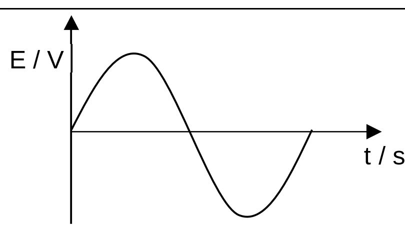
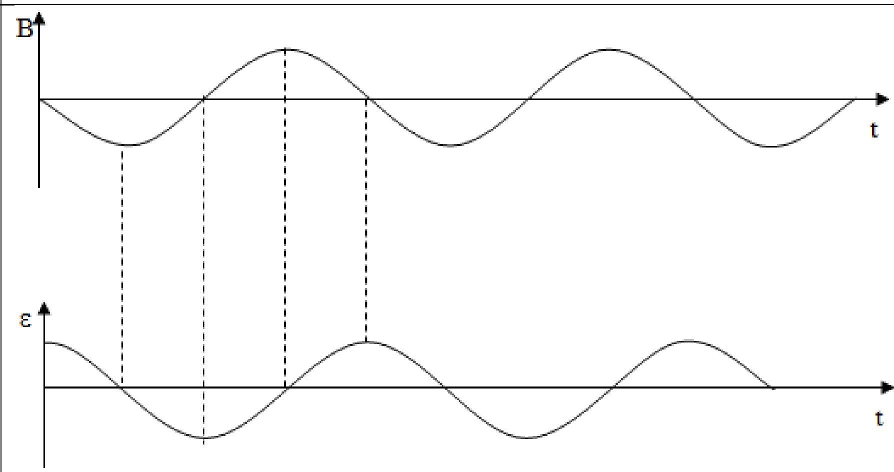
TUTORIAL 17: EMI SOLUTIONS

Level 1 Solutions

1	B. Refer to Example 2.	[1]
2(a)	Magnetic flux is defined as the product of the magnetic flux density and the area *normal* to the field through which the field is passing. Magnetic flux linkage in a coil is defined as the product of the magnetic flux passing through a coil and the number of turns of the coil.	[1] [1]
2(b)	The magnetic flux density is defined as the force acting per unit current in a wire of unit length at right-angles to the field whereas magnetic flux is defined as the product of the magnetic flux density and the area *normal* to the field through which the field is passing.	[1] [1]
2(c)	Faraday's Law states that magnitude of an induced emf is directly proportional to the rate of change of magnetic flux-linkage.	[1]
2(d)	Lenz's Law states that the direction of the induced emf is such that its effects oppose the change which causes it. The induced emf produces effects which opposes the change in the magnetic flux linkage. Consequently, work has to be done **by an external agent** to overcome this opposition and energy is conserved. Hence the electrical energy associated with the induced current is derived from the work that is done **by the external agent** to overcome the change in magnetic flux. If the effects of the induced emf do not oppose the change in magnetic flux, there will be a gain in energy without any work done. This violates the law of conservation of energy.	[1] [1] [1] [1]
3	**"its axis parallel to a uniform magnetic field" means the <u>B field vector is perpendicular to the plane</u> containing the cross-sectional area of the coil.** EMF $= \Delta N B A/\Delta t$ $= 120 \times (80\text{m} - 20\text{m}) \times 0.07 / 4.0$ $= 130$ mV	[1] [1]

