Level 3 Physics: Demonstrate understanding of electrical systems – AC Electricity - 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"

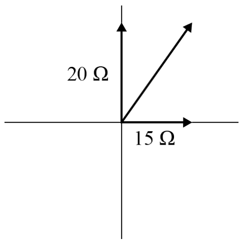
Question	Evidence	Achievement	Merit	Excellence
2019(1) (c)	Alternating current in the reader induces a changing magnetic field in the payment machine coil. When the coil in the card is near enough the changing magnetic field of the payment machine coil creates a change flux inside the card coil, which then induces a voltage in the coil.	• Changing current / voltage in payment machine coil produces a changing magnetic field / flux • Change in flux in card induces voltage	• Full response **Do NOT accept induced current induces a voltage.**	
(d)	Resonance under the condition ($X_L = X_C$) $X_L = \frac{1}{2\pi f C}$ $427\ \Omega = \frac{1}{2\pi \times 13.6 \times 10^6 \times C}$ $C = 2.74 \times 10^{-11}$ F	• $X_L = X_C$ • $X_C = 427\Omega$ • C = 2.74 x 10^{-11} F	• X_L = X_C AN D • C = 2.74 x 10^{-11} F	

2018(3) (b)	$I_{lamp} = \frac{V_{lamp}}{R_{lamp}}$ $= \frac{4.64\text{ V}}{5.00\ \Omega} = 0.928\text{ A}$ $X_L = \frac{V_L}{I} = \frac{11.1\text{ V}}{0.928\text{ A}}$ $= 11.96\ \Omega$ $X_L = 2\pi fL$ $11.96\ \Omega = 2\pi \times 50\text{ Hz} \times L$ $L = 0.0380698\text{ H} = 0.0381\text{ H}$	• X_L = 12.0 Ω • I = 0.928 A • I_{max} = 1.31 A • Θ = 67.3°	• L = 0.0381 H with correct working shown. (SHOW question)	
(c)	Vector Diagram $X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 400\text{ Hz} \times 9.45 \times 10^{-7}\text{F}}$ $= 421.0448\ \Omega$ $X_L = 2\pi f L = 2\pi \times 400 H \times 0.0381\text{ H}$ $= 95.72853\ \Omega$ $Z^2 = X_{total}{}^2 + R^2$ $Z^2 = (421.0448\ \Omega - 95.72853\ \Omega)^2 + (5.00\ \Omega)^2$ $Z = 325\ \Omega$	• X_{total} = 325 Ω ($X_C - X_L$) • X_L = 96 Ω • X_C = 421 Ω • Z = 3368 Ω	• Z = 325 Ω with correct working shown.	

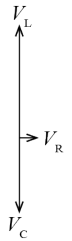
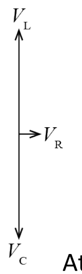
(d)(i) (ii)	$f_o = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(3.81\times10^{-2}\text{ Hz})(9.45\times10^{-7}\text{ F})}}$ $= 838.768\text{ Hz} = 839\text{ Hz}$ This is higher than the 400 Hz of the power supply. Resonant frequency can be lowered by increasing *L* and / or increasing *C*. *C* can be increased by: • pushing the plates closer together / using a thinner piece of rubber (lower *d*) • larger copper plates (larger *A*) • using a higher dielectric material (larger ε_r). *L* can be increased by: • adding more coils • using a core with higher permittivity • larger core / coil area • reduce the length of the coil whilst keeping the number of coils the same.	• f_o = 839 Hz • Recognizes resonant frequency can be lowered by increasing *L* and / or *C*. • Suggests one change that would increase *L* or *C*. • Decrease Z • $X_L = X_C$	• f_o = 839 Hz AND Suggests any physical change that results in higher *C* OR higher *L*. AND Links it to raising *C* OR *L* to lower f_o. • Incorrect resonant frequency is calculated. AND At least one change is suggested that would raise/decrease *L* AND *C* (depending whether incorrect f is too small or too large). • f_o = 839 Hz AND Suggests that both Land C must increase.	• Correct resonant frequency is calculated. AND At least one change is suggested that would raise *L* AND *C*.

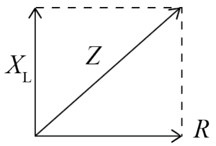
2017(3) (a)	$V_{max} = \sqrt{2}V_{rms} = \sqrt{2} \times 12.0 = 17.0 \text{ V (or 17 V)}$	Correct answer.		
(b)	$Z = \sqrt{50^2 + 23.5^2} = 55.2\ \Omega$ $I = \dfrac{12.0}{55.2} = 0.217 \text{ A (or 0.22 A)}$	One correct answer.	Both correct answers.	
(c)	The capacitance will increase because the dielectric constant will increase. Hence the reactance of the capacitor will decrease. $X_c = \dfrac{1}{2\pi fC}$	Effect on capacitance or reactance of the circuit.	Links to the effect on circuit current.	
(d)	$f = \dfrac{1}{2\pi\sqrt{LC}}$ $X_L = 2\pi fL \Rightarrow L = \dfrac{X_L}{2\pi f} \Rightarrow L = \dfrac{35.7}{2\pi \times 150} = 0.03762 \text{ H}$ $X_C = \dfrac{1}{2\pi fC} \Rightarrow C = \dfrac{1}{2\pi \times 150 \times 23.5} \Rightarrow C = 4.485 \times 10^{-5} \text{ F}$ $f = \dfrac{1}{2\pi\sqrt{0.03787 \times 4.515 \times 10^{-5}}} \Rightarrow f = 122 \text{ Hz}$ At resonance, the reactance of the inductor is equal to the reactance of the capacitor and they are of opposite phase, cancelling each other. Hence the impedance of the circuit is a minimum and is equal to the resistance of the resistor. Hence the size of the circuit current at resonance is a maximum as current is inversely proportional to resistance.	L = 0.0376 H $C = 4.485 \times 10^{-5}$ F X_C & X_L cancel out Z is minimum $Z = R$	f = 122 Hz Correct explanation	Correct answer for calculation and explanation.

