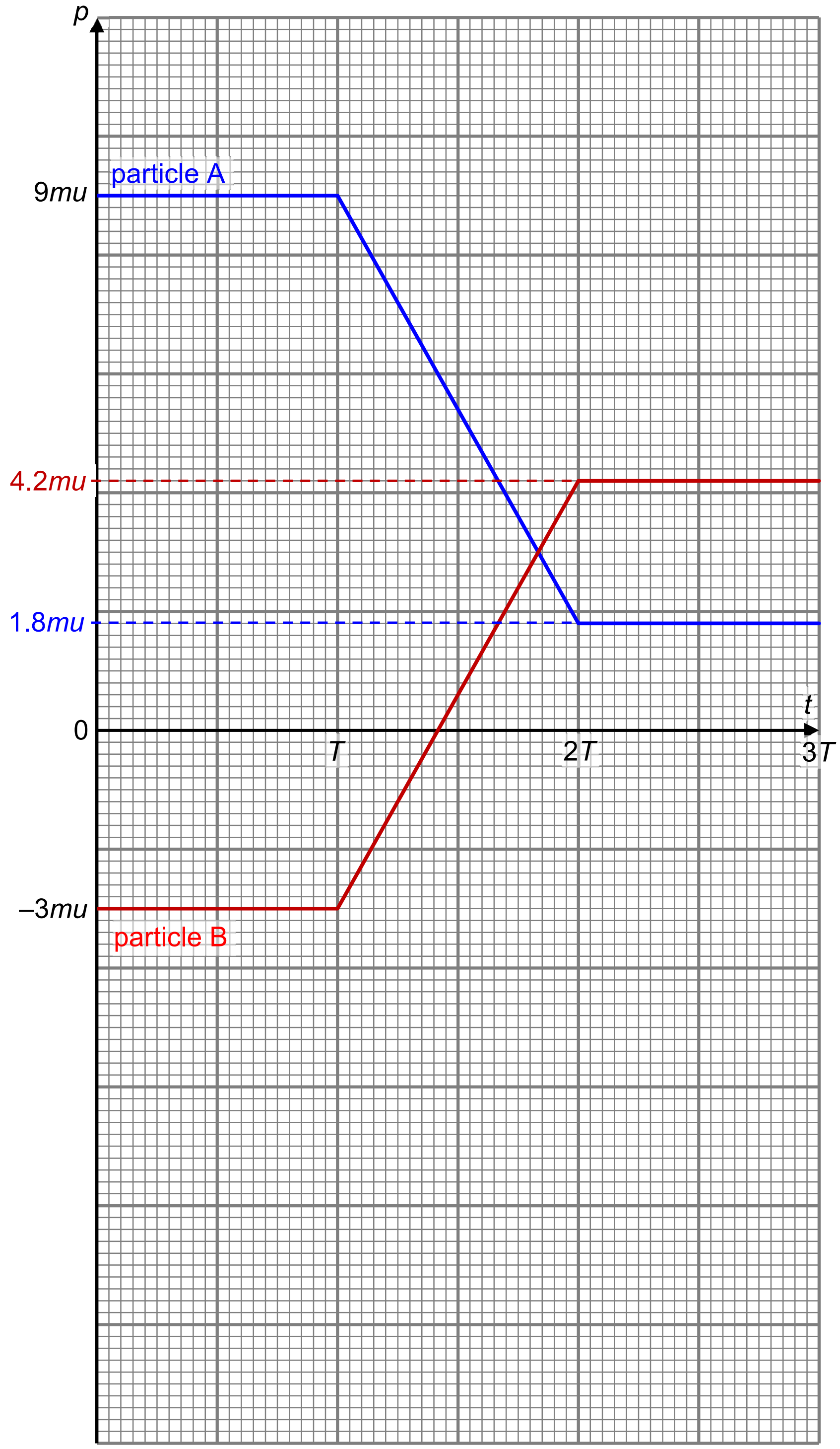
2022 H2 Physics Preliminary Examination Solution

Paper 2

1 (a) (i)



(ii) As there are no **resultant** external forces acting in the horizontal direction on the system of particles A and B, total momentum of the system is conserved in the horizontal direction by the principle of conservation of momentum.

Since the momentum of particle A decreases by 7.2*mu* (36 small squares) after the collision, the momentum of particle B should increase by 7.2*mu* (36 small squares) so that the total momentum remains constant at all times.
OR
Since the momentum before the collision is 6.0*mu*, the total momentum of the system remains constant at 6.0*mu* at all times.

(b) Solution 1

relative speed of approach $= u_A - u_B = u - (-3u) = 4u$

relative speed of separation $= v_B - v_A = 4.2u - 0.2u = 4u$

Since the relative speed of approach and the relative speed of separation are equal, the collision is elastic.

Solution 2

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

before collision:

$$E_{k,before} = \frac{{p_{A,before}}^2}{2m_A} + \frac{{p_{B,before}}^2}{2m_B} = \frac{(9mu)^2}{2(9m)} + \frac{(-3mu)^2}{2m} = 9mu^2$$

after collision:

$$E_{k,after} = \frac{{p_{A,after}}^2}{2m_A} + \frac{{p_{B,after}}^2}{2m_B} = \frac{(1.8mu)^2}{2(9m)} + \frac{(4.2mu)^2}{2m} = 9mu^2$$

Since the kinetic energy of the system before and after the collision remains the same, the collision is elastic.