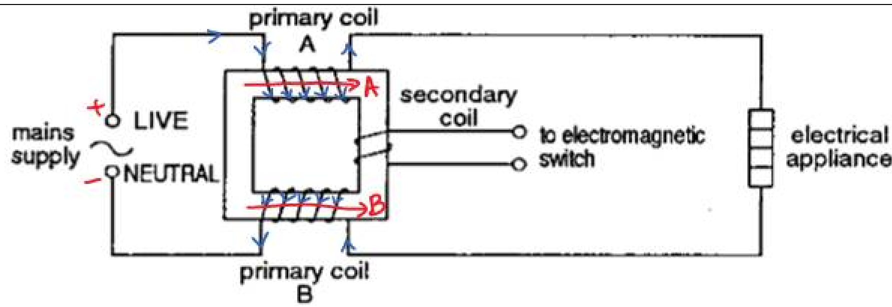
Level 2 Solutions

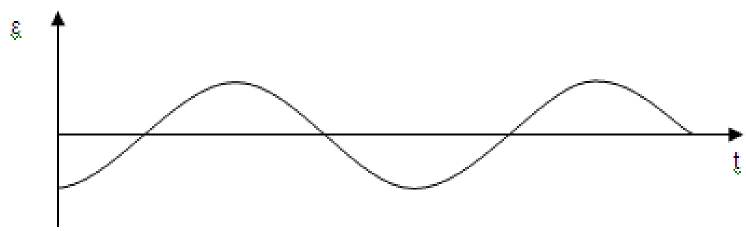
4	A • The current in the solenoid sets up a B-field. • **"Original current" = Applied emf ÷ Tot Resistance of circuit.** • The **iron** rod **strengthens** the B-field, **ie increases the flux density B,** **(Topic 16: EM Learning Outcome (d);** **B =** $\mu_r\mu_o nI$ -NOT in Syll). μ_r:relative permeability of the medium (soft iron) • 1. **When the rod is "far eough" fr solenoid:** equivalent to being "not there at all": current = "original current" • 2. W**hen the iron rod is entering** the solenoid: (**ie while partially in solenoid**), the **flux linkage increases with time**.This **induces an emf** in the solenoid. By Lenz's law the direction of the **induced emf** is **opposite that of the applied emf** (by the battery); **resulting emf decreases,** causing the current in the solenoid to decrease (momentarily). **(See the dip, the one that occurs earlier in time.)** • 3. "**Deep within the solenoid":** **Here B has increased to its max; it remains constant (until it "starts to leave the solenoid).** **Hence flux linkage is no longer changing when the rod is deep within the solenoid; no more induced emf;** **resulting current reverts to its original value.** • **4. When the iron rod is leaving** the solenoid: **flux linkage is decreasing**. This induces an emf. By Lenz's law the direction of the **induced emf will be in the same direction as that of the applied emf**; **resulting emf increases,** causing the current in the solenoid to increase momentarily. **(See the spike up, the one that occurs later in time.)** • 5. When rod is completely out of the solenoid: Induced emf becomes zero; **flux linkage becomes constant again**; no more induced emf; resulting current reverts to original value.	
5(a)		[1]
5(b)	By Faraday's law, the induced EMF is **equal** to the rate of change of magnetic flux linkage, which is determined by the velocity of the magnet.	[1] [1] [1]

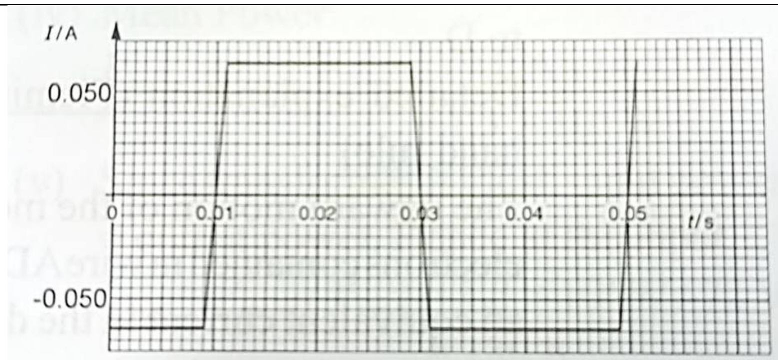
	The graph is **sinusoidal because the velocity of the magnet is varying sinusoidally** according to the simple harmonic motion of the spring.	
5(c)	**Explanation in terms of Energy:** When a resistor is connected **energy from the induced EMF is dissipated in the resistor** (in the form of Joule heating) this energy comes from the energy of oscillations. Thus the motion of the magnet becomes more **damped** and amplitude **decreases**. OR **Explanation in terms of induced Force :** When a resistor is connected, **induced current starts to flow in the s circuit**. By Lenz's law, this induced current will produce a magnetic field to oppose the oscillations. **Thus, when the bar magnet is <u>approaching the coil</u>, the top end of the coil will be a magnetic pole which <u>repels</u> the magnet. And when the magnet is <u>receding</u>, the induced magnetic pole of the top end of the coil will be exerting an <u>attractive force</u> on the magnet**. Thus the motion of the magnet becomes more damped and amplitude decreases.	[1] [1] [1] [1] [1] [1]
6(a)(i) 6(a)(ii)	 **<u>Elaboration</u>**: (i) Deduce (fr given I-t graph), $I = - I_o \sin wt$ eqn (A) Since $B = \mu_0 nI$, eqn (B), $B = \mu_0\, n\, (- I_o \sin wt)$, (1) Fr eqn (1) & (A), $\Rightarrow$ B-t graph : **Same shape** as I-t graph & **in phase** as well. (ii) Deduce $B_o = \mu_0 n I_o$ (2) $E - - d\Phi/dt = - d\,(NBA)/dt = - AN\, dB/dt$ where $B = - B_o \sin wt$ (3) fr (1) & (2) $= - AN\,[\,-B_o\, w \cos wt\,]$ $= +(\,AN\mu_o n I_o w\,) \cos wt$ Hence E-t graph: **+cosine graph;** & hence **out of phase by 90^0 wrt I-t graph**	[1] [1]

