EM2: Electromagnetism, Electromagnetic Induction, Alternating Currents

MCQ Solutions

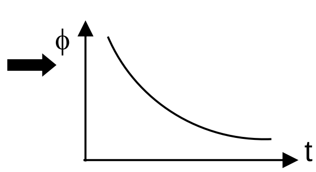
1	Ans: A F_B – mg = ma BILsinθ – mg = ma 0.04 x I x 0.3 x sin60º – (0.004 x 9.81) = 0.004 x 0.02 I = 3.78 A
2	Ans: C $torque=(NBIL)x=40\times0.010\times0.0050\times0.0080\times0.0160 \approx 2.6\times10^{-7}\,Nm$
3	Ans: B In order for the coil to balance, $F_B \times l_{AB} = mg \times l_{FA}$ $B \times l_{BC} \times l_{FA} = mg \times l_{FA}$ To evaluate this question, we make the balancing mass as the subject of the equation: $$m = \frac{BIl_{BC}I_{AB}}{gI_{FA}}$$ Option A: so if current decreases (and all else kept constant), the balancing mass must decrease. Option B: if l_{BC} increases, the balancing mass must also increase. Option C: if pivot moves towards the solenoid, then l_{AB} decreases, but l_{AF} increases. So the fraction on the left hand side must decrease. Therefore a smaller balancing mass is needed. Option D: when the number of solenoid turns decrease, the magnetic flux density (B) decreases. Hence balancing mass also decreases.
4	Ans: A Note that for circular motion, magnetic force is directed towards the centre of the circle. By FLHR, for the force to point towards the centre of the circle/spiral, you must have either a) positive charge with B field pointing out of the paper OR b) negative charge with B field pointing into the paper. Hence only options A, B, and D are possible. Since we have circular motion with changing radius, we should form an equation with Magnetic force, radius of circle and speed (since we want to find speed). $$Bqv = \frac{mv^2}{r}$$ $$v = \frac{Bqr}{m}$$ Since the radius of the circle is decreasing, the speed of the particle must be decreasing. Hence the only possible set of answers is A.
5	Ans: D Magnetic force provides centripetal force

	Bqv = mrω^2, Bqrω = mrω^2, Bq = 2πm/T T = $\dfrac{2\pi m}{eB}$
6	Ans: A Since one particle has –q, the other particle must have +q charge as they separated from a neutral charge. By COM, the two particles separated with the same speed, opposite direction. But since their charges are opposite, the magnetic force acting on them is the same. So, they will move along the same circle and meet after completing half a circle (half T) $$F = Bqv = \frac{mv^2}{r}$$ $$r\omega = v = \frac{Bqr}{m}$$ $$\frac{2\pi}{T} = \frac{Bq}{m}$$ $$T = \frac{2\pi m}{Bq}$$ Therefore, time taken, ½ T is $\frac{\pi m}{Bq}$.
7	Ans: D We form a circular motion equation with Magnetic force, radius and speed: $$Bqv = \frac{mv^2}{r}$$ Option A: We make the quantity we want to find in each option as the subject of the equation. $m = \frac{Bqr}{v}$; $m_P = \frac{Bq0.5r_Q}{2v_Q} = \left(\frac{1}{4}\right)\frac{Bqr_Q}{v_Q} = \left(\frac{1}{4}\right)m_Q$ Option B: By FLHR, the charge must be positive (since its movement follows the direction of conventional current). Option C: Using the findings from option A, initial momentum of P is $m_P v_P = \left(\frac{1}{4}m_Q\right) \times 2v_Q = \left(\frac{1}{2}\right)m_Q v_Q$ Option D: We make the quantity we want to find in each option as the subject of the equation.

	$\frac{m}{q} = \frac{Br}{v}$ $\frac{m_P}{q_P} = \frac{B(0.5r_Q)}{2v_Q} = \left(\frac{1}{4}\right)\frac{Br_Q}{v_Q} = \left(\frac{1}{4}\right)\frac{m_P}{q_P}$ (option is correct)
8	Ans: B A is wrong because force on charge should be perpendicular to field. $Bqv = \frac{mv^2}{r}$ $r = \frac{mv}{Bq}$ [1] Hence, C and D is wrong from [1], $r = \frac{mwr}{Bq}$ $w = \frac{Bq}{m}$ $T = \frac{2pm}{Bq}$ Hence, B is correct.
9	Ans: D B field direction and electron direction are parallel, hence no force.
10	Ans: C Option **A** $E = 0$, $B = 0$, Newton's 1st Law Option **B** $E = 0$, $B \neq 0$, proton travels parallel to B field. Option **C** $E \neq 0$, $B = 0$, impossible, velocity will increase in the direction of E field. Option **D** $E \neq 0$, $B \neq 0$, crossed fields (velocity selector)
11	Ans: C E and B_1 form a velocity selector, so the ions entering B_2 have the same speed. Inside B_2, the ions travel in a circular path: Centripetal force = magnetic force $\frac{mv^2}{r} = B_2qv$ $r = \frac{mv}{B_2q}$ $\therefore r_B = r_A \frac{m_B}{m_A}\frac{q_A}{q_B}$

	$= 3.7 \text{ x } \frac{1}{1.5} \times \frac{2}{1}$ $= 4.9$ cm
12	Ans: A If you apply FLHR to that one electron, you can easily tell that it experiences a magnetic force. You can also imagine this happening to other conduction electrons, which will cause an accumulation of negative charges eventually at the top of the rod, and a net positive charge at the bottom. This creates an electric field inside the rod. Hence an electron in the middle will also experience an electric force.
13	Ans: C magnetic force = electric force $Bqv = qE$ $v = \frac{E}{B} = \frac{20 \times 10^3}{0.25}$ magnetic force in main chamber = centripetal force $\frac{mv^2}{r} = Bqv$ $r = \frac{mv}{Bq}$ $= \frac{(116 \times 1.66 \times 10^{-27})(\frac{20 \times 10^3}{0.25})}{0.25(1.60 \times 10^{-19})}$ ≈ 0.385 m Therefore, diameter $\approx$ 0.770 m.
14	Ans: D When current in wire Y doubled, field strength at X due to Y = $2B_Y$, the magnetic force on X due to Y = $2B_Y(I)(L) = 2F$, The magnetic force on Y due to X = $B_Y(2I)(L) = 2F$, opposite in direction. (obeying Newton's 3rd Law)
15	Ans: B Forces on E due to A and C cancelled off. Force on E due to D in the direction of B is greater than the force on E due to B in the direction of D as force produced depends on the product of the currents in the two wires.
16	Ans: A

	By FLHR, Magnetic forces on PQ and RS are equal and opposite in direction (hence cancels out). PS experiences an attractive magnetic force towards XY. QR experiences a repulsion. Since PS is nearer, the attractive magnetic force it experiences should be larger than the repulsion of QR. Hence the loop experiences a net force towards XY, and move towards it.
17	Ans: B
18	Ans: C For current carrying conductors, when there are unlike currents flowing across them, there will be a repulsive force between them. Since the current is varying in strength, the force will vary from zero to maximum and back.
19	Ans: B
20	Ans: C Recall that magnetic flux density, $B = \Phi/A$ Hence, the smallest cross-sectional area will give the largest variation in magnetic flux density for the same amount of magnetic flux (magnetic flux in concentrated within the soft-iron ring). **Points to note:** At any time the magnetic flux is the same for all the coils. The flux density is largest where the area is smallest, so the largest variation of flux density is for coil C.
21	Ans: C By Fleming's RHR, induced current flow from X to Y in the rod, hence Y is of higher potential. Induced current will cause an opposing effect to the change and thus the magnetic force will be directed to the left.
22	Ans: B When the switch is closed, there is a change in magnetic flux through the ring. By Faraday's law, an e.m.f. is induced in the ring. By Lenz's law, the direction of induced current is such that it opposes the change in magnetic flux causing it. Hence, the induced current in the ring causes the ring to move away from the solenoid.
23	Ans: A When soft-iron core is removed, the magnetic flux linkage decreases. Thus induced emf decreases and the height of trace decreases. The number of cycles remains the same.
24	Ans: C **The iron core should be pulled out of coil 2** as the soft iron core reinforces the B-field created by coil 1 passing into coil 2. By removing the soft iron core from coil 2, the B-field experienced by coil 2 is reduced,

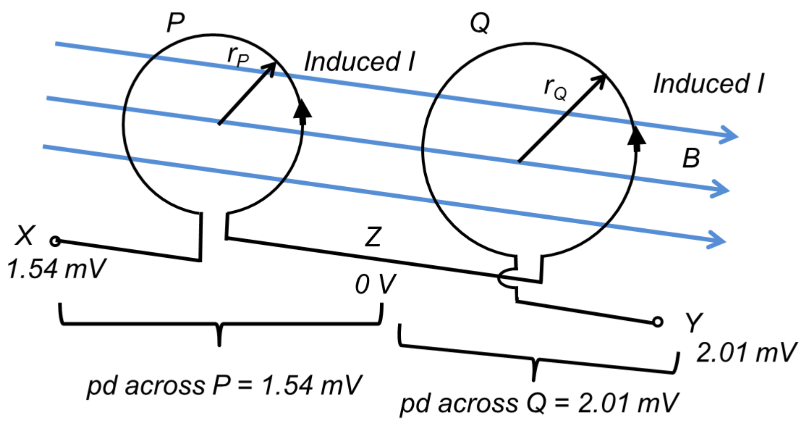
	thus the induced e.m.f will also drop in magnitude. **R_1 should be increased** to reduce the current flowing through coil 1, thus reducing the strength of the B-field generated by coil 1.
25	Ans: C The tube with the highest conductivity will induce the largest current and hence the largest opposing force to its downward motion and hence falls the slowest, thus rubber falls the fastest, followed by lead, then copper.
26	Ans: D By reducing the speed of rotation, the time taken for it to complete one cycle will be doubled. By halving the speed, the rate at which the magnetic flux changing is decreased. The induced e.m.f. will also be halved. The other options will only reduce the amplitude of the e.m.f. to half its value without changing the period.
27	Ans: A $\Phi = \mathrm{N}B_{\perp}\mathrm{A}$ $\Delta\Phi = 8 \times 50 \times 10^{-6} \times \cos 22.5^{o} \times 0.004$ (note that we must use the component of B field that is perpendicular to the area.) $E = \frac{\Delta\Phi}{\Delta t}$ =0.93 μV
28	Ans: C $E = \frac{\Delta\Phi}{\Delta t}$ So we can find emf from the **gradient** of the Φ vs. t graph.
29	Ans: B $I = \frac{\varepsilon}{R} = \frac{\Delta\Phi}{\Delta t}\left(\frac{1}{R}\right) = \frac{4.0\times10^{-5}}{5.0}\left(\frac{1}{2.0}\right) = 4.0\times10^{-6}$ A The current remains constant as the rate of change of flux is constant.
30	Ans: A Since rod is moving at constant v, graph of B vs r will be similar to graph of ϕ vs t  Since gradient drops as t increases, $\frac{d\phi}{dt}$ decreases as conductor PQ moves away →magnitude of induced emf decreases.