(c) By Newton's second law, **resultant** force $F_R = \frac{dp}{dt}$, which is given by the gradient of the graph in Fig. 1.1.

During collision, from $t = T$ to $t = 2T$, the gradient of the graph for particle A is $-\frac{7.2mu}{T}$. The gradient of the graph for particle B is $\frac{7.2mu}{T}$.

Hence the horizontal resultant force on particle A, which is the force on A by B has magnitude $\frac{7.2mu}{T}$ and the horizontal resultant force on particle B, which is the force on B by A also has the same magnitude of $\frac{7.2mu}{T}$.

Since the gradients have opposite signs, this imply that the two forces are opposite in direction.

This is consistent with Newton's third law as the force on A by B and the force on B by A are equal in magnitude and opposite in direction.

Comments

(a) **(i)** Generally well done. The most careless mistake made was to read the vertical axis values wrongly and either draw 4.2*mu* at the wrong position (e.g. small squares above 4.0*mu*) or draw it at the right position, but quote the value of 4.1*mu* instead. Please note that each small square is equivalent to 0.2*mu* on the vertical axis.

(ii) Weak responses failed to include the condition for momentum conservation, which is that there must be **no resultant external forces** on the system. Weak candidates tend to forget either the entire condition, or leave out the word "resultant", which is key – in this case, there could be external forces on the system (e.g. weight, normal contact force) but since these forces cancel out, the resultant external force is therefore zero. Hence, total momentum of the system is conserved.

Other weak responses did not include sufficient details about how the graphs were drawn by including relevant values (e.g. 6.0*mu*, increase/decrease by 7.2*mu*).

(b) Generally well done. Most mistakes were careless mistakes, which mostly involved:

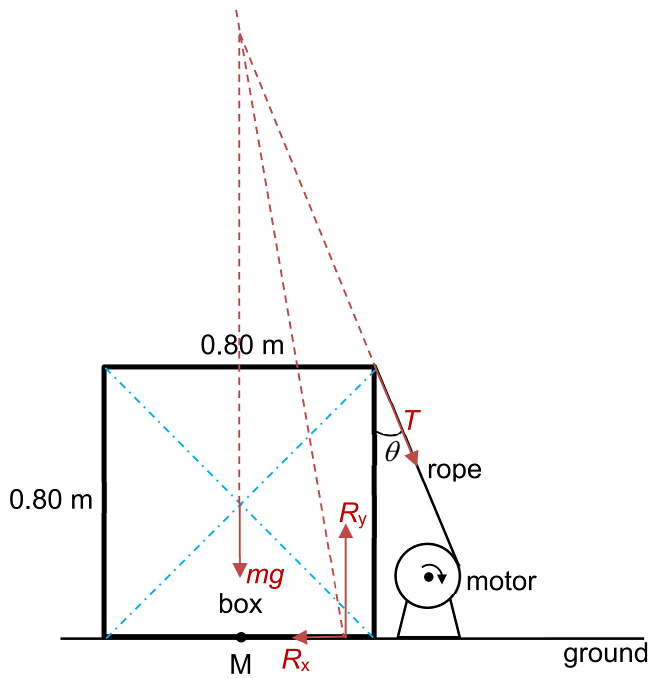
1. Using the wrong mass / speed values (e.g. stating particle B has mass 3*m* instead of *m*, or it has initial speed *u* instead of 3*u*)
2. Confusing momentum for velocity (e.g. stating particle A's initial kinetic energy is $\frac{1}{2}(9m)(9mu)^2$ instead of $\frac{1}{2}(9m)u^2$)
3. Using the kinetic energy formula $\frac{p^2}{2m}$ incorrectly (e.g. stating particle A's initial kinetic energy is $\frac{(9mu)^2}{2m}$ instead of $\frac{(9mu)^2}{2(9m)}$)

Some candidates were also unable to correctly state the reasoning for why it is an elastic collision, especially with equating **the relative speed of approach with the relative speed of separation**.

(c) Many candidates lost the first mark because of an improper definition of what $\frac{dp}{dt}$ or the gradient of the momentum-time graph meant – it refers to the **resultant** force on the particle, not just the force. This was marked particularly strictly as it was a specific weak point identified amongst our candidates in the 2021 A-Level Physics Examinations.

Since the question asked for how the **graphs** demonstrated Newton's Third Law, candidates are expected to go into sufficient detail about what aspects of the graph demonstrate the Law. For example, including the expression $\frac{7.2mu}{T}$ for the gradients of the graphs during the collision is expected, in order to compare their equal magnitudes. Similarly, when referring to the forces being opposite in direction, candidates should specifically pinpoint that it is the opposite signs of the gradient of the graph that demonstrate this fact. Weak responses attempted at the above, but no credit was given to responses that did not show enough detail.

