2020 Raffles Institution Preliminary Examinations – H2 Physics

Paper 3 – Suggested Solutions

Section A

1 **(a)** **(i)** The direction of motion after collision will be along the same line of motion before collision.
OR
The direction of velocities after collision will be along the line joining their centres of gravity.

(ii) Their relative speed of separation is equal to their relative speed of approach.

(b) Take direction to the right as positive.

By conservation of linear momentum,

$$mu_1 + 2m(-u_2) = mv_1 + 2mv_2$$
$$m(4.0) + 2m(-2.0) = mv_1 + 2mv_2$$
$$0 = mv_1 + 2mv_2 \quad \text{----- (1)}$$

Since collision is elastic,

$$u_1 - (-u_2) = v_2 - v_1$$
$$4.0 - (-2.0) = v_2 - v_1$$
$$v_2 = 6.0 + v_1 \quad \text{----- (2)}$$

Subst. (2) into (1),

$$0 = mv_1 + 2m(6.0 + v_1)$$
$$0 = m(12 + 3v_1)$$
$$v_1 = \frac{-12}{3} = -4.0 \text{ m s}^{-1}$$

Velocity of A is –4.0 m s^{-1} i.e. body A moves to the left with speed 4.0 m s^{-1}.

From (2), $v_2 = 6.0 + (-4.0) = 2.0 \text{ m s}^{-1}$

Velocity of B is 2.0 m s^{-1} i.e. Body B moves to the right with speed 2.0 m s^{-1}.

(c) In the collision in Fig. 1.3, the styrofoam <u>increases</u> the <u>duration of impact</u> as it is compressible. Thus, for the same change in momentum, the <u>impact forces</u> experienced by the balls are <u>smaller</u> compared to the collision in Fig. 1.2. Hence the <u>external gravitational forces (weight)</u> on the balls are <u>comparable in magnitude</u> to the impact forces and they <u>contribute to the change in the momentum of the system such that the momentum of the system is no longer conserved</u>.

Comments

(a) **(i)** Did not accept "parallel" to initial line of motion, "horizontal axis" etc.

(ii) Did not accept "kinetic energy is conserved", "$u_1 - u_2 = v_2 - v_1$" as question asks to "describe subsequent motion" (i.e. qualitative description of speed/ velocity is required).

(b) Some are still unaware that $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ and $u_1 - u_2 = v_2 - v_1$ are vector equations, so they forget to substitute numbers with negative signs for the velocities which are in the opposite direction. Note that u_1 and u_2 in the question are speeds.

(c) Poorly done. This part reveals common misconception about the principle of C.O.M. Many students reasoned that since the speeds after collision have reduced (as styrofoam has absorbed some energy), the total momentum is not conserved. This is far from the truth. Think of this example: suppose the collision in (b) results in a completely inelastic collision, then $m(4.0) + 2m(-2.0) = 3mv \Rightarrow v = 0$, final v < u_1 or u_2 but total momentum is still conserved. Basically, students need to understand one has to use a vector sum approach when adding individual momenta.

Some students mixed up C.O.M. with conservation of kinetic energy and erroneously concluded that the collision being inelastic (loss of k.e.), violates C.O.M.

Another common issue is students did not recognize the force exerted by the styrofoam is an internal force (not an external force), acting within the new system of Fig. 1.3. Students should have seen questions where a spring is attached to one colliding body and the spring force is regarded as an internal force in the system, else ideal gas molecules bouncing off each other due to contact forces (also internal forces) in a closed system. What constitutes as external force is the gravitational force acting on bodies A and B. For the system in Fig. 1.2, gravitational force could be treated as negligible simply because the duration of impact was very short (hence collision force is much bigger than gravitational force/ or impulse due to gravity is negligible during the short instant). This is not so for Fig. 1.3. Very few students explained correctly.

2 **(a)** **(i)** Gravitational potential is taken to be <u>zero</u> at <u>infinity</u>.

Since <u>gravitational forces</u> are <u>attractive</u>, the <u>work done by an external force</u> in moving a mass from infinity to the point is <u>negative</u> as the <u>displacement and external force are in opposite directions</u>.

(ii) The <u>work done per unit mass</u> by an <u>external force</u> in bringing a small test mass from <u>infinity to a point 0.98×10^7 km</u> (OR point Q) from the <u>center of Star X</u> is <u>-3.0×10^{12} J kg^{-1}</u>.

(iii) Since gravitational potential $\phi = -\frac{GM}{r} \Rightarrow \phi \propto -\frac{1}{r}$

$$\frac{r_R}{r_Q} = \frac{\phi_Q}{\phi_R} = \frac{3.0 \times 10^{12}}{1.0 \times 10^{12}}$$

$$r_R = \frac{3.0 \times 10^{12}}{1.0 \times 10^{12}}\left(0.98 \times 10^7\right) = 2.94 \times 10^7 \text{ km}$$

(iv) work done by the external force

$$= m\left(\phi_Q - \phi_R\right)$$

$$= 1200\left(-3.0 - \left(-1.0\right)\right) \times 10^{12}$$

$$= -2.4 \times 10^{15} \text{ J}$$

(b) **(i)** Gravitational force provides the centripetal force for the stars to orbit about the common centre of mass of the system.

$$\frac{GM_Y M_Z}{(x_1 + x_2)^2} = M_Y x_1 \omega^2 = M_Z x_2 \omega^2$$

Since ω for both stars is the same,

$$\frac{x_1}{x_2} = \frac{M_Z}{M_Y} = \frac{1.45 \times 10^{28}}{2.62 \times 10^{30}} = 0.00553$$

*If the ratio of masses is quoted directly to calculate, it must be stated that C is also the centre of mass.

(ii) If they do not have the same angular velocity, the gravitational force between them on either star will not be towards C for them to orbit around C.
OR
The two stars must always be on opposite sides of C so that the gravitational force between them is always pointing towards C, providing the centripetal force.
OR
If they do not have the same angular velocity, the centre of mass at point C will not be stationary. Point C should be stationary as there is no net force acting on the system.

