Raffles Institution
Year 5-6 Physics Department

2022 H2 Physics Preliminary Examination Solution

Paper 3 – Section A

1 **(a)** The gas molecules exert no intermolecular forces on one another except during collisions.

(b) **(i)** **1.** $p_B V_B = n_B R T_B$

$$n_B = \frac{p_B V_B}{R T_B}$$

$$= \frac{(2.0\times10^{5})(3.0\times10^{-2})}{(8.31)(300)}$$

$$= 2.4067 = 2.4 \text{ mol (shown)}$$

2. Solution 1

$$\text{total internal energy} = U_A + U_B$$

$$= \frac{3}{2}p_A V_A + \frac{3}{2}p_B V_B$$

$$= \frac{3}{2}(3.0\times10^{5})(2.0\times10^{-2}) + \frac{3}{2}(2.0\times10^{5})(3.0\times10^{-2})$$

$$= 18000 \text{ J}$$

Solution 2

$$\text{total internal energy} = U_A + U_B$$

$$= \frac{3}{2}n_A R T_A + \frac{3}{2}n_B R T_B$$

$$= \frac{3}{2}(1.8)(8.31)(400) + \frac{3}{2}(2.4)(8.31)(300)$$

$$= 17949.6 = 17900 \text{ J}$$

(ii) **1.** Total internal energy is conserved as this container is a closed system.

$$\text{total internal energy} = U_A' + U_B' = 17900$$

$$\frac{3}{2}n_A RT + \frac{3}{2}n_B RT = 17900$$

$$\frac{3}{2}RT\,(n_A + n_B) = 17900$$

$$T = (17900)\left(\frac{2}{3}\right)\left(\frac{1}{(8.31)(1.8+2.4)}\right)$$

$$= 341.91 = 342 \text{ K}$$

2. As gas A is at a higher pressure than gas B, it expands and does work against the pressure of gas B, hence work done W on gas A is negative.

As gas A is at a higher temperature than gas B, heat is transferred from gas A to gas B, hence heat supplied Q to gas A is negative.

Since $\Delta U = Q + W$, the increase in internal energy ΔU is negative which implies that the internal energy of gas A decreases. Since $\Delta U \propto \Delta T$ (or $U = \frac{3}{2}nRT$), the temperature of gas A decreases.

(iii) Vacuum does not contain any particles and has no pressure. Hence in expanding, gas A does no work and does not transfer heat to any other body. Hence by the first law of thermodynamics, there is no change in internal energy and no change in temperature.

Comments

(a) The direct reason why the microscopic potential energy of an ideal gas is zero is due to the absence of intermolecular forces between the molecules. This is the only acceptable answer.

Candidates who wrote that the molecules are assumed to be very far apart and do not interact did not get any credit.

Many candidates mentioned that intermolecular forces are attractive in nature, which is incorrect. It could be both attractive and repulsive.

(b) (i) 1. This part was well done. However, many students did not explicitly state the numerical value of n_B to a greater number of significant figure than the final answer of 2.4 mol, which is mandatory for questions that require candidates to prove a specific numerical value of a particular physical quantity.

2. Most candidates arrived at the correct answer by using $U_A + U_B = \frac{3}{2}p_AV_A + \frac{3}{2}p_BV_B$ or $U_A + U_B = \frac{3}{2}n_ART_A + \frac{3}{2}n_BRT_B$. There are a handful who solved it using $U_A + U_B = \frac{3}{2}n_AN_{avo}kT_A + \frac{3}{2}n_BN_{avo}kT_B$, but this is more tedious.

The most common mistake here is probably due to candidates' own carelessness such as not multiplying by the factor of $\frac{3}{2}$ or not multiplying by the correct constants.

(ii) 1. This part was poorly done.

In addition, those who approached this question from the perspective that both pressure and temperature of gases A and B will eventually equalise in the final state of equilibrium, met with a dead end and could not get an answer.

Yet many other candidates approached this part by applying $pV = nRT \Rightarrow T = \frac{pV}{nR}$ to the entire system of gas A and gas B. The problem with this is what will the final pressure p of the system be?

Many candidates erroneously calculated final pressure as $p = \dfrac{2.0\times10^5 + 3.0\times10^5}{2} = 2.5\times10^5$ Pa which has no basis.

Candidates who did this correctly approached this problem from the perspective that since the container is insulated all round, there is no heat transfer to or from the system of gas A and B, hence the total internal energy of the system is conserved, and things become very easy!

2. This part exposes candidates' lack of understanding and focus in both the requirement and the context of the question.

Many candidates overlooked the fact that the question made a reference to gas A and not the entire system thus missing out on the context. That being the case, many candidates concluded that heat transferred to the system is zero ($Q = 0$) when they should have considered heat transfer from gas A to gas B (as $T_A > T_B$) which is negative ($Q_A < 0$).

A number of students failed to mention the important point that (change in) internal energy of ideal gas is proportional to (change in) its thermodynamic temperature hence when internal energy of gas A decreases, its temperature decreases; not getting full credit as a result.

(iii) This is another question in which candidates performed poorly.

Many candidates did not realise that the piston has been removed and gas A is free to expand into the section where gas B was before and being replaced with a vacuum. This expansion does not require work to be done by gas A; it's a free expansion due to the vacuum where there are no gas molecules hence work done by A is zero. Some candidates came to the conclusion that work done by gas A is zero because there is no change in volume of gas A (so $p\Delta V = 0$) which is not true, as gas A expands.

Many other candidates approached this question using the ideal gas equation $pV = nRT$ and wrote that as gas A expands, its volume V increases and its pressure p decreases proportionately thus its temperature remains unchanged. By doing so, candidates are actually already assuming that the temperature remains constant and not proving it, hence not answering the question.

Some candidates wrote that since the system is a closed one, the internal energy of the system is conserved hence its temperature did not change. This was not given credit as it lacks explanation as internal energy is always conserved for this closed system. Candidates are expected to consider changes in both work and heat energy transferred to or from gas A and how these affect its internal energy and therefore should explicitly mention them in their explanation.

2 **(a)** **(i)** x_0 is the decrease in height of the load and is the extension of the spring when the load is at the equilibrium position.

decrease in G.P.E. $= mgx_0$

<u>Solution 1</u>
magnitude of the external force at the equilibrium position, $F = mg$

increase in E.P.E. $= \frac{1}{2}Fx_0 = \frac{1}{2}mgx_0$

<u>Solution 2</u>
increase in E.P.E. $= \frac{1}{2}kx_0^{\,2} = \frac{1}{2}(kx_0)x_0 = \frac{1}{2}mgx_0$
where k is the spring constant and $kx_0 = mg$ <u>at equilibrium</u>

comparing the expressions for G.P.E. and E.P.E,
decrease in G.P.E. = 2 × increase in E.P.E. (shown)

(ii) The decrease in G.P.E. is greater than the increase in E.P.E. as there is <u>negative work done by the external force in lowering the load</u> slowly.

(b) **(i)** at equilibrium, $kx_0 = mg \Rightarrow k = \frac{mg}{x_0}$ where k is the spring constant

$$\text{E.P.E. at lowest point} = \frac{1}{2}ke^2 = \frac{1}{2}\left(\frac{mg}{x_0}\right)(2x_0)^2 = 2mgx_0$$

(ii) **1.** G.P.E. $= mgh$ where h is the distance from the lowest point
G.P.E. varies linearly with distance.

at lowest point: G.P.E. $= 0$
at highest point: G.P.E. $= mg(2x_0) = 2mgx_0$
at equilibrium position: G.P.E. $= mgx_0$

2. E.P.E. $= \frac{mg}{2x_0}e^2$ where e is the extension of the spring and the distance from the highest point.
E.P.E. and distance follows a quadratic relationship.

from (b)(i), at lowest point: E.P.E. $= 2mgx_0$
at highest point, spring is at its natural length: E.P.E. $= 0$
at equilibrium position: E.P.E. $= \frac{1}{2}mgx_0$

3. $$\text{K.E.} = \frac{1}{2}m\left(\pm\omega\sqrt{x_0^{\,2}-x^2}\right)^2 = \frac{1}{2}m\omega^2\left(x_0^{\,2}-x^2\right) = -\frac{1}{2}m\omega^2x^2 + \frac{1}{2}m\omega^2x_0^{\,2}$$

K.E. and displacement follows a quadractic relationship.