2



(a) Since the wheel is in rotational equilibrium,

$Tr = \tau$

$T = \frac{\tau}{r} = \frac{5.0}{0.20} = 25$ N

(b) Since the box is in equilibrium,

horizontally, (not required to answer this part)

$T_x - R_x = 0$

$R_x = T\sin 20°$

vertically,

$R_y - T_y - mg = 0$

$R_y = T\cos 20° + mg$

By the principle of moments, taking moments about point M,

$$R_y d = T_x h + T_y\left(\frac{h}{2}\right)$$

$$d = \frac{h}{R_y}\left(T_x + \frac{1}{2}T_y\right)$$

$$= \frac{0.80}{T\cos 20° + mg}\left(T\sin 20° + \frac{T\cos 20°}{2}\right)$$

$$= \frac{0.80T}{T\cos 20° + mg}\left(\sin 20° + 0.5\cos 20°\right)$$

$$= \frac{0.80(25)}{25\cos 20° + 2.0(9.81)}\left(\sin 20° + 0.5\cos 20°\right)$$

$$= 0.3766 = 0.377 \text{ m}$$

(c) Solution 1

As θ increases, the increased clockwise moment about point M due to the tension exceeds the maximum anticlockwise moment possible due to the normal contact force when the normal contact force is at the corner ($d = 0.40$ m) of the box. The box will rotate clockwise about the bottom right corner.

Solution 2

As θ increases, *d* increases to balance the increasing moment due to the tension and if $d > 0.40$ m, this implies that the contact force needs to act outside the box for the box to be in equilibrium. Since it is not possible for the contact force to act outside the box, there is a maximum value for θ .

Solution 3

As θ increases, the horizontal component of the tension in the rope increases. If the horizontal component exceeds the maximum friction on the box by the ground, the box will slide.

Comments

(a) Most candidates are able to arrive at the correct answer. Some thought that it is equal to the weight, while some others incorrectly included a cos 20° here.

(b) Poorly attempted.

Many candidates used weight to calculate moments, but since M is the mid-point of the base of the uniform square box, the weight of the box does not cause any moment about point M.

Many candidates used either one the horizontal or the vertical component of *T* to form the equation using Principle of Moments, neglected the fact that both components of *T* cause clockwise moments about M.

Some candidates tried to find the perpendicular distance from M to the rope, but only few managed to correctly solve using this method due to incorrect calculations of this distance.

(c) Decently attempted.

Weak responses mainly did not explain why equilibrium is not maintained beyond the angle (some even merely paraphrased the question), or were not specific about the direction of moments in their explanation.

Some candidates also mentioned that the rope will break beyond the maximum angle, but that is not answering the question about equilibrium.

3 **(a)** $\omega = \dfrac{v}{r} = \dfrac{0.240}{0.080} = 3.0 \text{ rad s}^{-1}$

(b) **(i)** Consider vertical equilibrium of the bob,

$T\cos\theta = mg$

$$T = \frac{mg}{\cos\theta} = \frac{1.5 \times 9.81}{\cos 30^\circ} = 16.991 = 17.0 \text{ N}$$

(ii) The horizontal component of tension provides the centripetal force for the bob's horizontal circular motion.

$$T\sin\theta = m\omega^2 R$$
$$T\sin\theta = m\omega^2\left(d + L\sin\theta\right)$$
$$d = \left(\frac{T}{m\omega^2} - L\right)\sin\theta = \left(\frac{16.991}{1.5 \times 3.0^2} - 0.250\right)\sin 30^\circ = 0.5043 = 0.504 \text{ m}$$

(c) The <u>weight</u> of the bob is always <u>acting vertically downwards</u>. Hence the <u>tension in the string needs to have an upward vertical component</u> to keep it in <u>vertical equilibrium</u>. So the string cannot be horizontal and θ must be smaller than 90°.

The statement is <u>valid</u>.

Comments

(a) This part is meant to be straightforward but some candidates preferred the tedious way by first determining period from $T = \dfrac{2\pi r}{v}$ and then calculating angular velocity from $\omega = \dfrac{2\pi}{T}$ rather than just using $\omega = \dfrac{v}{r}$.

(b) **(i)** Some candidates resolved forces wrongly and stated vertical equilibrium of forces as $T = mg\cos\theta$ or $T\sin\theta = mg$. These are fundamental errors which should have been avoided.

Some candidates tried solving this by resolving forces horizontally which is not possible as there are two unknowns (*d* and *T*).

(ii) Many candidates made a careless computational error here. They failed to square the value of ω when substituting values into the equation $T\sin\theta = m\omega^2\left(d + L\sin\theta\right)$.

Another common mistake here is failure to convert the value of *v* from cm s^{-1} to m s^{-1} for those who used $T\sin\theta = \dfrac{mv^2}{(d + L\sin\theta)}$.

(c) Many candidates' answers lacked precision and displayed failure to realise that the gist of the answer lies in the vertical equilibrium of the bob as it moves in a horizontal circle. This is because if $\theta = 90°$, then the string-bob system would be horizontal implying that tension would not have an upward vertical component to balance the downward weight of the bob and therefore impossible to achieve. Hence $\theta < 90°$.

Many candidates failed to specify that tension must have a vertical, upward component. They simply wrote "vertical component of tension" or simply "component of tension" without specifying the direction, which is not sufficiently precise to deserve credit.

In addition, many candidates did not explain that due to the downward weight and upward, vertical component of tension being equal in magitdue and opposite in direction, the bob is able to attain vertical equilibrium and not just equilibrium because horizontally, the bob is indeed experiencing centripetal acceleration.

Some other erroneously perplexing answers are "weight provides the vertical component of tension" which is nonsensical and "when the upward vertical component of tension cancels weight, the bob becomes stationary" which is a fundamental misconception. The bob cannot be stationary as it is moving in a circle!

