JC3 Common Test 2002

Section B- Answer all the questions
(You are advised to spend not more than 70 minutes in this section)

26(a) Is an explosion an elastic or inelastic situation? Explain. [2]

Inelastic because there is an increase of total kinetic energy after explosion. Hence there is no conservation of total kinetic energy of the system.

(b) Two blocks of masses *M* and 3*M* are placed on a horizontal, frictionless surface. A light spring is attached to one of them. A cord initially holding the blocks together is burned (see **Figure. 26.1**); after this, the block of mass 3*M* moves to the right with a speed of 2.00 ms^{-1}.

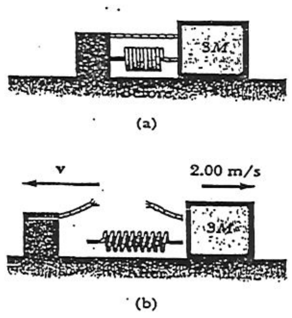


Figure. 26.1

(i) What is the speed of the block of mass *M*? [2]

Conservation of total momentum:

$0 = 3M(2.0) + Mv$

$V = -6.0 \text{ m s}^{-1}$.

(ii) Find the original elastic energy in the spring if *M* = 0.350 kg. [2]

- Conservation of Total kinetic energy:

Initial Elastic energy stored = KE of masses

$= \frac{1}{2}(3M)2^2 + \frac{1}{2}(M)6^2$

$= 8.4$ J

$MV_1 + M_2V_2 =$

$U_1 - U_2 = V_2 - V_1$

Q26c. Suggested Solution

Method 1

Moving from A to B,
Loss in GPE of M = Gain in its KE

$5Mg = \frac{1}{2}Mu^2$

$u = \sqrt{10g} = 9.9$

M collides with 3M at 9.9 ms^{-1}.

Collision is elastic, hence total momentum is conserved.

$M(9.9) = 3M(4.5) - Mv$

$v = 3.6 \text{ ms}^{-1}$

M rebounds with this speed after collision.

Moving up the slope,
All KE is converted to maximum GPE at maximum height, h.

$\frac{1}{2}M(3.6)^2 = Mgh$

$h = 0.66m$

Method 2

Moving from A to B,
Loss in GPE of M = Gain in its KE

$5Mg = \frac{1}{2}Mu^2$

$u = \sqrt{10g} = 9.9$

M collides with 3M at 9.9 ms^{-1}.

Collision is elastic, hence total kinetic energy is conserved.

$\frac{1}{2}M(9.9)^2 = \frac{1}{2}Mv^2 + \frac{1}{2}3M(4.5)^2$

$v = 6.10 \text{ ms}^{-1}$

M rebounds with this speed after collision.
Moving up the slope,

All KE is converted to maximum GPE at maximum height, h.

$\frac{1}{2}M(6.1)^2 = Mgh$

$h = 1.90m$

Method 3

Let u be the speed of M just before collision and v be the speed of M just after collision.
Collision is elastic, hence total momentum and kinetic energy is conserved.

$Mu = Mv + 3M(4.5)$ (1)

$\frac{1}{2}Mu^2 = \frac{1}{2}Mv^2 + \frac{3}{2}M(4.5)^2$ (2)

Solving equations (1) and (2), v = -4.5.
Moving up the slope,
All KE is converted to maximum GPE at maximum height, h.

$\frac{1}{2}M(4.5)^2 = Mgh$

$h = 1.03m$

Method 4

Since surface is frictionless, total energy is conserved throughout the process.

Initial total energy of system = initial GPE of M = 5Mg

Final total energy of system = Mgh + $\frac{3}{2}M(4.5)^2$

where h is the final height reached by M.