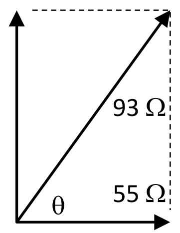
2016(3) (a)	$V_{peak} = V_{rms} \times \sqrt{2}$ $V_{peak} = 6.00 \times \sqrt{2} = 8.49\text{ V}$	Correct answer.		
(b)	Iron in the core will increase the coil's reactance. Impedance = reactance + resistance Increasing the reactance causes the impedance to increase. $V = IZ \quad \text{so} \quad I = \frac{V}{Z}$ This causes the current to decrease (*V* is constant).	X_L / L / Z increases.	X_L / L and Z increases.	

(c)	$X_L = \omega L \qquad \omega = 2\pi f$ $X_L = 2\pi f L$ $X_L = 2\pi \times 1000 \times 3.18 \times 10^{-3}$ $X_L = 20.0\ \Omega$  Resistance = 15.0 Ω Reactance = 20.0 Ω Impedance = $Z = \sqrt{R^2 + X^2}$ $Z = \sqrt{15^2 + 20^2}$ $Z = 25.0\ \Omega$ $I = \frac{V}{Z} = \frac{6.00}{25.0} = 0.24\text{ A}$	Correct phasor diagram with labels Correct inductor reactance Correct working for Z and I but uses L as X_L or f as ω	One error	Correct phasor diagram, and calculation of impedance AND current. I = 0.24 (*I* = 0.212 A)

(d)	The voltages across the capacitor and inductor are out of phase (opposite direction), so partially (or totally) cancel out. The supply voltage is constant. So the resistor voltage will increase and the current will increase. $\left(I = \frac{V_s}{Z}\right)$ OR The reactance of the inductor and capacitor are out of phase (opposite direction), so partially (or totally) cancel out. $\left(Z = \sqrt{X_C^2 + X_L^2}\right)$ The supply voltage is constant, so the current will increase. $\left(I = \frac{V_s}{Z}\right)$	Voltage or reactance phasors are out of phase, so partially cancel out. Impedance decreases, so current increases. (The supply voltage is constant.)	Voltage or reactance phasors are out of phase, so partially cancel out. AND Impedance decreases, so current increases. (The supply voltage is constant.)	
2015(1) (a)	$\omega = 2\pi f$ $\omega = 2\pi \times 50 = 314$	$\omega = 314\ \text{s}^{-1}$		
(b)	$X_L = \omega L = 2\pi f L$ $X_L = 2\pi \times 50 \times 0.150 = 47.1\ \Omega$	Correct workings shown. **(SHOW THAT Q)**		

(c)	$V_L = IX_L = 0.656 \times 47.1 = 30.9\text{ V}$ $V_R = IR = 0.656 \times 10.0 = 6.56\text{ V}$ 	Calculates values for V_L and V_R. OR Draws phasors to represent V_C and V_L and V_R with correct phase shift.	Calculates values for V_L and V_R. AND Draws phasors to represent V_C and V_L and V_R with correct phase shift.	Calculates values for V_L and V_R. AND Draws phasors to represent V_C and V_L and V_R with correct phase shift and **correct sizes.**
(d)	In an AC circuit, V_L and V_C are 180° out of phase. At resonance, $X_L = X_C$ so $X_L - X_C = 0$ $Z = R$ so $I = \frac{V}{R} = \frac{12}{10} = 1.20\text{ A}$	V_L and V_C are 180° out of phase. $X_L = X_C$ $V_L = V_C$ I = 1.20 A (no explanation)	The impedance of the inductor and the capacitor cancel out, due to the opposite phase of the capacitor and the inductor therefore $Z = R$. OR $X_L = X_C$, $Z = R$ OR Excellence answer but no explanation that Z is minimum	Explains why the impedance of the circuit is a minimum ie it equals the resistance of the circuit at resonance, describing the equal reactance but opposite phase of the inductance and the capacitance so $I = \frac{V}{R} = \frac{12}{10} = 1.20\text{ A}$
2014(1) (a)(i)	$\frac{N_p}{N_s} = \frac{V_p}{V_s}$ $\frac{3000}{600} = \frac{240}{V_s}$ $V_s = 48\text{ V}_{rms}$	$V_s = 48\text{ V}_{rms}$		