4 **(a)** The gravitational force due to a mass is always attractive. Hence, the external force required to bring a small test mass from infinity to a point in the gravitational field of the mass always acts in the opposite direction to the displacement of the small test mass. The work done per unit mass by the external force is thus negative and gravitational potential is always negative.

The electric force due to a negative or positive source charge on a small positive test charge is attractive or repulsive respectively.

For a negative source charge, the external force required to bring the small (positive) test charge from infinity to a point in the electric field acts in the opposite direction to the displacement of the small test charge. The work done per unit positive charge by the external force is thus negative and electric potential is negative.

For a positive source charge, the external force required to bring the small (positive) test charge from infinity to a point in the electric field acts in the same direction as the displacement of the small test charge. The work done per unit positive charge by the external force is thus positive and electric potential is positive.

(b) **(i)** **1.** The gravitational force on the moon by the planet provides the centripetal force.

$$\frac{GMm}{r^2} = \frac{mv^2}{r}$$

$$v = \sqrt{\frac{GM}{r}} = \sqrt{-\phi} \qquad \text{since } \phi = -\frac{GM}{r}$$

when $r = 1.07 \times 10^6$ km $= 10.7 \times 10^8$ m, $\phi = -1.2 \times 10^8$ J kg^{-1}

$$v = \sqrt{-\phi}$$
$$= \sqrt{-(-1.2 \times 10^8)}$$
$$= 10954 = 1.10 \times 10^4 \text{ ms}^{-1}$$

2. total energy $= E_p + E_k$

$$= m\phi + \frac{1}{2}mv^2$$

$$= m\phi - \frac{1}{2}m\phi$$

$$= \frac{1}{2}m\phi$$

$$= \frac{1}{2}(1.48\times10^{23})(-1.2\times10^{8})$$

$$= -8.88\times10^{30}\text{ J}$$

(ii) **1.** at the surface of the planet: $r = 0.7\times10^{8}$ m, $\phi_i = -18.1\times10^{8}$ J kg^{-1}

when the K.E. of the rock is zero, by conservation of energy,

$$E_i = E_f$$

$$m\phi_i + \frac{1}{2}mv^2 = 0 + m\phi_f$$

$$\phi_f = \phi_i + \frac{1}{2}v^2$$

$$= (-18.1\times10^{8}) + \frac{1}{2}(45\times10^{3})^2$$

$$= -7.975\times10^{8} = -7.98\times10^{8}\text{ J kg}^{-1}$$

Since the <u>gravitational potential</u> of the rock is <u>negative when its kinetic energy is zero</u>, the rock cannot reach infinity to escape.

2. From Fig 4.1, when $\phi_f = -7.98\times10^{8}$ J kg^{-1}, $r = 1.6\times10^{8}$ m

max. distance from surface $= (1.6-0.7)\times10^{8} = 9.0\times10^{7}$ m

Comments

(a) Candidates need to pay careful attention to the keywords/phrases and important concepts that is necessary in the explanation.

Some common mistakes that were penalised.

- stated to the effect that work done by an external force is opposite to displacement. This is incorrect as work is a scalar quantity. It should be, the external force acts in a direction opposite to displacement.
- not stating “per unit mass” or “per unit positive charge” for gravitational potential and electric potential respectively. Do note that saying “a unit mass” or “ a unit positive charge” is NOT its equivalence.
- neglecting to mention that the work done per unit mass/per unit positive charge in the context of gravitational/electric potential is strictly work done by an external force. In the case of work done, the force that does the work has to be clearly specified.
- misconception that the test charge in the definition of electric potential can be negative or positive. The test charge is a positive test charge.

(b) (i) 1. Candidates need to pay careful attention when reading the question. Quite a number of candidates read off the potential of the moon or determined the gravitational field strength by drawing a tangent at $r = 1.07 \times 10^8$ m .

A significant handful of candidates were not able to construct accurate tangent when determining the gravitational field strength from the graph provided. Full credit will not be awarded. Please review the practical skill required in tangent drawing.

2. This question was generally well done.

Candidates need to be aware that the total energy equation of an orbiting satellite cannot be used without derivation. This is the same for its kinetic energy. The necessary physics concepts must be shown in the process of derivation.

(ii) 1. Candidates need to pay attention to the demand of the question. This is a show question with an added emphasis on clear working; students need to be mindful of presenting clear physics concepts with appropriate substitution without skipping steps. Candidates will not be awarded full credit if details are missing.

This question has several potential approaches that requires the principle of conservation of energy.

The principle of conservation of energy was poorly stated for the question.

For conservation of energy, we should either equate

- total initial energy = total final energy
  (stating the different forms of initial and final energy specifically)
  OR
- increase in the different forms of energy = decrease in the different forms of energy
  (the different forms of enegies need to be stated clearly)

Candidates should never equate one energy to another i.e. KE = GPE.

Note too that using 'change in energy (represented by ΔE)' strictly refers to the 'final energy – initial energy', which can result in a positive or negative value. If the final energy is more than the initial energy, the change in energy is a positive value (i.e. increase in energy). If the final energy is less than the initial energy, the change in energy is a negative value (i.e. decrease in energy).

However, when we state 'increase / decrease in energy', this value is a positive value (i.e. increase in energy = final energy – initial energy and decrease in energy = initial energy – final energy).

In the context of deriving escape speed, it is important to show understanding that both final KE and final GPE are zero. Variants of $\text{KE} = \text{GPE}$ or $\text{KE} \geq \text{GPE}$ for the rock to escape are considered unclear working.

