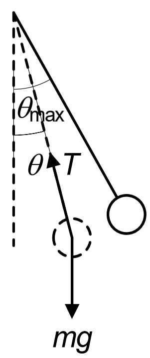
Raffles Institution
Year 5-6 Physics Department

2021 Year 5 H2 Physics Promotional Examination Solution

Section A

Qn	Ans	Solution
1	A	$F = 6\pi\eta rv \Rightarrow \eta = \dfrac{F}{6\pi rv}$ $\eta = \dfrac{\text{base units of } F}{(\text{base units of } r)(\text{base units of } v)} = \dfrac{\text{kg m s}^{-2}}{(\text{m})(\text{m s}^{-1})} = \text{kg m}^{-1}\ \text{s}^{-1}$
2	B	For $X+Y$: percentage uncertainty $= \dfrac{(\Delta X + \Delta Y)}{(X+Y)} \times 100\% = \dfrac{(0.1+0.1)}{(51.0+49.0)} = 0.20\%$ For $X-Y$: percentage uncertainty $= \dfrac{(\Delta X + \Delta Y)}{(X-Y)} \times 100\% = \dfrac{(0.1+0.1)}{(51.0-49.0)} = 10\%$ For XY and $\dfrac{X}{Y}$: percentage uncertainty $= \left(\dfrac{\Delta X}{X} + \dfrac{\Delta Y}{Y}\right) \times 100\% = \left(\dfrac{0.1}{51.0} + \dfrac{0.1}{49.0}\right) \times 100\% = 0.40\%$
3	B	Since the ball is thrown and caught at the same height above the ground, $s_y = 0$ Taking upwards as positive: $0 = u_y t - \dfrac{1}{2}gt^2$ $u\sin\theta = \dfrac{1}{2}gt \ \Rightarrow \ \sin\theta = \dfrac{gt}{2u}$ ------- (1) Since Jill is running towards the ball at speed $v = 8.9$ m s^{-1}, $s_x = (u\cos\theta)t = d - vt \ \Rightarrow \ \cos\theta = \dfrac{d-vt}{ut}$ ------- (2) where $d = 15$ m $\dfrac{(1)}{(2)}$: $\tan\theta = \dfrac{\frac{gt}{2u}}{\frac{d-vt}{ut}} = \dfrac{gt^2}{2(d-vt)} = \dfrac{(9.81)(0.49)^2}{2[15-(8.9)(0.49)]} \Rightarrow \theta = 6.32°$ From (1): $u = \dfrac{gt}{2\sin\theta} = \dfrac{(9.81)(0.49)}{2\sin 6.32} = 21.8 \approx 22$ m s^{-1}
4	A	Consider the forces on the crate and present as a system, $T - (M+m)g = (M+m)a$ $a = \dfrac{30-(2.0+0.30)(9.81)}{(2.0+0.30)} = 3.2335$ m s^{-2} Consider forces on the present, $N - mg = ma$ $N = m(a+g) = 0.30(3.2335+9.81) = 3.91 = 3.9$ N

5	**B**	By the conservation of energy before the projectile explodes, decrease in K.E. = increase in G.P.E. $\frac{1}{2}(2m)(20)^2 - \frac{1}{2}(2m)v^2 = (2m)g(9.0)$ speed at the peak, $v = 14.947\text{ m s}^{-1}$ (horizontally to the right) By the conservation of momentum, momentum before explosion = momentum after explosion $(2m)(14.947) = m(40) + mv_X$ $v_X = -10.106\text{ m s}^{-1} = -10\text{ m s}^{-1}$ speed of X $= 10\text{ m s}^{-1}$ (Conservation of momentum can be applied though there is an external gravitational force acting on the projectile. This is because the force of explosion between X and Y is much larger than the gravitational force. Thus, the effect on their momentum by the gravitational force is negligible.)
6	**C**	Let the angle that the beam makes with the horizontal be θ. Taking moments about P, $Mg(x\cos\theta) = k(9.0-4.0)(2.0\cos\theta)$ $Mgx = k(9.0-4.0)(2.0)$ ----- (1) Taking moments about Q, $Mg(2.0-x)\cos\theta = k(6.5-4.0)(2.0\cos\theta)$ $Mg(2.0-x) = k(6.5-4.0)(2.0)$ ----- (2) $\frac{(2)}{(1)}$: $\frac{2.0-x}{x} = \frac{2.5}{5.0} = \frac{1}{2}$ $x = 4.0 - 2x$ $x = \frac{4.0}{3} = 1.33 = 1.3\text{ m}$ Alternative solution: $\frac{T_P}{T_Q} = \frac{6.5-4.0}{9.0-4.0} = \frac{1}{2}$ Taking moments about C.G., $T_P \times x = T_Q \times (2.0-x)$ $\frac{x}{2.0-x} = \frac{T_Q}{T_P} = 2$ $x = \frac{4.0}{3} = 1.33 = 1.3\text{ m}$