Hence 5Mg = Mgh + $\frac{3}{2}M(4.5)^2$

h = 1.90 m

27. A pilot was assigned to navigate the space shuttle, sent to repair a faulty communication satellite which is in a *geostationary* orbit.
Mass of Earth = 6.00×10^{24} kg.
Radius of Earth = 6.38×10^{6} m
1 day = 8.64×10^{4}s

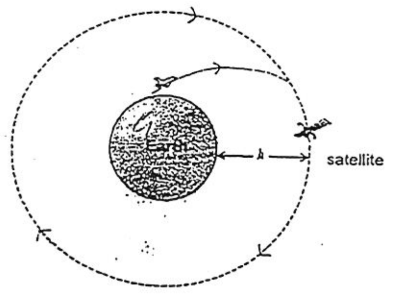
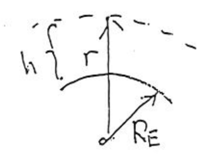


Figure 27.1 (not drawn to scale)

(a) Explain why the *geostationary* orbit must be on the same plane as the Earth's equator. [1]

To have common axis of rotation as the Earth.

(b) Determine the height h of the *geostationary* satellite from the Earth's surface. (Assume the Earth is spherical.) [3]



$\frac{GM_E m}{r^2} = mr\left(\frac{2\pi}{T}\right)^2$ where M_E = mass of Earth, m = mass of

$r^3 = \frac{(6.67\times10^{-11})(6.0\times10^{24})(8.64\times10^4)^2}{4\pi^2}$

$r = 4.23 \times 10^7$ m

$h = r - R_E$

$= 4.23\times10^7 - 6.38\times10^6$

$= 3.59\times10^7$ m

(c) Calculate the orbital speed of the satellite. [1]

$V = r\omega$

$= (4.23\times10^7)\left(\frac{2\pi}{8.64\times10^4}\right)$

$= 3.08\times10^3$ m s^{-1}

(d) Determine the *gravitational potential difference* that the space shuttle experienced in its journey from the Earth's surface to the satellite's orbit. [2]

$\Delta\phi = \phi_r - \phi_{RE}$

$= \left(-\frac{GM_E}{r}\right) - \left(-\frac{GM_E}{R_E}\right)$

$= (6.67\times10^{-11} \times 6.0\times10^{24})\left(\frac{1}{6.38\times10^6} - \frac{1}{4.23\times10^7}\right)$

$= 5.32\times10^7$ J kg^{-1}

(e) Assuming the space shuttle is launched from Earth's equator, determine the minimum initial speed which the space shuttle must possess in order to reach the satellite's orbit. You may ignore the effects of air resistance. [3]

Applying conservation of energy,

$K.E_{RE} + GPE_{RE} = K.E_r + GPE_r$

$K.E_{RE} = K.E_r + (GPE_r - GPE_{RE})$

$\frac{1}{2}mu^2 = \frac{1}{2}mv^2 + 5.32\times10^7 m$

$u^2 = v^2 + 2\times5.32\times10^7$

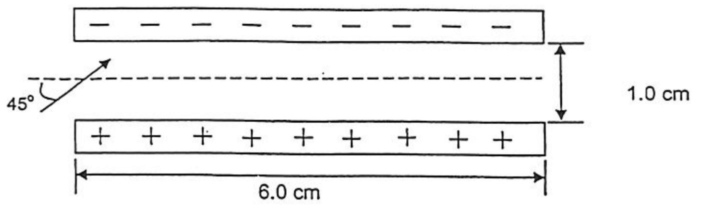
$u = \sqrt{(3.08\times10^3)^2 + 2\times5.32\times10^7}$

$= 1.08\times10^4$ m s^{-1}

(f) In practice, the required speed with which the space shuttle is launched, relative to the Earth's surface, is less than that calculated in **(e)**. Explain. [1]

As the Earth is rotating, the space shuttle takes advantage of the angular rotation of the Earth for extra push in launching.

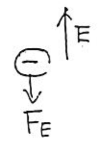
28. Suppose electrons enter the uniform field midway between two plates, moving at an upward 45° angle as shown below. The electric field strength in the region between the two plates is 5.0×10^3 NC^{-1}.