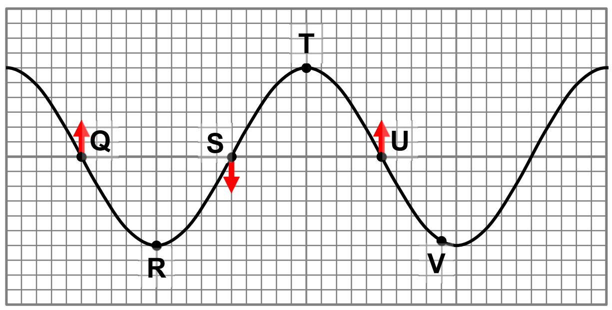
No credit is given to candidates who use the escape speed equation without derivation.

2. This question was surprisingly poorly done. The two common mistakes were:

1. Did not subtract the radius of the planet as the question asked for the maximum distance from the surface of the planet.
2. A consequence of a poorly stated conservation of energy where the final GPE of the rock was calculated using $\text{KE} = \text{GPE}$ after substituting $v = 45\ \text{km s}^{-1}$.
   The above equation is incorrect and the correct form should be:

$$\text{decrease in KE} = \text{increase in GPE}$$
$$\text{KE}_{\text{inital}} - 0 = \text{GPE}_{\text{final}} - \text{GPE}_{\text{initial}}$$
$$\text{KE}_{\text{inital}} = \text{GPE}_{\text{final}} - \text{GPE}_{\text{initial}}$$

5 **(a)**



(b) Particles R and T are <u>momentarily at rest</u>.

(c) **(i)** in phase: any pair of points a wavelength apart

(ii) In antiphase: any pair of points half-wavelength apart

(d) Particle U leads particle V by a phase of

$$\frac{\Delta x}{\lambda} \times 2\pi = \frac{4\ \text{small squares}}{20\ \text{small squares}} \times 2\pi = 0.4\pi\ \text{rad}$$

Therefore, V leads U by a phase of $\phi = 2\pi - 0.4\pi = 5.0265 = 5.03$ rad

Comments

(a) Most candidates were able to answer this correctly. Some candidates indicated the velocity vectors for R and T are incorrect as R and T are instantaneously at rest.

(b) Most candidates are able to identify that R and T are at rest. However, candidates who merely mentioned that R and T are antiphase or moving in simple harmonic motion are not awarded the mark because the question specifically want the state of the particles at this instant of time, rather than at all times.

(c) It pays to read the question clearly as the answer must exclude the points Q, R, S, T and U.

(d) This question was poorly done. Only 1 student managed to answer this correctly. Most candidates are able to determine the phase difference (U leading V) between U and V but failed to understand the concept of "V leading U".

6 **(a)** **(i)**

$$P = \frac{V^2}{R}$$

$$R = \frac{V^2}{P} = \frac{(6.0)^2}{3.0} = 12\ \Omega$$

(ii)

$$R = \frac{\rho L}{A}$$

$$\rho = \frac{RA}{L}$$

$$= \frac{(12)\left(\pi \times \left(\frac{78 \times 10^{-6}}{2}\right)^2\right)}{0.020}$$

$$= 2.8670 \times 10^{-6} = 2.87 \times 10^{-6}\ \Omega\ \text{m}$$

(iii) The value of the resistivity calculated in (a)(ii) is about 50 times that stated in the table of constants.

The table of constants states the resistivity of tungsten at room temperature whereas the resistivity value in (a)(i) is the resistivity at a much higher temperature when the light bulb is in use.

When temperature increases, the lattice ions in tungsten gain thermal energy and vibrate with larger amplitudes. This increases the collisions between the free electrons and the lattice ions which hinder the movement of the electrons. Hence, resistivity increases with increasing temperature.

(b) **(i)**

p.d. across Y, $V_Y = \left(\dfrac{\frac{R}{2}}{\frac{R}{2} + \frac{R}{4}}\right)(6.0) = 4.0\ \text{V}$

current through Y, $I_Y = \dfrac{V_Y}{R} = \dfrac{4.0}{12}\ \text{A}$

$$Q = I_Y t$$

$$= \left(\frac{4.0}{12}\right)(2 \times 60)$$

$$= 40\ \text{C}$$

(ii) Consider $I = Anvq = Anev$.

Since both filaments are identical, Ane is constant. Hence the current I through the filament is directly proportional to the mean drift velocity v of the electrons in the filament i.e. $I \propto v$.

The current through Y is twice the current through Z as the potential difference across Y is twice the potential difference across Z (OR the total current flowing through 2 bulbs and 4 bulbs in parallel are equal).

Therefore, the mean drift velocity of the electrons in Y is twice that of the electrons in Z.

