully charged, the current is zero, so no energy is stored by the inductor ($E = ½LI^2$). When the capacitor discharges, Q goes down, so less energy is stored. While the capacitor is discharging, there is increasing current in the circuit, so energy is stored by the inductor. The energy stored by the inductor comes from the energy lost by the capacitor.	A capacitor stores energy in an electric field. An inductor stores energy in a magnetic field. Energy of capacitor decreases and energy of inductor increases. When the capacitor is fully charged, the current is zero, so no energy is stored by the inductor. When the capacitor discharges, V / Q goes down, so less energy is stored. While the capacitor is discharging, there is increasing current in the circuit, so energy is stored by the inductor. Energy of inductor increases because current in the circuit increases.	Energy (in the electric field) of the capacitor is decreasing because energy depends on charge / *V*, and charge / *V* is decreasing. Energy (in the magnetic field) of the inductor is increasing because energy depends on current, and current is increasing. Energy is transferred from the electric field of the capacitor to the magnetic field of the inductor.	Full explanation linking the rate of drop in energy stored in electric field of capacitor to rise in energy stored in magnetic field of inductor. OR Energy (in the electric field) of the capacitor is decreasing because energy depends on charge / *V*, and charge / *V* is decreasing. AND Energy (in the magnetic field) of the inductor is increasing because energy depends on current, and current is increasing.

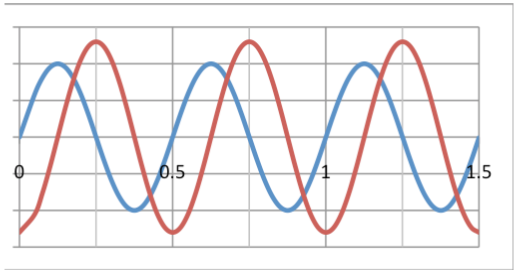
2013(2) (a)	$E = \frac{1}{2}LI^2 = 0.5 \times 0.510 \times 1.70^2 = 0.73695 = 0.737\text{ J}$	Correct answer 0.737 (J).		
(b)	$V = Ir \Rightarrow r = \frac{120}{1.70} = 70.588 = 70.6\,\Omega$ (*r* is the internal resistance of the inductor). The maximum current is inversely proportional to *r.*	Correct value 70.6 Ω. Correct explanation.		
(c)	When the switch is closed the current starts to increase from zero, and so there is increasing flux in the coil. The emf induced by the changing flux will oppose the changing current making it take longer to build up to its maximum value.	ONE correct statement. OR Greater the inductance, the longer the time for the current to reach the max value. T is directly proportional to L ($\tau = \frac{L}{R}$),	Both correct statements.	
(d)	Nothing because the gap AB is effectively on open switch so nothing changes.	Nothing.	Nothing. Because the gap acts as an open switch / circuit. Do not accept being in parallel as a reason.	

(e)	When switch 1 is opened. the current in the circuit will drop to zero and while it is changing a voltage is induced in the inductor. Because there is no longer a battery in the circuit, the induced voltage is no longer limited by the voltage of the battery so the rate of change of current, and hence induced voltage, depends on the time constant of the circuit. As the gap is effectively a huge resistance the time constant is very small so the rate of change of current and hence induced voltage is very high – high enough to produce a spark.	Recognition that the battery is no longer limiting the size of the induced voltage. OR Large induced voltage across inductor linked to change in current when switch 1 is opened. OR Current dies very quickly. OR Energy stored in the inductor is released.	Large induced voltage across inductor linked to rapid change in current when switch 1 is opened. AND Due to very short time (constant). OR Kirchoff's law does not apply due to switch being open. OR The Induced voltage can exceed the battery voltage due to the open switch.	Explanation shows complete understanding that opening the switch will produce a very high induced voltage because the rate of change of current will be very high because the time constant will be very small because the resistance will be very big.
2012(2) (a)	As the motor turns, the flux through the coils of the motor changes, inducing an EMF across the ends of the coil. The EMF is proportional to the rate of change of flux so the faster the motor spins the greater the EMF. The induced EMF will oppose the EMF from the battery, so it will limit the current in the coil. (This limits the amount of energy that is used from the battery.) (When switch is closed, the current is changing and it induces a voltage.)	ONE correct statement.	TWO correct statements.	Full correct answer linking Motor rotation to change of flux. The Induced EMF increase with greater speed as rate of change of flux increase Induced emf opposing the current so current is reduced.