(i) Find the potential difference between the two plates. [1]

$E = \frac{V}{d}$, $V = Ed = (5.0\times10^3)(1.0\times10^{-2})$
$= 50$ V

(ii) For an electron which just enters the field as shown in the figure, draw a diagram to show the electrostatic force acting on the electron and the direction of the electric field. Determine the magnitude of this force. Hence find the acceleration of this electron. [3]

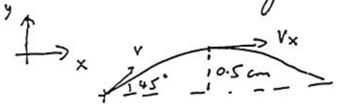


Electric force, $F_E = qE$
$= (1.6\times10^{-19})(5.0\times10^3)$
$= 8.0\times10^{-16}$ N

Acceleration of e^-, $a = \frac{F_E}{m_e}$
$= \frac{8.0\times10^{-16}}{9.1\times10^{-31}} = 8.78\times10^{14}$ ms^{-1}

(iii) What maximum speed can this electron have to avoid striking the upper plate? Ignore fringing of the field. [3]

To avoid striking the plate, the maximum height is 0.5 cm, ie 0.005 m



At max. height, $v_y = 0$
$v_y^2 = u_y^2 + 2as$
$u_y^2 = 2(8.78\times10^{14})(0.005)$
$u_y = 2.963\times10^6$
$u_y = V\sin45°$

V: maximum speed to avoid hitting the plate.

(iv) Determine the kinetic energy lost by the electron from the point of entry to the highest position between the two plates reached by the electron. [2]

K.E at max. height $= \frac{1}{2}mv_x^2$
$= \frac{1}{2}(9.11\times10^{-31})(4.191\times10^6\cos45°)^2 = 4.00\times10^{-18}$ J

K.E at entry $= \frac{1}{2}mV^2 = \frac{1}{2}(9.11\times10^{-31})(4.191\times10^6)^2 = 8.00\times10^{-18}$ J
K.E lost = K.E at entry − K.E at max. position
$= (8.00 - 4.00)\times10^{-18}$ J
$= 4.00\times10^{-18}$ J

OR: K.E lost = w.d against e-field = $F.\Delta x = 8.0\times10^{-16}\times(0.005)$
$= 4.0\times10^{-18}$ J

29 (a) Explain why it is usual to transmit energy along overhead power lines as a.c. [2]

Transformer works on A.C. With A.C, voltage can be step up or step down easily.

(b) A transformer, to be used in a low voltage power supply, is connected to the 240 V r.m.s., 50 Hz, sinusoidal a.c. mains supply and gives an r.m.s. output voltage of 12 V. There are 1800 turns on the primary coil.

(i) Calculate the number of turns on the secondary coil. [1]

$\frac{N_s}{N_p} = \frac{12}{240}$

$\therefore N_s = \frac{1}{20}\times1800 = 90$

(ii) Assuming that there are no energy losses, calculate the current in the primary coil when the current in the secondary coil is 9.0 A. [1]

$V_pI_p = V_sI_s$
$I_p = 9(\frac{12}{240})$
$= 0.45$A

(iii) A 2.5 Ω, resistor is connected across the secondary coil. Calculate the rate at which electrical energy is transformed into internal energy in the resistor.

(iv) Calculate the peak value of the output voltage of the transformer. [1]

$V_0 = \sqrt{2}\, V_{rms}$

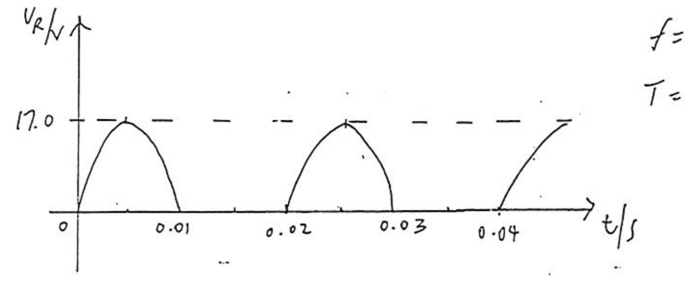
$= \sqrt{2}\,(12)$

$= 17\ V$

(v) The output from the transformer is rectified by the use of a diode in series with the load. Sketch the output waveform, showing clearly how the value of the voltage across the load changes with time. Your graph should include suitable voltage and time scales. [2]