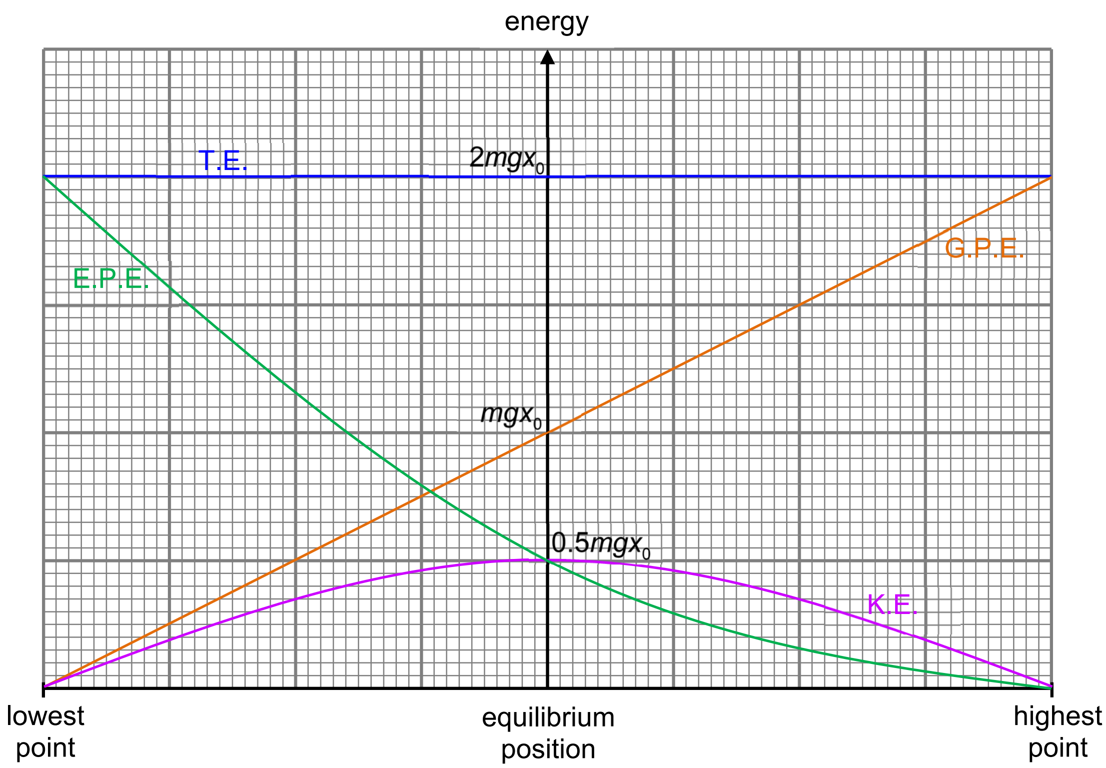
at lowest and highest points: $\text{K.E.} = 0$
at equilibrium position:

$$\text{max. K.E.} = \frac{1}{2}m\omega^2x_0^{\,2} = \frac{1}{2}m\left(\frac{k}{m}\right)x_0^{\,2} = \frac{1}{2}\left(\frac{mg}{x_0}\right)x_0^{\,2} = \frac{1}{2}mgx_0$$

*total energy can be deduced from the energies at the lowest and highest points
*maximum K.E. expression can be deduced, knowing the total energy, G.P.E. and E.P.E. at the equilibrium position

4. Total energy at any position is the sum of the G.P.E. , E.P.E. and K.E. at that position.
Total energy remains constant for a system with no energy losses.

*correct relationship between the energies at equilibrium position
*graphs clearly labelled



Comments

(a) (i) This is a 'show' question where the end result is given. Hence, clear explanations are required in the derivation of the end result. Just presentating the equations and substitutions without explaining $F = mg$ or $kx_0 = mg$ <u>because the mass is in equilibrium</u>, is not complete. The weaker candidates erroneously equated loss in GPE to gain in EPE in this part and ended up with an equation of "2 = 1" and yet failed to recognise that something was wrong.

(ii) In explaining work done on a system, the direction of the specific force and the direction of the displacement have to be clearly specified as it determines if the work done is positive or negative, which affects whether the different forms of energy increase or decrease. Candidates should also note that the direction should be attributed to the force and not the work since work has no direction. E.g. a statement such as “the direction of work done is opposite to the displacement” is clearly wrong.

(b) (i) The concepts applied to derive the expression have to clearly stated. Just giving equations without being clear conceptually why these equations were used, will not be awarded full credit. Even clear, short statements will suffice.

It has been emphasised many times that presentation of concepts and workings are very important in Physics. Just arriving at the final answer without clear presentation will often be penalised as it is doubtful whether the candidate truly understands what he / she is doing.

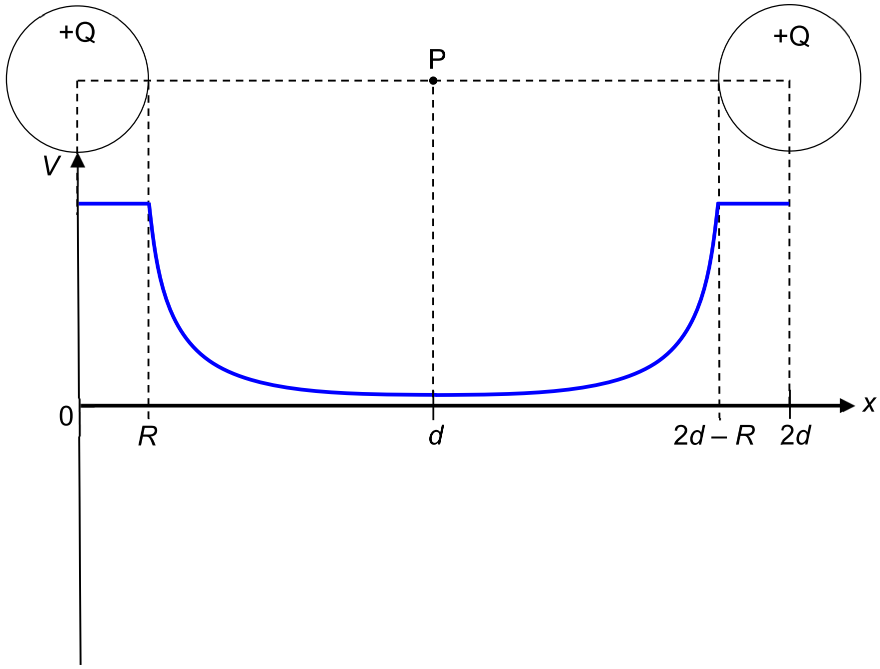
(ii) When a graph grid is given, the scales of the axes usually need to be marked out at regular intervals like in any typical graph. The precise positions of the graphs, especially at critical points like the axes intercepts / turning points / where the graphs cut one another, are thus important (its like plotting a graph using the grids).

The question also stated to use the answers in the earlier parts to draw the energy graphs. This means that these values /answers should be indicated on the graphs.