Using FRHR, induced current is from Q to P, therefore P is at higher potential.

31 Ans: B

E = *Blv*, where *v* is the horizontal component of the rod's velocity. From P to Q, the rod is moving vertically and *E* is zero. From Q to R, as the rod rolls down the slope, the component of its weight parallel to the slope caused its velocity to increase. Hence its hor velocity increases at a constant rate and E increases linearly. From R onwards, the rod is moving in projectile motion. Its hor velocity is constant and E remains constant.

32 Ans: A



$$E_P = -\frac{d\phi}{dt} = -A\frac{\Delta B}{\Delta t} = -(0.14^2\pi)0.025 = 1.54\times10^{-3}\,\text{V}$$

$$E_Q = -\frac{d\phi}{dt} = -A\frac{\Delta B}{\Delta t} = -(0.16^2\pi)0.025 = 2.01\times10^{-3}\,\text{V}$$

The decrease in the magnetic field causes an induced e.m.f. in loops P and Q. Since the field is decreasing to the right of the loop, the induced current direction will be counter-clockwise in both loops. The induced e.m.f. of loop P is equal to the potential difference between X and Z , where Z is the common potential point between the two coils P and Q, while the induced e.m.f. across Q is equal to the potential difference between Z and Y.

To find the potential difference $V_x - V_Y$, the potentials of X and Y with respect to Z has to be known first.
Since the current is counter-clockwise in loop P, the potential at Z is lower than the potential at X. Similarly, for loop Q, the potential at Z is lower than at Y. Hence the potential difference V_X-V_Y = 1.54 mV – 2.01 = -0.47 mV

33 Ans: B

The outer loop generates a B field within itself that is pointing into the paper .

$$E = \frac{d\Phi}{dt} = \frac{d(\text{NBA})}{dt}$$

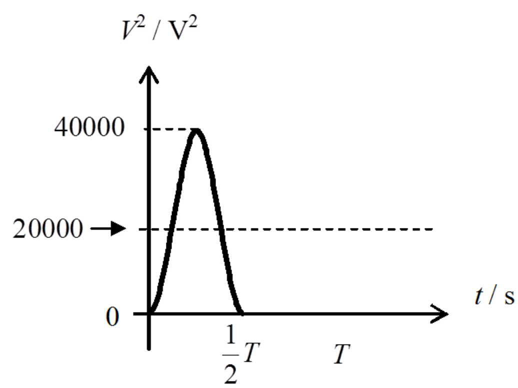
Since there is a linear relationship between current in the outer loop and the B-field it generates, the rate of change of B with time should be constant. Hence, the induced emf

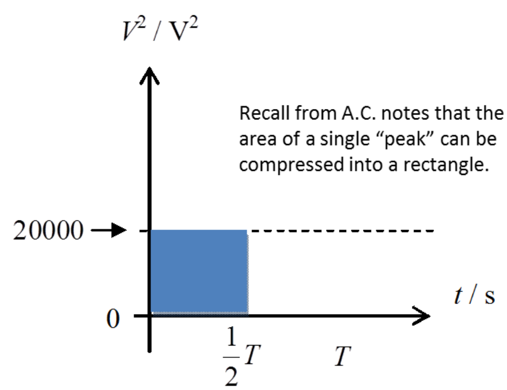
	in the inner loop should be **constant**. By Lenz law, the inner loop will generate a B field to oppose the increase of magnetic flux linkage into the paper. Hence the induced B field should point out of the paper, which arises from an **anticlockwise** current.
34	Ans: C As triangle enters into magnetic field, area increases at an increasing rate, thus induced emf increases and induced current increases until the whole triangle is inside the magnetic field. As triangle exits from the magnetic field, area decreases at an increasing rate, and induced current increases to maximum until the triangle leaves the magnetic field.
35	Ans: D A is true as the magnetic forces will be towards the left for both coils. B is true as the induced current in coil 1 is anticlockwise while the induced current in coil 2 is clockwise. C is true as the increase in area entering into the B-Field is at a decreasing rate, hence rate of change of flux linkage is decreasing, induced e.m.f and hence current is decreasing.
36	Ans: A Induced emf in section PQ has a greater magnitude compared to that due to PR because PQ is longer compared to PR. Using FRHR, Q has a higher potential than R.
37	Ans: C $E = -\frac{d(N\phi)}{dt}$ $= -\frac{d(NBA\cos\omega t)}{dt}$ $= \omega NBA\sin\omega t$ $\therefore E_{\max} = \omega NBA$ $= (2\pi\frac{1800}{60})(30)(4.0\times10^{-5})(\frac{\pi(1.0\times10^{-2})^2}{4})$ $= 1.8\times10^{-5}V$
38	Ans: B

<table>
<tr><td></td><td>$|e| = \left|-\frac{d(N\Phi)}{dt}\right| = \frac{\Delta(N\Phi)}{\Delta t} = \frac{B\pi r^2}{T} = \frac{3.6\times10^{-5}\times\pi\times\left(\frac{2.3}{2\times100}\right)^2}{\left(\frac{60}{1500}\right)} = 3.74\times10^{-7}V$</td></tr>
<tr><td>39</td><td>Ans: C

When magnet A moves down, it induces a N pole in the left coil. This cause the induced I to flow, which results in the right coil inducing a N pole beneath magnet B. This results in magnet B experiencing an upward force.</td></tr>
<tr><td>40</td><td>Ans: C

Increasing separation of magnets result in a weaker B field through the coil.</td></tr>
<tr><td>41</td><td>Ans: A

$\sqrt{\frac{2(I_o^2)+(2I_o)^2}{3}} = \sqrt{2}\,I_o$</td></tr>
<tr><td>42</td><td>ANS: B
Graphical approach:
Step 1: Considering just 1 “cycle”, square the function.


Step 2: Find the mean-square value $\langle V^2\rangle$


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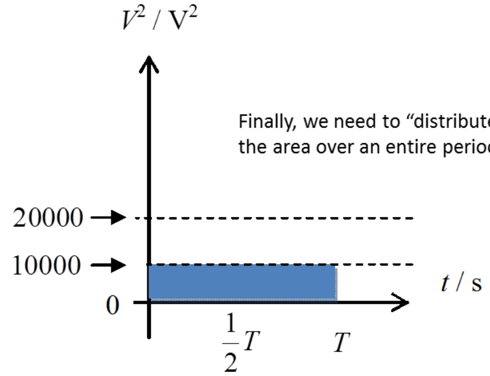
	 So, $\langle V^2 \rangle$ = 10 000 V^2 Step 3: Find the root-mean-square value Finally, $V_{rms} = \sqrt{\langle V^2 \rangle} = \sqrt{10000} = 100$ V
43	Ans: C $I_{\text{RMS}} = \sqrt{\dfrac{2^2 \times \frac{T}{2} + 1^2 \times \frac{T}{2}}{T}} = 1.58$ A $\langle P \rangle = I_{\text{RMS}}^2 \times R = 1.58^2 \times 100 = 250$ W
44	Ans: D $P_{av} = (I_{rms})^2 R > 0$ $I_{av} = 0$ for a sinusoidal function.
45	Ans: B $P = \dfrac{V^2}{R}$ $800 = \dfrac{(240)^2}{R}$ $R = \dfrac{240^2}{800}$ $P_1 = \dfrac{120^2}{R} = \dfrac{120^2}{\frac{240^2}{800}}$ $= (\frac{1}{4})(\frac{240^2}{R}) = (\frac{1}{4})(800)$ $= 200$ W
46	Ans: B For a sinusoidal ac: $V_{RMS} = \frac{V_0}{\sqrt{2}}$ Average power = $(V_{RMS})^2$/ Total resistance

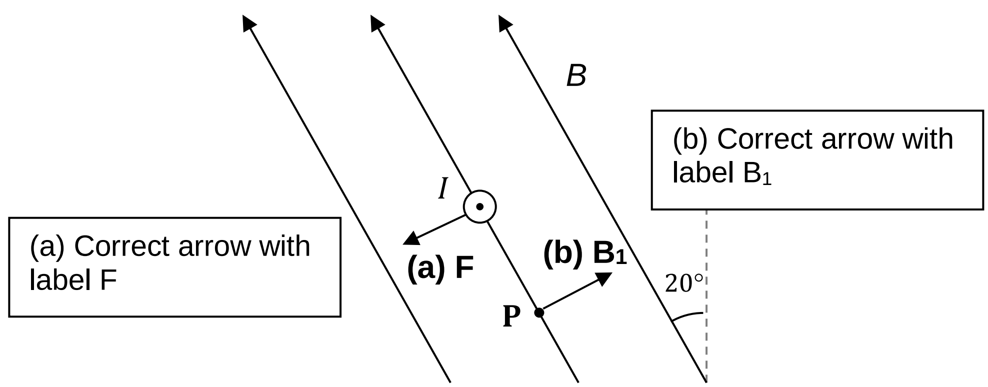
	Average power = $\frac{\left(\frac{V_0}{\sqrt{2}}\right)^2}{\frac{R}{2}} = \frac{V_0^2}{R}$
47	Ans: B Let *R* be the resistance of the fuse. The fuse will break when the power *P* dissipated in it exceeds $I_{rms}^2 R = (13^2)R$. Even when the power supply is changed to a d.c. source, the same fuse will still break when $P > (13^2)R$. This means that the fuse will break when the d.c. current exceeds 13 A.
48	Ans: B $P = \frac{mc\Delta\theta}{t}$ => $t = \frac{mc\Delta\theta}{P}$ For steady d.c $t = \frac{mc\Delta\theta}{I^2 R}$ as $P = I^2R$ For a.c with resistance 2R, $t_{ac} = \frac{mc\Delta\theta}{(\frac{I}{\sqrt{2}})^2 2R} = \frac{mc\Delta\theta}{I^2 R}$ as $P_{ac} = (\frac{I}{\sqrt{2}})^2 2R$ t_{ac} =*T*
49	Ans: B Current from the generator = $\frac{P}{V} = \frac{2000000}{240000} = 8.33A$ Power loss in the cables = $I^2R = 8.33^2(1500) = 104166W = 104\ kW$
50	Ans: B I_{rms} = P/V = 8.333 A to 9.09 A Corresponding I_0= 11.8 A to 12.9 A Expression for $I = I_0 \sin\omega t$ ω = 2π(50) = 314 rad s^{-1}
51	Ans: C dc: $I^2Rt = Q$ ac: $\left(\frac{I_o}{\sqrt{2}}\right)^2 Rt = \frac{Q}{4} = \frac{1}{4}\left(I^2Rt\right)$, thus $\left(\frac{I_o}{\sqrt{2}}\right)^2 = \frac{1}{4}(6)^2 \Rightarrow I_o = 3\sqrt{2}$A