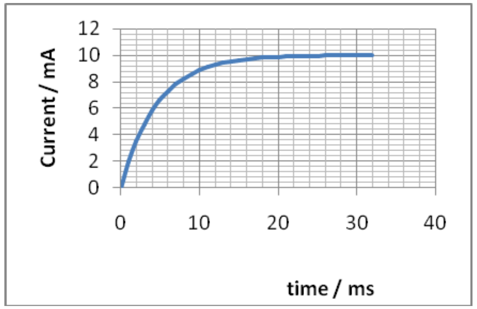
2011(3) (a)	Resistance of circuit: 2.0 + 4.0 + 300 = 306 Ω Current in circuit $I = \frac{V}{R} = \frac{1.48}{306} = 4.83 \times 10^{-3}$ A = 4.84 mA	Correct resistance.	Correct answer.	
(b)	The voltage across the load will be much lower than in (a) because • The cell will drive a large current through the switch because it is a low resistance path • causing a larger voltage drop across the internal resistance and the inductor because the total voltage around the loop cannot exceed 1.48 V OR Assuming the switch has no resistance, there is no voltage drop across the switch, even with a high current. The load is in parallel with the switch so it too has no voltage – hence the voltage is much lower than in (a).	Lower voltage with one bullet point reason. OR Zero / much lower voltage.	Correct answer (much lower Voltage across load) with clear complete reasoning.	

(c)	When the switch turns off, there is rapid drop in current, so a large emf is induced in the forward direction to keep the current going (by Faraday's law). Because this emf is proportional to the rate of change of current, the rapid decrease in current produces an emf greater than the battery.	Voltage induced in the coil / due to change in I / Φ / magnetic field.	High Voltage induced in the coil / due to rapid change in I / Φ / magnetic field.	Complete answer showing clear link between induced voltage, rapid drop that causes it: also states or implies that this must only be from the switch opening in order to add to the cell EMF (because Lenz's law applies).
(d)	Applying Kirchhoff's voltage law: $V = 1.48 + 15 = 16.48$ $R = 2 + 4 + 300 = 306$ $I = \frac{V}{R} = \frac{16.48}{306}$ $V = IR = \frac{16.48}{306} \times 300 = 16.16\text{ V}$	Adds resistors to find total resistance in circuit.	Correctly writes equation using Kirchhoff's voltage law. OR correct current OR Correct ratio $V = 300 / 306 \times 16.48$	Correct answer.
2010(1) (c)(i)	An emf is <u>induced</u> due to a rapid change of current / flux when the switch is opened. The emf > 25 V so the bulb lights. The bulb cannot light when only connected to 12 V.	High enough voltage / >25V / much higher than 12V induced in the coil / due to change in I / ϕ / magnetic field	High enough Voltage / >25V / much higher than 12V induced in the coil/due to rapid change in I / ϕ / magnetic field	[1] Complete answer showing clear link between sufficient voltage, rapid change that causes it: also states <u>or implies</u> that this is the only time that the light will go on.

(ii)	They have to wait for the current to build up in the inductor before switching off. AND The time constant for the circuit is 0.79 s, so 10 s much longer than this. OR The change in current / flux needs to be large enough to cause a high enough voltage to be induced.	They have to wait for the current to build up in the inductor before switching off.	Complete answer.	
2010(3) (a)	$\phi_{max} = BA = 0.35 \times 0.015 = 5.25 \times 10^{-3}\ \text{T m}^2$ (or 0.0053)	Correct answer.		
(b)	$V_{max} = BAN\omega = 0.35 \times 0.15 \times 500 \times 220$ $= 577.5\ \text{V}$ $V_{rms} = \frac{V_{max}}{\sqrt{2}} = \frac{577.5}{\sqrt{2}} = 408 = 410\ \text{V}$	Correct V_{max}. or correctly converts a V_{max} to V_{rms} by dividing by $\sqrt{2}$ (1.414), or correct answer without unit or to wrong s.f.	Correct answer. Must be to 2 sf and with units V.	

