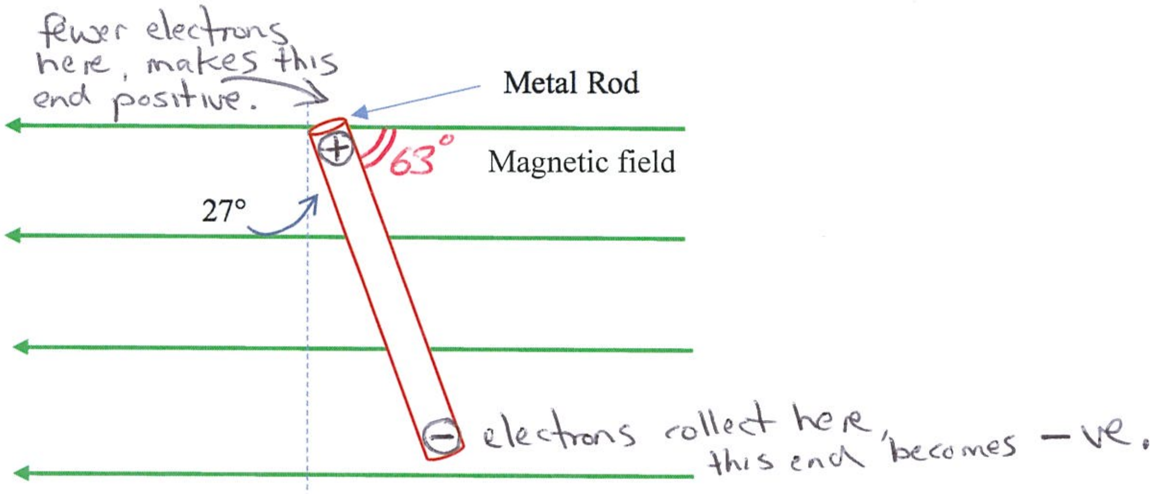
Year 12 ATAR Physics

Electromagnetic Induction Test 2018

NAME: ANSWERS

Total Marks – 55

1.
A metal rod of length 1.70 m is viewed from above and is falling through air (into the page) under the influence of gravity. The rod is in a region of magnetic field going left which has a flux density of 948 mT. The rod is at an angle of 27° from being perpendicular to the field lines as shown.



a) At this instant the rod has a speed of 8.70 m s^{-1} into the page. Calculate the emf induced across the rod. (3)

angle between the conductor and the B-field, θ where $\theta = 90 - 27 = 63°$

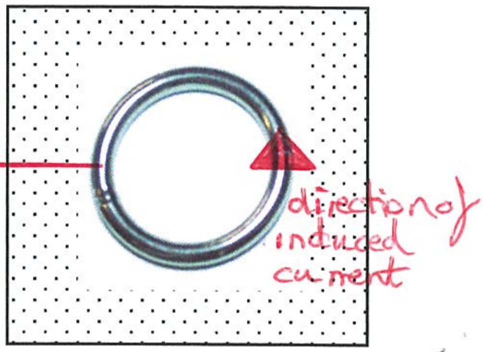
$$\mathcal{E} = BLv\sin\theta$$
$$= 0.948 \times 1.7 \times 8.7 \times \sin 63$$
$$= 12.5\text{ V}$$

b) Explain how a potential difference is established across the metal rod in this situation by identifying regions of relative charge difference / polarity. (2)

- Right Hand rule predicts conventional current would flow to the TOP end of the rod, therefore electrons would collect at the opposite end (as shown on the diagram).
- Lower end becomes negative, due to the buildup of electrons, and upper end is left positive, due to a depletion of electrons
- thus a potential difference/voltage/emf is created.

2. (4 marks)

The diagram below shows a ring of wire of radius 2.00 cm, which is immersed in a uniform magnetic field of intensity 50.0 mT. The ring is pulled to the left and is clear of the magnetic field in 0.15 s.



a) Indicate on the ring the direction of any induced current.