52	Ans: A Peak-to-peak voltage = 2.00 × 4=8.00V Peak voltage = 4.00V Rms voltage = $\frac{4}{\sqrt{2}} = 2.83V$
53	Ans: D Alternating voltage supply is chosen over direct voltage supply for transmission of electrical power in transformers because of the need for **high** voltage transmission. This high voltage helps to reduce power loss during transmission.
54	Ans: B Period of transmitted voltage should remain the same, while the peak value doubles (due to the number of turns in the secondary coil).
55	Ans: D V_S=$\sqrt{P \times R} = \sqrt{50 \times 2} = 10V$ V_P=$\frac{N_P}{N_S} \times V_S = \frac{2000}{50} \times 10 = 400V$
56	Ans: C Power generated = VI = 7200 W Output current = 1.6 A Power lost = i2R = 5.12 W Percentage power lost = 5.12/7200 × 100% = 0.071%
57	Ans: C For 100 % efficiency, $\frac{I_s}{I_p} = \frac{N_p}{N_s}$ $I_s = \frac{N_p}{N_s} \times I_p = \frac{1200}{500} \times 0.25 = 0.60$ A For 83 % efficiency, $I_s = 0.83 \times 0.60 = 0.50$ A
58	Ans: B When X is at higher potential, the top diode conducts and the total resistance is 100 Ω. When Y is at higher potential, the bottom diode conducts and the total resistance is 600 Ω.
59	Ans: A For half-wave rectified current, $I_{rms} = \frac{I_o}{2} = 1A$ (See answer for question 37 for method to determine I_{rms}) Average heat dissipated = $(I_{rms})^2 R = 5W$
60	Ans: A

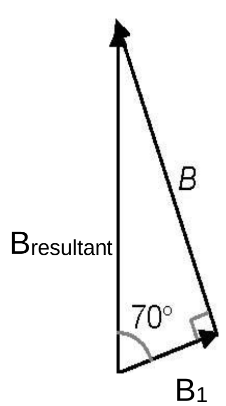
	For half-wave rectified voltage, $V_{rms} = \frac{V_o}{2} = \frac{6\times\sqrt{2}}{2} = 4.24V$ (See answer for question 37 for method to determine V_{rms}) Average power dissipated = $\frac{(V_{rms})^2}{R} = 9W$

Solutions for Short Structured Questions

1 **(a)**
(b)



(c)



Right-angle triangle with resultant pointing up

$B/B_1 = \tan 70°$
$= 2.7$

Or using the components method.

(d) direction is to the right using FLHR

$B_{resultant}$ = B/sin 70 = 0.0426 T
Magnitude = $B_{resultant}$ IL = 0.0426 x 4.0 x 0.30 = 0.0511 N = 0.051 N

[AJC2012/III/2]

2(a) The magnetic flux density of a magnetic field is defined as the force per unit length per unit current acting on an infinitely long current carrying conductor placed perpendicularly to the magnetic field. **B1**

(b)(i) Charge =+2e = 3.2 x 10^{-19} C **B1**

Mass = 4 u = 4 x 1.66 x 10^{-27} = 6.64 x10^{-27} kg

OR

Mass = 4 m_P = 4 x 1.67 x 10^{-27} = 6.68 x 10^{-27} kg

As this is a "state" question, there is no need for the student to show the working for obtaining the answers.

OR

Mass = 2 u + 2 m_P = 2 x 1.66 x 10^{-27} + 2 x 1.67 x 10^{-27} = 6.66 x10^{-27} kg

(All the three methods for finding mass are only estimates)

(b)(ii)1. The centripetal force required for circular motion in the *x*-*y* plane is provided by the magnetic force acting on the alpha particle,

$$\Rightarrow \quad B\,q\,v_T = \frac{m\,v_T^{\,2}}{r}$$

$$\Rightarrow \quad v_T = \frac{B\,q\,r}{m} = \frac{0.519\,(3.2\times10^{-19})\,0.02}{6.64\times10^{-27}}$$ **M1**

$$\Rightarrow \quad v_T = 5.00\times10^{5}\ \mathrm{m\,s^{-1}}$$ **A1**

or $v_T = 4.97\times10^{5}\ \mathrm{m\,s^{-1}}$

(b)(ii)2.

$$T = \frac{2\pi r}{v_T} = \frac{2\pi(2.00\times10^{-2})}{(5.00\times10^{5})}$$ **M1**

= 2.51 x 10^{-7} s **A1**

or T = 2.53 x 10^{-7} s

(b)(ii)3.

$$\frac{v_T}{v_Z} = \tan 60^o \ \Rightarrow\ v_z = \frac{v_T}{\tan 60^o} = \frac{5.00\times10^{5}}{\tan 60^o} = 2.89\times10^{5}\ \mathrm{m\,s^{-1}}$$ **A1**

or $v_Z = 2.87\times10^{5}\ \mathrm{m\,s^{-1}}$

(b)(ii)4. Pitch, p = $v_Z T = (2.89\times10^{5})(2.51\times10^{-7}) = 0.0725\ \mathrm{m} = 7.25\ \mathrm{cm}$ **A1**

or p = 7.26 cm

(c) The alpha particle will experience an electrical force/acceleration in opposite direction to the magnetic field, (reducing v_z but not affecting the transverse speed v_T). **B1**

Hence, the pitch of the helical trajectory will start reducing in distance, though the period of revolution will stay the same. **B1**

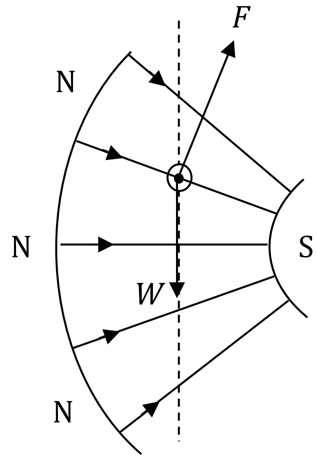
OR

the pitch decreases to zero and eventually the alpha particle subscribes a helical path in a reverse in direction to the B-field with an increasing pitch, though the period of revolution stays the same.

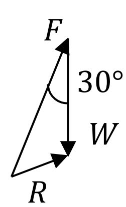
[HCI2012/II/4]

3(a) Magnetic flux density is defined as the force acting on a straight conductor of unit length, carrying unit current, placed perpendicularly to the magnetic field.
SI unit: Tesla

(b)(i)



(b)(ii) $F = 0.20 \times 5.5 \times 0.080 = 0.088$ N



$R^2 = (0.088)^2 + 0.030^2 - 2(0.088)(0.030)\cos 30^\circ$

$R \approx 0.064$ N

(c)(i) As wire cuts the magnetic field, it experiences a change in magnetic flux. According to Faraday's law, an e.m.f. is induced across wire.

(c)(ii) $E = Blv$

$0.16 = (0.20)(0.080)v$

$v = 10 \text{ ms}^{-1}$

[PJC2012/III/4]

4(a) The magnetic flux density is the force acting per unit current in a wire of unit length placed at right-angles to the field

whereas magnetic flux is the product of the magnetic flux density and the area normal to the field through which the field is passing.

4(b)(i)

induced e.m.f. $\varepsilon = BLv$

induced current $I = \dfrac{\varepsilon}{R} = \dfrac{BLv}{R}$

magnetic force $F = BIL = \dfrac{B^2L^2v}{R}$

4(b)(ii) largest possible magnetic force = mg

4(b)(iii) As wire PQ falls, velocity increases and induced e.m.f. (or current) increases, causing brightness to increase ($P=I^2R$)

As velocity increases, opposing magnetic force also increases and eventually terminal velocity is reached and the brightness stays constant.

4(b)(iv) Increase the mass of wire PQ
so that terminal velocity will increase and induced e.m.f. (or current) will increase, causing brightness to increase ($P=I^2R$).

[SAJC2012/II/4]

5 **(a)** magnetic force on particle is always normal to direction of motion and it provides the centripetal force for circular motion [1]

(b) **(i)** the momentum/speed is becoming less [1]
so the radius is becoming smaller [1]

(ii) 1. Spirals are in opposite directions [1]
so oppositely charged. [1]

2. Equal initial radius [1]
so equal initial speeds [1]

6 **(a)** **(i)** 50 mT [1]

(ii) flux linkage = BAN
$= 50 \times 10^{-3} \times 0.4 \times 10^{-4} \times 150 = 3.0 \times 10^{-4}$ Wb [1]

(b) **(i)** Faraday's Law of Induction states that induced voltage/emf is proportional/equal to the rate of change/cutting of flux (linkage) [2]

(c) **(i)** new flux linkage $= 8.0 \times 10^{-3} \times 0.4 \times 10^{-4} \times 150$
$= 4.8 \times 10^{-5}$ Wb [1]
change $= (0.48 - 3.00) \times 10^{-4} = -2.52 \times 10^{-4}$ Wb [1]

(d) **(ii)** Induced emf = -(-2.52 x 10^{-4})/0.30 = 8.4 x 10^{-4} V [1]

for a small change in distance *x*
(change in) flux linkage decreases as distance increases, [1]
so speed must increase to keep rate of change constant [1]

[TJC2012/III/4]
[TJC2012/II/4]

7 A long bar magnet X is suspended from a helical spring such that one pole of the magnet lies within a short cylindrical coil as shown in Fig 3.1.

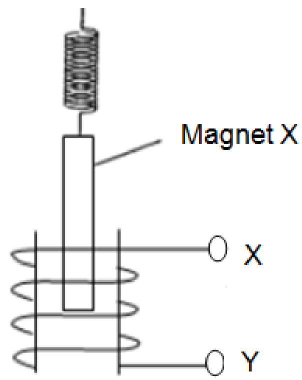
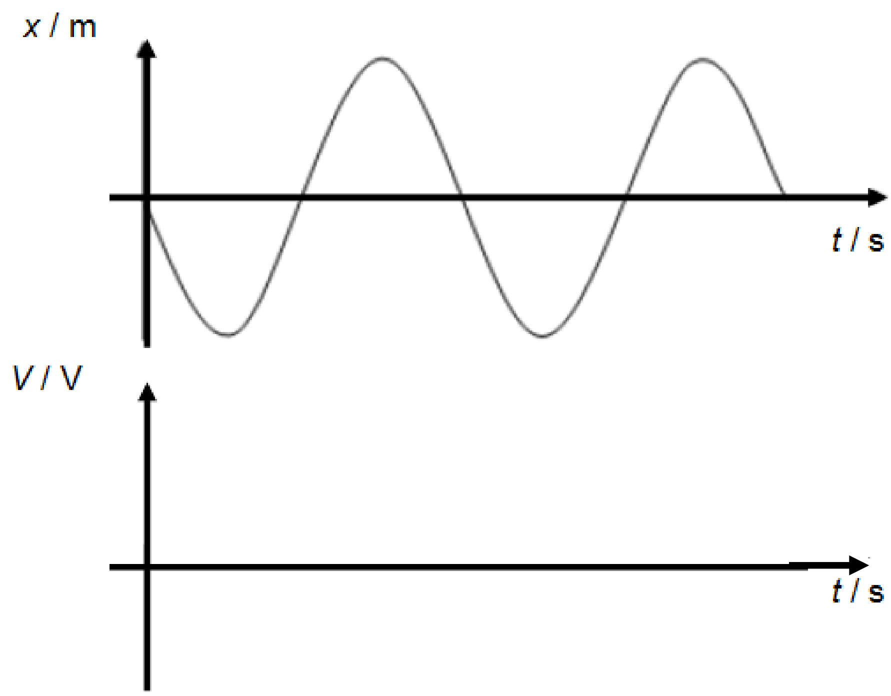


Fig. 3.1

The magnet is made to oscillate vertically such that one pole of the magnet oscillates in and out of the coil. The experiment is conducted in a draught free environment.