7	**D**	Since the block is in equilibrium, resultant force and resultant moment about any point must be zero. For the block not to slide down, there must be frictional force acting upwards along the slope on the block to counter the component of its own weight downwards along the slope. Since the lines of forces of the normal contact force, frictional force and weight must coincide, this point of intersect has to be along the vertical where the line of force of the weight meets the surface of the slope. The contact force of the slope on the block, which is the vector sum of the normal contact force and frictional force, must then act at this point of intersection. Furthermore, the contact force must also pass through the centre of gravity (C.G.) of the block, so that the resultant moment about its C.G. is zero. The contact force is thus pointing vertically upwards, ensuring that the resultant force in both the vertical and horizontal directions are zero.
8	**D**	$F_{net} = \frac{dp}{dt} = \frac{m\Delta v}{\Delta t} = \frac{m(v-u)}{t} \Rightarrow mv = Ft$ (since $u = 0$) $E_k = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{1}{2}\frac{(Ft)^2}{m} \Rightarrow E_k \propto \frac{1}{m}$ Gain in KE $= E_{k,final} - E_{k,inital} = E_{k,final}$ since $E_{k,inital} = 0$ $\frac{E_{k,final,P}}{E_{k,final,Q}} = \frac{m_Q}{m_P} = \frac{2m}{m} = 2.0$
9	**D**	The answer can be deduced by elimination. The pendulum is describing part of a circular path. Hence the tension of the string when it is vertical must be greater than *mg*, so that there is a resultant force towards the centre of the circular path. At angular position θ, $T - mg\cos\theta = \frac{mv^2}{L}$ (1)  By the principle of conservation of energy, increase in K.E. = decrease in G.P.E. $\frac{1}{2}mv^2 - 0 = mgL(\cos\theta - \cos\theta_{max})$ $mv^2 = 2mgL(\cos\theta - \cos\theta_{max})$ Substituting into (1), $T = 2mg(\cos\theta - \cos\theta_{max}) + mg\cos\theta = mg(3\cos\theta - 2\cos\theta_{max})$

10	**B**	Recall or derive: $E_T = -\dfrac{GMm}{2r}$ and $E_k = \dfrac{GMm}{2r}$ When the satellite experiences atmospheric drag, its total energy decreases. When its total energy decreases (i.e. becomes more negative), its orbital radius decreases and its kinetic energy increases. Since kinetic energy is proportional to $v^2{}_{orbital}$, orbital speed also increases.
11	**C**	The speed of the mass is next zero again when it is at the amplitude on the other side of the equilibrium position. $0.50 = \dfrac{1}{2}T$ $T = 1.0$ s $v_{\max} = \omega x_{\max} = \dfrac{2\pi}{T}x_{\max} = \dfrac{2\pi}{(1.0)}(0.10) = 0.6283 = 0.63 \text{ m s}^{-1}$
12	**C**	Resonance occurs when the cart moves over the grooves at 8.0 m s^{-1}. At this speed, the frequency which the cart moves over the grooves = driving frequency of the oscillations = natural frequency of mass spring system frequency which the cart moves over the grooves $= \dfrac{1}{2\pi}\sqrt{\dfrac{25}{0.050}} = 3.5588$ Hz separation between the grooves $= \dfrac{v}{f} = \dfrac{8.0}{3.5588} = 2.247 = 2.2$ m
13	**A**	$v = f\lambda \Rightarrow \lambda = \dfrac{v}{f} = \dfrac{300}{500} = 0.60$ m $\phi = \dfrac{0.75}{0.60} \times 2\pi = 2.5\pi$ Equivalently, $\phi = 2.5\pi - 2.0\pi = 0.50\pi$ rad
14	**D**	Option A: The particles between adjacent segments are in antiphase. Option B: The speed of the wave (energy transfer) is given by the product of frequency and wavelength. Option C: The separation between the node and adjacent antinode is a quarter of a wavelength.
15	**C**	A stationary wave is formed by the superposition of two progressive waves of the same amplitude and has the same wavelength as its component waves. At the antinode the waves undergo constructive interference: $2A_{progressive} = A_{stationary}$ $A_{progressive} = \dfrac{A_{stationary}}{2} = \dfrac{2}{2} = 1$ cm $L = \dfrac{3}{2}\lambda$ $\lambda = \dfrac{2}{3}(45) = 30$ cm