$f = 50\ Hz$

$T = \frac{1}{50} = 0.02\ s$



(vi) State and explain briefly how the output can be smoothed. [2]

By adding a capacitor in parallel to the output. The capacitor stores charges & is thus able to maintain the p.d. across the output even when the diode is in reverse bias & there is no applied p.d due to the source

30 (a) A side view of a simple electron gun is shown in **figure 30.1**. Show that the speed with which electrons emerge from the anode of this gun will be about $2 \times 10^7\ ms^{-1}$ when the potential difference between the cathode and the anode is 1200V. [2]

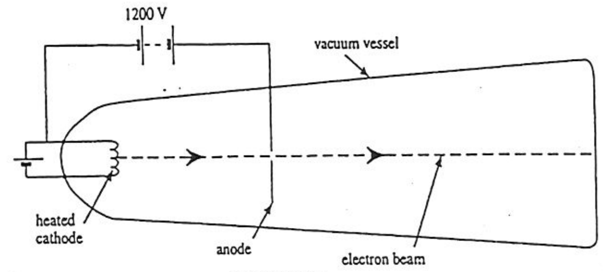


Figure 30.1

KE gain by each e^- = EPE lost

$\frac{1}{2}mv^2 = qV$

$\frac{1}{2}(9.11\times10^{-31})\,v^2 = (1.6\times10^{-19})(1200)$

$v = 2.05\times10^7\ ms^{-1}$

$\approx 2\times10^7\ ms^{-1}$

(b) Electrons emerging horizontally from the electron gun in part **(a)** then enter a uniform magnetic field which is directed upwards in the plane of the diagram (see **figure 30.1**). Calculate the magnitude of the force on an electron in this magnetic field of flux density 0.080 T. [2]

$F = Bqv$

$= (0.080)(1.6\times10^{-19})(2.05\times10^7)$

$= 2.63\times10^{-13}\ N$

(c) Draw the path of an electron passing through the field described in part **(b)** on each of the two diagrams shown in the figure below. No further calculations are expected. [2]

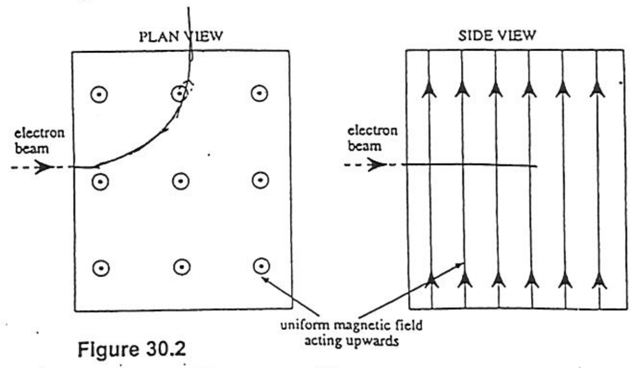


Figure 30.2

(d)(i) State whether the speed of an electron changes while it is in the magnetic field. Explain you answer. [2]

It does not change as the force is always perpendicular to the motion of the electron according to Fleming's Left Hand rule.

(ii) State, with a reason, whether the force on the electron alters while it is in the magnetic field. [2]

The magnitude of the force does not change as $|F| = Bqv$ & $B, q, \& v$ are constant. The direction of the force is always changing.