The displacement of the magnet from its equilibrium position with time is shown below. The rate of magnetic flux linkage induced in the coil can be taken to be directly proportional to the velocity of the magnet.



(a) Using the axes above, sketch the corresponding graph to show how the induced e.m.f *V* varies with time *t*. [2]

Cosine graph (one mark only if –cosine graph is drawn instead).

(b) Using Faraday's Law of electromagnetic induction, explain the variation of the e.m.f with respect to your graph drawn.

Faraday's Law states that the induced emf is proportional to the rate of change of magnetic flux linkage. [B1]
Since the velocity varies sinusoidally with time, the rate of magnetic flux linkage also varies sinusoidally with time. [B1]
From Faraday's law, emf varies sinusoidally with time. [B1] [3]

(c) The experiment is modified by connecting terminals X and Y to another solenoid and with an identical Magnet Y as shown in Fig. 3.2.

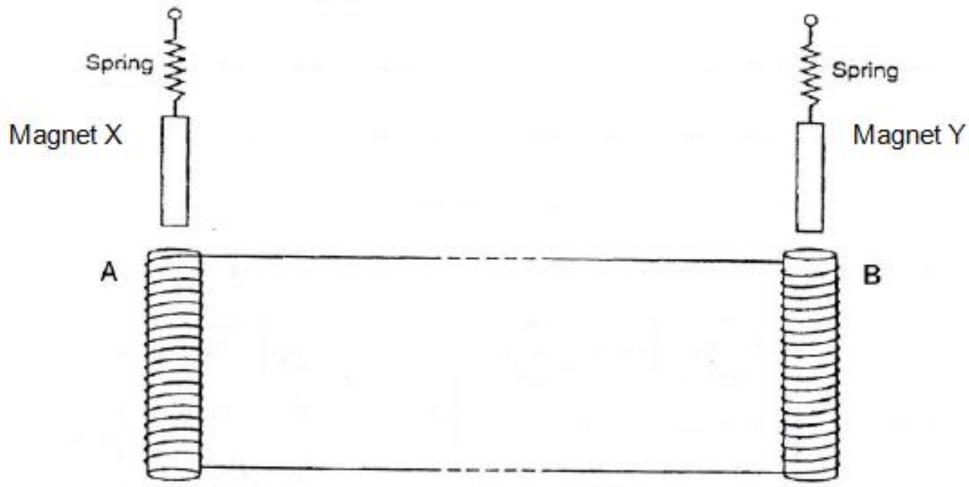


Fig. 3.2

Magnet X is pulled downwards, after which it oscillates in and out of the solenoid.

(i) Explain the effects on Magnet Y due to the oscillation of Magnet X.

As magnet X oscillates, the magnetic field lines cut the solenoid. This change of flux linkage produces an alternating induced emf in coil A. [B1]
Since the circuit is closed, an alternating induced current flows in B. [B1]
The magnetic poles in coil B will vary periodically, setting Magnet Y into forced oscillation. [B1]
The frequency of oscillation of Y is equal to that of X.

[3]

(ii) Explain if Magnet X will continue to oscillate after a long period of time.

It will experience damping and eventually to a stop. [B1]
By Lenz's law induced current will flow to oppose the change in magnetic flux linkage in A, thus Magnet X will experience an opposing magnetic field due to the induced current. [B1]

[2]
[TPJC2012/III/3]

8 **(a)** There is a change in the magnetic flux/flux linkage through a coil as the magnet passes it. [1] By Faraday's Law, emf is induced which is directly proportional to the rate of change of flux. [1]

(b) the cart has accelerated (between A and B) or is going faster/has more KE (at B) [1]
rate of change of flux is greater, hence greater emf induced for B [1] (student must make an attempt to explain that flux change takes place over a shorter time.)

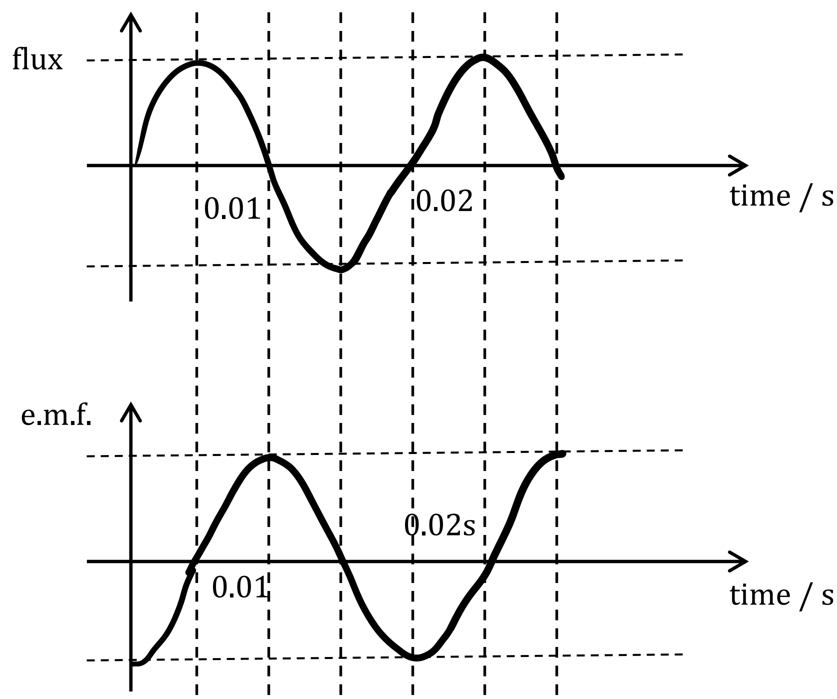
(c) the direction of the induced emf opposes the change producing it [1]
as the coil passes point A, the magnetic flux/field is increasing as the coil passes point B, the flux is decreasing [1]

(d) magnet is going faster (at B) or has accelerated (from A to B) [1]
the time for which the flux is changing is less [1]

[YJC2012/III/4]

9 **(a)** Faraday's Law states that the **magnitude of the induced e.m.f** is directly **proportional** to the **rate of change of magnetic flux linkage** or the **rate of cutting of magnetic flux.** 2
Lenz's Law states that the **polarity of the induced e.m.f.** is such that it may produce **an effect that opposes the flux change** that causes it. 1

(b) **(i)**



1

1

(ii)
- 1 mark for double the amplitude 1
- 1 mark for double the frequency 1

(iii) As the angle between the planes of the two coils were slowly increased from zero to 90°, the ***magnetic flux linking with the small coil*** will decrease to zero. 1

The trace on the screen of the c.r.o. which shows the induced e.m.f. in the small coil will thus also decrease to zero. 1

[HCI2013/III/3]

10 **(a)** **(i)** When the magnet is approaching the coil, there is an increase in magnetic flux threading through the coil.

When the magnet is leaving the coil, there is a decrease in the magnetic flux threading through the coil. [B1 with the previous statement]

According to Lenz's law, the direction of the current induced in the coil is such as produce an effect to oppose the change in magnetic flux threading through the coil, the deflections are therefore in opposite directions. [B1]

(ii) The magnet accelerates (increases in speed) as it falls through the coil and hence the rate of change of magnetic flux linkage is larger. [B1]

According to Faraday's law, the rate of change of magnetic flux linkage is proportional to the magnitude of the e.m.f. induced. A larger e.m.f. induced gives a larger deflection and hence the second deflection is larger than the first. [B1]

(b) **(i)** Change in magnetic flux linkage

(ii) 1.0 Wb s^{-1}

[IJC2013/II/5]

11 **(a)** **(i)** When the coil is rotating, there is a continuous change in the angle between the magnetic field and the area enclosed by the coil, thus the <u>magnetic flux linkage is continuously changing</u>. <u>By Faraday's Law of Electromagnetic Induction</u>, <u>an e.m.f. is induced</u>. [M1]

Since the induced e.m.f. is formed <u>in a closed circuit</u>, <u>induced current will flow.</u> [A1]

Note: Do not accept "flux cutting".

(ii) Angular velocity, ω = 2πf = 2π(50) = 100π
Magnetic flix linkage, Φ = NBA sin ωt (since at t = 0 s, Φ = 0 Wb)
= (30)(0.8)(2.5) sin (100πt)
= 60 sin (100πt)

Induced e.m.f., E = $-\dfrac{d\phi}{dt}$

$= -\dfrac{d[60\sin(100\pi t)]}{dt}$ [B1]

= - 100π(60) cos (100πt)
= - 6000π cos (100πt)

Current, $I = \frac{E}{R}$

$= -\frac{6000\pi\cos(100\pi t)}{40}$ [B1]

$= -150\,\pi\cos(100\pi t)$

$= -471\cos(100\pi t)$

(iii)

The series diode produce half wave rectification → $I_{rms} = I_o/2$

Power dissipated = $(I_o/2)^2 \times R$ [M1]

= $(471/2)^2 \times 40 = 2220$ kW [A1]

(b) **(i)**

- As the conductor rotates through a small region of constant magnetic field directed into the conductor it experiences a change in magnetic flux linkage and therefore according to Faraday's Law an emf is induced. This generates eddy currents on its surfaces (perpendicular to the field of the permanent magnet) [M1]

- By Lenz's law these circulating currents produce a magnetic field that opposes the magnetic field produced by the permanent magnets. [M1]

- In the event the disc deviates from the axis XX', the repulsive force experienced by the surface closer to one magnet will be greater and thus restore the conductor to the central axis. [A1]

(ii) There is no contact between the electrodynamic bearing and the rotating part thus practically no wear and tear. Traditional ball bearings align through contact and therefore have a limited lifetime. [B1]

[MJC2013/II/3]

12 (a)