(c)	 The induced voltage will vary according to a negative cosine graph. This is because the magnitude of the voltage is equal to the rate of change of magnetic flux. $\varepsilon = -\frac{\Delta\phi}{\Delta t}$ So *V* is max and positive when the gradient of the ϕ–*t* line is steep and negative, etc.	Either Faraday or Lens'z law correct in words or graph (+cos or –sin).	Correct graph (–ve cosine curve). OR Either Faraday's or Lenz's law correctly explained.	Graph (or description of V/t as negative cosine curve / or lagging by ¼ cycle) correct and links to Faraday's law.
2009(2) (a)	A voltage is induced in an inductor when the flux in it is changing. Flux changes when the current changes. As the current is continuously changing, there will always be an induced voltage.	Idea of changing current or flux	Induced voltage linked to changing flux which is linked to changing current.	
(b)(i)	$V_L = L\frac{\Delta I}{\Delta t}$ $= 5.50 \times \frac{(9.00 - 8.00)\times 10^{-3}}{5.00\times 10^{-3}} = 1.10$ V	Correct working.		

(b)(ii)	The direction of the induced voltage is the same as the supply. The current is decreasing. The voltage induced by this changing current will be such that it will try to stop the current decreasing, and so will be in the same direction as the supply.	Correct direction clearly indicated.	Correct reason	
(c)	$V_L = -L\frac{\Delta I}{\Delta t} \Rightarrow \frac{\Delta I}{\Delta t} = -\frac{V_L}{L}$ Need to find V_L $V_S = V_R + V_L$, $V_R = IR = 7.75 \times 10^{-3} \times 1.2 \times 10^{3} = 9.3$ V $V_L = 11.5 - 9.3 = 2.2$ V $\frac{\Delta I}{\Delta t} = \frac{2.2}{5.5} = 0.40\ As^{-1}$	Correct calculation of V_R.	Correct calculation of V_L.	Correct answer.

(d)	 $\tau = \frac{L}{R} = \frac{5.5}{1200}$ = 4.6 ms $I = \frac{V}{R} = \frac{12}{1.2}$ = 10 mA At t = 4.6 ms, current plotted at 63% of its final value: i.e. at 6.3 mA.	Correct shape graph. OR [2]Correct calculation of time constant or final current.	Correct calculation of time constant and final current. Correct shape of graph is.	Complete correct graph with correct plot at t = 1τ. Can be used for either criterion 1 or 2.
2008(1) (f)	$\tau = \frac{L}{R} \Rightarrow L = \tau R$ $L = 1.2 \times 10^{-3} \times 7.90 = 9.48 \times 10^{-3}$ H $= 9.5 \times 10^{-3}$ H (= 9.5 mH)	Correct Value 2 sf + correct units (H) and in 3(a) (m^2).		

(g)	An inductor is a component that has significant inductance, *L*. As the current changes $\frac{\Delta I}{\Delta t}$ an emf is produced which opposes the flow of the current. Reduces the rate of change of current. Back emf decreases over time Hence current increase over time to a steady rate – bulb brightens gradually This opposing emf cannot be bigger than the forward emf, putting a limit on $\frac{\Delta I}{\Delta t}$. The bulb only glows when sufficient current (ΔI) flows which, due to 3, is after certain time.	delay is because the inductor produces a magnetic field, which induces a back emf in the inductor. OR The inductor limits rate of change of current.	Inductance related to back emf, hence limit on build-up of current / brightness.	Complete answer links equation to gradual build-up of current and decreasing rate of change of current/decreasing back emf
(h)	$\left(\frac{\Delta V}{\Delta t}\right) = \frac{200}{0.002} = 100 \times 10^3$	Correct working. – any appropriate slope calculation with data from graph OR use dV/dt from sin function		
(i)	The 6 V is the rms value because the rms value of ac is the equivalent dc voltage that gives the same average power as the ac. As the lamp is about the same brightness the power output must be about the same.	Rms.	Rms with reason: same average power as dc, or same brightness / heating and light effect as dc.	

(j)	$\varepsilon = -M\frac{\Delta I}{\Delta t}$ $M = \frac{\varepsilon}{\left(\Delta I/\Delta t\right)} = \frac{\varepsilon_{max}}{\left(\Delta I/\Delta t\right)_{max}}$ $M = \frac{6\times\sqrt{2}}{8.7} = 0.98\text{ H } = 1\text{ H}$	Correct calc of peak voltage (8.48 V). OR use rms voltage gives *M* = 0.69/0.7 H		Correct answer.
2007(2) (a)	While the current is changing, the flux in the coil is changing. This changing flux will link the turns of the coil, inducing a voltage across it.	Idea of changing current causes a back EMF or an opposing voltage or correctly explains $\varepsilon = -L\frac{\Delta I}{\Delta t}$ Using voltage ideas not current)	Idea of changing current AND Changing current linked to changing flux (or changing magnetic field) and hence induced voltage.	
(b)	$\varepsilon = -L\frac{\Delta I}{\Delta t} \Rightarrow 0.004 = L\left(\frac{1.62-0.13}{1.2}\right) = L\frac{1.49}{1.2}$ $L = \frac{4.0\times10^{-3}\times1.2}{1.62-0.13}$ $= 3.2215 \times 10^{-3} = 3.2 \times 10^{-3}$ H		Correct answer.	