To draw the graphs correctly, you need to spend time to understand the scenario given in the question. How the energies vary is specific to this particular oscillation. Candidates should not just draw from memory without paying attention to details and modifying to suit the context. This clearly shows lack of in depth understanding of the concepts and a lack of effort to understand the problem at hand.

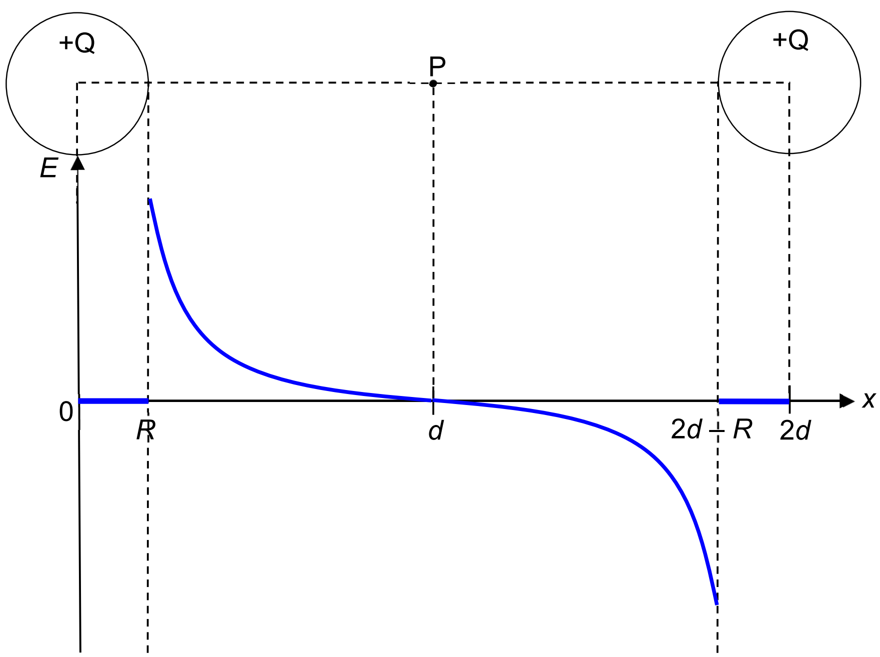
At A Levels, the solution / explanation must be specific / precise / in context to solve that particular problem presented. General understanding and general statements such that it seems one solution fits all problems, is definitely not good enough.

3 (a) (i)



* symmetrical about $x = d$
*constant potential within each sphere, same potential in both spheres

(ii)



* symmetrical about $x = d$
* $E = 0$ within each sphere

(b) **(i)** Solution 1

At point P, the electron is equidistant from each sphere and since each sphere carry the same amount of positive charge, the electric force acting on the electron due to sphere A is equal in magnitude and opposite in direction to the electric force on the electron due to sphere B.

Hence, the resultant electric force acting on the electron is zero.

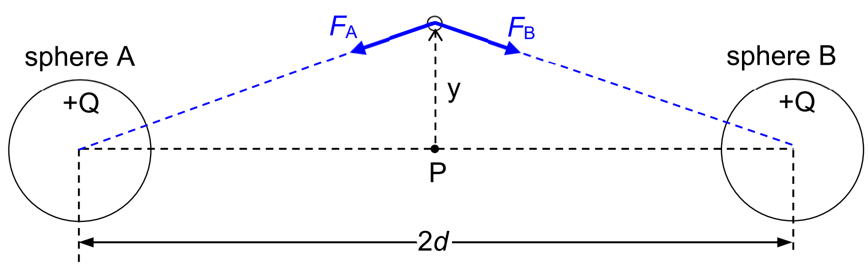
(the force due to sphere A, $F_A = \dfrac{Qe}{4\pi\varepsilon_0 d^2}$ is acting to the left and the force due to sphere B, $F_B = \dfrac{Qe}{4\pi\varepsilon_0 d^2}$ is acting to the right)

Solution 2

Point P is equidistant from each sphere and since each sphere carry the same amount of positive charge, the electric field strength at point P due to sphere A is equal in magnitude and opposite in direction to the electric field strength due to sphere B. Hence, the resultant electric field strength at point P is zero.

Since the resultant electric force on the electron at point P is the product of the resultant electric field strength at point P and the elementary charge, the resultant electric force is zero.

(ii) **1.**



*F_A and F_B act along lines joining electron and centres of A and B, point towards the centres

*arrows are of the same length

2. The resultant force on the electron is acting vertically downwards, opposite to its upward displacement y.

$F_R = -F_A \cos\theta - F_B \cos\theta$

where θ is the angle that F_A or F_B makes with the vertical

Since $F_A = F_B = \dfrac{Qe}{4\pi\varepsilon_0}\dfrac{1}{\left(\sqrt{d^2+y^2}\right)^2} = \dfrac{Qe}{4\pi\varepsilon_0(d^2+y^2)}$

$$F_R = -2F_A\cos\theta$$

$$= -2\frac{Qe}{4\pi\varepsilon_0(d^2+y^2)}\left(\frac{y}{\sqrt{d^2+y^2}}\right)$$

$$= -\frac{Qe}{2\pi\varepsilon_0}\left(\frac{y}{\left(d^2+y^2\right)^{\frac{3}{2}}}\right)$$

3. Since Q, e, m_e, d and ε_0 are constants, $a \propto (-y)$.

The acceleration *a* of the electron is directly proportional to its displacement *y* from the equilibrium position P.

The negative sign implies that the acceleration *a* acts in the opposite direction to the displacement *y* from the equilibrium position P. Hence, the acceleration points towards the equilibrium position.

This satifies the condition for simple harmonic motion where $a = -\omega^2 y$. The electron will oscillate in simple harmonic motion along the vertical axis through point P with angular frequency $\omega = \sqrt{\dfrac{Qe}{2\pi\varepsilon_0 m_e d^3}}$.

Comments

(a) (i) This is a standard question that involved graphing the scalar sum of the potentials between two positively charged conducting spheres. Please make an effort to review the *V*–*r* graphs and *E*–*r* graphs carefully. Candidates should be able to identify the characteristics that distinguish the *V*–*r* and *E*–*r* graphs graphs for point charges and conducting spheres.

Common mistakes include:
1. No labels for the x-axis (BOD was given here)
2. Sketching the *V*–*r* graph between two positive **point charges**
3. Lack of symmetry about $x = d$
4. Forgetting that potential is a constant within the conducting sphere.

(ii) Please note that there is no ecf from **(a)(i).**

Common mistakes include:
1. Sketching the *E*–*r* graph between two positive **point charges**
2. Taking the positive potential gradient instead of the negative potential gradient when sketching the *E*–*r* graph.
3. Forgetting that there is no electric field within a conductor.

Please note that candidates must clearly draw the line to indicate that $E = 0$ within each sphere.

If there was no clear pencil line within those regions, it will be assumed that an incomplete attempt was made and hence no credit given.

(b) (i) Generally well done.

No credit is given if either magnitude or direction was not explicitly mentioned within the explanation.

Candidates who mentioned that the forces/electric fields 'cancel out' with no further elaboration will not be given credit.

Candidates who mentioned that resultant force is zero because electric field strength is zero with no further elaboration will also not be given credit.

(ii) **1.** Candidates need to pay careful attention to details. The length of a vector denotes its magnitude and the arrowhead, its direction. A significant number of candidates did not pay careful attention to ensure equal length of the arrows when drawing F_A and F_B and a handful of students could not identify the direction of the electric forces which should be acting along the lines joining the electron and the centres of spheres A and B directed towards their centres.