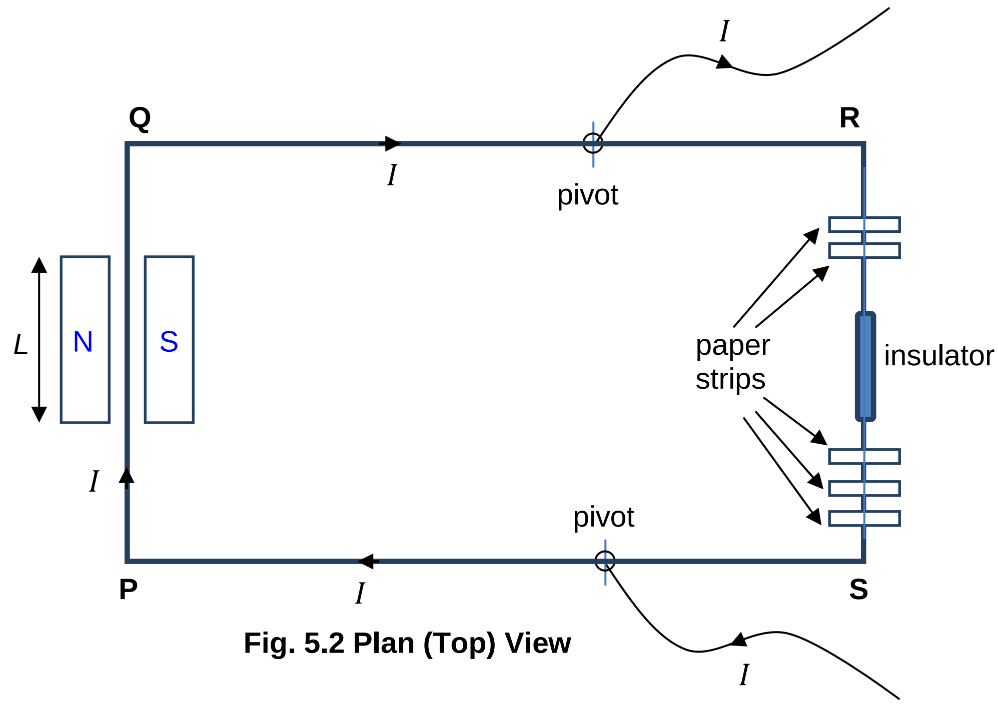


Fig. 5.2 Plan (Top) View

(b) Total mass of paper = 5 × (3.0 × 10^{-2}) × (4.0 × 10^{-3}) × 80 = 0.048 g

(c) Let x be the distance of arm RS from the pivots.

Taking moments about the pivots,

F_m (2x) = mgx

2BIL sin 90^o = mg

$$B = \frac{mg}{2IL} = \frac{(0.048\times10^{-3})\times9.81}{2\times1.2\times(5.0\times10^{-2})} = 3.924\times10^{-3}\,\text{T} \approx 3.9\times10^{-3}\,\text{T (2 s.f.)}$$

(d) **(i)** When the coil is placed between the poles of the magnet with its plane perpendicular to the magnetic field, the magnetic field lines pass through the plane of the coil and there is magnetic flux through the coil (and hence there is magnetic flux linkage with the coil). This magnetic flux (and hence flux linkage) reduces to zero when the coil is removed to a region of negligible magnetic field. According to Faraday's Law, an e.m.f. will be induced in the coil whenever there is a change in the magnetic flux linkage in a circuit or coil and the magnitude of this induced e.m.f. is proportional to the rate of change of flux linkage.

(ii) Induced e.m.f. $E = \dfrac{\Delta(NBA\cos\theta)}{\Delta t}$

$$= \frac{25\times(3.924\times10^{-3}\cos0^{o} - 0)}{0.040}\left(\frac{\pi\left(1.5\times10^{-2}\right)^2}{4}\right)$$

$$= 4.3\times10^{-4}\,\text{V (2 s.f.)}$$

[RI2013/III/5]

13 **(a)** **(i)** Into the plane of the paper. B1

(ii) Magnetic force provides centripetal force. M1

$Bev = mv^2/r$

$Be = mv/r$

$v = 2\pi r/T$ M1

$Be = r/T)/r$

$T = 2\pi m/Be$ M1

(b) **(i)** B-field reverses the direction of the proton (increasing the path length) (accept change in direction) B1

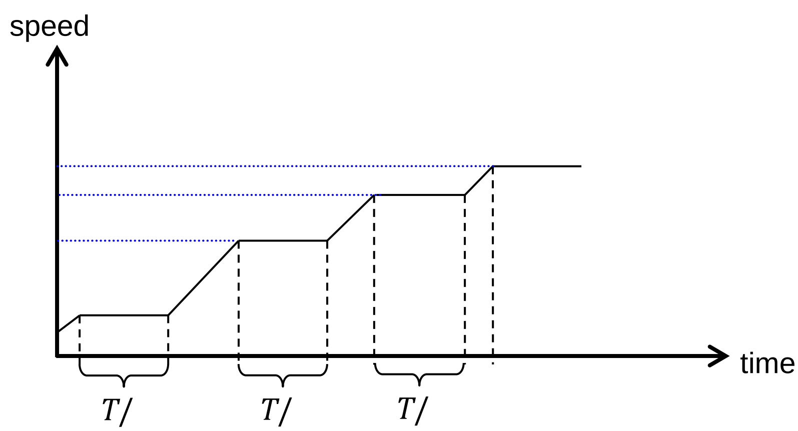
E-field increases the speed/kinetic energy of the proton (accept accelerates the motion) B1

(ii) time interval for E-field portion – getting shorter (speed increases) B1

time interval for B-field portion – constant (period independent of v) (T/2)

increase in speed is getting smaller for E-field portion B1

speed is constant for B-field portion



[RVHS2013/III/3]

14 **(a)** **(ii)** Solution:

As ionized gas moves perpendicularly into the magnetic field, the cutting of magnetic flux linkage (or the change of magnetic flux linkage through the area swept by the plasma) induces an electromotive force (e.m.f.) in the direction perpendicular to the plane of the magnetic flux density and plasma flow. Hence e.m.f. is induced across the electrodes as suggested by Faraday's law. **B1** **B1**

Alternate solution:

In the microscopic view, as charged gas particles move perpendicularly into the magnetic field, a magnetic force will push the positive ions to one electrode and negative ions to the other. Hence a potential difference, i.e. e.m.f. is built between the electrodes. **B1** **B1**

(iii) Electrode Y **A1**

(iv) For conventional generators with moving parts, original energy will be converted to mechanical energy and then converted to electrical energy. Every conversion will decrease its efficiency. Hence if energy is directly converted from thermal energy to electricity, efficiency should be higher. **B1**

(b) **(i)** **B1**

u/ m s^{-1}	P/ W	P/u^2 / W s^2 m^{-2}
0.4	2	12.5
0.8	7.5	11.7
1.2	17.5	12.15
1.8	39.5	12.19

Average value of P/u^2 = 12.135

Since the difference in values of P/u^2 is not more than 4% of the average value (relatively constant), P can be concluded to be directly proportional to u^2 for a specific fluid with a specific electrical conductivity. **B1** **B1**

(ii) New graph is stretched to the right of original graph. **B1**

(iii)
- Magnetic flux density
- Density of fluid (greater charge carrier density so more move towards the electrode per unit time)
- Separation between the electrodes (greater separation means the same number of charged particles take a longer time to reach the electrodes. Since Power is RATE of energy converted (from kinetic energy of plasma to electrical energy □ definition of e.m.f.), P decreases).

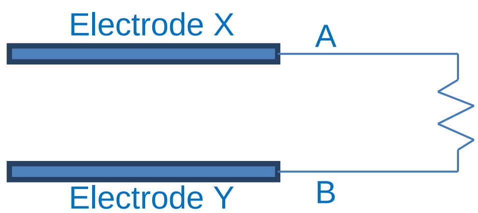
(c) As the potential of the electrodes build up, there will be an electric force on the charged ions. Hence the charged ions will not be collected at the electrodes. Instead, they will flow in the direction of the plasma flow and go upstream through the continuous **B1**

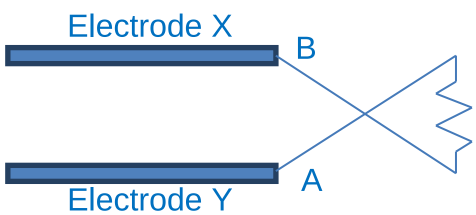
electrodes as there will be a higher concentration of charges at the downstream as compared to the upstream. **B1**

Hence a significant amount of voltage generated is not used by the external load and thus it has a low efficiency. **B1**

(d) A mechanical device is needed to switch the current back and forth. The connectors A and B are required to switch their connections with the electrodes X and Y as shown in the diagram below at a very high speed. **B1**

A mechanical motor maybe used here to switch the connectors. **B1**





[CJC2015/II/6]

15 **(a)** mean P = ¼ (peak P) for half-rectified wave C1

$I_{rms}{}^2R$= ¼ ($I_o{}^2R$)

I_{rms} = ½ I_o

peak current, $I_o = 2\,(5 \times 10^{-3})$ C1

peak voltage across R, $V_o = I_oR = 2\,(5 \times 10^{-3})(2.0 \times 10^3) = 20$ V A1

(b) timebase: f = 50 Hz, T = 20 ms→ 4 squares M1

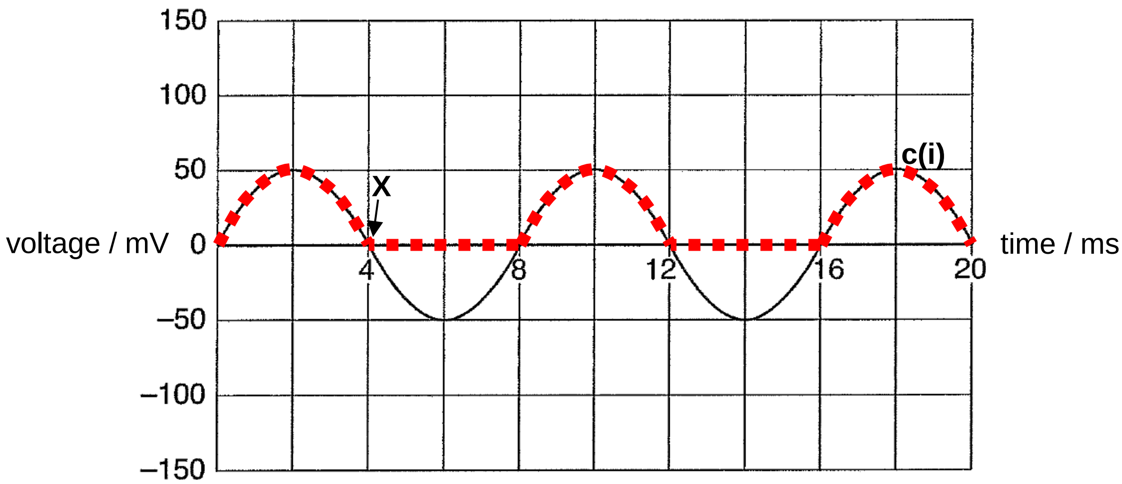
voltage gain: V_o = 20 V→ 4 squares M1

shape: half-rectified wave M1

[RVHS2013/III/4]