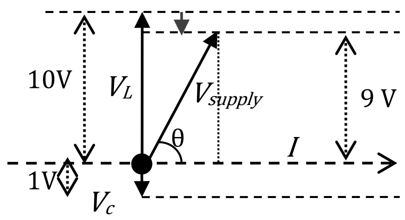
(ii)	$V_{peak} = \sqrt{2} \times V_{rms}$ $V_{peak} = \sqrt{2} \times 48$ $V_{peak} = 67.9\text{ V}$	V_{peak} = 67.89 V $V_{peak} = \sqrt{2} \times V_{rms}$ **used with incorrect** V_{rms}.		
(b)	The rms voltage is the root mean squared voltage. The rms is a kind of average voltage used because the average of a sin function over time is zero. The rms voltage has the same magnitude as the DC voltage that would deliver the same power output as the AC voltage being described.	The rms is a kind of average voltage, used because the average voltage is zero because the voltage varies / sin wave. The rms voltage has the same magnitude as the DC voltage that would deliver the same power output as the AC voltage being described. Sketch showing AC voltage, average *V* and V_{rms}. Peak values reached for a short time only because of sin curve / *V* increasing and decreasing (it is the average *V* is **wrong**).		
(c)	$X_L = 2\pi fL = 2 \times \pi \times 50.0 \times 0.0165 = 5.184\ \Omega$ $Z = \sqrt{X_L^2 + R^2}$ $Z = \sqrt{5.184^2 + 3.69^2} = 6.36\ \Omega$ 	X_L= 5.2 Ω. Correct method of calculating *Z* using incorrect reactance. Correct phasor. No phasor but correct explanation.	Correct phasor diagram drawn with correct explanation. *Z* = 6.36 Ω.	

(d)	$X_C = X_L = 5.184$ $I_{rms} = \frac{V_{rms}}{R} = \frac{48.0}{3.69} = 13.01\text{ A}$ $V_C = I \times X_C = 13.01 \times 5.184 = 67.4\text{ V}$	$X_C = X_L$ $V_C = V_L$ $Z = R$ Calculated f_0 and then X_C (X_L correct in 1c).	$I_{rms} = \frac{V_{rms}}{R} = \frac{48.0}{3.69}$ $= 13.01\text{ A}$ Calculated f_0 and then X_C (X_L not calculated in 1c)	$V_C = I \times X_C = 13.01 \times 5.184$ $= 67.4\text{ V}$
2013(3) (a)	$X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 450 \times 15.0 \times 10^{-6}}$ $= 23.58 = 24\ \Omega$	Correct answer.		
(b)	The current is in phase with the resistance and the supply voltage is in phase with the impedance.  $\theta = \cos^{-1}\frac{55}{93} = 53.74$ Current lags the supply voltage by 54° or 0.94 rad.	Recognition that voltage phase difference is the same as impedance phase difference. OR θ is labelled correctly in the diagram	Correct answer. 54° or 0.89 rad	
(c)	$X_{tot} = X_L - X_C$ $Z^2 = X_{tot}^2 + R^2 \Rightarrow X_{tot} = \sqrt{Z^2 - R^2}$ $\Rightarrow X_{tot} = \sqrt{93^2 - 55^2} = 74.99\ \Omega$ $\Rightarrow X_L = 74.99 + 23.58 = 98.57 = 99\ \Omega$	Correct X_{tot}. 75Ω OR If the value of XL is substituted as 98.6 and then Z is calculated as 93 Ω.	Correct answer 99 Ω.	

(d)	To bring the circuit to resonance, the frequency must be changed to make the two reactances equal in value. X_L is directly proportional to *f* and X_C is inversely proportional to *f* so changing the frequency will increase one but decrease the other. $X_L > X_C$ and so to decrease X_L and increase X_C, frequency must be **decreased**.	Recognition that the frequency has to be **decreased** to make the $X_c = X_L$. OR Recognition that the frequency has to be **decreased**, as by decreasing *f*, the X_L decreases and X_C increases.	Achievement + By decreasing *f*, the X_L decreases and X_C increases.	
(e)	$220 = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{L \times 15.0 \times 10^{-6}}}$ $L = 0.0350 \text{ H}$	Correct answer. 0.0350H.		
(f)	When the circuit is in resonance, the current is greatest because the reactance is zero and so the impedance is smallest. When the current is greatest the sound from the speaker is loudest. The current decreases rapidly either side of resonance because the reactance increases either side of resonance. So if the frequency is reduced quickly through the resonant frequency and down below it, there will be a brief surge of current and so a brief burst of sound.	Recognition that the max sound happens at resonance. OR Recognition that the frequency must be changed down through the resonant frequency. OR Current-frequency diagram.	Achievement. AND Maximum current at resonance explained.	Full explanation linking greatest sound to maximum current and zero reactance / impedance = *R* at resonance Rapid decline in current either side of resonance requires bringing the frequency quickly through the resonant frequency.
2012(3) (a)	$2\pi fL = X_L$ $2\pi \times 2.7 \times 10^7 \times 1.00 \times 10^{-6} = X_L$ $= 169.6\ \Omega$ $\approx 170\ \Omega$	[2]Correct working.		