31 (a) An operational amplifier of open-loop gain 10^5 operates with supply voltage ± 14 V. What is the voltage across its input terminals when it has just been saturated? [1]

When op amp is just saturated, $V_0 = 14V$

$A_0(V^+ - V^-) = 14$

$V^+ - V^- = \frac{14}{10^5} = 1.4 \times 10^{-4} V$

(b) The circuit below shows how an operational amplifier is set up.

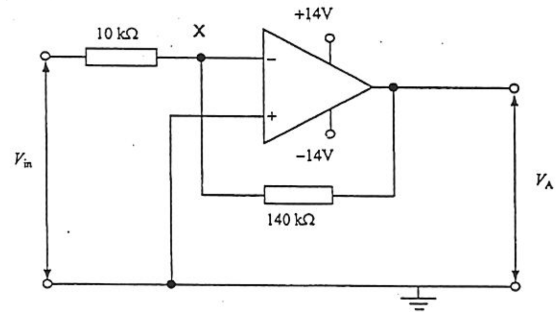


Figure 31.1

(i) State the potential at point X. [1]

Potential at X = 0V (Virtual Earth Approximation)

(ii) Determine the gain of the circuit shown in figure 31.1. [2]

$\text{Gain} = -\frac{R_f}{R_i}$

$= -\frac{140}{10} = -14$

(iii) An alternating voltage as shown in figure 31.2 is now applied across the inputs of the circuit. Copy figure 31.2 and, on the same axes, sketch the output voltage and label it as A. Include appropriate values of voltage in your sketch. [2]

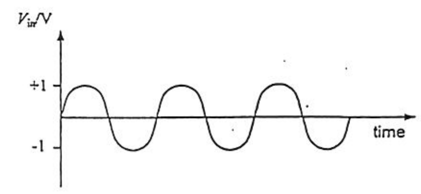
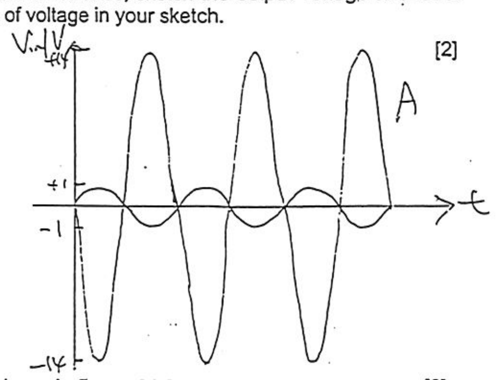


Figure 31.2



(iv) Determine the gain of the circuit shown in figure 31.3. [2]

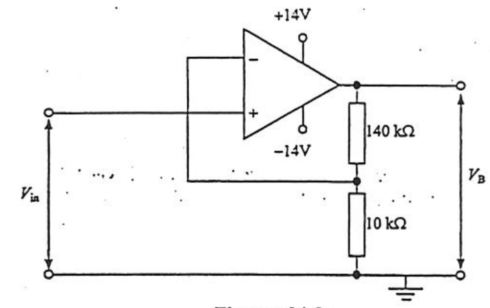
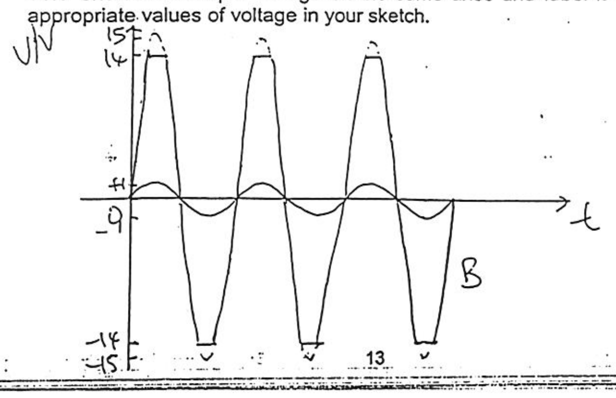