Comments

(a) **(i)** In answering qualitative questions, students are reminded to do so concisely, after having fully understood the requirements of the question. Students are to use appropriate and accurate keywords/phrases/terms and structure their sentences in some logical sequence as well as avoid beating around the bush.
For this part, many students defined what gravitational potential is. This is not required.

Students were penalised due to one or more of the following mistakes/oversights/ambiguities:

- Stated that external force acts in a direction opposite to gravitational force, when it should have been "opposite to displacement" as how work is defined i.e. the product of force and displacement (parallel to the force). In addition, phrases like "direction of motion" or any other non-quantifiable terms used in place of displacement are not acceptable.
- Stated to the effect that work done by an external force is opposite to displacement. Work is a scalar quantity and does not have an associated direction. So the above-mentioned statement is incorrect.
- Did not state that gravitational potential at infinity is zero. Some erroneously mentioned that gravitational potential at infinity is negative. In addition, quite a number of students did not make it clear that the (negative) work is actually done by an external force.

(ii) Common mistakes in this part are not stating "per unit mass" in "work done per unit mass" and also not explicitly stating that the work per unit mass is done by an external force.

(iii) Generally well done other than mistakes involved in the transfer of the numerical answer in terms of kilometres which some students mistook to be in metres. Several students made computational error when they calculated the factor GM from information given of point Q, ending up with the wrong order of magnitude.

(iv) Students who made mistakes here either didn't understand that external force and displacement act in opposite directions hence work done by external force should be a negative value or they got the order of subtraction wrong i.e. initial gravitational potential energy at R – final gravitational potential energy at Q, when it should have been the other way round.

(b) **(i)** A very common mistake here is that students equated the gravitational force on star Y to the gravitational force on star Z in attempting to determine the ratio $\frac{x_1}{x_2}$.

From the perspective of Newton's third law, this isn't wrong but students would not be able to determine the ratio as gravitational force is based on the total distance between the centres of the two stars.

Another common mistake here is to equate gravitational force of each star to their corresponding centripetal forces separately and erroneously came up with the relationship $\frac{M_Y}{x_2^3} = \frac{M_X}{x_1^3}$. Just like the first point, students who made this mistake failed to realise that the distance used in centripetal force is the orbital radius of the star i.e. distance from centre of the star to point C while gravitational force is based on the total distance between the centres of the stars as mentioned above.

Many other students equated the gravitational potential due to star Z at point C to that due to star Y at the same point. This is incorrect as the values of gravitational potential due to both stars at point C are not the equal.

(ii) Here, many students failed to comprehend the question in its entirety i.e. to explain reason/s for why the two stars must rotate with the same angular velocity about C i.e. their common centre of orbit. Many dismissed the importance of point C being the common centre of orbit, hence their anwers are focused on scalar quantities.

The most common incorrect answer students wrote was that both stars would have the same magnitude of gravitational forces acting on them according to Newton's third law, hence their centripetal forces would also be equal, magnitude-wise, resulting in angular velocity being the same.

Many others mentioned that in order to maintain the same distance between the stars, their angular velocity must be the same. Some students stated that the two stars and point C must remain in a straight line without further elaboration. Others merely mentioned statements like "to rotate about common centre C, the stars must have the same orbital period hence the same angular velocity" and "to remain as a binary star system, they must have the same angular velocity".

No credit is given for such answers mainly because they do not explain that in order for the two stars to orbit about common centre C with the same angular velocity, the gravitational forces on the stars must be directed towards C. This also necessarily means that the two stars must be on opposite sides of C and that the centres of the two stars and C must always lie in a straight line.

3 **(a)** **(i)** The gravitational force on the Moon and the gravitational field of the Earth are in the same direction towards the Earth as they are always attractive in nature.

(ii) The electric force on the electron is towards the positive point charge while the electric field of the positive point charge is pointing away from it (OR in the opposite direction to the force).

(iii) The direction of the force on the electron is perpendicular to the direction of the magnetic field.

(b) **(i)** For point charge,

$$V = \frac{Q_S}{4\pi\varepsilon_0 r}$$

Subst. point (1.00 cm, 780 V) on the curve,

$$Q_S = V \times 4\pi\varepsilon_0 r$$
$$= (780)(4\pi)(8.85\times10^{-12})(1.00\times10^{-2})$$
$$= 8.67\times10^{-10} = 8.7\times10^{-10} \text{ C (shown)}$$

*Allow substitution of any point on the curve.

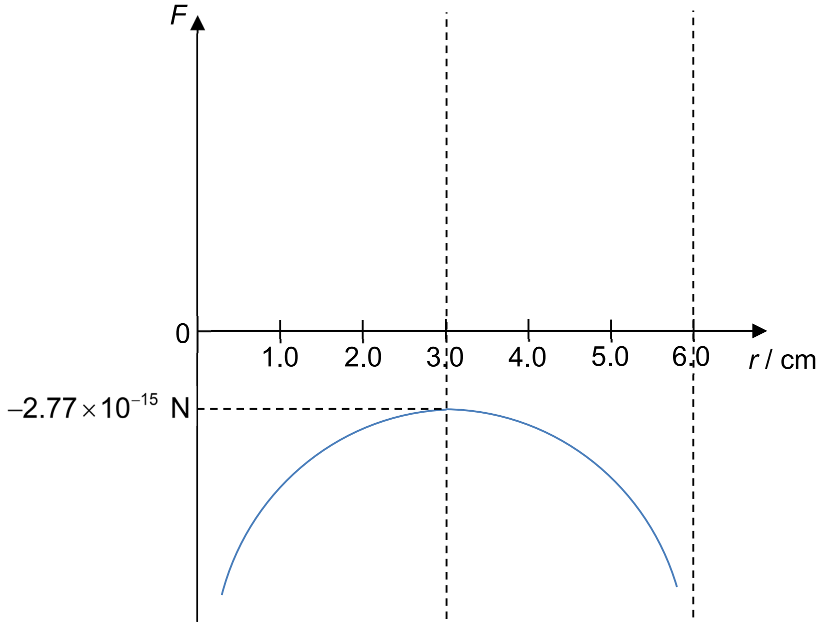
(ii) At $r = 2.0$ cm, $V_i = 390$ V

maximum distance is when electron just comes to rest
increase in E.P.E. = decrease in K.E.

$$\Delta\text{E.P.E.} = -\Delta\text{K.E.}$$
$$q(\Delta V) = -\left(0 - \frac{1}{2}mu^2\right)$$
$$-e(V_f - V_i) = \frac{1}{2}mu^2$$
$$V_f = V_i - \frac{1}{2}\frac{mu^2}{e} = 390 - \frac{1}{2}\frac{(9.11\times10^{-31})(8.4\times10^6)^2}{(1.60\times10^{-19})} = 189.12 \text{ V}$$

From Fig. 3.1, at $V = 190$ V, $r = 4.10$ cm
Maximum distance is 4.10 cm.