(b)	$Z=\sqrt{170^2+47^2}$ $Z=176.4\ \Omega$ $I=\frac{V}{Z}$ $I=\frac{5.00}{176}$ $I=0.0283\text{ A}$	[2]Correct impedance. 176.4 Ω OR Incorrect impedance but consequentially correct calculation for current. [1]3 sf for the current value.	[2] Correct current. 28.3mA	
(c)	At resonance $X_C = X_L$ $X_C=\frac{1}{2\pi fC}$ $169.6=\frac{1}{2\pi\times 2.70\times 10^7\times C}$ $C=3.47\times 10^{-11}\text{ F}$	[1]Demonstrates knowledge that at resonance. $X_c = X_L$. [1] 3 sf	[2]Correct answer.	

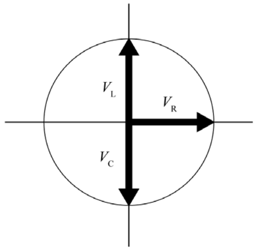
(d)	The current caused by 49 MHz circuit is much smaller than the current caused by 27MHz. At 49 MHz, XL increases and Xc decreases, increasing the overall impedance, thus current decreases and the toy car does not respond due to smaller current. At 27.0 MHz $Z = 47\ \Omega$ the current will be $I = \frac{5.00}{Z}$ $I = \frac{5.00}{47}$ $I = 106\text{ mA}$ At 49.0 MHz $2\pi \times 4.90 \times 10^7 \times 1.00 \times 10^{-6} = X_L$ $307.9\ \Omega = X_L$ $X_C = \frac{1}{2\pi \times 4.90 \times 10^7 \times 3.47 \times 10^{-11}}$ $X_C = 93.6\ \Omega$ $Z = \sqrt{(307.9 - 93.6)^2 + 47^2}$ $Z = 219\ \Omega$ $I = \frac{5.00}{219} = 22.8\text{ mA}$	Circuit has greater impedance to 49 MHz. OR 49 MHz produces less current. [1 or 2]Finds current 106 mA at 27.0 MHz.	At 49 MHz, X_L increase and X_c decreases. (So, the total impedance increases) and the current decreases. [1 or 2] Correct current 106mA and correct Z at 49 MHz, 219 Ω. OR Incorrect value for 106 mA, but correct value 22.8 mA.	[2]Correct current values 106 mA and 22.8 mA.

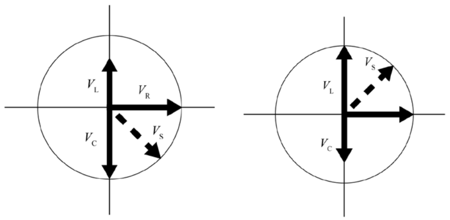
2011(1) (d)	• When the input voltage > V_c, the capacitor **charges**. • When the input voltage < V_c, the **capacitor discharges**. • Because it **takes time** to charge and discharge, the voltage across the capacitor remains more stable than the input. • Because V_c is proportional to Q. • This works if the **time constant** for the circuit is similar or larger than the time period of the signal.	[1]Links smoothing to **charge / discharge** of capacitor.	[1]Explanation includes **time taken** for capacitor to charge / discharge.	[1]Clear links between time constant, changing charge on the capacitor and output voltage.
2011(2) (a)	$Z = \frac{V}{I} = \frac{10}{0.3} = 33\ \Omega$	[2]Correct working and answer.		
(b)	Time period for the supply is 2.0 s. $\omega = \frac{2\pi}{T} = \frac{2\pi}{2.0} = 3.14\ \text{s}^{-1}$ $X_C = \frac{V}{I} = \frac{1}{0.3} = 3.3\ \Omega = \frac{1}{\omega C}$ $C = \frac{1}{\omega X_C} = \frac{1}{3.14 \times 3.3} = 0.096\ \text{F}$	[2]Correct calculation of ω, T, f or X_c.	[2]Correct calculation of ω and X_c.	[2]Complete correct answer.
(c)	 $\sin\theta = \frac{9}{10}$ $\theta = 64°$ or 1.1 rad.	[1]Shows V_L, V_C V_S phasors in the correct directions.	[2]Complete diagram showing enough correct detail for calculation of phase angle.	[2]Complete correct answer.

(d)	$V_L > V_C$ resonance occurs when $V_L = V_C$ (and $X_L = X_C$) $X_L \propto f$ and $X_C \propto \frac{1}{f}$ Thus the frequency should be reduced, decreasing X_L and increasing X_C	[1]Demonstrates understanding of the condition for resonance. OR Demonstrates understanding of how capacitive and inductive reactance are related to frequency.	[1]Demonstrates understanding of the condition for resonance, AND Demonstrates understanding of how capacitive and inductive reactance are related to frequency.	
2011(2) (c)	At resonance $X_C = X_L$ $\frac{1}{\omega C} = \omega L$ $\frac{1}{LC} = \omega^2$ $2\pi f = \sqrt{\frac{1}{LC}}$ $f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$	[1]Understanding that at resonance $X_C = X_L$	[1]Complete proof.	
(d)	Vary *f* and watch the ammeter. When current is max you are at the resonant frequency.	[1]Correct method which must involve measuring voltage or current only.		