- current only flows once L.H.S. of ring has left the field. Current will flow anti-clockwise.

b) If the ring has a resistance of 0.03 Ω, find the average current induced.

$\mathcal{E} = \frac{N(\varphi_2 - \varphi_1)}{t}$; $N = 1$, $\varphi_2 = BA_{max}$, $\varphi_1 = 0$

$\therefore \mathcal{E} = \frac{(BA_{max} - 0)}{t}$

$= \frac{0.05 \times \pi (0.02)^2 - 0}{0.15}$

$= 4.19 \times 10^{-4}$ V

$I = \frac{\mathcal{E}}{R} = \frac{4.19 \times 10^{-4}}{0.03}$

$\therefore I = 0.0140$ A $= 14.0$ mA

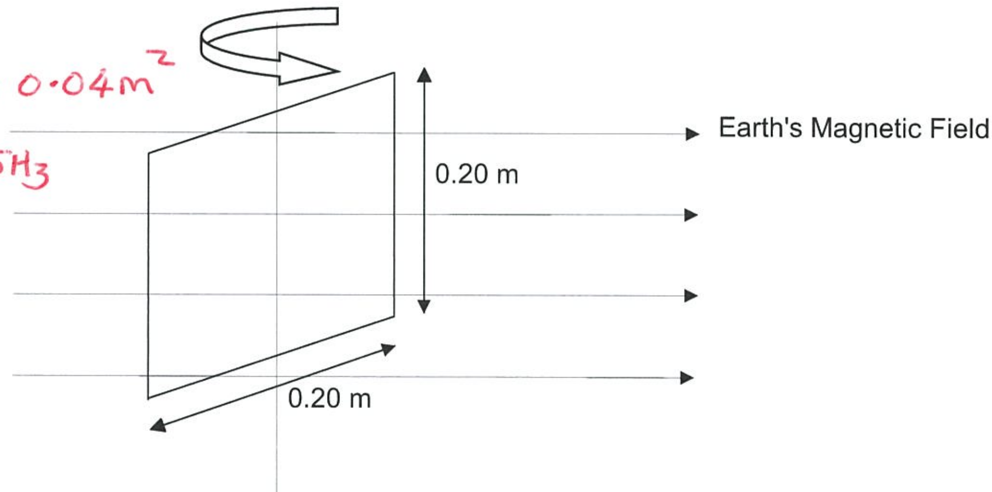
3. A rectangular coil has measurements 0.2 m x 0.2 m as shown below:

$N = 100$

$A = 0.2 \times 0.2 = 0.04 \text{ m}^2$

$f = \frac{1500}{60} = 25$ Hz

$B = 20 \times 10^{-6}$ T



This coil consists of 100 turns of wire and rotates about a vertical axis at 1500 rpm, as indicated in the above diagram. The horizontal component of the earth's magnetic field at this location is 20 μT. **Derive** an expression for the **average** voltage induced in the coil by the earth's field and then use it to calculate the **magnitude** of this induced voltage. (5 marks)

- flux changes from its max. value, $\varphi_{max} = BA$ (when plane of the coil is parallel to the B-field) to its min. zero value (when plane of the coil is perpendicular to the B-field) every $\frac{1}{4}$ turn.
- this happens every $\frac{T}{4}$ seconds, where T = time period of the coil,
- so, $\mathcal{E}_{av.} = \frac{N(\varphi_{max} - 0)}{T/4}$ $\therefore \mathcal{E}_{av.} = \frac{4NBA}{T}$ but $f = \frac{1}{T}$,

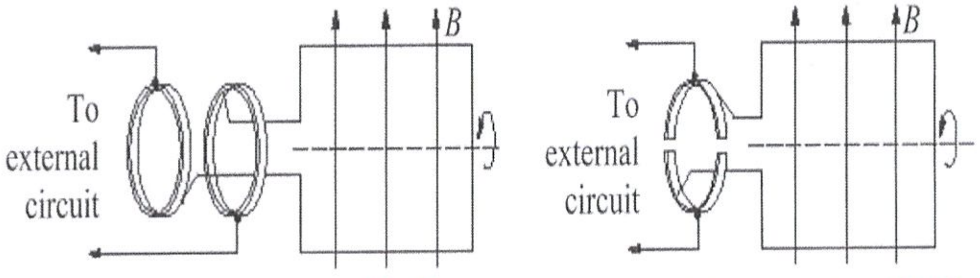
$\therefore \mathcal{E}_{av} = 4BANf$.