16 **(a)** BA = 0.050 × 0.050 × 0.026
= 6.5×10^{-5} Wb
[No marks if unit is missing or given wrongly, & accept T m^2]

(b) a point where curve crosses t-axis



(c) **(i)** Half wave rectified waveform in dashed line

(ii) For full-wave, $V_{rms} = V_0 / \sqrt{2}$
<P> half wave = ½ <P> full wave
= ½ × V_0^2 / R
= ½ × $(50 \times 10^{-3})^2 / 5$
<P> half wave = 1.25×10^{-4} W
<u>OR</u>
For half-wave $V_{rms} = V_0 / 2$
<P> = $V_{rms}^2 / R = (25 \times 10^{-3})^2 / 5$
<P> = 1.25×10^{-4} W

[AJC2013/III/4]

16 (a) (i) $\Phi = BA$

Total $\Phi_{big\ loop}$ = 4.00 (2.00) B = 8.00 B

Total $\Phi_{small\ loop}$ = Y (1.00) B = Y B [1]

$\frac{\Phi_{big\ loop}}{\Phi_{small\ loop}} = \frac{8.00\ B}{Y\ B} = \frac{4}{1}$ (ratio obtained from graph)

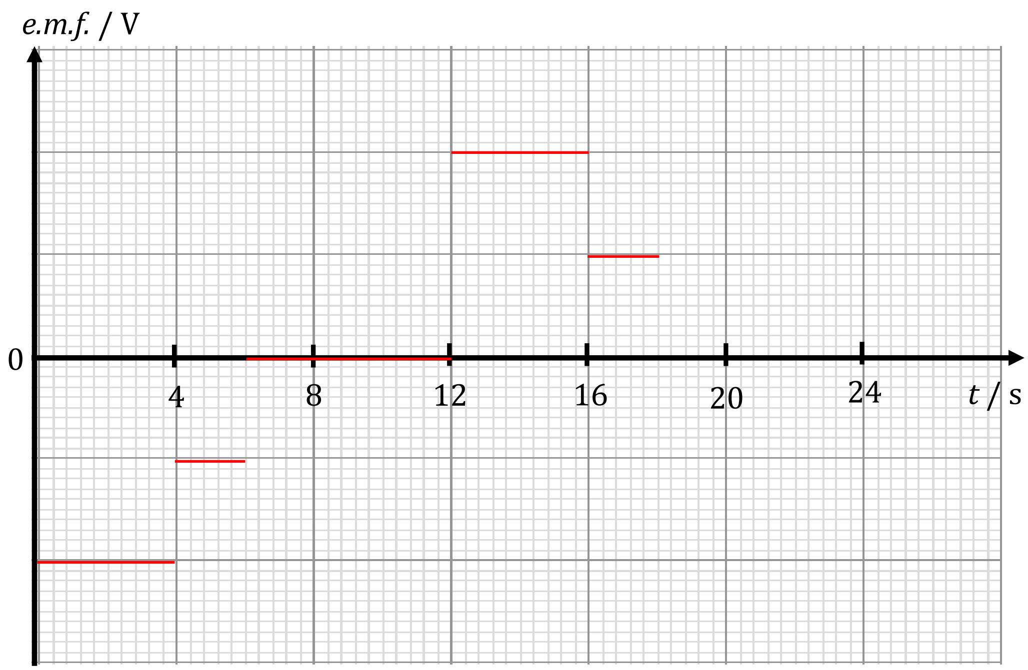
Y = 2.00 m [1]

(ii)

Straight lines [1]

Ratio correct (including time) [1] [2]

(iii)



From t = 0 s to 12 s,
Horizontal lines [1]
Correct ratio of emf induced (including negative emf for 1st 6 seconds) [1]

To get last [1], graph must be perfectly correct from 0-18 s (no ecf given) [3]

(b) **(i)**

- When metal frame enters the magnetic field, it experiences an increase in magnetic flux linkage. By Faraday's Law, an induced emf is set up in the frame. [1]
- Since the light bulb and metal frame provides a closed conducting path, by Lenz's Law, an induced current will flow in the frame in the direction that sets up a magnetic field that opposes the change which is the motion of the metal frame. [1]
- This will produce a magnetic force on the frame to slow it down. In order for the frame to move at constant speed, an external force must be applied such that resultant force on frame is zero. [1]

(ii)

- entering the magnetic field: To the right
- leaving the magnetic field: To the right

[1]

If either answer is wrong, no mark awarded.

[HCI2015/III/2]

Solutions for Long Structured Questions

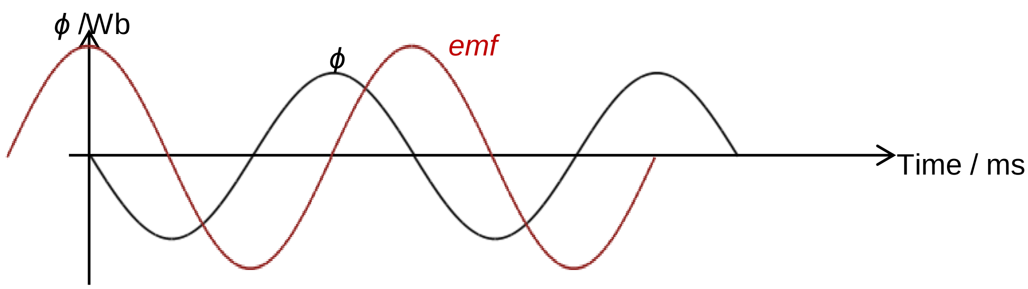
Question 1

(a) The magnitude of induced emf is directly proportional to

the rate of change of magnetic flux linkage **B1**

or the rate of cutting of magnetic flux. **B1**

(b)



B1

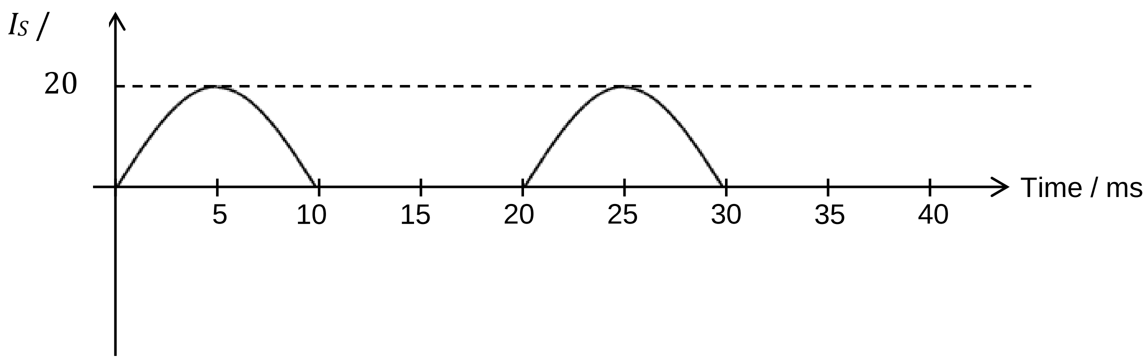
(c)

$$\frac{V_s}{17\sqrt{2}} = \frac{60}{1800} \Rightarrow V_s = \frac{17\sqrt{2}}{30} = 0.801\,\text{V}$$

M1

A1

(d)



Correct period and half-wave rectified **B1**

Correct peak current $I_S = \frac{V_S}{R} = \frac{0.801}{4} = 200$ mA **B1**

(e)

$$R = \frac{V}{I} = \frac{0.8}{0.1} \Rightarrow 8.0\ \Omega$$

A1

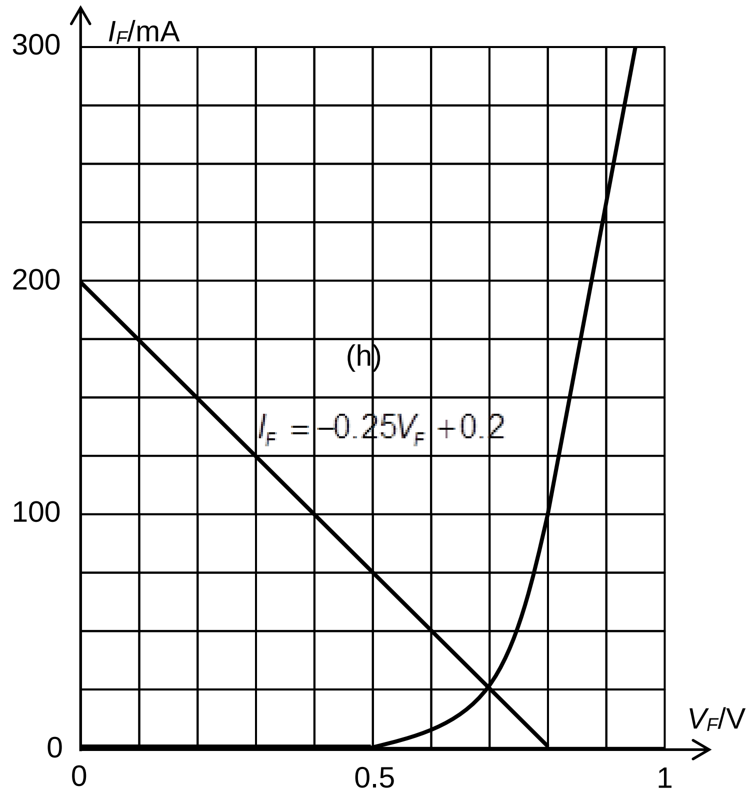
(f)

$$V_S = V_F + I_F R$$

$$I_F = \frac{V_S - V_F}{R}$$

B1

(g)



M1

A1

Peak I_F = 25 mA

(h) When the p and n sides are joined together, due to concentration gradient, electrons <u>diffuse</u> from the n side to the p side, and holes from the p side to the n side. **B1**

The electrons and holes <u>recombine</u> near the junction. **B1**

This leads to depletion region with <u>unbalanced charges</u>: positively charged donor ions on the n-side and negatively charged dopant ions on the p-side. **B1**

A <u>barrier electric potential/field</u> opposes the diffusion of majority charge carriers. **B1**

As the forward bias voltage increases, the <u>barrier potential/field decreases</u>, leading to (exponential) increase in number majority charge carriers energetic enough to overcome the barrier, hence resistance decreases.

(i)

$$E = \frac{hc}{\lambda} \Rightarrow (1.43)(1.60 \times 10^{-19}) = \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{\lambda}$$ **M1**

$\lambda = 869$ nm **A1**

Infrared **A1**

(j) The electrons in the conduction band and the holes in the valence band occupy a small **B1**

but finite range of energy levels.