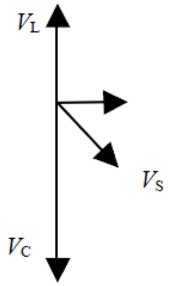
(e)	$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$ $C = \frac{16.8 \times 8.85 \times 10^{-12} \times 0.0500 \times 0.0650}{0.0150}$ $C = 3.22 \times 10^{-11}$ F $f = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$ $= \frac{1}{2\pi}\sqrt{\frac{1}{0.786 \times 10^{-3} \times 3.22 \times 10^{-11}}}$ $= 1.00 \times 10^6$ Hz $(1.00$ MHz$)$ Or shows that $X_C = \frac{1}{\omega C} = \frac{1}{2\pi} \times 10^6 \times 3.24 \times 10^{-11} = 4941$ $X_L = 2\pi \times 10^6 \times 0.786 \times 10^{-2} = 4939$	²Correct value for *C*.	²Complete proof.	
(f)	When ε_r 16.9 $C = \frac{\varepsilon_0 \varepsilon_r A}{d} = \frac{8.85 \times 10^{-12} \times 16.9 \times 3.25 \times 10^{-3}}{1.5 \times 10^{-2}}$ $= 3.24 \times 10^{-11}$ F Or $C = \frac{16.9}{26} \times 4.99 \times 10^{-11} = 3.24 \times 10^{-11}$ F $X_C = \frac{1}{\omega C} = \frac{1}{2\pi \times 10^6 \times 3.24 \times 10^{-11}} = 4912\ \Omega$ $X_L = 2\pi \times 10^6 \times 0.786 \times 10^{-3} = 4939\ \Omega$ $Z = \sqrt{R^2 + (X_L - X_C)^2}$ $Z = \sqrt{15^2 + (4939 - 4912)^2} = 30.89\ \Omega$ $I = \frac{V}{Z} = \frac{16}{30.89} = 0.518$ A	²Correct calculation of *C* or either *X*, replacement evidence for *e*.	²Correct calculation of *Z*.	²Complete proof.

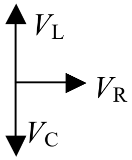
(g)	At resonance Z = R $I = \frac{16}{15} = 1.07 \text{ A}$ This reduces to 0.52 A. This produces a change in current of 0.57 A which is proportionally greater (51%). So changes in moisture causing tiny changes in permittivity cause large changes in current which are easily measured. Compared with the capacitance meter, where small changes in ε_r make 0.6% change in C: 3.22×10^{-11} F → = 3.24×10^{-11} F	[1]Comments on changes in C or *I* relative to sensitivity.	[1]Qualitative comparison. Change in current is bigger than the change in capacitance.	[1]Calculated *C* and *I* values which change, or Δ*C* and Δ*I*. Recognition that the change in current is greater than the change in capacitance, using numbers.
2009(1) (a)	$X_C = \frac{1}{\omega C} = \frac{1}{2\pi \times 200 \times 10^{-6}} = 795.77$ = 800 Ω	[2]Correct answer		
(b)	Increasing *f* will increase ω and hence, because $X_c = \frac{1}{\omega C}$, it will decrease X_c. The current will thus increase because *V* = *IZ*, *V* is fixed but *Z* depends on X_c	[1]Idea increase in frequency decreases reactance	[1]Achievement plus decrease in reactance linked to increase in current.	

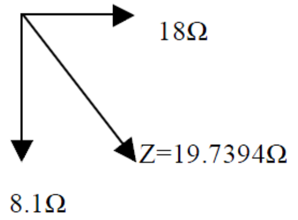
(c)	At low frequency X_C is very large ($X_C \propto 1/f$) but X_L is very small ($X_L \propto f$). R is constant in all circuits so Z depends on X. Circuit A has a capacitor only so has very low current ($I \propto 1/X$). Circuit B has both a capacitor and an inductor but the high capacitor reactance is only slightly reduced by the low inductor reactance and so also has a low current. Circuit C has only an inductor so has a high current.	[1]Correct choice with some explanation.	[1]Clear explanation of why the current is high in C **and** why it is low in the other two circuits.	
(d)	For same current at same *V* need same impedance. Because *R* is the same, need same reactance: $X_C = \frac{1}{\omega C} = X_L = \omega L$ $\Rightarrow \omega = 2\pi f = \sqrt{\frac{1}{LC}} = 10\,000$ $\Rightarrow 2\pi f = 10^4 \quad \Rightarrow f = 1591 \quad = 1600$ Hz	[1]Idea of same reactance OR [2]Correct answer with wrong (e.g. resonance implied) explanation.	[2] Correct answer.	
(e)(i)		[1]Correct diagram.		