$\therefore \mathcal{E}_{av} = 4 \times 20 \times 10^{-6} \times 0.04 \times 100 \times 25$

$\mathcal{E}_{av} = 0.0080$ V (= 8.0 mV).

4.

Two types of generator are shown below. Generator P has slip rings and Generator Q has a commutator.



Generator P = A.C. Generator Q = D.C.

a) What is the function of the *brushes* in a generator?

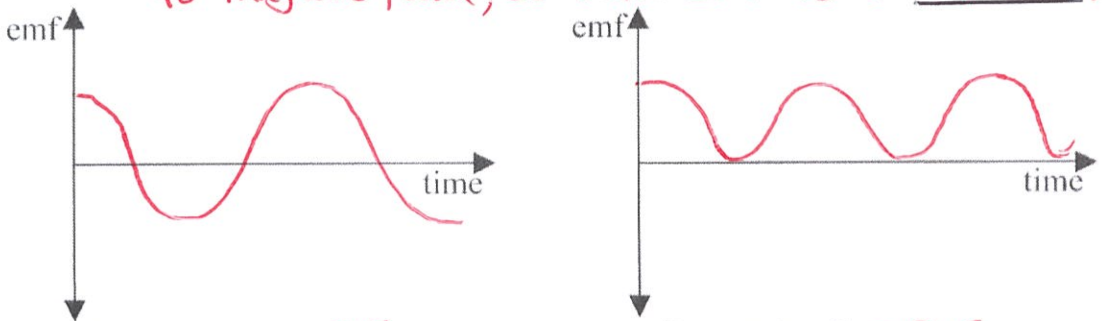
[1 mark]

maintains temporary (non-permanent) contact between the rotating coil and the external circuit, so wires do NOT become twisted.

b) Sketch a graph of the emf against time for each of the generators. You need not add a scale to the axes.

[2 marks]

- both coils start with their plane parallel to magnetic field, so initial EMF is a maximum.



Generator P = A.C. **Generator Q** = D.C.

c) Why are AC generators rather than DC generators usually used in large- scale electrical power production?

[2 marks]

- transformers are used throughout large-scale power production
- transformers ONLY operate from A.C. input power sources, as they provide the required changing magnetic flux.

d) An AC generator has a 0.012m^2, 300-turn coil rotating in a magnetic field of 0.20 T. The average output is 240 V. At what frequency does it rotate?

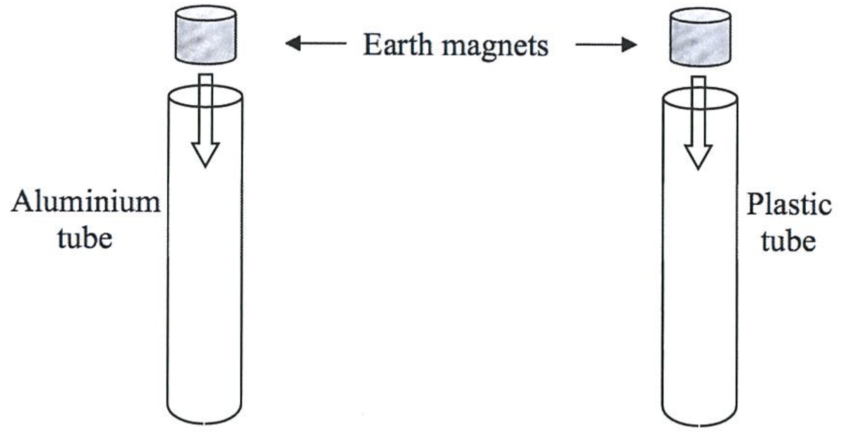
[2 marks]

$\mathcal{E}_{av} = 4BANf \quad \therefore f = \frac{\mathcal{E}_{av}}{4BAN}$

$\therefore f = \frac{240}{4 \times 0.2 \times 0.012 \times 300} = \frac{240}{2.88}$

$\therefore f = 83.3\ Hz$ (or 5000 rpm).