(iii) **1.**



*Asymptotes at 0 cm and 6 cm with turning point / symmetry at 3 cm
*Graph below horizontal axis
(value of *F* at turning point not required)

2. In the presence of the negative charge T, the resultant electric force that is opposite to the motion of the electron is now larger. Hence the electron will experience a larger deceleration and will achieve a smaller maximum distance.

Comments

(a) Many failed to answer the question. The question asked for the direction of the force with respect to the field. Hence answers must include the directions of the force and the field relative to each other. It is so very important to take note of the question requirements and answer them.

(b) **(i)** When you are required to 'show' a numerical value, you should always write out clearly the equation used, all substitutions and the non-rounded off value before rounding it off to the final numerical value stated in the question. This has been explicitly stated by the Cambridge examiners as they need to see evidence that you have computed the value, and not just assume it to be the value given.

Like all 'show' questions, include short statements to explain your working.

(ii) The principle of conservation of energy was very poorly stated. Please learn to state it properly as it is a very important concept used in many areas.

In addition, do remember that in electric fields, the charges can be positive or negative and hence the signs of the potential and potential energy (scalar quantities) can be positive or negative. Thought and care have to be given to this. Refer to the given solutions to how to present properly.

For conservation of energy, we should either equate

- total initial energy = total final energy OR
- increase in the different forms of energy
  = decrease in the different forms of energy
  (note that 'increase' and 'decrease' already indicate that we are looking at the absolute magnitudes of the energy changes, and your formulae should reflect that)

We never ever equate absolute energies e.g. K.E. = G.P.E. We only equate the changes in energy.

Note that the symbol 'Δ' specifically means 'change = final – initial' in whatever circumstance (i.e. energy, momentum, velocity e.t.c.). It does not mean the positive difference. Hence it needs to be used with care.

(iii) **1.** As mentioned before, all 'sketches' still need to include important points / features to show important concepts.

Here the important points to note are

- positions of asymptotes
- position of turning point
- sign of the graph
- shape of the graph

S and T are point charges not conducting spheres. Such information given in the question is important to note. Do be very clear in the differences in the graphs for point charges and conducting spheres.

2. Many did not include point S and how point T changes the scenario in their answers. Answers given seem to suggest point S has no effect anymore as the answers only focused on the effect due to T alone.

The concept of resultant force due to the presence of two electric fields, and how this change in resultant force change the acceleration/deceleration of the electron needs to be clearly explained. These concepts of resultant force and acceleration are necessary in any explanation with regards to the motion of an object. Again key phrases need to be used and not just simply state 'attract' and 'repel' without linking it to forces and acceleration.

Note that even with T present, the decrease in K.E. of the electron and the increase in E.P.E. of the electron is the same as when only S is present without T. Hence the work done against the electric force is the same for both cases. However, since the resultant electric force that is opposite to the motion of the electron is larger when T is present, the displacement will be smaller.

Such crucial concepts and clear thinking needs to be studied and analysed in detail during your revision.

4 **(a)** The distinguishing factor between e.m.f. and p.d. is the energy conversion.
The e.m.f. of a source is the amount of electrical energy per unit charge that is converted from other forms of energy when charge passes through the source.
The potential difference V between two points in a circuit is the amount of electrical energy per unit charge that is converted to other forms of energy when charge passes from one point to the other.

(b) **(i)** Voltmeter reading will give E_1 when $I = 0$.
horizontal-intercept $= E_1 = 9.0$ V

(ii) from $V = E_1 - Ir_1$ where V is the terminal p.d. of battery

$$I = \frac{E_1}{r_1} - \frac{1}{r_1}V$$

A plot of I against V will give a straight line graph with gradient $-\frac{1}{r_1}$ and vertical intercept $\frac{E_1}{r_1}$.

$$\text{gradient} = \frac{4.50 - 0}{0 - 9.0}$$

$$-\frac{1}{r_1} = -0.50$$

$$r_1 = 2.0\ \Omega$$

OR

$$\text{vertical intercept} = \frac{E_1}{r_1} = 4.50$$

$$r_1 = \frac{E_1}{4.50} = \frac{9.0}{4.50} = 2.0\ \Omega$$

*Allow substitution of any point on the line.

(c) **(i)** **1.** Potential difference across the uniform resistance wire XY

$$V_{XY} = \frac{R_{XY}}{R_T}E_1 = \frac{R_{XY}}{R_{XY} + R + r}E_1 = \frac{4.0}{4.0 + 4.0 + 2.0}(9.0)$$

$$V_{XY} = 3.6\text{ V}$$

When S is opened, at balanced length

$$E_2 = V_{XJ} = \frac{L_{XJ}}{L_{XY}}V_{XY} = \frac{0.75}{1.0}(3.6)$$

$$E_2 = 2.7\text{ V}$$

2. $V_{XJ} = \frac{L_{XJ}}{L_{XY}} V_{XY} = \frac{0.30}{1.0}(3.6) = 1.08\text{ V}$

When S is closed, at balanced length

$V_{5.0\Omega} = V_{XJ}$

$\frac{R_{5.0\Omega}}{R_{5.0\Omega} + r_2} E_2 = 1.08$

$\frac{5.0}{5.0 + r_2}(2.7) = 1.08$

$r_2 = 7.5\ \Omega$

OR

p.d. across cell C $= V_{XJ} = \frac{L_{XJ}}{L_{XY}} V_{XY} = \frac{0.30}{1.0}(3.6) = 1.08\text{ V}$

current in test circuit

$I = \frac{V_{XJ}}{R_{5.0\Omega}} = \frac{1.08}{5.0} = 0.216\text{ A}$

since $V_{XJ} = E_2 - Ir_2$

$r_2 = \frac{E_2 - V_{XJ}}{I} = \frac{2.7 - 1.08}{0.216} = 7.5\ \Omega$

(ii) When wire PQ is connected in parallel to wire XY, the <u>effective resistance will be less</u> than the resistance of wire XY alone. By potential divider principle, the <u>potential difference across the wire XY will be smaller</u>.