(ii)	 V_S is the vector sum of V_L, V_R and V_C. The current is in phase with V_R. At 100 Hz $V_C \gg V_L$ and so the reactance is capacitive and the supply voltage lags the resistor voltage. As the frequency increases X_C and X_L get more equal in size until at 2.9 kHz they are equal. Further increase in frequency makes $V_L \gg V_C$ and so the reactance becomes inductive and the supply voltage leads the current. Evidence of understanding can be shown in the phasor diagram, in the explanation or both.	[1] V_S phasor shown to go from lagging to leading the current. OR How V_s is related to the three other voltages is shown. OR Link between V_R and I is shown.	[1] Effect of frequency on the phase lead and lag described, but not linked to current. OR Explanation shows some idea of how the relative sizes of the LC voltage phasors affect the phase of V_S with respect to I.	[1] Complete answer describing the phase lead and lag, linked to current.

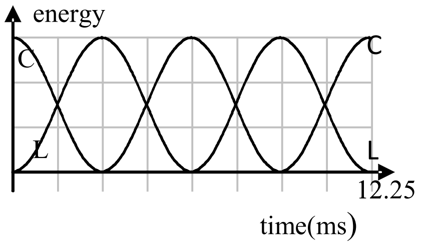
2008(2) (a)	The current in the coil produces a magnetic field. When there is an alternating current there is a changing magnetic field. The field through the metal pan is changing, so induces an emf (Faraday), which will cause a current because the metal is a conductor. This current will dissipate heat due to its resistance.	[1] Mentions induced current / voltage **in pan**	[1] Changing magnetic field induces (eddie) current(s) in the metal pan that result in heating.	[1] Full answer linking changing current in coil to heat with at three points linked clearly.
(b)	$X_L = 2\pi fL$ $= 2\pi \times 27 \times 10^3 \times 1.30 \times 10^{-3} = 221\ \Omega$	[2] Correct working. OR use X_L =221 to work backwards to *f* or *L*.		
(c)	$X_c = \frac{1}{2\ fC}$ $C = \frac{1}{2\ fX_c}$ $= \frac{1}{(2\pi \times 27 \times 10^3 \times 358)}$ $= 1.65 \times 10^{-8}\ \text{F}$	[2] Correct working.		

(d)		[1]Correct orientation of capacitor and inductor voltage phasors.	[1]Capacitor voltage phasor is longest, inductor phasor longer than resistor voltage phasor and supply voltage phasor shows correct understanding of phasor addition.	
(e)	$V_S = I Z$ $I = \frac{V_s}{Z}$ $Z = \sqrt{((X_C - X_L)^2 + R^2)}$ $= \sqrt{((358 - 221)^2 + 70.0^2)}$ $= 153.8\ \Omega$ $I = \frac{200}{154} = 1.30$ A With rounding $Z = 154.6$ so $I = 1.29$ A.		[2]Correct impedance (accept correctly worked solutions that have rounding errors).	[2]Correct answer (Accept correctly worked solutions that have rounding errors).
(f)	The iron pan increases the magnetic field / flux around the coil (compared with a non-magnetic pan). Thus the change in field is greater, so the inductance is greater.	[1]Links to increased field / flux or change in field / flux. OR inductance increases	[1]Links to increased field and links change in field to inductance (e.g. Faraday's law, etc.).	
(g)	Resonance occurs when supply (driving) frequency = natural frequency / $X_C = X_L$ / $V_C = V_L$ / when supply frequency causes maximum current.	[1] One correct statement.		

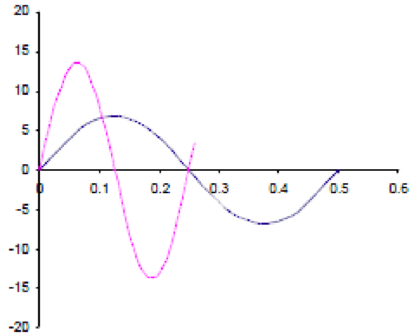
(h)	At resonance, impedance = resistance = 70.0 Ω. $I = \frac{V}{R} = \frac{200}{70.0} = 2.86 \text{ A}$		[2] Correct answer.	
2007(2) (c)		[1] Correct diagram. V_L leading etc Accept L,C,R or Xc, X_L, R		
(d)	Voltage phasors have a direct relationship with reactance vectors. If $X_C > X_L$, X_{tot} is capacitative and so, when combined with *R*, will give a vector ↘. The phasor for V_{supply} will therefore be in the same direction. As phasors rotate anticlockwise, and as *I* is in phase with V_R, *I* will lead V_{supply}. V_{supply} is the vector addition of the directions of V_R and (V_c-V_L).	[1] V_{supply}. lags.	[1] Must explain why V_{supply}. lags. Can use diagrams with explanation	[1] States (or proves) Vc or V_L in same direction as their reactances or V_{supply} in same direction as Z.
(e)	$\omega = 2\pi f \;\; = 2 \times \pi \times 81.6$ = 512.708 = **513 rad s^{-1}**	[2] Correct answer.		