2006(2) (a)	$\varepsilon = -L\frac{\Delta I}{\Delta t}$ $\Delta I = \frac{25}{220} = 0.113636$ $\varepsilon = 0.35 \times \frac{0.113636}{5 \times 1.59091 \times 10^{-3}}$ = 5.00000 = 5.0 V	Recognition that when the current is steady the inductor offers no impedance.	Correct working for V using incorrect ΔI *OR* Correct ΔI.	Correct working.
(b)	$\varepsilon = -\frac{\Delta\phi}{\Delta t}$ $\Delta\phi = 5.00000 \times 5 \times 1.59091 \times 10^{-3}$ = 0.039773 = 0.040 Wb		Correct answer (Accept if $\phi = LI$ used).	
(c)	When the switch is closed, the inductor is in a closed loop and so the voltages around the circuit must sum to zero (Kirchhoff's Law). This means the maximum voltage across the inductor is limited to 25 V. (Or: When the switch is closed the time constant of the circuit means the current will rise fairly slowly, meaning that the rate of change of current, and hence induced voltage, will be low.) When the switch is opened the broken circuit causes the current to collapse very quickly and this high rate of change of current induces a high voltage in the inductor.	One correct and relevant statement.	Induced voltage linked to higher rate of change of current / flux when switch opened compared to when switch closed. OR Difference in induced voltage explained in terms of Kirchhoff's Law.	Merit plus a reason given for the high rate of change of current / flux when switch is opened.

2005(2) (a)	$R = \frac{V}{I} = \frac{12}{0.152} = 78.9 = 79\ \Omega$ Note: Units and SF mark for this question	Correct answer. Answer rounded to 2sf PLUS TWO correct units from Q1e, 2a, 2c, 2d		

(b)	The coil acts as inductor. When the current is turned on the coil produces a magnetic field. Because there is now a magnetic field where there was none before, there has been an increase in magnetic flux. This change in magnetic flux induces a voltage. The direction of the voltage will act to oppose the increase in magnetic flux and therefore will oppose the supply voltage, hence slowing down the rate at which the current builds up in the circuit.	ONE correct and relevant statement: When switched on there has been a change in current. There has been an increase [change] in magnetic flux [field]. Voltage is induced. (Induced) voltage opposes battery (voltage). Back emf produced. Do not accept opposing or back currents as a relevant statement.	Explanation correctly includes EITHER Faraday's law - Change in current produces a change in magnetic flux *OR* Change in magnetic flux (field) induces a voltage Accept $\varepsilon = \frac{\Delta\varphi}{\Delta t}$ as long as terms are explained. OR Lenz's law - The direction of the (induced) voltage will act to oppose the increase in magnetic flux or increase in current OR The direction of the (induced) voltage will act to oppose the battery (voltage) $\varepsilon = (-)\frac{\Delta\varphi}{\Delta t}$ Only if (-) is explained If they use back currents in their linkages, they cannot get Merit.	Complete explanation correctly includes BOTH Faraday's and Lenz's laws. Change in current produces a change in magnetic flux Change in magnetic flux (field) induces a voltage The direction of the voltage will act to oppose the increase in magnetic flux or the battery voltage or the increase in current.

(c)	$I_{max} = 0.152$ A Time constant = time for current to reach 63% of I_{max} (= 0.63 × 0.152 = 0.0958 A) From graph this occurs at t = 2.0 ms Hence $\tau = 0.0020 \pm 0.002$ s But $\tau = \frac{L}{R} = \frac{L}{79}$ $L = 79 \times 0.0020 = 0.158 = 0.16$ H ***or*** slope of line is approx $\frac{0.14}{2 \times 10^{-3}} = 70$ (accept ± 10) $L = \frac{V}{slope} = \frac{12}{70} = 0.17$H **Watch consistency with 2(a).**		*Correct time constant* *τ =0.002 s (2 ms)* ***or*** *consistent L from incorrect value of τ.* *(Must be a reasonable value 0.0020 ± 0.0002 or* *2.0 ± 0.2)* *Eg* *157.89 H (from τ =2 s)* ***or*** Correct slope 70 ± 10	Correct answer.