2. This question was not well done.

Common mistakes include:

1. Identifying the distance between the electron and the sphere incorrectly. Variations included $F_A = \frac{Qe}{4\pi\varepsilon_0 d^2}$ or $F_A = \frac{Qe}{4\pi\varepsilon_0 y^2}$
2. Forgetting to square the distance between the electron and the sphere. i.e. $F_A = \frac{Qe}{4\pi\varepsilon_0 \sqrt{d^2 + y^2}}$

Most candidates did not score full credit because they were not able to show / explain that the resultant force on the electron always act in opposite direction to the displacement y from its equilibrium position which is indicated by the '–' sign in the final expression.

Candidates whose final expression consist of a '–' sign due to substitution of $q = -e$ will not be given full credit.

3. Most candidates recognise that the electron will move in simple harmonic motion upon release. However, description supporting the conclusion lacked details in many scripts. Students need to use the information provided to add depth to their discussion.

In the context of the question, it is important that the expression for the angular frequency of the simple harmonic motion to be explicitly mentioned.

4 **(a)** **(i)** Using Fleming's left hand rule, the magnetic force acting on the electron is always perpendicular to the direction of its linear velocity. Hence the direction of the electron's velocity changes, but its speed remains constant.

Since magnetic flux density B, charge of electron e and speed of electron v are constant, the magnitude of the magnetic force Bev remains constant.

This magnetic force provides the centripetal force and hence the electron will be in uniform circular motion.

(ii) The magnetic force on the electron provides the centripetal force.

$$\begin{aligned} Bqv &= mr\omega^2 \\ Bq(r\omega) &= mr\omega^2 \\ Bq &= m\omega \\ Bq &= m(2\pi f) \\ f &= \frac{Be}{2\pi m_e} \\ &= \frac{(2.8\times10^{-5})(1.60\times10^{-19})}{2\pi(9.11\times10^{-31})} \\ &= 7.8267\times10^5 = 7.83\times10^5 \text{ Hz} \end{aligned}$$

(b) **(i)** $Bqv = \frac{mv^2}{r} \quad \Rightarrow \quad r = \frac{mv}{Bq} \quad \Rightarrow \quad r \propto v$ (since B, m and q are constant)

The speed of the second electron is $\sqrt{2}$ times the speed of the first electron. Since $r \propto v$, the radius of its circular path is $\sqrt{2}$ times the radius of the circular path of the first eletron.

(ii) $T = \frac{2\pi r}{v} = \frac{2\pi}{v}\left(\frac{mv}{Bq}\right) = \frac{2\pi m}{Bq}$

The period of revolution is independent of the speed of the electron. The period of revolution for both electrons is the same.

(iii) The magnetic force is always perpendicular to the direction of the linear velocity / displacement of each electron. There is no displacement in the direction of the magnetic force and the work done by the magnetic force on each electron is always zero.

(c) The electric and magnetic fields are pointing perpendicularly into the paper. The electron experiences a constant electric force directed perpendicularly out of the paper while it undergoes uniform circular motion.

The electron will accelerate out of the paper in a helical path with increasing pitch.

Comments

(a) **(i)** This part was poorly attempted and showed the lack of understanding of the conditions for circular motion. It should be noted that this question has been asked repeatedly in the A Levels over the past 3 years. So candidates are advised to be clear of the concepts.

- It is insufficient to only state that the magnetic force is perpendicular to the direction of velocity. The effect of the direction of the force is that the magnitude of the velocity remains unchanged while the direction of velocity changes constantly. This must be clearly articulated.

- There were many vague statements such as '*linear velocity remains unchanged*'. Velocity has both direction and magnitude. In the case of circular motion, direction changes while magnitude does not. This has to be clearly articulated.

- The other main point is that the magnitude of the magnetic force is constant. This ensures that the path of the charge has a constant radius.

- Some vague/confusing directions used such as 'velocity is the ***right*** of the charge'. There is no reference to what is right and left in this case. Some students gave long explanations about the direction of current due to the movement of the charge. This is not necessary.

(ii) Calculations were generally well done. A few candidates did not show substitution of values and were penalised 1 mark here.

Quite a few were careless in transcription. Obtaining the answer of 7.83×10^5 Hz but writing only 7.83 Hz in the answer space!

(b) **(i)**

- When asked to state the effect on a variable given the change in another variable, candidates are advised to always give numerical values where possible. In this question, it was stated that kinetic energy of the second electron is twice that of the first. Hence, it is not difficult to deduce that the velocity, and hence radius would be $\sqrt{2}$ of the first electron. Many answers only stated that there was an 'increase' in the radius.

- Many answers only stated the relationship $r = \frac{mv}{Bq}$ followed by the (correct) conclusion about the new radius. However, there was no explanation as to why the candidate concluded that $r \propto v$. Do remember to always state which quantities are constants, leading to the conclusion that the 2 non-constant variables are directly proportional to one another. BOD was given here.

- Similarly, there were answers that just stated that $r \propto v$ without any accompanying equations, followed by the correct conclusion. BOD was given here.

- Some candidates used the equation $v = r\omega$ to conclude that $r \propto v$, without explaining why ω is constant were not given credit here.

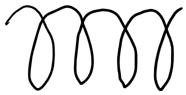
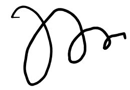
(ii) This was generally well done, but candidates are advised to write their explanations clearly.

The question asks for the effect on the period. Many wrote about how the angular velocity ω is constant (as $\omega = \frac{Bq}{m}$, and *B*, *q* and *m* are constants) and simply concluded that *T* is therefore also constant. The answers were given credit. However, a more complete answer should also state that $T = \frac{2\pi}{\omega}$.

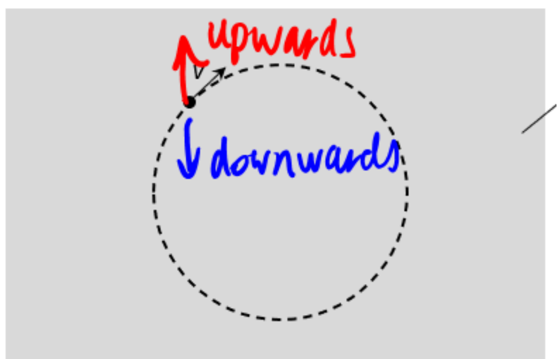
(iii) Many answers stated that 'distance moved' instead of 'displacement'. Work done is the product of force and displacement. These were given BOD but please note that BOD may not be awarded for such mistakes in the A Levels!

Quite a few answers stated that "*work done by the centripetal force is zero because in 1 revolution, the change in displacement of the charge is zero*". This is not the reason why there is no work done by the centripetal force!!