For the potential difference across XJ' to be E_2 at balance point, the balance length of the XJ' must be <u>larger</u> than 0.75 m.

Comments

(a) There were many students who were not aware that energy conversion was the distinguishing factor for e.m.f. and p.d. which is surprising since this is explicit as one of the learning outcomes of the syllabus.

(b) **(i)** This was generally well done.

A small handful of students made the mistake of misreading the scale of the x-axis and gave E_1 to be 8.5 V instead.

Another small handful of students assumed that it was *V*–*I* graph and interpreted accordingly.

(ii) Since the data is read off a graph, answers are expected to be quoted to half the smallest square precision. Full credit for (b) will not be given.

(c) **(i)** **1.** A significant handful of students calculated the total resistance of the driver incorrectly. Variations of this mistake included:

1. $R_T = R_{XY} + R + r = 4.0 + 5.0 + 2.0$ (transferred the value of variable resistor R incorrectly) and
2. $R_T = R_{XJ} + R + r = 3.0 + 4.0 + 2.0$ (a changeable R_T dependent on the balanced length)

In such questions where you are provided with quite a bit of data, students should read carefully, annotate accordingly in the diagram and do a quick check to ensure annotations are accurate.

2. The following are some of the common mistakes made:

1. Current in the test circuit $I = \frac{V_{XJ}}{R_{XJ}}$
2. $V_{r_2} = V_{XJ}$ => $\frac{r_2}{R_{5.0\Omega} + r_2} E_2 = V_{XJ}$

The correct formula for the 2nd mistake should be: $V_{r_2} = \frac{r_2}{R_{5.0\Omega} + r_2} E_2 = V_{XJ} - E_2$

Students should also take note not to round off their answers too early to avoid a less accurate final answer.

(ii) The answers provided lacked the rigour of a state and explain question. Students should be very clear in presenting a coherent and systematic analysis that leads to a conclusion that answers the question.

Many students were not explicit with the direct consequence of the addition of wire PQ in parallel with wire XY i.e. the effective resistance across XY will decrease. Many students referred to the effective resistance of the circuit when they meant the effective resistance across XY or they missed that point entirely and proceeded to discuss the impact of the addition of wire PQ to the total resistance of the driver circuit.

Many students who started their explanation with the total resistance of the driver circuit decreasing failed to give a coherent line of reasoning to explain why the potential difference across XY will decrease.

Since this is a qualitative question, students should avoid answering the questions using algebraic symbols such as V_{XY} and instead write in prose the potential difference across XY etc. If symbols are used, they should be clearly defined at their first appearance.

Students should also be careful not to substitute the term “potential difference” with the term “voltage”.

Students who performed a correct calculation of the final balance length with little or no effort in giving a proper qualitative analysis will not be given full credit.

5 **(a)** **(i)** With S closed, the current flow in coil Y is clockwise when viewed from Q.

When S is opened, the clockwise current in coil Y, when viewed from Q, decreases. This causes the magnetic flux density of coil Y in the direction QP to decrease.

Hence the magnetic flux linkage through coil X also decreases. By Faraday's Law, an e.m.f. would be induced in coil X. By Lenz's law, the induced current in coil X would flow clockwise so as to produce a magnetic flux density in the same direction as that of coil Y to oppose this decrease.

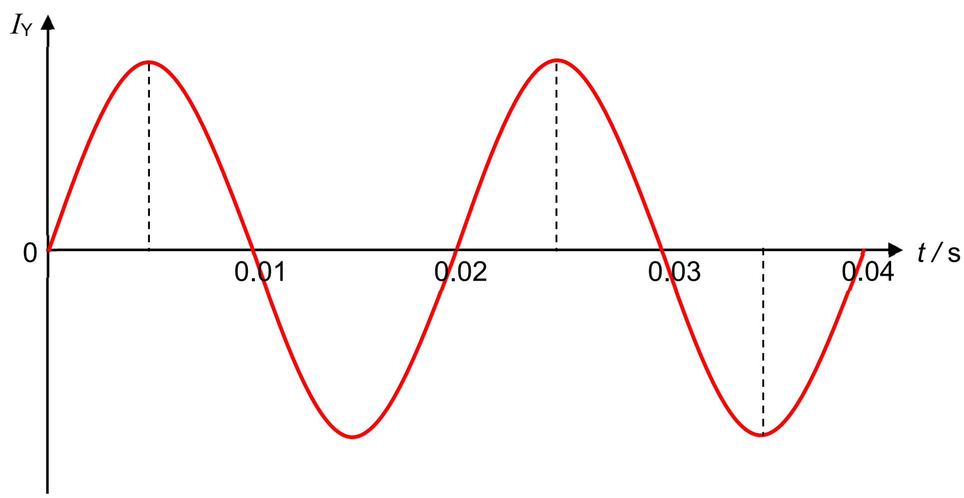
However, the LED would be reverse biased to the clockwise current flow in coil X and would not light up.

(ii) When the resistance of R decreases, the clockwise current in coil Y, when viewed from Q, increases. This causes the magnetic flux density of coil Y in the direction QP to increase.

Hence the magnetic flux linkage through coil X also increases. By Faraday's Law, an e.m.f. would be induced in coil X. By Lenz's law, the induced current in coil X would flow anticlockwise so as to produce a magnetic flux density in the opposite direction to that of coil Y to oppose this increase.