6(b)(i)	Since $E = +(AN\mu_o n I_o w)\cos wt$, Comparing it with the general eqn, $E = E_o \cos wt$ $\Rightarrow$ the amplitude $E_o = wAN\mu_o nI_o$ eqn (C) The ferrous core causes the **permeability of the medium** to become $\mu_r\mu_o$ where $\mu_r > 1$. Hence amplitude of E, ie E_o increases when the ferrous core is introduced. As for **frequency of E, (the output), it depends only on the frequency of the input current. Since the input freq remains constant, the freq of E remains unchanged**.	
6(b)(ii)	$I = -I_o \sin(\omega t)$, $\omega = 2\pi f$ **Since $E = +(AN\mu_o nI_o w)\cos wt$,** **As frequency f of current increases**, **angular frequency ω also increases**. Hence amplitude of E ($wAN\mu_o nI_o$) and **frequency of E-t increase.**	[1] [1]
6(b)(iii)	Increase in the amplitude of the current $\mathbf{I_o}$ will increase **the amplitude of E; see eqn (C).** **Since freq of input current remains unchanged, freq of output E is also unchanged.**	[1] [1]
7	Induced emf = rate of change of magnetic flux linkage $= \frac{\Delta NBA}{t} = 75\frac{\Delta B}{t}(0.05)(0.08)$ Emf = RI = (8)(0.1) = 0.8 V $\frac{\Delta B}{t} = \frac{0.8}{75(0.05)(0.08)} = 2.67\ \text{T s}^{-1}$	[1] [1]
8	**Assume the blades are rotating in a horizontal plane.** Consider the area 'swept' by the moving rod **(ie blade)** $A = \pi(r)^2$ $B = 5.0 \times 10^{-5}$ T f = 2 Hz Induced emf = $\frac{\Delta NBA}{t} = \frac{5.0\times10^{-5}(\pi)(3)^2}{0.5}$ **Consider a time = 1 period,T = 1/f** = 2.83 mV	[1] [1]
9(a)	There is no magnetic force when particle is **stationary** or when it is **moving parallel to the magnetic field**.	[1] [1]
9(b)(i)	The **current flows in the same direction in each coil** of the spring.	[1] [1]