(f)	**This is a SHOW question** $X_C = \frac{1}{\omega C} = \frac{1}{512.708 \times 2.00 \times 10^{-4}}$ $= \frac{1}{0.1025415}$ (= 9.75214Ω)	[2] Correct working.		
(g)	$V = IZ, Z^2 = (X_C - X_L)^2 + R^2$ $\Rightarrow Z^2 = (9.75214 - 1.65)^2 + 18^2$ $\Rightarrow Z = 19.7394$ $\Rightarrow I = \frac{15}{19.7394}$ = 0.75990 **= 0.76 A** 		[2]Consistent answer with incorrectly calculated Z. Must use a vector diagram for calculation of Z **OR** Correct formula but have incorrectly substituted or calculated Z	[2]Correct answer. $I = \frac{15}{19.7394}$ = 0.75990 A **= 0.76 A**
(h)	The car becomes part of the core of the coil, which increases inductance.	[1]Idea of car becoming the part of the core.		

(i)	Increasing the inductance of the coil increases its reactance and so brings its reactance closer to the capacitor reactance. This means the total reactance decreases. As the impedance is a combination of resistance and reactance, decreasing the reactance will also decrease the impedance. As the current is inversely proportional to the impedance, decreasing the impedance will increase the current.		[1]Current increases and either of X_L increases (as L increases) and $X_L \rightarrow X_C$ or $(X_L - X_C) \rightarrow 0$ OR Resonance occurs and states one of its conditions $X_L = X_C$, $V_L = V_C$, Z at min $V_R = V_S$	[1]Current increases and X_L increases (as L increases) and $X_L \rightarrow X_C$ and Z reduces
(j)	$I = \frac{V}{Z}$, at resonance Z = $\Rightarrow I = \frac{15}{18}$ = 0.83333 **= 0.83 A**		[2]Correct answer.	
(k)	$X_L = \omega L = X_C = 9.75$ $\Rightarrow L = \frac{9.75}{512.708}$ = 0.01902= **19 mH**		[2]Correct answer.	

(l)	$E = ½QV$, $Q = VC \Rightarrow E = ½CV_C^2$ At resonance $V_C = I_{max}X_C$ $\Rightarrow E = ½ \times 200\times10^{-6} \times (0.83333 \times 9.75)^2$ = 0.0066015 **= 0.0066 J = 6.6mJ** **OR** $E = ½LI^2 = E = ½ \times 0.01902 \times 0.833^2$ =**0.006604J** **Watch consistency with 2j (I = 0.8333) and 2k (L = 19 mH).**	If use $V_C = 15\sqrt{2}$ (21.21V) E = 45mJ V_C =15 E = 22.5mJ $V_C = (0.833 \times 9.75) \times \sqrt{2}$ $= 8.1245 \times \sqrt{2}$ E = 13.2 mJ	**²**Correct answer consistent with incorrectly calculated V_C. or Uses formula $E = ½LI^2$	**²**Correct answer. or Uses formula $E = ½LI^2$ and (consistently) subs L and I to correctly calculate E
(m)			[1] Graph shapes are correct except that only one half cycle shown (unless the time axis label shows this cycle is ½ period).	[1] Graph shapes are correct. Axis label correct. T = 12.25 s
2006(3) (a)	$\omega = 2\pi f$ $= 2 \times \pi \times 50$ = 314.159 = 310 rad s^{-1}	[2] Correct answer.		
(b)	$X_L = \omega L$ $= 314.159 \times 8.3\times10^{-2}$ = 26.0752 = 26 Ω	[2] Correct working.		

(c)	$X_C = X_{tot} + X_L$ or $X_L - X_{tot}$ $X_{tot} = \sqrt{Z^2 - R^2}$ $Z = \frac{V}{I} = \frac{12}{0.42}$ = 28.5714 $X_{tot} = \sqrt{28.5714^2 - 8.5^2}$ = 27.2778 $\therefore$ $X_C = X_{tot} + X_L$ (X_C must be +ve) = 27.2778 + 26 = 53.2778 = 53 Ω	[2] Correct Z. [1] Recognition of the phasor relationship between reactance, resistance and impedance.	[2] Correct X_{tot} or correct X_C consistent with incorrect X_{tot}.	[2] Correct answer.
(d)	The current in the circuit depends on the total impedance. Total impedance is the combination of resistance and total reactance. Total reactance is the difference between the inductor reactance and the capacitor reactance. Changing the capacitance of the capacitor will change the reactance of the capacitor, and hence the total impedance, and hence the current.	[1] Change in capacitance causes a change in reactance / impedance.	[1] Change in capacitance causes a change in capacitor reactance and therefore a change in total reactance / impedance.	[1] Recognition that current depends on impedance, and a change in capacitance causes a change in capacitor reactance, causing a change in total reactance, and hence impedance.
(e)	$I = \frac{V}{R} = \frac{12}{8.5}$ = 1.41176 = 1.4 A		[2] Correct answer.	