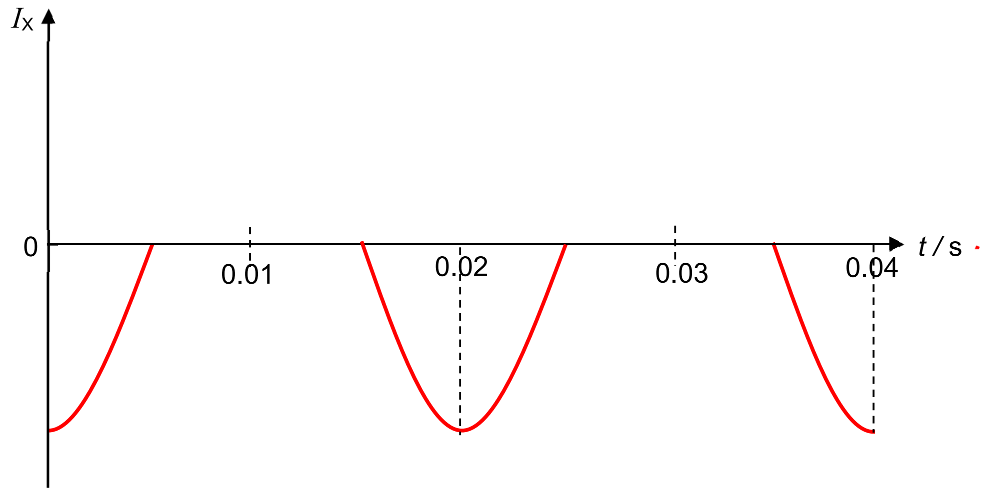
The LED would be foward biased to the anticlockwise current flow in coil X and would light up momentarily.

(b) **(i)**



*Positive sine graph
*Correct period indicated on *t* axis

(ii)



*Cosine graph and rectified
*Negative cosine graph and rectified in the correct regions

Comments

(a) (i) (ii) The answers to these first 2 parts of the question reveal students' understanding (or lack of) of the concepts in EMI.

There is still some confusion between magnetic flux density, magnetic flux and magnetic flux linkage.

Many students were unable to use the terms 'reverse biased' and 'forward biased' to describe the bias of the LED.

No credit was awarded to defining Faraday's and Lenz's law without any link to the question.

To get the first mark in both parts, there must be a clear indication of what causes the <u>change in magnetic flux linkage</u> in coil X and this leads to emf induced according to Faraday's Law. The change (whether increase or decrease) should also be specified. There were many incomplete answers that mentioned a decrease/increase in the magnetic flux density in coil Y due to the decrease/increase in current, without mentioning that in turn, the magnetic flux linkage would change. Faraday's Law mentions magnetic flux linkage, so the correct terms should be used.

The second mark was awarded if students could explain and identify the direction of the induced current using Lenz's law and the right hand grip rule. When describing the direction of current in a coil, it is advisable to use the terms 'anticlockwise' or 'clockwise' instead of 'upwards', 'downwards' which can be rather confusing.

For part (ii), the third mark was awarded for recognising that the LED would only be lit up momentarily.

In part (i), many students stated that once the switch is open, the current becomes zero. It is important to note that the current will decrease, and this is what leads to the change in magnetic flux linkage.

Students are reminded to write clearly and legibly for long qualitative questions as such. There were many whose explanations could not be deciphered.

(b) **(i)** This part was well done. Some students had difficulty calculating the value of the period.

(ii) This part was not well done. Most students did not consider rectification and sketched full wave forms (both sine and cosine).

6 **(a)** **(i)** When each incident electron collides with the metal target, it interacts with the nucleus of the metal atom, causing the electron to <u>decelerate</u> and slow down.

The <u>loss in kinetic energy of the electron is emitted as an X-ray photon</u>.

<u>Different electrons lose different amounts of kinetic energy</u>. So the <u>X-ray photons</u> emitted from the deceleration of different electrons <u>have a range of energy values</u>, forming a wide continuous spectrum of wavelengths.

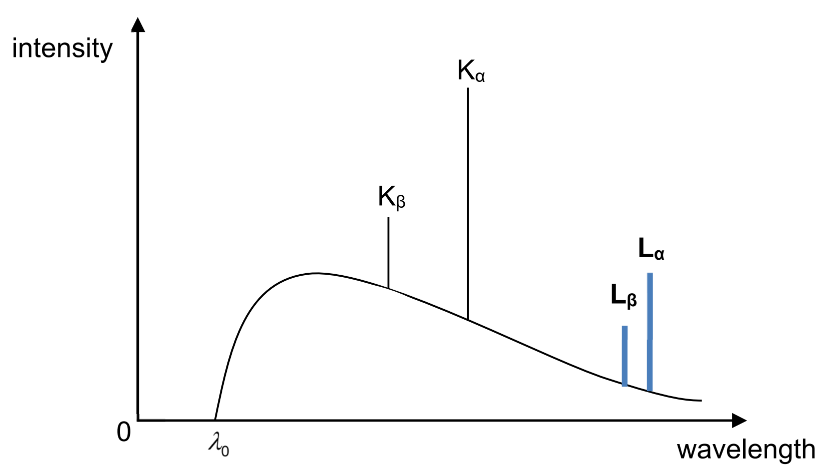
(ii) When electrons are accelerated,
increase in kinetic energy = decrease in electric potential energy = $e(\Delta V)$

When electrons hit the metal target and lose all their kinetic energy, X-ray photons of the minimum wavelength are formed.

Hence $e(\Delta V) = \dfrac{hc}{\lambda_0}$

$$\lambda_0 = \frac{hc}{e(\Delta V)} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(1.60\times10^{-19})(50000)}$$
$$= 2.49\times10^{-11} \text{ m}$$

(iii)



<u>**Both**</u> L_α and L_β are on the right side of K series.

L_α on the right of L_β

Note: the relative spacing between the K series compared to the L series may differ for different metals, hence this is not a marking point here.

(b) **(i)** Photoelectric equation

$hf = eV_S + \Phi$

$V_S = \frac{h}{e}f - \frac{\Phi}{e}$

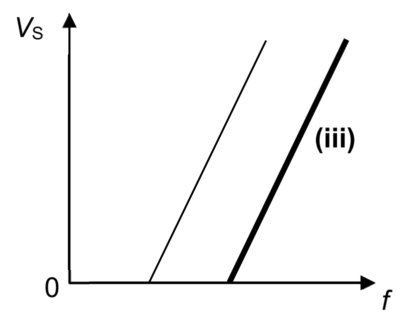
Graph of V_S against f is therefore a straight line graph with gradient $\frac{h}{e}$.