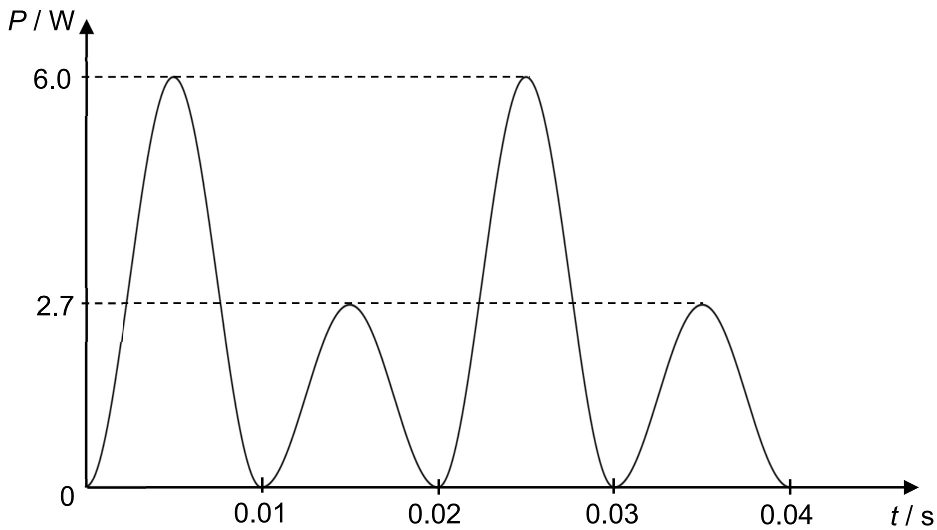
(c) **Diode in forward bias** *(current flows through the parallel arrangement of 2 bulbs on the left, and only through the diode on the right)* :

$V_Y = 6.0$ V , peak power in $\text{Y} = 2(3.0) = 6.0$ W

Diode in reverse bias *(current flows through the parallel arrangement of 4 bulbs on the right, and the parallel arrangement of 2 bulbs on the left)* :

$V_Y = 4.0$ V , peak power in $\text{Y} = 2\left(\dfrac{4.0^2}{12}\right) = 2.6667 = 2.7$ W

$T = \dfrac{1}{f} = \dfrac{1}{50} = 0.02$ s



Comments

(a) **(i)** As expected, this part was well done. But please show clear substitution of values.

(ii) Mostly well done, except for a few careless mistakes. There were also several candidaites who did not know that the prefix "μm" means "$\times 10^{-6}$"!

(iii)
- This question asked for comparison between the 2 values of resistivity. Many answers only stated that the calculated value is larger than the value from the table, and that the tungsten filament in **(a)(ii)** was hot. A proper comparison should state that the filament in **(a)(ii)** was at a higher temperature as it was in use, while the value in the table of constants gives the filament at room temperature (or when it is not in use).

- Instead of using 'lattice ions' , many answers stated 'tungsten atoms', 'particles', 'molecules'. These were given BOD, but please note that they are not entirely correct.

- Simply mentioning that the "*temperature increase leads to increased frequency of collisions between lattice ions and electrons*" is not sufficient. It should be mentioned that the lattice ions vibrate at "*larger amplitudes*", leading to the increased frequency of collision.

- It is incorrect to state that the increase in temperature increases the "collisions between the electrons", or increases the "collisions between the atoms". The collisions are "between the lattice ions/lattice structure and the electrons".

(b) (i) This part was surprisingly not so well done. Many candidates found the correct value of the current in the circuit, but did not divide this by 2 to find the current in the bulb Y.

(ii)
- When possible, answers should state specific numerical values. In this question, it was not difficult to deduce that the current in Y is twice that in Z, and hence conclude that the drift velocity in Y is twice of Z. Many answers simply stated that the drift velocity in Y is larger.

- The relationship between current and drift velocity should also be clearly explained. The equation $I = Anvq = Anev$ can be found in the formula sheet, but students must state clearly that *A*, *n* and *e* are constant before they can conclude that $I \propto v$.

- Some candidates do not understand what '*n*' in the equation means. Some stated that *n* is the total number of electrons in the wire while others stated that it is the number of moles of electrons in the wire! Such answers were given no credit even if the conclusion was correct.

(c) Many candidates are still not drawing smooth turning points where power is zero. This is a sine squared (or cosine squared) graph, and not a modulus sine/cosine graph.

7 (a) (i) <u>Solution 1</u>

$$A_0 = \lambda N_0$$
$$= \left(\frac{\ln 2}{50.2 \times 60 \times 60}\right)\left(\frac{2.00 \times 10^{-9}}{240 \times 10^{-3}} \times \left(6.02 \times 10^{23}\right)\right)$$
$$= 1.9241 \times 10^{10} = 1.92 \times 10^{10} \text{ Bq}$$

<u>Solution 2</u>

$$A_0 = \lambda N_0$$
$$= \left(\frac{\ln 2}{50.2 \times 60 \times 60}\right)\left(\frac{2.00 \times 10^{-9}}{240 \times 1.66 \times 10^{-27}}\right)$$
$$= 1.9254 \times 10^{10} = 1.93 \times 10^{10} \text{ Bq}$$

(ii)

$$\text{number of decays required} = \frac{1140}{\left(5.71 \times 10^{6}\right)\left(1.60 \times 10^{-19}\right)}$$
$$= 1.2478 \times 10^{15} = 1.25 \times 10^{15}$$

(iii) Solution 1

$$N_{required} = N_i - N_f$$
$$= N_0 - N_0 e^{-\lambda t}$$
$$1.25 \times 10^{15} = \left(\frac{2.00 \times 10^{-9}}{240 \times 10^{-3}} \times \left(6.02 \times 10^{23}\right) \right) \left(1 - e^{-\frac{\ln 2}{50.2} t} \right)$$
$$0.249 = 1 - e^{-\frac{\ln 2}{50.2} t}$$
$$t = -\frac{50.2}{\ln 2} \times \ln 0.751$$
$$= 20.738 = 20.7 \text{ h}$$

Solution 2

$$N_{required} = N_i - N_f$$
$$= N_0 - N_0 e^{-\lambda t}$$
$$1.25 \times 10^{15} = \left(\frac{2.00 \times 10^{-9}}{240 \times 1.66 \times 10^{-27}} \right) \left(1 - e^{-\frac{\ln 2}{50.2} t} \right)$$
$$0.249 = 1 - e^{-\frac{\ln 2}{50.2} t}$$
$$t = -\frac{50.2}{\ln 2} \times \ln 0.751$$
$$= 20.738 = 20.7 \text{ h}$$

(b) The statement is incorrect because the activity of a radioactive sample is also proportional to the number of radioactive nuclei (besides being inversely proportional to its half-life).