	Since **attractive forces** experienced by **parallel conductors** when current flows through them in the same direction, **each coil of the spring experiences attractive forces due to the neighbouring coils**.	
9(b)(ii)	The spring is **compressed** (because the **forces are attractive**.)	
9(c)	When the spring is **oscillating**, there is a **change in flux linkage** in the coil [**or flux-cutting]** to generate an **induced EMF**. **According to Faraday's Law**, the induced emf is **equal** to the rate of change of flux linkage, thus the **induced emf fluctuates as the velocity** of the **oscillations varies with time**. **By Lenz's law**, this induced emf produces an effect that **opposes** the change in flux linkage by **adding to or subtracting from the battery's emf**. Therefore the **resultant emf in the circuit fluctuates**, causing the **current in the spring to fluctuate.**	[1] [1] [1]
10(a)	The current in the cable must be alternating so that the magnetic field generated around the cable would be varying. A varying magnetic field will cause a varying magnetic flux linkage in the coil which is required to induce an emf in the small coil by Faraday's Law.	[1] [1]
10(b)	A. The flux linkage for the other 3 options are **always zero**, **ie not changing wrt time.** Therefore no induced emf. **Elaboration:** 1. By the **Right-Hand Grip rule**, the B field due to the varying current in the vert cable is directed **perpendicularly into the page** on the right side of the cable. 2. Thus flux linking the coil in options C & D is zero all the time as the area of the coil perpendicular to B is zero. Hence no emf is induced. 3. In B, the emf induced in the 2 halves of coil (left & right) will cancel out each other to produce a net induced emf of zero. 4. In A, the **area** of the coil exposed to the varying B field is maximum; hence the rate of change of flux in option A is max. Hence induced emf is max.	[1]
11(a)	Magnetic flux linkage = NBA cos θ = (500) (5.0×10^{-2}) (2.5×10^{-2}) cos **0º** = 0.625 Wb	[1] [1]
11(b)(i)	Average emf through the first quarter $= N\dfrac{\Delta\phi}{t}$ = [**0.625 – 0**] ÷ (0.25×10^{-3}) = 2500 V	[1] [1]
11(b)(ii)	Since induced emf = $N\dfrac{d\phi}{dt}$ by Faraday's Law, the **maximum emf = maximum gradient of graph** {which occurs at 0.25 ms, 0.75 ms, 1.25 ms etc }	[1]

12(a)(i) & (ii)	 **Use RH Grip Rule for the 2 primary coils.**	[1] [1]
12(b)	Due to the direction of currents in coils A and B, the **magnetic fields due to coils A and B cancel each other out at the secondary coil**. **Assume secondary coil is symmetrically placed wrt the 2 primary coils.** As a result, the secondary coil does not experience any change in magnetic flux linkage as the flux linkage is always zero (with respect to time). Thus by Faraday's Law, no emf is induced in the secondary coil.	[1] [1] [1]
12(c)(i)	When the currents in coils A and B are **unequal**, a **(non-zero) <u>net magnetic flux</u> is generated in the core of the transformer (and at the sec coil)** that **varies** according to the frequency of the mains supply.	[1] [1]
12(c)(ii)	According to Faraday's law, the **changing magnetic flux linkage at the secondary coil** induces an EMF in the secondary coil that is **equal** to the rate of change of the flux linkage.	[1]
13(a)	When the **magnetised string vibrates**, the **magnetic field** experienced by the **pickup coil fluctuates (as the dist betw the magnetised string & coil varies).** **{Why does B field at coil *<u>fluctuate</u>* as magnetised string vibrates?}** Thus the **flux linkage of the pickup coil changes** By **Faraday's law** of electromagnetic induction, an **emf** that is **equal** l to the rate of change of magnetic flux linkage is **induced in the coil.**	[1] [1] [1]
13(b)(i)	The signal must be amplified because the **induced emf typically has a very small amplitude.** (since the magnetic flux density and the rate of vibration of the string is low)	[1]
13(b)(ii)	A **nylon** string **cannot be magnetized by the permanent magnet** and so would not be able to generate any magnetic field. Thus it would not be able to induce any emf in the pick-up coil.	[1]
14(a)	For **alternating** input voltage, the magnetic field generated by the primary coil is varying, causing a **changing** flux linkage in the secondary coil and emf is induced by Faraday's Law. If the input voltage of the primary coil is a direct voltage (of **constant magnitude**), there would be **no change in flux linkage**, resulting in no induced emf.	[1] [1]
14(b)	According to **Lenz's law**, the effect of the induced emf must oppose the change that causes it.	[1] [1]