$\text{gradient} = \frac{h}{e} = \frac{6.63 \times 10^{-34}}{1.60 \times 10^{-19}} = 4.14 \times 10^{-15}$

(ii) workfunction $\Phi = hf_0$

$$\Phi = (6.63 \times 10^{-34})(5.55 \times 10^{14})$$
$$= 3.68 \times 10^{-19}\ \text{J} \quad \text{(3 s.f.)}$$
$$= \frac{3.68 \times 10^{-19}\ \text{J}}{1.60 \times 10^{-19}\ \text{C}}$$
$$= 2.30\ \text{eV} \quad \text{(3 s.f.)}$$

(iii)



New graph is shifted to the right but with the same gradient.

Comments

(a) **(i)** Students should not confuse themselves with the different processes in the syllabus. This question asked for the formation of the "*continuous* spectrum of the X-ray spectrum", and NOT the following :

- Characteristic peaks of X-ray spectrum – which is due to removal of electrons in the inner-shells of the atoms and de-excitation of electrons from the higher shells to take their place, and emitting photons as a result.
  *** **However**, do note that if question asked for **X-ray spectrum** in general, then you will need to include this discussion of characteristic peaks, continuous spectrum as well as the significance of the minimum wavelength.

- Photoelectric effect – due to photons hitting surface of metal causing an emission of electrons.
-
- Emission line spectrum of visible light – due to excitation of atom from bombarding photons or electrons, atoms then de-excite to give off photons. (Note that the characteristic peaks of X-ray are also a kind of emission line spectrum.)

Students should revise all the above processes carefully and not mix them up in your answers.

Students also need to be careful when using discriptions like “the electron *transfers* its energy to a X-ray photon”. This will give the wrong impression that the photon is already present and gets energy from the electron. This is not the case, the loss of of kinetic energy of the electron gives rise to the emission of X-ray photons.

Note that the *continuous* spectrum is due to the range of kinetic energy that can be lost by the electrons. Some students however erroneously mentioned that it is because the electrons are *moving* with a range of kinetic energy, therefore giving rise to photons with a range of energy values.

When making reference to the energy of photons, avoid using the phrase “kinetic energy of photon”. Kinetic energy is normally associated with objects with mass. Photons are massless. Hence simply says “energy of photon….”.

(ii) The relative intensity of the various peaks is not assessed in this question but in most cases, the “alpha” is of a higher intensity than the “beta” of a particular series (e.g. K_α is normally higher in intensity than K_β).

(b) **(i)** Note that the value of *e* and *h* given in the data page is quoted to 3 s.f. – hence the value calculated in this part should be 3 s.f. and not 2 s.f.
In this question, V_s is plotted against *f*, hence the gradient is *h* / *e*.
If KE_{max} is plotted against *f*, then the gradient is given by *h*.
When doing calculations, students should have the habit of first quoting the equation, then show subsitution of values, before finally writing the answer to the correct s.f.
When final answer is wrong, there will not be method marks if substitution of values is not shown.

(iii) Note that the horizontal intercept is equal to the threshold frequency and since workfunction = hf_0, a larger workfunction will mean a greater threshold frequency – the new graph should be shifted to the right.
And also since the gradient is $\frac{h}{e}$, which is a constant, the two lines should be parallel to each other.

Section B

7 (a) (i) An ideal gas is a gas which obeys the equation of state $pV = nRT$ at all values of pressure p, volume V and temperature T, where R is the molar gas constant.

(ii)

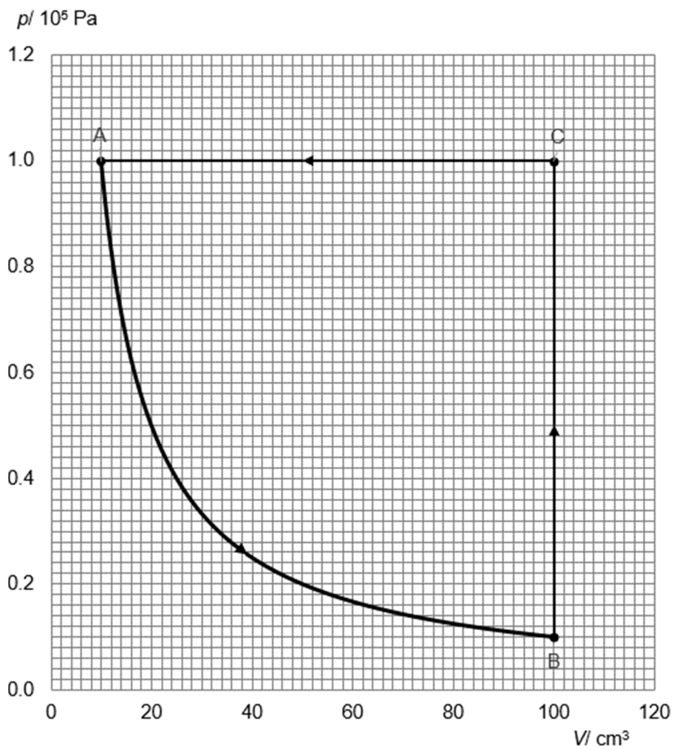
$$n = \frac{pV}{RT} = \frac{\left(1.00\times10^{5}\right)\left(10.0\times10^{-6}\right)}{\left(8.31\right)\left(27.0+273.15\right)}$$

$$= 4.01\times10^{-4} \text{ mol (3 sf)}$$

(b) (i) The first law of thermodynamics states that the **increase** in the internal energy of a system is equal to the **sum** of the heat supplied to the system and the work done on the system, and the **internal energy** of a system depends **only** on its state.

(ii) 1. Move the piston outwards slowly, so that heat can be conducted through the metal cylinder from the environment to the gas.

2.



*Arrow indicating direction of process from A to B.
*Accuracy of curve: through (20, 0.5), (25,0.4), (40, 0.25) and (50, 0.2).