(k) This large current produces a huge density/number of electrons in the conduction band and holes in the valence band near the junction region **B1**

OR

This large current results in more electrons in (the bottom of) the conduction band than in (the top of) the valence band

Leading to population inversion so stimulated emission can take place. **B1**

Total 20

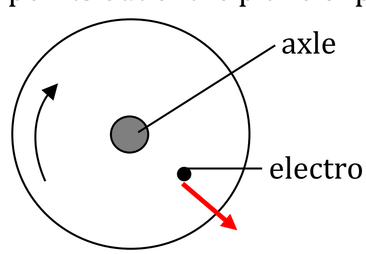
[HCI2012/III/7]

2 **(a)** Faraday's law states that the induced e.m.f. ε is directly proportional to the rate of change of magnetic flux linkage Φ (or the rate of cutting of magnetic flux). [B1]

Lenz's law states that the induced e.m.f. will be directed such that the current which it causes to flow opposes the change that is producing it. [B1]

(b) **(i)** B-field points out of the plane of paper [B1]

(ii)



[B1]

(iii) As the disc rotates more quickly, the <u>rate of change of magnetic flux experienced by the disc increases</u> and <u>by Faraday's Law</u>, [M1]
the <u>induced e.m.f. increases</u> too. [A1]

(iv) When the <u>speed of rotation is low</u>, the <u>induced e.m.f. is less than the potential difference from the d.c. supply</u>. Thus, current flow through the galvanometer in one direction (e.g. to the right). [B1]

If the <u>speed of rotation is increased further</u>, <u>induced e.m.f. will be greater than the potential difference from the d.c. supply</u>. The current and thus the galvanometer changes direction. [B1]

(iv) Induced e.m.f

$= $ Total rate of change of magnetic flux

$= $ no. of revolution per unit time $\times$ flux change per revolution

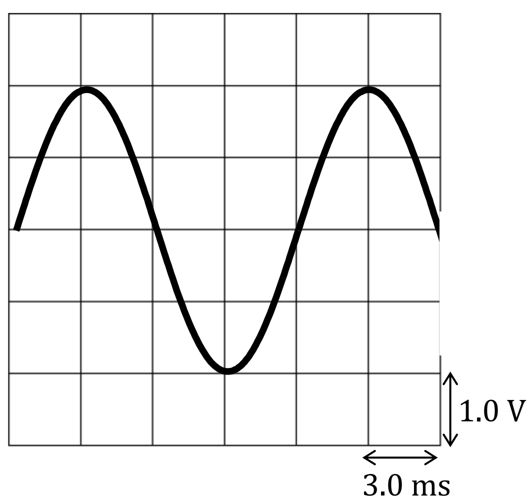
$= f \times \mu_o n I_s (S)$ [M1]

$$\text{Induced current} = \frac{V_{net}}{R} = \frac{\mu_o n I_s (S)(f) - E}{R}$$ [A1]

or

$$\text{Induced current} = \frac{V_{net}}{R} = \frac{E - \mu_o n I_s (S)(f)}{R}$$

(c) **(i)**



[B1]: one and a half waves
[B1]: peak to peak has 4 divisions
**also accept cosine graph*

(ii) $E_{r.m.s} = \frac{E_o}{\sqrt{2}} = \frac{2.0}{\sqrt{2}} = 1.4\text{ V}$ [B1]

(iii)

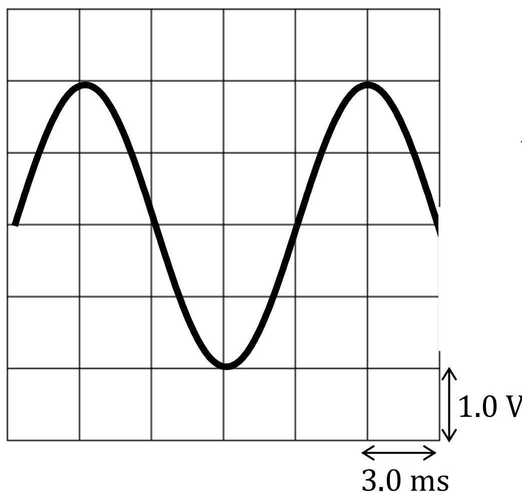
$$E_{\max} = \omega NAB$$

$$B = \frac{E_{\max}}{\omega NA} = \frac{E_{\max}}{\left(\frac{2\pi}{T}\right)NA}$$

$$= \frac{2.0}{\left(\frac{2\pi}{12\times10^{-3}}\right)(20)(2000\times10^{-6})}$$ [M1]

$$= 9.5\times10^{-2}\ \text{T}$$ [A1]

(d) **(i)**

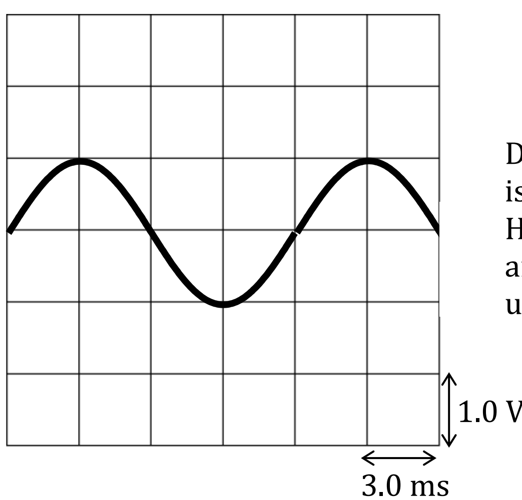


[B1] graph & explain

As turns n doubled, induced e.m.f doubled.
Frequency remains unchanged.

**also accept cosine graph*

(ii)



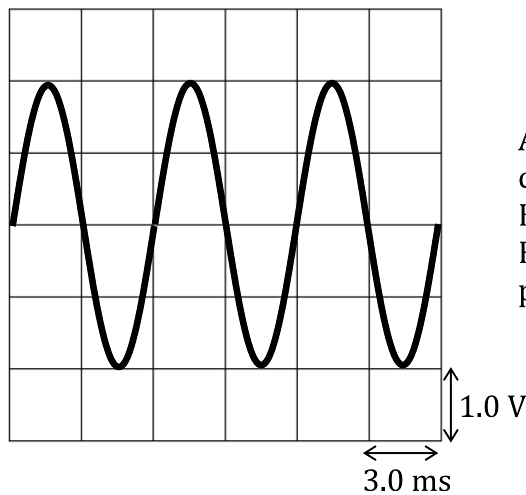
[B1] graph

[B1] explain

Due to high permeability, there is minimal attenuation of B. Hence both peak to peak value and frequency remain unchanged.

**also accept cosine graph*

(iii)



[B1] graph

As frequency is doubled, rate of change of flux is doubled. Hence induced e.m.f. doubles. Frequency is doubled, the period is halved

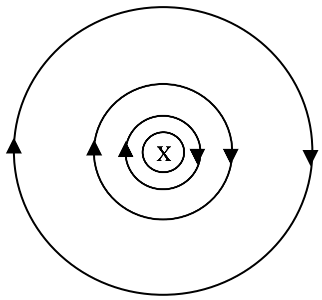
[B1] explain

**also accept cosine graph*

3(a) Magnetic flux density is the force *per unit length per unit current* acting on a straight current-carrying wire placed *perpendicular* to the magnetic field.

SI unit: tesla

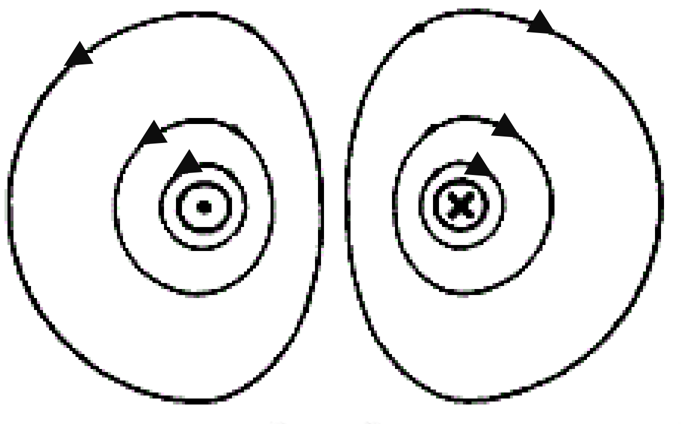
b(i)



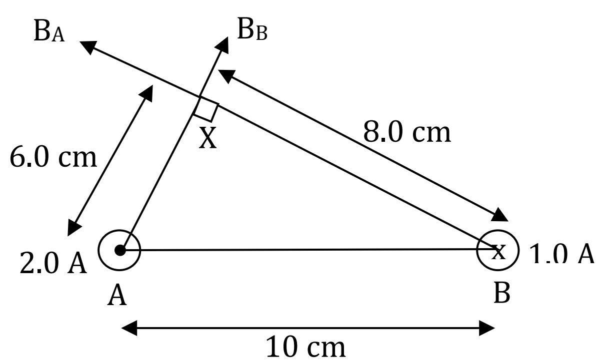
Lines must have

increasing gap

(ii)1



2



$B_A = \dfrac{4\pi \times 10^{-7} \times 2.0}{2\pi \times 0.060}$

$= 6.67 \times 10^{-6}$ T

$B_B = \dfrac{4\pi \times 10^{-7} \times 1.0}{2\pi \times 0.080}$

$= 2.50 \times 10^{-6}$ T

Resultant B = $\left(\sqrt{6.67^2 + 2.50^2}\right) \times 10^{-6}$

$= 7.1 \times 10^{-6}$ T

(c)(i) For the current balance to remain horizontal, the magnetic force acting on XY must be downward. So by Fleming's left hand rule, the *north* pole must be nearest to XY.