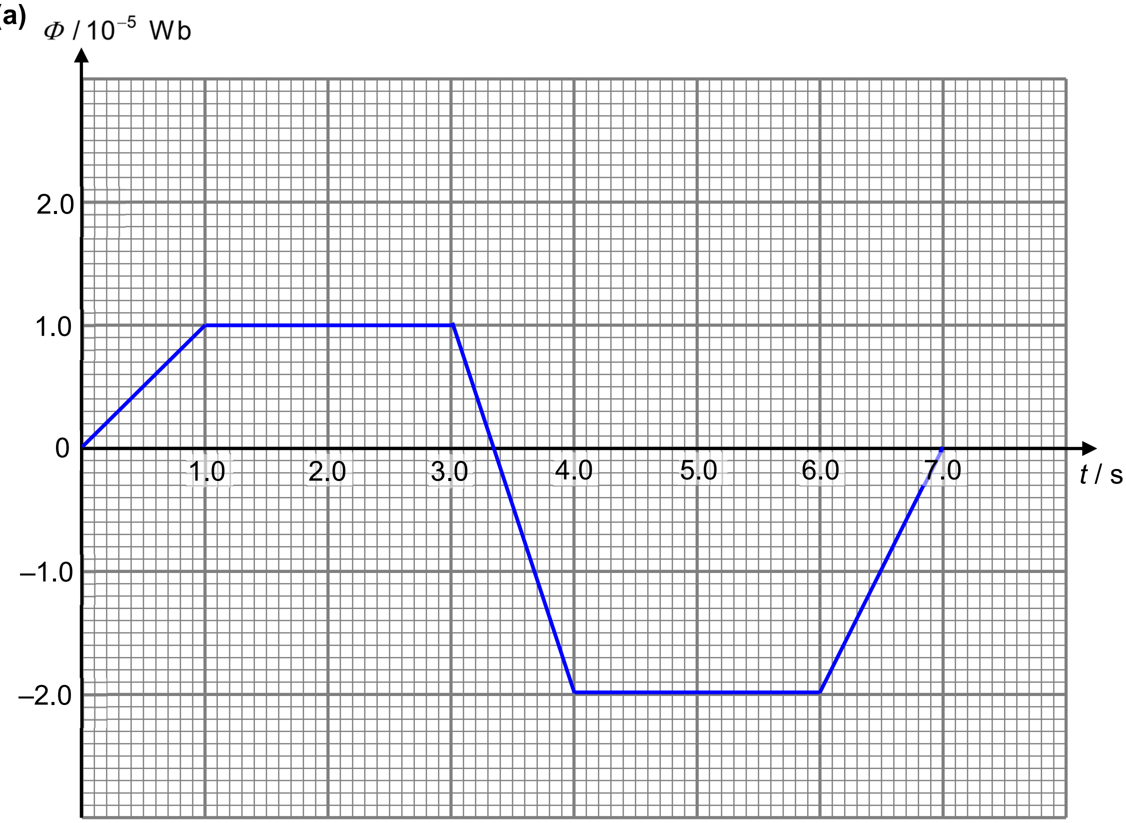
(c) It must be noted that a spiral path is NOT the same as a helical path. Students who only used the term 'spiral' were not given credit.

Helical path:  Spiral path: 

Another common issue here was the use of 'upwards', 'downwards' to describe the direction of the field and force. This is confusing, because from the view of the diagram in the question, 'upwards' and 'downwards' would be taken as vertically upwards/downwards along the plane of the paper. What most candidates meant was 'perpendicularly out of/into the the plane of the paper'.



5 **(a)**



(b) By <u>Faraday's Law</u>, an <u>e.m.f. is induced in the coil when there are changes in the magnetic flux linkage of the coil</u> as it moves through the fields.

By <u>Lenz's Law</u>, the induced e.m.f. causes a <u>current to flow around the coil</u> such that <u>it induces a magnetic force that acts on the coil in the direction opposite to the direction of the coil's velocity</u>. This magnetic force causes the coil to decelerate.

Hence, in order to maintain constant velocity, <u>an external force</u> of the same magnitude as the magnetic force <u>needs to be applied in the direction of the coil's displacement</u>, which results in <u>work done</u> on the coil.

(c) The maximum e.m.f. is induced when there is a maximum rate of change of magnetic flux i.e. when it is transitioning from P to Q, where the gradient of the flux-time graph is the steepest.

By Faraday's Law,

$$
\begin{aligned}
\left|E_{\text{max}}\right| &= \left|-\frac{d\Phi}{dt}\right| \\
&= \left|-\frac{\left(-2.0\times10^{-5}\right)-\left(1.0\times10^{-5}\right)}{4.0-3.0}\right| \\
&= 3.0\times10^{-5}\ \text{V}
\end{aligned}
$$

Comments

(a) The most common conceptual mistakes include:

1. Not realising the magnetic flux should change sign when the coil moves from field P to field Q, which results in a magnetic flux graph that is all positive.
2. Drawing curved portions for the graph – the graph should consist only of straight lines, including when the magnetic flux is changing because the individual fields are all uniform.
3. Having the wrong time durations for the coil transitioning in and out of the fields.
4. Thinking that the area *A* in the magnetic flux formula *BA* is the total area of the field (9.0 cm^2) when it should be the area of the coil (1.0 cm^2).
5. Confusing magnetic flux (*BA*) with magnetic flux density (*B*) when labelling values on the vertical axis.

The most common careless mistakes include:

1. Drawing the induced e.m.f.-time graph instead.
2. Not drawing the magnetic flux graph for the full duration of the motion (from the moment it starts entering P to the moment it fully exits Q).
3. Not noticing that the vertical axis is in units of 10^{-5} Wb, and not Wb.
4. Not including values for (at least) the key points of the graph (e.g. maximum and minimum magnetic flux, the time for each turning point when the magnetic flux begins changing.)

(b) Most candidates were able to state Faraday's and Lenz's Law and apply them adequately to the context of the question. Most responses however failed at the last point, which is to adequately describe why work must be done by an external force to maintain the coil's constant velocity.

1. Many responses stop short of talking about work done, and instead only talked about the need for an external force to ensure zero net force.
2. Many responses jump straight to work done, without really describing the direction of the external force adequately and how that leads to work done (force times displacement).
3. Many responses had poor phrasing when using these scientific terms – this is something the A Levels are very particular about! The most common one is to assign work done to a direction (e.g. work must be done in the direction of the velocity). This is wrong because work done is a scalar quantity – it does not have a direction, unlike force or displacement which are vector quantities.

   This mistake is especially common for candidates who violated point 2 above – because they did not show a proper logical flow in their ideas. The proper flow should be:

   - Change in magnetic flux leads to e.m.f. induced (Faraday's Law).
   - E.m.f. leads to current in coil, which causes coil to experience a leftwards force.
   - Hence, <u>rightwards</u> external force (of equal magnitude) is needed.
   - This external <u>force acting in direction of displacement</u> leads to (positive) work done.

   However, candidates who jumped from Lenz's Law (second bullet point) to work done (fourth bullet point) without describing the direction of the external force separately (third bullet point) will end up with cumbersome and easily misinterpreted statements like "work done by an external force in the opposite direction of the induced force". Is the later description of the direction referring to the external force (correct) or the work done (wrong)? The A Levels have commented that our students do not use proper scientific terms and language adequately, so this point has been marked more strictly.

(c) Many of the weaker candidates seem to have forgotten the basic concept of Faraday's Law: since $\varepsilon = -\frac{d\Phi}{dt}$, the maximum e.m.f. induced must correspond to the steepest part of the gradient of the magnetic flux-time graph they have just drawn in part **(a)**! Instead, they attempt to apply formulas like BLv incorrectly and end up with the wrong method and answer.

Some candidates drew the wrong graph in **(a)**, but if they calculated the gradient of the steepest part of their graph correctly, they will be given credit as they showed understanding of the above key point. If they found the gradient of a point that is not the steepest, no credit is given.

A common careless mistake is, again, to forget that the vertical axis in units of 10^{-5} Wb, and not Wb. Hence, their e.m.f. values will be off by five orders of magnitude.

A common presentational mistake is to not properly show their working for how the gradient is calculated – this includes explicitly showing which two points on the graph were taken and substituted into $\frac{y_2 - y_1}{x_2 - x_1}$. One mark was deducted for poor working.

6 **(a)** The photoelectric effect is only observed when the frequency of the electromagnetic radiation incident on a particular metal is at least a minimum frequency. It does not depend on the intensity of the radiation. This is the threshold frequency and each metal has its own threshold frequency.

This can only be explained if electromagnetic radiation is made up of discrete quanta of energy known as photons.

The energy of each photon is hf, where h is the Planck constant and f is the frequency of the radiation.

An electron in the metal requires a minimum energy to leave the surface of the metal in the photoelectric effect. This minimum energy is the work function Φ of the metal.