Figure 31.3

$\text{Gain} = 1 + \frac{R_f}{R_i} = 1 + \frac{140}{10}$

$= 15$

(v) The same input signal V_{in}, is applied to the input leads of circuit shown in figure 31.3 Sketch the output voltage on the same axes and label it as B. Also, include appropriate values of voltage in your sketch. [2]



Solution

Q33(a) (i) (1) I = 0, E = 0.54 V

(2) V = IR

0.48 = 30 x 10^{-3} R

R = 16 Ω

(3) r = (E – V) / I = (0.54 – 0.48) / 30 x 10^{-3} = 2 Ω

(ii) η = P_{out} / P_{in} = IV / P_{in} = (5 x 10^{-2} x 0.1) / 10 x 10^{-3} = 0.05

(b) (i) (1) Loop abcea: 3 – 4I_1 + 5I_2 = 0

Loop cdec: -2I_3 + 6 – 5I_2 = 0

Junction c I_1 + I_2 = I_3

-2 (I_1 + I_2) + 6 – 5 I_2 = 0

2 I_1 + 7 I_2 = 6 => 4 I_1 + 14 I_2 = 12

4 I_1 - 5 I_2 = 3

=> 19 I_2 = 9

=> I_2 = 0.474 A

=> I_1 = 1.34 A

=> I_3 = 1.82 A

(2) Q = CV_{cd} = 10 x 10^{-6} x 2 x 1.82 = 3.6 x 10^{-5} C

(ii) (1) Q_{total} = $Q_{10\mu F}$ + $Q_{5\mu F}$

3.63 x 10^{-5} + (5 x 10^{-6} x 6) = (10 + 5) x 10^{-6} x V

V = 4.42 V

$E_{10\mu F}$ = ½ CV² = ½ (10 x 10^{-6})(4.42)² = 9.77 x 10^{-5} J

(2) The charges in the 5μF capacitor re-distribute to the 10μF capacitor / The 5μF capacitor discharges while the 10μF capacitor charges up , until the 2 capacitors reaches the same potential difference.

Solution:

32. (a)(i) Air above coin moving with some speed due to student's breath; air below coin stationary. By Bernoulli's principle, air above coin at lower pressure than air below coin. This produces net upward force on coin.

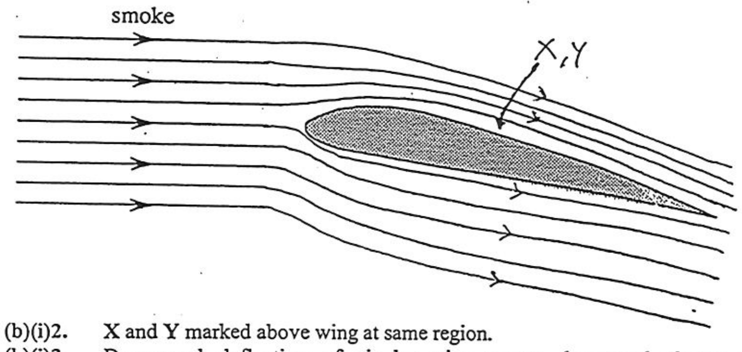
(a)(ii) Bernoulli's equation gives $P_b - P_a = \frac{1}{2}\rho_{air}v^2$, where P_a = pressure of air above coin; P_b = pressure of air below coin; v = speed of student's breath. For minimum speed, weight of coin = lift force on coin

$\Rightarrow mg = (P_b - P_a)A = \frac{1}{2}\rho_{air}{v_{min}}^2 A$, where A = surface area of coin

$\Rightarrow v_{min} = \sqrt{\frac{2mg}{\rho_{air}A}} = \sqrt{\frac{2At\rho_{nickel}g}{\rho_{air}A}} = \sqrt{\frac{2(1.5\times10^{-3})(6400)(9.81)}{1.2}} = \underline{12.5\ \text{ms}^{-1}}$.