So radioactive materials with a long half-life can have high activity if the number of radioactive nuclei is large.

Comments

(a) **(i)** Wrong answers are due to inability to use the correct quantities. For example, use of 240 kg instead of 240×10^{-3} kg, use of 50.2 h instead of 50.2×3600 s, use of number of moles instead of number of nuclei. Candidates are expected to be able to convert units from one form to another quickly and correctly. The other common mistake is use of m_p instead of u to find mass of nucleus.

(ii) Weaker candidates do not know how to convert MeV to J.

(iii) Weaker candidates solved the problem through unit analysis – since time was required, they wrongly used the answer of **(a)(ii)** divided by that of **(a)(i)**.

(b) Many candidates were unable to quote the correct equation. A few of those who quoted correctly, did not understand the significance of the symbols.

8 (a) (i) 1.

$$d = \frac{\text{velocity of droplets}}{\text{frequency of droplet emission}}$$
$$= \frac{20}{110000}$$
$$= 1.8182 \times 10^{-4}\ \text{m} = 182\mu\text{m}$$

2.

$$\text{mass of droplet} = \rho\left(\frac{4}{3}\pi r^3\right)$$
$$= \left(\frac{0.84\times10^{-3}}{10^{-6}}\right)\left(\frac{4}{3}\pi\right)\left(\frac{80\times10^{-6}}{2}\right)^3$$
$$= 2.2519\times10^{-10} = 2.25\times10^{-10}\ \text{kg}$$

(ii) 1.

$$F = \frac{q^2}{4\pi\varepsilon_0 d^2}$$
$$= \frac{\left(-1.0\times10^{-13}\right)^2}{4\pi\left(8.85\times10^{-12}\right)\left(182\times10^{-6}\right)^2}$$
$$= 2.71\ \times10^{-9}\ \text{N} = 2.7\ \text{nN (shown)}$$

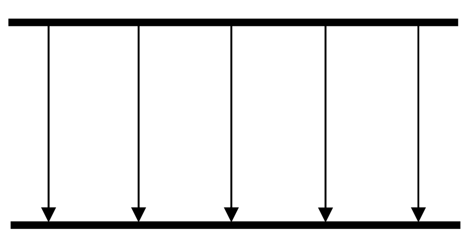
2.

$$a = \frac{F}{m}$$
$$= \frac{2.71\ \times10^{-9}}{2.25\times10^{-10}}$$
$$= 12.0444 = 12.0\ \text{m s}^{-2}$$

(iii) The "guard droplets" <u>increase the distance</u> between the charged droplets, <u>reducing</u> the large <u>accelerations</u> due to the electrostatic forces, which could have caused <u>uneven or irregular printing due to uneven spacing of the droplets / changing velocities of droplets / droplets colliding with one another.</u>

Note: Students should link back to the overall context of printing and how the large repulsions / accelerations might cause problems in printing.

(b) (i)



*at least 5 parallel lines, equally spaced and pointing down

(ii) $E = \frac{\Delta V}{d} = \frac{10000}{0.010} = 1.0\times10^{6}\ \text{N C}^{-1}$

(iii) 1. Perpendicularly out of the page.

2. The magnetic force provides the centripetal force.

$$Bqv = \frac{mv^2}{r}$$

$$B = \frac{mv}{rq}$$

$$= \frac{\left(2.25\times10^{-10}\right)(20)}{(0.260)\left(1.0\times10^{-13}\right)}$$

$$= 1.7308\times10^{5} = 1.73\times10^{5}\text{ T}$$

It is <u>not practical / feasible</u> to use a magnetic field to deflect an ink droplet as the required magnetic flux density is <u>too large</u>. (As a reference, MRI machines operate at around 1.5 T to 3 T, and those are already considered very strong magnetic fields that require many safety protocols during its operation!)

(c) **(i)**

$$Q = Pt$$

$$= I^2Rt$$

$$= (0.50)^2(30)\left(0.010\times10^{-6}\right)$$

$$= 7.5\times10^{-8}\text{ J}$$

(ii)

$$Q = mc\Delta\theta + ml_v = 7.5\times10^{-8}\text{ J}$$

$$m = \frac{7.5\times10^{-8}}{(2090)(80-25)+\left(444\times10^{3}\right)}$$

$$= 1.3418\times10^{-13} = 1.34\times10^{-13}\text{ kg}$$

*energy equation must be written

(iii)

$$V = \frac{m}{\rho} = \frac{1.34\times10^{-13}}{\left(1.17\times10^{-3}\right)/10^{-6}} = 1.1453\times10^{-16}\text{ m}^3$$

$$x = \frac{1.1453\times10^{-16}}{\left(20\times10^{-6}\right)^2}$$

$$= 2.8632\times10^{-7}$$

$$= 0.286\times10^{-6}\text{ m} = 0.286\,\mu\text{m}$$

(iv) There are <u>significant heat losses to the surroundings</u> and not all of the heat produced from the heating element goes into heating the ink layer.