The electron absorbs energy only from one photon in the particulate theory. Hence for photoemission to occur, the energy of each photon $hf \geq \Phi$. The minimum frequency $f = \Phi/h$ is the threshold frequency.

(b) **(i)** Solution 1

horizontal-intercept gives the threshold wavelength $\lambda_0 = 4.4 \times 10^{-7}$ m as $E_{max} = 0$

$$\Phi = \frac{hc}{\lambda_0}$$
$$= \frac{(6.63 \times 10^{-34})(3.00 \times 10^{8})}{4.4 \times 10^{-7}}$$
$$= 4.5205 \times 10^{-19} = 4.52 \times 10^{-19} \text{ J}$$

Solution 2

$$\frac{hc}{\lambda} = \Phi + E_{max}$$
$$E_{max}\lambda = (-\Phi)\lambda + hc$$

for the graph of $E_{max}\lambda$ against λ, gradient $= -\Phi$, vertical-intercept $= hc$

$$\text{gradient} = \frac{(1.10 - 0.10) \times 10^{-25}}{(2.0 - 4.2) \times 10^{-7}} = -4.5455 \times 10^{-19}$$
$$\Phi = -\text{gradient} = 4.5455 \times 10^{-19} = 4.55 \times 10^{-19} \text{ J}$$

(ii) **1.** for $\lambda = 2.0 \times 10^{-7}$ m, $E_{max}\lambda = 1.10 \times 10^{-25}$ J m

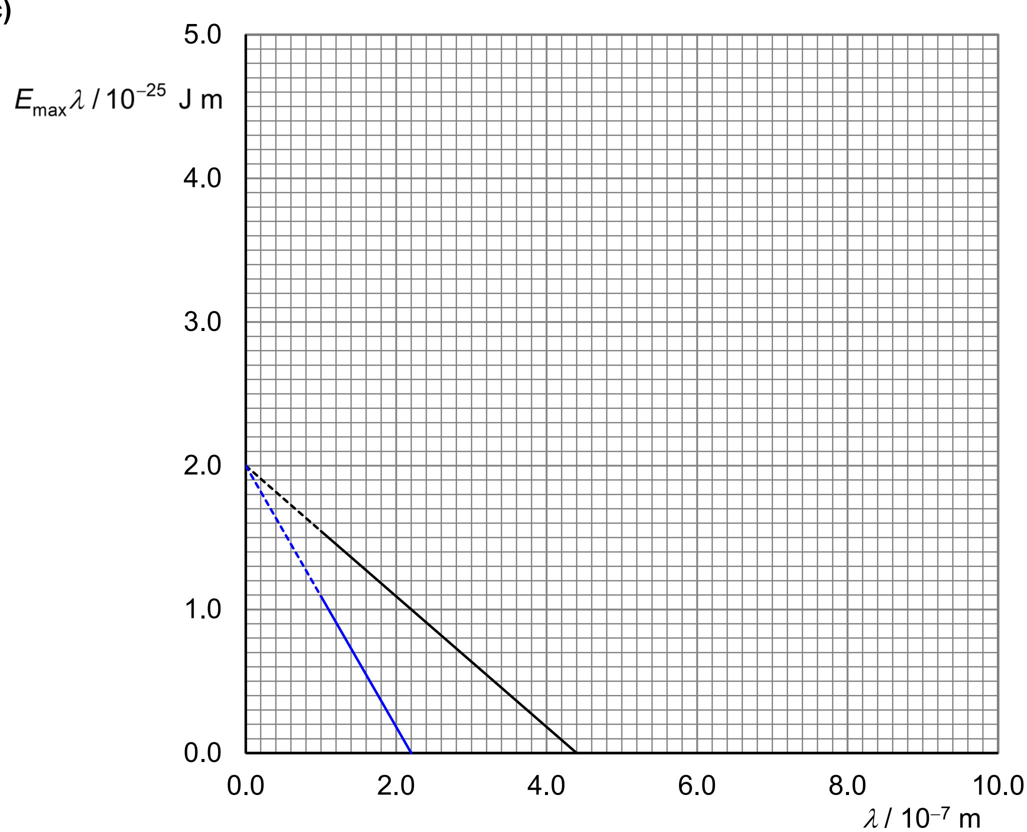
$$E_{max} = \frac{1.10 \times 10^{-25}}{2.0 \times 10^{-7}} = 5.5 \times 10^{-19} \text{ J}$$
$$eV_S = E_{max}$$
$$V_S = \frac{1.10 \times 10^{-25}}{(2.0 \times 10^{-7})(1.60 \times 10^{-19})}$$
$$= 3.4375 = 3.44 \text{ V}$$

2.

$$E = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{p^2}{2m}$$
$$p = \sqrt{2mE}$$

$$\lambda = \frac{h}{p}$$
$$= \frac{h}{\sqrt{2mE_{max}}}$$
$$= \frac{6.63\times10^{-34}}{\sqrt{2\left(9.11\times10^{-31}\right)\left(5.5\times10^{-19}\right)}}$$
$$= 6.6230\times10^{-10} = 6.62\times10^{-10}\text{ m}$$

(c)



*straight line graph with same vertical intercept
*twice the gradient, straight line cuts λ-axis at 2.2×10^{-7} m

Comments

(a) Many candidates focussed on explaining at length why the wave theory is wrong, describing lines about intensity instead of describing about how existence of threshold frequency prove the particulate nature of electromagnetic radiation. This is not answering the question, and gains no credit.

Some candidates described the "dependence of photon energy on frequency", but this is not clear. Being directly proportional, or simply $E = hf$, should be mentioned to describe how the energy of each photon depends on f.

The most elusive mark was the fact that each electron absorbs energy only from one photon during the interaction, which is a key feature of the photon theory, unlike wave theory in which electrons can take time to accumulate energy.

(Note: There is no need to mention scientists' names if you are unsure about who made the discoveries, though these mistakes were not penalised. Some candidates gave credit for photoelectric effect to Heisenberg or even Rutherford. It is worth noting that out of all the great discoveries that Einstein made, his Nobel Prize was awarded for the photoelectric effect.)

(b) **(i)** Generally well done. Some candidates carelessly missed out the factors of 10^{-25} and 10^{-7}, or read the horizontal intercept at 4.0×10^{-7} m instead of 4.4×10^{-7} m.

(ii) **1.** A significant number of candidates thought the vertical axis represents maximum kinetic energy when it is in fact multiplied by the wavelength too.

2. Weaker candidates used $E=\frac{hc}{\lambda}$ to find the de Broglie wavelength, when this formula applies to only photons! It was discovered before Quantum Physics that photons carry momentum $p=\frac{h}{\lambda}$. de Broglie's hypothesis (which was his PhD thesis) was that matter behaved in a similar manner, hence $\lambda=\frac{h}{p}$, but not in terms of energy, hence $E\neq\frac{hc}{\lambda}$.

A significant number of candidates used wavelength = 1.0×10^{-7} m when the question asked for 2.0×10^{-7} m.

Note that the question specifically asked for 2.0×10^{-7} m, so we will follow it. The meaning of "maximum kinetic energy" is **not** to find the shortest wavelength, but the fact that the emitted photoelectrons **have a range of kinetic energies** even though the energy of incident photons is the same. This is in fact what the E_{max} in the question is all about, and indeed the design of this question is to test this concept.

(c) Most candidates are able to see that the vertical-intercept, *hc* would remain the same, but many candidates could not get see that the horizontal intercept would be halved. Many careless responses had horizontal intercept at 2.0×10^{-7} m or at 2.4×10^{-7} m.

For such sketches, linearising the equation would be very helpful in determining how the intercept(s) and gradient would change. Candidates who showed such working in **(b)(i)1.** (using the gradient method) were able to deduce that the vertical intercept remains constant at *hc*, while the gradient is twice that of the given graph.