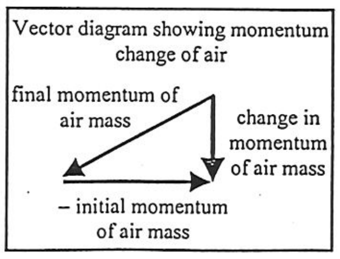
(a)(iii) $P_b - P_a = \frac{1}{2}\rho_{air}v^2 = \frac{1}{2}(1.2)(12.5)^2 = \underline{94.2\ \text{Pa}}$.

(b)(i)1. Diagram showing streamline flow above and below wing.

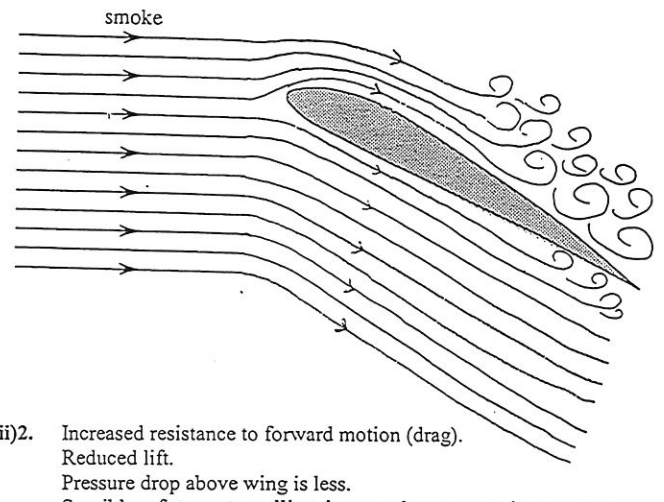


(b)(i)2. X and Y marked above wing at same region.

(b)(i)3. Downward deflection of air by wing causes downward change in momentum of air. By Newton's 2nd law, there will be a resultant downward force by wing on air. By Newton's 3rd law, there will therefore be an equal and opposite upward force or lift by air on wing.



(b)(ii)1. Diagram showing turbulent flow above wing, little or none below wing.



(b)(ii)2. Increased resistance to forward motion (drag).
Reduced lift.
Pressure drop above wing is less.
Sensible reference to stalling, increased power requirement, etc.

34 (a) (i) towards rear of the boat.

(ii) 1. increase the current in the bar

2. increase the current in the field coil

(iii) When there is current flowing in both the bar & the coil, the coil exerts a force on the bar towards the rear. By Newton's 3rd Law, the bar exerts an equal force to the front on the coil. Since both the coil & the bar are on the boat, the boat experiences zero net force. Hence, it will not be propelled

(b) (i) Ionisation is the removal or addition of electrons from atoms to form ions.
Once ionised, the ions become mobile charge carriers and hence can carry charge.

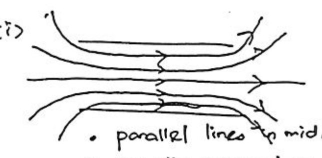
(ii) When current is passed through the water, the coil exerts a force towards the rear on the water. The water, in turn, exerts a forward force on the coil hence the boat by Newton's 3rd Law. Hence, the boats moves forward.

(iii) For constant speed of 8.0 ms⁻¹, net force = 0.

$\therefore \quad BIl - F_D = 0$

$\Rightarrow \quad B = \frac{12000}{(1000)(1.5)} = 8.0\,T$ ✱

(c) (i)



- parallel lines in middle
- equally spaced in middle
- point to right
- diverge at ends.

(ii). Current change in solenoid causes a change in B-field of solenoid, B_s

- $\Phi = A_c B_s$, changes ~~experienced by~~ of coil
- By F's law, ε is induced in coil and hence is recorded in voltmeter.

(iii) (1) Emf recorded is less as the magnetic flux density at end of P is smaller. Hence Φ & $\Delta\Phi$ is smaller.

(2) Emf recorded is more as B_s is much larger due to ferrous core.