(iii) Since process is isovolumetric / isochoric, work done on the gas is zero, i.e. $\Delta U = Q + W = Q$.

For a monatomic ideal gas, $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2}\left(p_C V_C - p_B V_B\right)$.

Hence, heat supplied $Q = \Delta U = \frac{3}{2}\left(p_C V_C - p_B V_B\right)$

$$= \frac{3}{2}\left(1.00\times100 - 0.10\times100\right)\times10^{5}\times10^{-6}$$

$$= 13.5 \text{ J (shown)}$$

OR: use $T_i = 300.15$ K , $T_f = 3001.5$ K ; $\Delta U = \dfrac{3}{2} nR\Delta T$.

*Must show explicit substitions of correct numerical values in SI units.

(iv) **1.** For the isothermal process A→B, the change in internal energy is zero (ie ΔU_{AB} = 0). (Accept U returns to original value or no change in U in a cycle.)

For the isovolumetric process B→C, the work done is zero. Hence, the change in internal energy is equal to the heat supplied (ie ΔU_{BC} = 13.5 J from **(b)(iii)**).

Since the gas returns to its initial state, net change in the internal energy of the gas for cyclic process is zero.
(i.e. $\Delta U_{ABCA} = \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CA} = 0 + 13.5 + \Delta U_{CA} = 0$).

Hence, the change in internal energy for process C to A is –13.5 J (or the internal energy decreases by 13.5 J.)

Mathematical proof:

$$\Delta U = \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CA}$$
$$0 = 0 + 13.5 + \Delta U_{CA}$$
$$\Delta U_{CA} = -13.5 \text{ J}$$

2. Since the work done on the gas is positive (or work done on system) (i.e. compression) **and** the internal energy of the gas decreases (or change in internal energy is negative) (i.e. temperature decreases), the rate at which heat is removed from the gas is faster than the rate at which work is done on the gas.

(c) **(i)** N is the number of particles / atoms / molecules.
m is the mass of **one** particle / atom / molecule.
$\langle c^2 \rangle$ is the mean square speed of the particles / atoms / molecules. (“s” compulsory)

(ii) The gas particles exert no intermolecular force on one another, except during collisions.

(iii)

$$pV = \frac{1}{3} Nm\langle c^2 \rangle = NkT$$
$$\frac{1}{2} m\langle c^2 \rangle = \frac{3}{2} kT$$

Hence, average K.E. of a particle = $\dfrac{3}{2}kT$.

*If using $pV = nRT$, need to show $\dfrac{nR}{N} = \dfrac{R}{N_A} = k$.

(iv) $\text{K.E.} = \frac{1}{2} m c_{rms}{}^2 = \frac{3}{2} kT$

$$c_{rms} = \sqrt{\frac{3kT}{m}}$$
$$= \sqrt{\frac{3\left(1.38 \times 10^{-23}\right)\left(27.0 + 273.15\right)}{\left(\frac{0.014}{6.02 \times 10^{23}}\right)}}$$
$$= 730 \text{ m s}^{-1}$$

OR

$$\text{K.E.} = \frac{3}{2} kT = \frac{3}{2}\left(1.38 \times 10^{-23}\right)\left(27.0 + 273.15\right) = 6.2131 \times 10^{-21} \text{ J}$$
$$m = \frac{M_{molar}}{N_A} = \frac{0.014}{6.02 \times 10^{23}} = 2.3256 \times 10^{-26} \text{ kg}$$

$$c_{rms} = \sqrt{\frac{2 \times \text{K.E.}}{m}}$$
$$= \sqrt{\frac{2 \times \left(6.2131 \times 10^{-21}\right)}{\left(2.3256 \times 10^{-26}\right)}}$$
$$= 730 \text{ m s}^{-1}$$

OR

$$c_{rms} = \sqrt{\frac{3RT}{M_R}} = \sqrt{\frac{3pV}{nM_R}} = \sqrt{\frac{3pV}{m_{gas}}}$$

Comments

(a) **(i)** Many students left out the 2nd part of the answer.

(ii) Conversion of °C to K is given in the formulae sheet – the use of 273 K is unacceptable.

(b) **(i)** Weaker students tend to miss out "increase", "sum", "only" and the 2nd part of the answer. Ambiguous statements are not awarded.

Students should follow the definitions given in the syllabus as they tend to make mistakes when they paraphrase definitions. Many did not include the 2nd part of the answer.

Students should also avoid the use of undefined symbols in definitions and explanations.

(ii) **1.** Weaker students failed to think / read carefully, and reproduced answers for an adiabetic process by wrongly stating that the process must be done quickly in an insulated container.

2. Students must learn to indicate the direction of a thermal process and to plot points / draw graph accurately.

(iii) Students must learn to be explicit in their answers, and to always write formulae and show substitutions in the correct units.

(iv) **1.** Students must learn to write neatly and succinctly – illegible writing and convoluted explanations will not be awarded. To avoid ambiguity, use words instead of symbols – for example, *Q* can be heat supplied or removed, and *W* can be work done on or by system.

They must also be careful in their choice of words. For example, adding or omitting the word "change" makes a difference to an answer.

2. Reasoning and conclusion must be consistent to earn any mark.

(c) **(i)** Weaker students were careless in their use of "a", "one" and "each" and singular/plural nouns. They must develop a greater awareness of their use of language.

(ii) Many students left out the 2nd part of the answer (not marked for in this exam).

(iii) Weaker students used convoluted proof, confusing themselves in the process. They also tend to conveniently (but wrongly) assumed that N=1, and used $pV=nRT$ (more difficult to prove) instead of $pV=NKT$ (much easier to prove).