6. A student has two identical looking hollow tubes, one made out of aluminium and the other made from a plastic material. She drops identical Earth magnets through each of these tubes, releasing them at the same time.



Discuss and explain her observations during this investigation. (4 marks)

Observations: ....

• Earth magnet falls QUICKLY through the plastic tube (as it would through air)

• Earth magnet falls very SLOWLY through the aluminium tube.

Explanation: ....

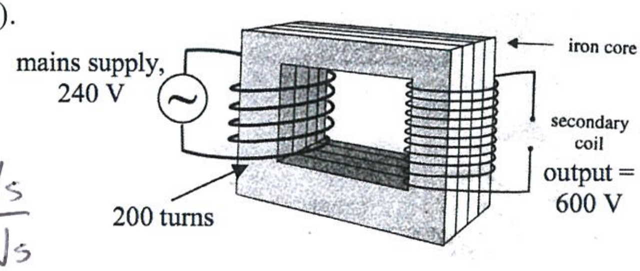
• plastic has a very high electrical resistance therefore virtually no induced current will be generated in the walls of this tube

• change in magnetic flux occurs as the walls of the aluminium (very LOW resistance) cut thro' magnets' field

• subsequent induced current provides an opposing magnetic field (Lenz's Law) on the magnet thus slowing its descent.

7. Study the transformers below and calculate their missing values. (3 marks)

a).



$$\frac{V_P}{N_P} = \frac{V_S}{N_S}$$

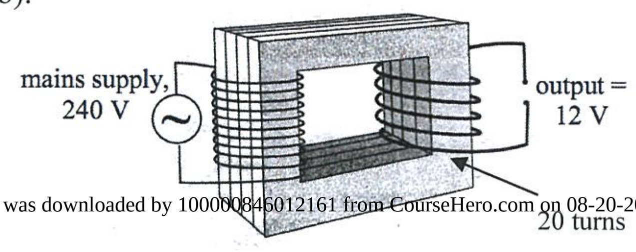
Find the number of turns on the secondary coil. $V_S = 600\,V$, $V_P = 240\,V$, $N_P = 200$ turns,

$N_S = N_P V_S / V_P$

$= (200 \times 600) / 240$

$= 500$ turns

b).

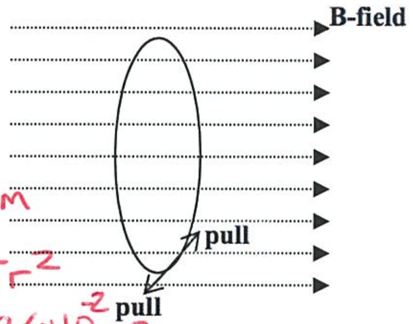


Find the number of turns on the primary coil. $V_P = 240\,V$, $V_S = 12\,V$, $N_S = 20$ turns

$N_P = V_P N_S / N_S = \frac{240 \times 20}{12}$

$= 400$ turns

8. A 1.0 m length of copper wire is formed into a single, circular coil and held inside a uniform magnetic field such that the plane of the coil is perpendicular to this field. The ends of the coil are then pulled together and straightened out in a time of 8.0 ms.