Paper 3 – Section B

7 **(a)** **(i)** For a fixed tension (or load) in the string, the speed of the transverse progressive wave on the string is constant.

For stationary wave to be seen, the length of the string must be integer multiples of half-wavelength of the wave.

Since the length of the string is fixed, this means that only certain wavelengths and hence frequencies will produce observable stationary waves.

(ii) Since length of string L must be integer multiples of half-wavelength,

$$L = n \times \tfrac{1}{2}\lambda_n = n \times \tfrac{1}{2} \cdot \frac{v}{f_n} \qquad (v = f\lambda)$$

where n, the number of segments, is an integer.
Rearranging,

$$f_n = n\frac{v}{2L} \text{ (shown)}$$

(iii) $n = 4$ for a stationary wave with 5 nodes

$$v = \frac{2Lf_n}{n} = \frac{2 \times 0.600 \times 40.0}{4} = 12.0 \text{ m s}^{-1}$$

(iv) $f_n \propto v \propto T^{1/2}$

Solution 1

$$\frac{f_n'}{f_n} = \sqrt{\frac{T'}{T}} = \sqrt{0.98}$$

$$f_n' = \sqrt{0.98} f_n = \sqrt{0.98} \times 40.0 = 39.598 = 39.6 \text{ Hz}$$

Solution 2
Since $f_n \propto v \propto T^{1/2}$,

$$\frac{\Delta f_n}{f_n} = \frac{1}{2}\frac{\Delta T}{T} = \frac{1}{2} \times (-0.02) = -0.01$$

$$\Delta f_n = -0.01 f_n = -0.01 \times 40.0 = -0.4 \text{ Hz}$$

New frequency

$$f_n' = f_n + \Delta f_n = 40.0 + (-0.4) = 39.6 \text{ Hz}$$

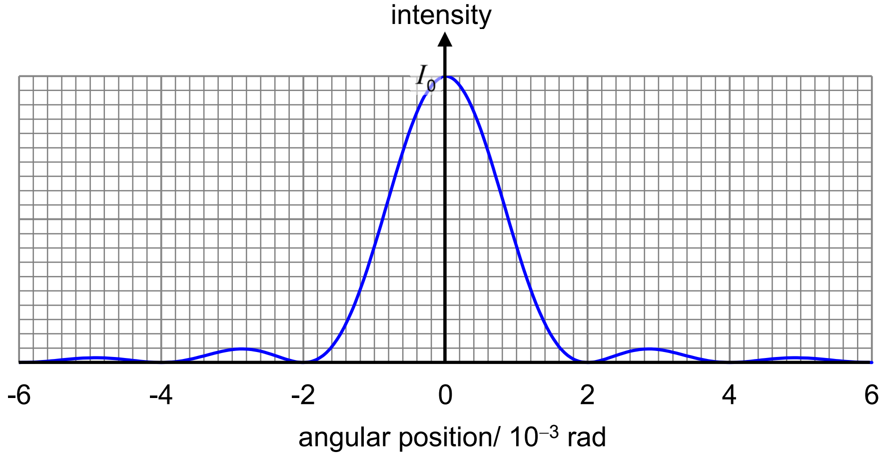
(b) **(i)** **1.** Using $b \sin\theta_m = m\lambda$ where $m = 1$

$$\theta_1 = \sin^{-1}\left(\frac{\lambda}{b}\right)$$

$$= \sin^{-1}\left(\frac{600 \times 10^{-9}}{0.30 \times 10^{-3}}\right)$$

$$= 2.0 \times 10^{-3} \text{ rad (shown)}$$

2.



*symmetrical about vertical axis
*width of central maximum ~ 2 x width of secondary maxima
*intensity of central maximum >> intensity of secondary maximum

3. For the two point sources to be just resolved,

$$\theta_1 = \theta_{\min} = 2.0 \times 10^{-3}$$

$$\frac{0.50}{D} = 2.0 \times 10^{-3}$$

$$D = \frac{0.50}{2.0 \times 10^{-3}} = 250 \text{ m}$$

The distance of the sources from the slit is 250 m.

(ii) **1.** Separation between 2 slits

$$a = 0.30 - 0.10 = 0.20 \text{ mm}$$

2. first minimum of single slit diffraction envelop:

$$\theta_1 = \sin^{-1}\left(\frac{\lambda}{b}\right) = \sin^{-1}\left(\frac{600 \times 10^{-9}}{0.10 \times 10^{-3}}\right) = 6.0 \times 10^{-3} \text{ rad}$$

single slit minima: $b \sin\theta_m = m\lambda$ --- (1)
double slit maxima: $a \sin\theta_n = n\lambda$ --- (2)
for $\theta_m = \theta_n$, $\frac{(1)}{(2)}$: $\frac{b}{a} = \frac{m}{n}$

missing orders of maxima of double slit interference pattern
$n = m\frac{a}{b} = m\frac{0.20}{0.10} = 2m$

An interference pattern is observed with <u>maxima occurring at intervals</u> of <u>3.0×10^{-3} rad</u>.

The pattern is modulated by a diffraction envelop with <u>minima occurring at intervals</u> of <u>6.0×10^{-3} rad</u>.

<u>Even orders of interference maxima are missing</u>.

3. Before applying the film, assume that the amplitude of the light at the central maximum is A_0, then $I_0 = kA_0^2$.

Amplitude at the central maximum due to each slit is now $A_0/3$.
(1/3 the number of original waves arrive at the central maximum)

Amplitude at central maximum due to both slits is $2A_0/3$.
(superposition of waves from each slit)

intensity of central maximum

$$I = k\left(\frac{2A_0}{3}\right)^2 = \frac{4}{9}\cdot kA_0^2 = \frac{4}{9}\cdot I_0$$

Comments

(a) (i) Many irrelevant answers such as why and how stationary wave was formed on the string were given. For qualitative questions, especially those with many marks, plan your points and ensure each point is relevant to answering the question and the points flow logically, before writing out in continuous prose.

This question is the same as example 2 of superposition notes or D2 in tutorial and yet students failed to understand what is required of the question.

(ii) Candidate should recognise that the length of the string must be multiple integer of half-wavelength.

Solutions quoting the first two or three mode of vibrations were accepted but may be penalised if more mark was allocated.

(iii) Clearly there were candidates who were unsure what 5 nodes meant. A number of candidates erroneously used $n = 5$ when calculating speed.

(iv) A decrease of 2% does not mean $1-\sqrt{0.02}$.

(b) (i) 1. Mark was not awarded for candidates using $\theta = \frac{\lambda}{b}$ unless they have shown an understanding that $\sin\theta \approx \theta$ prior to their proofs.

2. A number of candidates did not make use of the answer to **(b)(i)1.** Clearly the minima of the diffraction pattern are multiples of 2.0×10^{-3} rad, i.e., 2.0×10^{-3} rad, 4.0×10^{-3} rad and 6.0×10^{-3} rad.

Also the intensities of the secondary maxima should be much lower than the central maxima.

Last but not least, the intensity curve should not have any sharp turning point.

3. Quite a number of candidates did not relate the angular separation of the light sources to the Rayleigh criterion although most are able to calculate the distance of the sources from the slit.

(ii) **1.** Many candidates did not understand the meaning of slit separation. It is the distance between the centres of the two slits.
It is incredulous to see 0.10 mm as the answer as that is already the width of the opaque film. Even the diagram clearly showed that the slit separation is already greater than 0.10 mm.

2. Many students were unable to perform the required calculations and most did not understand the difference between **(b)(i)** and **(b)(ii)**. **(b)(i)** is just diffraction while **(b)(ii)** is interference with diffraction envelope.

Many answers simply regurgitated similar sounding answers from their tutorial without any calculations to support their arguments in the hope that they are lucky to strike the correct answers.