(ii) When horizontal, anticlockwise moment = clockwise moment about the pivot

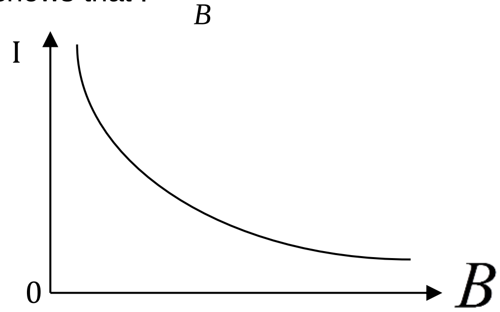
$$BIL(4.2) = mg(5.8)$$

$$B = \frac{mg(5.8)}{IL(4.2)}$$

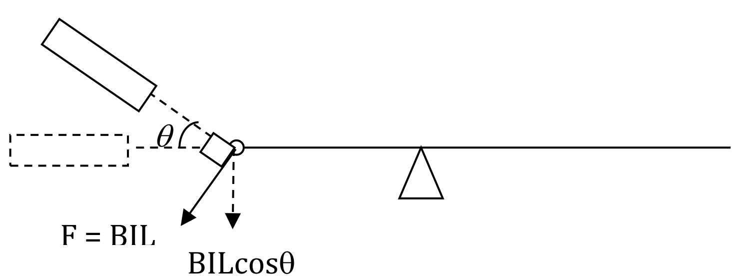
$$= \frac{0.15 \times 10^{-3} \times 9.81 \times 5.8}{1.2 \times 4.0 \times 10^{-2} \times 4.2}$$

$$= 4.2 \times 10^{-2} \text{ T}$$

(iii) Part (ii) shows that $I \propto \dfrac{1}{B}$



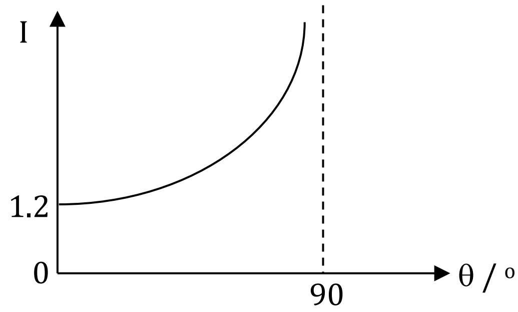
(iv)



This time the vertical force is BILcosθ. The equation in (ii) becomes:

$$BIL\cos\theta\ (4.2) = mg(5.8)$$

$$I \propto \frac{1}{\cos\theta} \qquad \text{(NB: B is kept constant)}$$



(v) The main disadvantage of the current balance is that the calculation of the current involves the dimensions of the coils. So the accuracy of the current measurement is limited by the accuracy with which the coils can be measured, and their mechanical rigidity.

[VJC2012/III/5]

4 (a) Induced e.m.f. / current acts in such a direction <u>to produce effects</u> to oppose the change causing it. B1

<u>Comments:</u> In many answers, it was not made clear that the induced e.m.f. gives rise to effects that tend to oppose the change giving rise to the e.m.f. Often the e.m.f. was stated to oppose the change in flux linkage.

(b) (i) Max dB/dt determined using tangent drawn at t = 0.0, 0.5 or 1.0 s
Values in range of 0.5 to 0.7 x 10^{-2} T s^{-1} B1
Emf induced = NAdB/dt = 240 x 2.5 x 10^{-4} x dB/dt = 0.30 to 0.50 mV A1

(ii) Zero emf at approximately correct times (0.20 to 0.26 s, 0.70 to 0.76 s) B1
Maximum at correct times, positive and negative emf. Correct phase. B1

(iii) Maximum speed of the magnet increases B1
Therefore maximum rate of change of flux also increases B1

(iv) Use a stronger magnet / use a coil with more turns / use a coil with a greater area / Use a soft iron core in the coil B1

(c) (i) Time between 2 magnets passing coil = 71 – 74 ms. B1
Time for 1 revolution = 284 – 296 ms.
Number of revolution per minute = 203 – 211 A1

(ii) Movement of magnet changes flux linkage with coil. B1
Based on Faraday's law,
emf induced is directly proportional to rate of change of flux linkage in the coil. B1

(iii) Peak induced emf = 1.5 x 5 mV = 7.5 mV B1
Maximum rate of change of flux = peak induced emf / N = 3.1×10^{-5} Wb s^{-1} A1

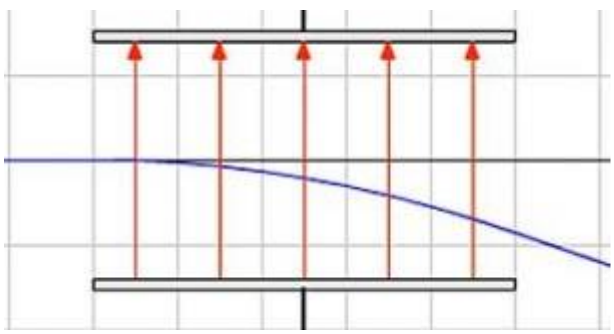
(iv) By Len'z law
magnet is being repelled as it approaches and attracted as it leaves the coil
thus the induced emf changes direction. B1

(v) Higher peaks and narrower and sharper peaks. B1
Positive and negative peaks closer together, B1
Sets of peaks closer together B1

(vi) Smaller resistance, therefore the induced current is higher M1
Stronger repelling and attractive forces
as the magnet approaches and leaves the coil.
Rate of revolution would be slower. A1

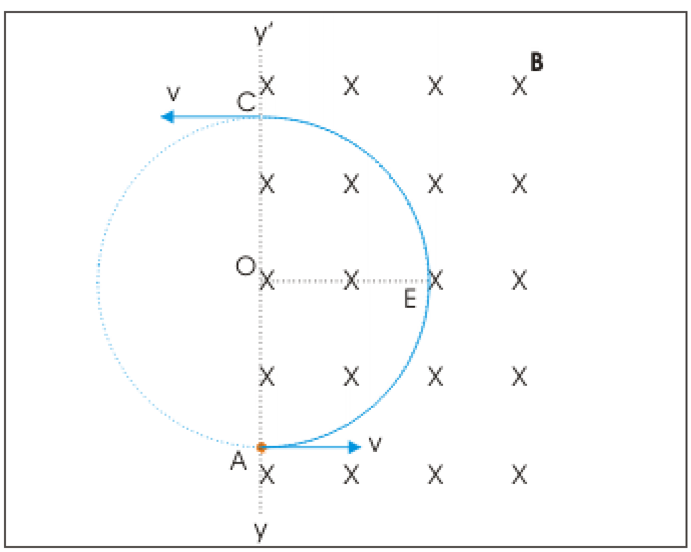
[DHS2013/III/8]

5 (a) (i)



The particle follows a parabolic path.

(ii)



The particle follows a circular path.

(b) **(i)** When electron is accelerated to the higher potential of 0 V, electron loses electric potential energy = $e\Delta V$

By conservation of energy,
Gain in kinetic energy = loss in EPE [B1]
$\frac{1}{2}(2.84 \times 10^{-26}) v^2 = (1.6 \times 10\text{-}19)(3000)$
$v = 1.83 \times 10^5$ m s^{-1} [A1]

(ii) When the negative ions enter into the region of electric and magnetic fields,
The ions experience a magnetic force to the left, [B1]
if P2 is set to be positive, the ions can experience an electric force to the right. [B1]

When the two forces balanced each other, the net force on the ions would be zero [B1]
and the ions can pass through without being deflected.

(iii) Magnetic force = electric force
$Bqv = eE$
$E = (0.83\ \text{T})(1.83 \times 10^5\ \text{m s}^{-1}) = 1.53 \times 10^5\ \text{V m}^{-1}$

(c) **(i)** Out of the plane of the paper

(ii) When the ions enter into the magnetic field, it experiences a magnetic force at right angles to the direction of motion of the ions. [B1]

The magnetic force provides the centripetal force, changing the direction of velocity of the ions and keeping the speed constant. [B1]

(iii) Magnetic force provides the centripetal force
$Bqv = mv^2/ r$ [C1]

$r = mv/Bq$ [C1]

Since the speed of the ions exiting point O have the same value, B is constant and charge the same,

Radius is proportional to the mass *m* of the ions [C1]

OA = 2(radius) is proportional to the mass *m* of the ions

(iv) The larger the mass, the greater the distance OA, and we can distinguish the different ions.

(d) **(i)** for same specific charge, no change to the speed

(ii) NO change, ions still pass through undeflected.

(iii) No change, since radius is proportional to q/m.

[IJC2013/III/8]

6(a) $v = r\omega$

$= \frac{l}{2} \times \omega = \boldsymbol{\frac{l\omega}{2}}$

6(b) Induced e.m.f. in vertical side is
E = B_0lvsinθ

$\therefore E = B_0 l \left(\frac{l\omega}{2}\right) \sin\theta$
$\therefore \boldsymbol{E = \frac{1}{2} B_0 l^2 \omega \sin\theta}$

6(c) Vertically downwards.

6(d) Q will be at a higher potential than P.

6(e) When t = 0, θ = 0°

$$\Rightarrow E = \frac{1}{2} B_0 l^2 \omega \sin 0^o = 0$$

When t = T / 4, θ = 90°

$$\Rightarrow E = \frac{1}{2} B_0 l^2 \omega \sin 90^o = \frac{1}{2} B_0 l^2 \omega$$

This is the e.m.f. induced in each of the two vertical sides.
Hence, the total e.m.f. induced in the structure would be equal to

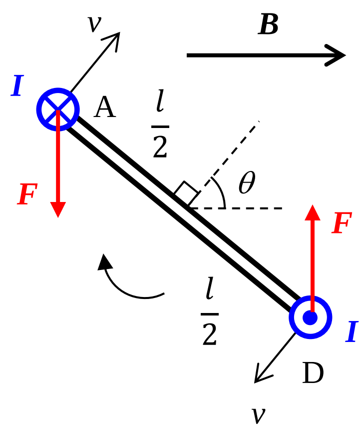
$$\Rightarrow E = 2 \times \frac{1}{2} B_0 l^2 \omega$$
$$\Rightarrow \boldsymbol{E = B_0 l^2 \omega}$$

Hence, the induced e.m.f. at time t is given by:

$$E = B_0 l^2 \omega \sin \omega t$$

$\mathbf{6(f)}\ \boldsymbol{I == \frac{B_0 l^2 \omega}{R} \sin\theta}$

6(g)



6(h) Torque on ring

$= \tau = (B_0 Il \sin 90^o) \times \frac{l}{2} sin\theta \times 2$

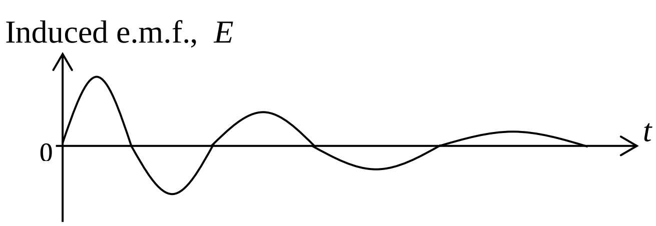
$$\therefore \tau = \left(B_0 \times \frac{B_0 l^2 \omega}{R} sin\theta \times l \right) \times \frac{l}{2} \sin\theta \times 2$$

$$\therefore \tau = \left(B_0 \times \frac{B_0 l^2 \omega}{R} sin\theta \times l \right) \times l \sin\theta$$

$$\therefore \boldsymbol{\tau} = \left(\frac{\boldsymbol{B_0}^{\boldsymbol{2}} \boldsymbol{l^4 \omega}}{\boldsymbol{R}} \right) \boldsymbol{sin^2 \theta}$$

6(i) The torque has the effect of retarding the rotational motion of the ring.

6(j) Due to the retarding torque, the rotational speed of the ring will slow down with time. Consequently, the induced e.m.f. will also be reduced with time.



6(k) The rotational mechanical energy of the ring is converted to electrical energy

and finally into heat energy which is dissipated to the surroundings.

[VJC2013/III/9]