$C = 2\pi r = 1$

$\therefore r = \frac{1}{2\pi}$

$\therefore r = 0.159\,m$

$\therefore$ area, $A = \pi r^2$

$\therefore A = 7.96 \times 10^{-2}\,m^2$

If the magnitude of the subsequent induced emf across the ends of the wire is 40 mV, prove that the strength of the magnetic field is 4.0 mT. (3 marks)

$\phi_{max} = BA = 7.96 \times 10^{-2} \times B$

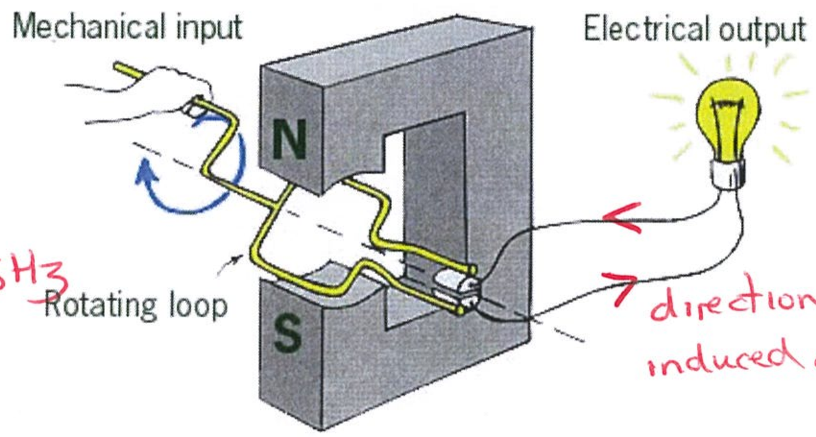
$\phi_{min} = 0$, $\varepsilon = 40 \times 10^{-3}\,V$, $N = 1$,

$\varepsilon = N(\phi_{max} - 0)/(8 \times 10^{-3})$

$\therefore 4 \times 10^{-3} = 7.96 \times 10^{-2} \times B / (8 \times 10^{-3})$

$\therefore B = \frac{40 \times 10^{-3} \times 8 \times 10^{-3}}{7.96 \times 10^{-2}} = 0.00402\,T$ $(= 4.0\,mT)$

9. The diagram shows a very simple d.c. generator used to light an LED.



$B = 0.2\,T$

$A = 60\,cm^2 = 0.006\,m^2$

$N = 1$ turn

$f = \frac{30}{60} = 0.5\,Hz$

The magnet provides a uniform field of strength 200 mT. The area of the coil of wire is 60 cm^2 and it can be rotated at a rate of 30 rpm.

a). List **four** modifications which would make the diode light more brightly (4 marks)

- increase strength of magnetic field
- rotate the coil faster
- increase the area of the coil
- increase the no. of turns of wire on the coil

b). **Indicate on the diagram** the direction in which the direct current would flow around the diode part of the circuit. (1 mark)

– using RIGHT HAND RULE – see diagram.

c). Calculate the average induced emf which the diode will experience. (4 marks)