3. Only a few candidates understood how the maximum intensity can be found. Amongst these, some did not explain it clearly and lost a mark.

Most other candidates merely took their chances and made some guesses without understanding what they were doing.

8 **(a)** The number *238* refers to the <u>number of nucleons in the nucleus</u> or <u>number of protons and neutrons in the nucleus</u>.

(b)

$$^{238}_{\boxed{92}}\mathrm{U} \rightarrow {}^{\boxed{234}}_{90}\mathrm{Th} + {}^{4}_{\boxed{2}}\mathrm{He}$$

(c) **(i)**

$$\begin{aligned} \text{kinetic energy} &= 40.0 \times \left(5.90 \times 10^{3}\right)\left(2.70 \times 10^{-18}\right) \\ &= 6.372 \times 10^{-13} \\ &= 6.37 \times 10^{-13} \text{ J (shown)} \end{aligned}$$

(ii)

kinetic energy, $E_k = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{p^2}{2m}$

Since uranium nucleus was initially at rest, by the principle of conservation of momentum,

$$\begin{aligned} p_{Th} + p_{\alpha} &= 0 \\ p_{Th} &= -p_{\alpha} \\ &= -\sqrt{2m_{\alpha}E_{\alpha}} \\ &= -\sqrt{2 \times \left(4 \times 1.66 \times 10^{-27}\right)\left(6.37 \times 10^{-13}\right)} \\ &= -9.1975 \times 10^{-20} = -9.20 \times 10^{-20} \text{ Ns} \end{aligned}$$

(iii)

$$E_{k,Th} = \frac{{p_{Th}}^2}{2m_{Th}} = \frac{\left(9.20 \times 10^{-20}\right)^2}{2\left(234 \times 1.66 \times 10^{-27}\right)} = 1.0895 \times 10^{-14} = 1.09 \times 10^{-14} \text{ J}$$

$$\begin{aligned} E_{k,\text{Total}} &= E_{k,Th} + E_{k,\alpha} \\ &= \left(1.09 \times 10^{-14}\right) + \left(6.37 \times 10^{-13}\right) \\ &= 6.479 \times 10^{-13} \text{ J} \\ &= \frac{6.479 \times 10^{-13}}{\left(10^{6}\right)\left(1.60 \times 10^{-19}\right)} \text{ MeV} \\ &= 4.0494 = 4.05 \text{ MeV} \end{aligned}$$

(iv) No other particles or photons were emitted during the decay.

(d) **(i)** Nuclear binding energy is the energy equivalent of the mass defect of a nucleus. It is the energy required to separate to infinity all the nucleons of a nucleus.

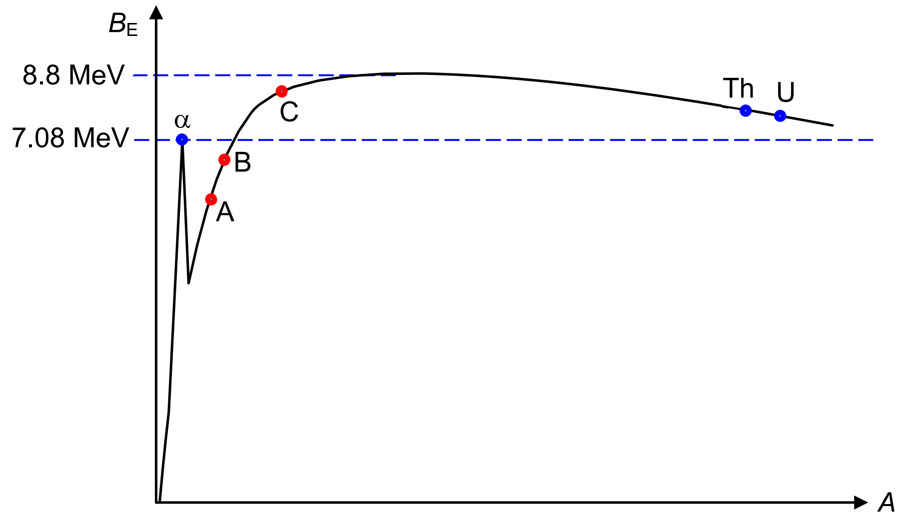
(ii) Possible nuclides: iron-56 (^{56}Fe), iron-58 (^{58}Fe), nickel-62 (^{62}Ni)

$B_E = 8.8$ MeV

(iii)

$$\begin{aligned} \Delta E = E_{k,\text{Total}} &= BE_{Th} + BE_{\alpha} - BE_{U} \\ 4.05 &= BE_{Th} + (4 \times 7.08) - (238 \times 7.57) \\ BE_{Th} &= 1777.39 \text{ MeV} \\ \frac{BE_{Th}}{A_{Th}} &= \frac{1777.39}{234} \\ &= 7.5957 = 7.60 \text{ MeV} \end{aligned}$$

(iv)



On the left part of curve, <u>He or α-particle on the sharp peak</u>.

On the right part of curve, U (7.57 MeV) above α (7.08 MeV), and <u>Th (7.60 MeV) just above U and just to its left</u>.

(v) **1.** Nuclear fusion occurs when two light nuclei combine to form a nucleus of greater mass.

2. All A, B and C on the left of the highest B_E point.
Nuclei A and B lighter than or on the left of C, but B_E of C is higher than both nuclei A and B.

Comments

(a) Some wrongly referred to 238 as the atomic number.

(b) Only two students who attempted this question got this wrong.

(c) **(i)** Candidates must learn to write proper statements and/or formulae before substituting numerical values in the correct units. In "*show*" questions, students <u>must show the intermediate value with more s.f.</u> before stating it to the correct s.f.

(ii) Some candidates used m_p instead of u in calculations of masses of nuclei.

(iii) Many wrong conversions and formulae were seen in this part due to carelessness or the lack of effort in deriving / memorising the correct equation.

(iv) All other answers were rejected.

(d) **(i)** Many candidates lost this mark when they neglected the first part of the answer or the idea of "separate to infinity". Although nuclear binding energy is numerically equal to the energy released when the nucleons combined to form the nucleus, this is not the definition.

(ii) Many candidates wrongly quoted uranium as they thought that B_E refers to binding energy when it means binding energy per nucleon, as stated in **(d)**. It is important to know these data in order draw the B_E-A curve correctly.

(iii) A large number of candidates were unable to derive or quote the equation correctly – they either neglected the kinetic energies of the products or swapped the binding energies of the products and reactants.

(iv) Th and U are near the end of the curve – the mark for Th and U is not awarded if they were drawn too far away from that end.

(v) **1.** Nuclear fusion need not release energy – this can happen when the product has a lower binding energy per nucleon that the original nuclei.

The use of “parent” nuclei to form “daughter” nucleus and vice-versa were rejected (the terms “parent” and “daughter” are used for radioactive decay). Since the question asked to explain the term “fusion”, answers containing “fusion” or “fuse” were rejected.

Note that “nucleus” is singular and “nuclei” is plural. Avoid using the term “nuclide” as it does not refer to the physical nucleus.

2. Note that the peak on the left refers to ${}^{4}_{2}\text{He}$ – the only nuclei to the left of the peak are ${}^{1}_{1}\text{H},\ {}^{2}_{1}\text{H},\ {}^{3}_{1}\text{H},\ {}^{2}_{2}\text{He},\ {}^{3}_{2}\text{He}$.

If the He-4 peak is chosen as C, the only combination for A and B are (i) ${}^{1}_{1}\text{H}$ (on the A – axis) and ${}^{3}_{1}\text{H}$, or (ii) ${}^{2}_{2}\text{He}$ and ${}^{2}_{2}\text{He}$ (both on same spot).