	Thus the **output emf** will change at the **same rate** as the **input voltage** so that "its effect will continually oppose the change of the input voltage." **A rigorous ans wld be similar to that in Q6 (b)(ii).**	
15(a)	***e.m.f.*** **=** $-\frac{dN\phi}{dt}$ **where ϕ = BAcosθ = BAcoswt, N = 1** **where θ = angle betw the normal to the coil & the B vector** **Hence:** The magnetic flux density of the magnet **(B)** The area of the loop **(A)** **Either** the speed of rotation of the loop **(w), or θ (=wt)**	 [1] [1] [1]
15(b)	**"assuming that t = 0 s for the coil in the position shown" defines the initial condition. Note where plane of coil is at t = 0 as specified in question.** Hence flux ϕ = BA**sin** wt. Using E **=** $-\frac{dN\phi}{dt}$ **where N = 1,** E-t will be **-**Cosine graph**.** 	[1]
16(a)	**{ Where does the B in coil Y come from?** **Ans: from the current flowing in coil X (solenoid). }** Max gradient (from B-t graph), $\frac{dB}{dt}$ = 2.4 x 10^{-2} / 0.009 = 2.67 Max I = $\frac{\max Emf}{total\ resistance} = \frac{NA\left(\frac{dB}{dt}\right)_{max}}{resistance\ of\ Y\ and\ R}$ = $\frac{500\times7.25\times10^{-4}\times 2.67}{5+10}$ = 0.968 / 15 = 0.0644 A	[1] [1] [1]

16(b)	 Shape Labelling of values Explanation: since current (in coil Y and R) α $-\frac{dB}{dt}$ [recall, emf = $-\frac{dNBA}{dt}$; current = $\frac{Emf}{total\ R}$] e.g. when gradient of B-t is constant & positive (t = 0 to 0.009s), current will be constant but negative! From 0.009 s to 0.011 s (i.e. near the first peak of the B-t graph), gradient of B-t is decreasing to zero then increasing. Hence the slant line (a slight curve **is better**) in the above current-time graph.	 [1] [1]

ASSIGNMENT

1(a)(i)	Magnetic flux is defined as the product of an area and the component of the magnetic flux density perpendicular to that area.	[1]
(b)	Φ = NBA = 500 x 0.035 x 2.5 x 10^{-3} = 0.0438 Unit: Wb *or* T m^2	 [1] [1] [1]
(c)(i)	The component of B perpendicular to the area changes / the idea that the area changes relative to the field direction — **B1** — Allow the idea that the direction of the field relative to the area of the coil varies with the orientation of the coil. Do not allow reference to cutting of the flux by the coil detail of how it varies / depends on cos θ / maximum when field is perpendicular to B / zero when area is parallel to B — **B1** E.g. "The component of B perpendicular to the area changes. The magnetic flux ϕ is BAcos Θ, where Θ is the angle between *B* and the normal vector to area *A.* (Thus, ϕ is maximum when area is perpendicular to field and Θ = 0°, ϕ is 0 when area is parallel to field and Θ = 90° .)"	[1] [1]
(ii)	The *magnitude* of the induced e.m.f. in a coil is directly proportional to the rate of change of the magnetic flux linking (or cutting) the coil.	[1]
(iii)	e.m.f. **max** when ϕ is **zero** or at 0.005 /0.015 /0.025 s — **(B1)** e.m.f **zero** when ϕ is a **max** or at 0.0 / 0.01/ 0.02 s — **(B1)** e.m.f. and ϕ have the same frequency — **(B1)** allow e.m.f and ϕ out of phase by π/2/ emf follows a sin curve — **(B1)** emf is the gradient of the graph — **(B1)** **MAX 3** — **B3**	[3]
(iv)	ε = (change in flux linkage) / time = 0.04375 / 0.005 (8.8 x 10^{-5} x 500) / 0.005 = 8.75	 [1] [1]
(v)	Max e.m.f. is **twice** the original value as the rate of flux change is **twice** the original Note: must say "twice", cannot say "larger"	[1] [1]

- End of tutorial solutions -