$\varepsilon_{av} = 4BANf$

$= 4 \times 0.2 \times 0.006 \times 1 \times 0.5$

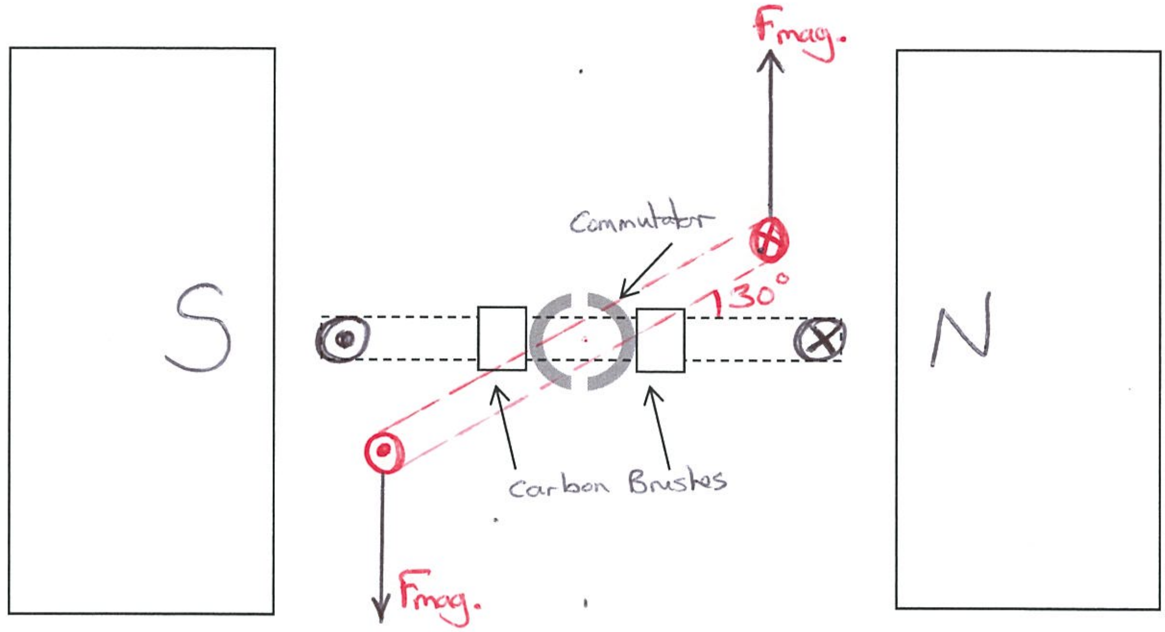
$= 0.0024\,V$ $(2.4\,mV)$.

d). Describe the necessary modifications which would turn the above arrangement into a simple a.c. generator.

(2 marks)

- replace the split-ring commutator with a pair of slip rings.

10. The diagram shows the side view of a DC electric motor. A square coil is placed flat in the uniform magnetic field between the North and South magnetic poles. Current direction in the coil is shown on the sides adjacent to the magnetic poles. The commutator and carbon brushes are also shown.



a) In which direction will the coil turn from this start position?

(1 mark)

- anticlockwise (using Fleming's Left Hand Rule).

b) Explain the function of the brushes and the function of the commutator.

(3 marks)

- commutator stops current flowing when the coil is in the vertical position (prevents deformation of the coil)
- commutator also keeps current flowing one-way only around the coil (maintaining rotation is one direction only)
- brushes provide temporary connection (prevents wires from twisting)

c) On the diagram above, use the symbols ⦿ and ⊗ to sketch the location of the coil sides adjacent to the magnetic poles after 30º of rotation from this start position. Put arrows on your symbols to indicate the direction of magnetic force acting on them.

- on diagram!

(2 marks)

d) At this new position after 30º of rotation from the start position; determine the torque value of the motor as a percentage of maximum torque.

(2 marks)

- max. torque occurs when coil is parallel to B-field, which is the original position
- at this point, the angle between the plane of the coil and the B-field is ZERO degrees, which suggest the torque varies as a COSINE function (since τ_{max} occurs when $\theta = 0^\circ$)
- so, at 30°, $\tau_{new} = \tau_{max} \times \cos 30 = 0.866\,\tau_{max}$

$\therefore \tau_{new} = 86.6\%$ of τ_{max}.

e) A single 120 mm length of wire, adjacent to one of the magnetic poles, experiences a 0.0280 N magnitude of force when a current of 5.30 A is present. Calculate the magnetic flux density between the poles.

(2 marks)

$L = 0.12\,m$,
$F = 0.028\,N$
$I = 5.3\,A$

$$F = BIL \quad \therefore \quad B = \frac{F}{IL}$$

$$\therefore B = \frac{0.028}{5.3 \times 0.12} = \frac{0.028}{0.636}$$

$$\therefore B = 0.044\,T \quad (44\,mT).$$

f) After the motor is switched on its rate of rotation increases. As this happens the net current in the coil decreases. Clearly explain why this happens.

(3 marks)

- as coil's motor rotates faster, it begins to act like a generator
- thus, an induced current will be generated within the coil, in the opposite direction to the operating current (Lenz's Law)
- since $I_{net} = I_{operating} - I_{induced}$, then I_{net} decreases!

END OF TEST ☺