(d) Advantage: Thermal inkjet printing has much <u>higher resolution</u>, resulting in better image quality, <u>due to smaller droplet sizes</u> for thermal inkjet printer at 10 μm compared to CIJ printer's at 80 μm.

Disadvantage: Thermal inkjet printing has much <u>smaller printing speeds due to a lower frequency of droplet ejection</u> for thermal inkjet printer at 18 kHz compared to CIJ printer's at 110 kHz.

Comments
Overall comments:

Candidates are generally very weak in converting units, and in their knowledge of prefixes. **Please revise how to convert units (e.g. 1 g cm^{-3} $\equiv$ 1000 kg m^{-3}) and prefixes for units (e.g. G, M, k, c, m, μ, n, p).** These are basic skills and knowledge that every Physics student must know by heart.

(a) **(i)** **1.** Generally well done by students who attempted it. Weak responses did not convert 1.8182×10^{-4} m to 182μm correctly.
Note: $1.8182 \times 10^{-4} \text{ m} = 181.82 \times 10^{-6} \text{ m} = 182 \mu\text{m}$

2. Surprisingly poorly done. Weak responses did not convert 0.84 g cm^{-3} to 840 kg m^{-3} correctly and/or did not convert 80μm to 80×10^{-6} m correctly.

The volume of a sphere is given by $\frac{4}{3}\pi r^3$, where r is the radius. Weak responses used the diameter instead of the radius, while others just used wrong formulas (e.g. πr^2, $4\pi r^2$, $\frac{4}{3}\pi r^2$, r^3, $\frac{2}{3}\pi r^3$). Candidates are strongly advised to revise and remember basic formulas like this.

(ii) **1.** Generally well done.

2. Generally well done.

(iii) Candidates are expected to explain that the guard droplets help space the charged droplets out so as to reduce the forces / accelerations experienced by the droplets. Candidates should also learn to think about endpoint of this argument, which should be the purpose of a printer – in other words, how do guard droplets help the printer function properly? What will happen to the printing if the droplets are pushed around by forces?

Candidates should learn to use specific, clear, and scientific language where appropriate when answering. For example, phrases like “it will affect the printing” is too vague and was not accepted.

(b) **(i)** The electric field strength between the parallel plates is uniform. So, the electric field lines should be equally spaced, symmetrical about both ends of the plates and perpendicular to the plates.

(ii) Most candidates were able to answer this correctly.

(iii) **1.** Many candidates were given the benefit of doubts for missing out “perpendicularly”.

2. Some candidates are unaware of the reasonable range of magnetic flux density and incorrectly claimed that 10^{-7} T is too small or 10^{5} T is feasible. Paying attention to the reasonable range of a physical quantity is a required skill.

Some candidates expressed the units of magnetic flux density as N m^{-1} A^{-1} instead of the convenient and most commonly used Tesla.

(c) **(i)** Weak responses did not use the correct formula, either using something like $P=\frac{I^2}{R}$ or $P=IR^2$. Other weak responses confused power P (rate of thermal energy dissipated) with the thermal energy Q, which led to formulas like $Q=I^2R$. A minority of candidates even confused the Q in the formula $Q=It$ as thermal energy, when it should be charge.

Candidates are reminded that studying for Physics should not comprise solely of blindly memorising formulas without even understanding what the terms mean. Instead, deep understanding is crucial to internalising the formulas so that they never forget them in an examination.

(ii) The most common mistake was the use of 444 instead of 444000 as the specific latent heat of vaporisation (1 kJ $\equiv$ 1000 J). Weak responses also did not include either the specific heat capacity term or the specific latent heat of vaporisation term in the calculations.

Candidates are expected to write the energy equation to explicitly show what the thermal energy supplied Q is used for. Students should not just jump straight to what the mass is equal to $\left(m=\frac{7.5\times10^{-8}}{(2090)(80-25)+\left(444\times10^{3}\right)}\right)$. Always state at the start of the working, the Physics concept used and write the equation, using standard symbols, in the way that shows the starting concept before doing any mathematical manipulation and substitution.

You are doing Physics, not merely a mathematical exercise!

(iii) Weak responses did not correctly identify the shape of the layer of ink as a cuboid of height x and a square cross-sectional area, and either did not square the $20\mu\text{m}$ or squared the x instead. Careless mistakes included using the wrong density of ink (value taken for the CIJ printer).

As usual, a common mistake made was the poor attempt at converting values such as 1.17 g cm^{-3} to 1170 kg m^{-3}, $20\mu\text{m}$ to 20×10^{-6} m and their final answer from 2.8632×10^{-7} m to $0.286\mu\text{m}$.

(iv) Generally well done by students who attempted it. Most candidates were able to correctly identify that not all the heat produced by the thin-film resistor is transferred to the layer of ink. Candidates are reminded to write proper sentences and statements.

(d) Strong candidates who answered correctly generally explained their reasoning very well. Weaker responses either left it blank, or gave an answer without proper reasoning and reference to the data / information given in the passage.