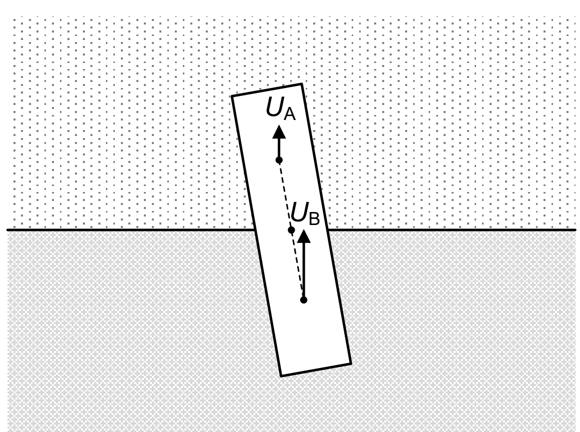
(iv) Students must develop a greater awareness of the order of magnitude of their final answers. Many calculated the rms speed to be more than the speed of light, and yet they did not review their working.

8 **(a)** **(i)** By the principle of flotation,

$$\text{weight of block} = \text{upthrust on block}$$
$$SL\rho g = \tfrac{1}{2}SL\rho_A g + \tfrac{1}{2}SL\rho_B g$$
$$\rho = \tfrac{1}{2}\rho_A + \tfrac{1}{2}\rho_B$$

(ii) Density of liquid B is greater than that of liquid A (A above B).
Since the volume of liquid displaced is the same for A and B, upthrust $U = V\rho g \propto \rho$
Hence $U_B > U_A$.

(b) **(i)**



*Upthrust drawn from respective centres of each half of the block (i.e. centre of mass of liquid displaced for each liquid)
*Longer arrow for U_B , correct labels

(ii) About C, the anticlockwise moment of force (or torque) due to U_B is greater than the clockwise moment of force (or torque) due to U_A. So there is a resultant anticlockwise moment, causing the block to rotate away from its original vertical orientation.

For stability (since block returns to its original vertical orientation), the weight of the block must produce a clockwise moment of force (or torque) about C.

So the centre of gravity of the block must be below C (along the centre line of the block).

(c) (i) **1.** upthrust in liquid A

$$U_A = S \times \left(\tfrac{1}{2}L + x\right)\rho_A g$$

2. upthrust in liquid B

$$U_B = S \times \left(\tfrac{1}{2}L - x\right)\rho_B g$$

(ii) Taking upwards as positive,
net force on the block = *ma*

$$S \times \left(\tfrac{1}{2}L + x\right)\rho_A g + S \times \left(\tfrac{1}{2}L - x\right)\rho_B g - SL\rho g = SL\rho a$$

$$\tfrac{1}{2}SL\rho_A g + \tfrac{1}{2}SL\rho_B g + Sx\rho_A g - Sx\rho_B g - SL\rho g = SL\rho a$$

subst. $\rho = \tfrac{1}{2}\rho_A + \tfrac{1}{2}\rho_B$

$$\tfrac{1}{2}SL\rho_A g + \tfrac{1}{2}SL\rho_B g + Sx\rho_A g - Sx\rho_B g - SL\left(\tfrac{1}{2}\rho_A + \tfrac{1}{2}\rho\right)_B g = SL\left(\tfrac{1}{2}\rho_A + \tfrac{1}{2}\rho_B\right)a$$

$$Sx\rho_A g - Sx\rho_B gA = \tfrac{1}{2}SL\left(\rho_A + \rho_B\right)a$$

$$x\left(\rho_A - \rho_B\right)g = \tfrac{1}{2}L\left(\rho_A + \rho_B\right)a$$

$$a = -\frac{2\left(\rho_B - \rho_A\right)g}{\left(\rho_B + \rho_A\right)L} \cdot x$$

(iii) For s.h.m., $a = -\omega^2 x$. So

$$\omega^2 = \frac{2\left(\rho_B - \rho_A\right)g}{\left(\rho_B + \rho_A\right)L}$$

$$\left(\frac{2\pi}{T}\right)^2 = \frac{2\left(\rho_B - \rho_A\right)g}{\left(\rho_B + \rho_A\right)L}$$

$$T = 2\pi\sqrt{\frac{\left(\rho_B + \rho_A\right)L}{2\left(\rho_B - \rho_A\right)g}}$$

(d) (i) The speed when C is at the interface (equilibrium position) is maximum.

$$v_0 = \omega x_0$$

$$x_0 = \frac{v_0}{\omega} = v_0\sqrt{\frac{\left(\rho_B + \rho_A\right)L}{2\left(\rho_B - \rho_A\right)g}}$$

$$= 0.40\sqrt{\frac{(1300 + 860)0.25}{2(1300 - 860)9.81}}$$

$$= 0.100 \text{ m}$$

(ii) Period of oscillation

$$T = 2\pi\sqrt{\frac{(\rho_B + \rho_A)L}{2(\rho_B - \rho_A)g}} = 2\pi\sqrt{\frac{(1300+860)0.25}{2(1300-860)9.81}} = 1.57 \text{ s}$$

(iii) At $t = 0$, $x = x_0$

Equation representing the motion of the block is

$x = x_0 \cos\left(\frac{2\pi}{1.57} \times t\right)$ where $x_0 = 0.100$ m.

when $x = \frac{1}{2}x_0$,

$x_0 \cos\left(\frac{2\pi}{1.57} \times t\right) = \frac{1}{2}x_0$

$\cos\left(\frac{2\pi}{1.57} \times t\right) = \frac{1}{2}$

$\frac{2\pi}{1.57} \times t = \frac{\pi}{3}$

$t = 0.262$ s

Comments

(a) (i) Some students claimed Archimedes' principle when it should really be the principle of flotation.
A few students missed out on "g", the acceleration of free fall.

(ii) To deduce which upthrust is greater, one must compare the density of liquids and volume of liquid displaced. It is also important to quote the formula $U = V\rho g \propto \rho$ so there will be no ambiguity.

(b) (i) The upthrust acts on a point known as the centre of buoyancy. This point is also the centre of gravity of the liquid displaced.

(ii) Some students did not address the moment of force due to U_A and U_B; only focusing on the moment due to *mg*.

(c) (ii) Some students did not consider weight of the block when applying $F_R = ma$.
Also the sign convention requires that upward forces are taken to be positive as the block is displaced upward.

(d) (i) A few students omitted *L* or *g* when computing the angular speed.

(iii) Some students who use $x = x_0 \sin\left(\frac{2\pi}{1.57} \times t\right)$ failed to realized that at $t = 0$, the centre of the block is at the equilibrium position, not x_0.