2005(2) (d)	$\phi = B \times A = 0.21 \times 5.20 \times 10^{-3}$ $= 1.092 \times 10^{-3} = 1.1 \times 10^{-3}$ Wb ***or*** $\phi = B \times A = 0.21 \times 5.20 \times 10^{-3} \times 500$ $= 1.092 \times 10^{-3} \times 500$ $= 0.546 = 0.55$ Wb	Correct answer. 1.1×10^{-3} Wb ***OR*** 0.55 Wb		
(e)	$V = -\frac{\Delta\varphi}{\Delta t} = -\frac{0.546}{t}$ t = time to turn from vertical to horizontal = $\frac{1}{4}$ period. $T = 0.5$ s, so $t = 0.125$ s $\Rightarrow V = \frac{0.546}{0.125} = 4.368 \text{ V} = 4.4 \text{ V}$	Correct time (0.125 s) ***OR*** Incorrect time but correct flux change. (For instance, 8.72×10^{3} V would be A)	Correct answer. **Look for consistency from 2(d).**	
(f)		**EITHER** voltage doubled (between 13 V and 15 V) Bottom or top would be sufficient **OR** Period halved. Does not need to be exact but intention of halving is indicated.	**BOTH** voltage doubled **AND** period halved.	

2005(3) (a)	$V_{max} = V_{rms} \times \sqrt{2} = 6.00 \times \sqrt{2}$ $= 8.48528$ **8.49 V**	Correct answer.		
(b)	As this is an AC circuit the voltages across the components are not in phase with each other, they have to be added vectorially. If use $V_S = \sqrt{V_R^2 + (V_C - V_L)^2}$ without some relevant explanation then **N**	ONE correct and relevant statement: voltages out of phase **OR** voltages added vectorially. **OR** shows a labelled LRC vector diagram (V_L, V_R, V_C not in the correct order)	voltages out of phase **AND** voltages added vectorially. **OR** shows a labelled LRC diagram. (must have V_L, V_R, V_C in the correct order) If V_S is shown it must lag the current or V_R.	
(c)	**This is a show question** $I = \frac{V_R}{R} = \frac{5.99}{18.5} = 0.324\text{ A} = 324\text{ mA}$ **Note: V_R must be 5.99 (not 6.00)** **OR** use V_L / X_L and $X_L = \omega L$ $X_L = 2\pi fL = 2\pi \times 100 \times 3.6 \times 10^{-3}$ $= 2.26\ \Omega$ $I = \frac{V_L}{X_l} = \frac{0.733}{2.26} = (0.324\text{ A})$ $(= 324\text{ mA})$	Correct answer.		

(d)	This is a show question $X_c = \frac{V_c}{I} = \frac{0.808}{0.324} = 2.494\ \Omega$ $X_C = \frac{1}{2\pi f C}$ $C = \frac{1}{2\pi f X_C}$ $= \frac{1}{2\pi \times 100 \times 2.494}$ $= 6.38 \times 10^{-4}$ $= 638\ \mu F$	Either $X_C = \frac{V_C}{I}$ ***or*** $X_C = \frac{1}{2\pi fC}$ ***or*** $X_c = \frac{1}{\omega C}$ seen in their working (alone or substituted into).	X_C correct (= 2.494 Ω) ***and*** $X_C = \frac{1}{2\pi fC}$ given or correctly substituted into.	Correct rearrangement $C = \frac{1}{2\pi \times 100 \times 2.494}$

(e)	**This is a show question** Resonant frequency when $X_C = X_L$ For this capacitor and inductor: $\frac{1}{2\pi fC} = 2\pi fL$ rearranging gives $f^2 = \frac{1}{4\pi^2 LC}$ $f = \frac{1}{2\pi\sqrt{LC}}$ $= \frac{1}{2\pi\sqrt{6.38\times10^{-4}\times3.6\times10^{-3}}}$ $= 105.0167$ (Hz) (= 105 Hz) **If the following is used there must be some relevant discussion given. Otherwise N.** $f = \frac{1}{2\pi\sqrt{LC}}$	*Any condition sufficient for resonance* $X_C = X_L$ $V_C = V_L$ X_L and X_C cancel out (or 180° out of phase) $V_S = V_R$ Minimum impedance Maximum current.	*The following statement given* $\frac{1}{2\pi fC} = 2\pi fL$	*Merit plus correct rearrangement and substitution into* $f = \frac{1}{2\pi\sqrt{LC}}$ $f = \frac{1}{2\pi\sqrt{6.38\times10^{-4}\times3.6\times10^{-3}}}$ $f = \frac{1}{9.522\times10^{-3}}$ (= 105 Hz)

(f)	When metal is brought close to the detector, the inductance of the inductor increases slightly. This has the effect of reducing the resonant frequency of the circuit, bringing it closer to the AC supply frequency. As a result the current in the circuit will increase to peak when the resonant frequency is 100 Hz. This will be shown in the circuit by an increased ammeter reading.	ONE correct and relevant statement. Typically, statements could be The inductance of the inductor changes **OR** The resonant frequency of the circuit changes (because of the metal) **OR** The current increases.	Links inductance changing and resonant frequency changing and reduced f_o Typically, linkages could be The inductance of the inductor changes, (reduces) lowering the resonant frequency (of the circuit) **OR** The inductance of the inductor changes. This causes X_C and X_L to be closer in value (or V_C and V_L to be closer in value). **OR** X_C and X_L are closer in value (or V_C and V_L are closer in value) so impedance is smaller, therefore the current increases.	The explanation clearly links the change in inductance, change in resonant frequency and increased current. The inductance of the inductor **increases**. This causes X_C and X_L to be closer in value (or V_C and V_L to be closer in value). Therefore the current will become larger (because the impedance is smaller).