Section B

1 (a) (i) upthrust $U = V\rho_{liquid}g$

$$= \frac{0.040}{8910}(1410)(9.81)$$
$$= 0.062097 = 0.062 \text{ N}$$

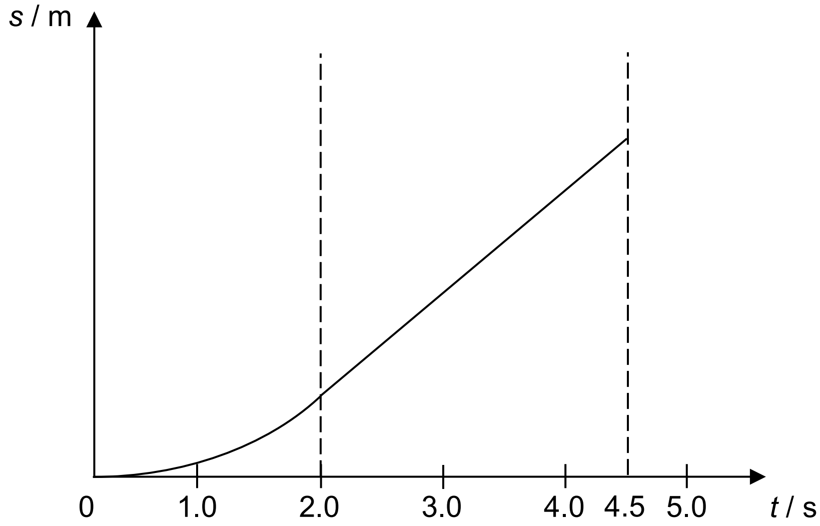
(ii) At terminal velocity, the resultant force on the sphere is zero.

$$mg = U + \beta v_T$$
$$0.040(9.81) = 0.062 + 0.26v_T$$
$$v_T = \frac{0.040(9.81) - 0.062}{0.26}$$
$$= 1.2708 = 1.27 \text{ m s}^{-1}$$

(iii)

$$F_{average} = \frac{\Delta p}{\Delta t} = \frac{mv_T - 0}{\Delta t}$$
$$= \frac{0.040(1.2708) - 0}{4.5}$$
$$= 0.011296 = 0.0113 \text{ N}$$

(b)



*Curved, increasing gradient (zero gradient at 0 s) from 0 s to 2.0 s, with label
*Straight line, constant gradient (smooth transition at 2.0 s) from 2.0 s to 4.5 s, with label

(c) When moving at terminal velocity, there is a constant drag force acting upwards on the sphere by the liquid. By Newton's Third Law, the sphere exerts an additional reaction force downwards on the liquid.

This increases the normal contact force between the container of liquid and the mass balance, as compared to X when the sphere is instantaneously at rest and experiencing a downwards acceleration (upthrust less than weight).

Hence, Y is larger than X.

Comments

(a) **(i)** Please note the following for all show questions:
1. All working and numerical substitution of values have to be written down explicitly.
2. Computation is required and please write down the more precise value prior rounding off to the value given in the question.

(ii) A significant handful of students made the following mistakes:
1. Inaccurate free body diagram of the sphere i.e. missing forces such as weight, upthrust or drag force.
2. Careless mistakes in computation.

(iii) Partial credit is given for the following:
1. Change in velocity, Δv is computed as $v_{initial} - v_{final}$ or there is lack of clarity in the substitution for Δv.
2. Negative sign was included when asked for magnitude.

(b) Many students did not label the graphs explicitly despite values provided on the horizontal axis.

Students tend to forget that the initial gradient for the *s*–*t* graph should be zero.

A handful of students were confused with the time that the sphere takes to reach terminal velocity. It should be 2.0 s and not 2.5 s.

A significant handful of students drew the *v*–*t* graph instead of the s–*t* graph. No credit will be given.

(c) This question was very poorly done. Common misconceptions include that the reading of the mass balance is given by the
- 'normal contact force exerted by the sphere on the mass balance'
- 'net force acting on the sphere'
- 'moving sphere exerting a force'
- 'resultant/net force acting on the mass balance'

The mass balance reading is due to the normal contact force between the container of liquid and the mass balance. There is no contact force that exists between the sphere and the mass balance since they are not in direct contact. Since the reading on the mass balance is due to the normal contact force between the container of liquid and the mass balance, it would be most appropriate (and convenient) to select the container of liquid as the system for your free body diagram analysis.

Students need to be more mindful of the terms that they use. There is a stark difference between a force and a net/resultant force. The reading of the mass balance is due to a physical force that is acting on the mass balance. This force is not the net force (which according to Newton's Second Law gives rise to an acceleration). At terminal velocity, the net force on the sphere is zero but there are reaction forces acting on the container of liquid by the sphere due to the upthrust and drag force that the container of liquid acts on the sphere according to Newton's Third Law. Students have to be more careful with their free body diagram analysis as it is important to account for all the physical forces acting on the selected system of interest.

A significant number of students were not aware that immediately after the string was cut, the sphere was not in equilibrium. i.e. the sphere experiences a downward acceleration since weight is greater than upthrust, which causes it to sink.

2 **(a)** **(i)** Since the lower portion of the string is horizontal, the string forms a right angle triangle with the two fixed points on the rod.

Let r be the length of the lower portion of the string.

$$(4L)^2 + r^2 = (8L - r)^2$$

$$16L^2 + r^2 = 64L^2 - 16Lr + r^2$$

$$16L(3L - r) = 0$$

since $L \neq 0,\ 3L - r = 0$

$$r = 3L$$

(ii) Let θ be the angle that the upper portion of the string makes with the rod.

$$\cos\theta = \frac{4L}{5L} = \frac{4}{5}$$

Consider the vertical forces on the ring,

$$T\cos\theta = mg$$

$$T = \frac{mg}{\cos\theta} = \frac{5}{4}mg$$

(iii) Consider the horizontal forces on the ring,

$$T + T\sin\theta = mr\omega^2$$

$$\omega^2 = \frac{1}{mr}\left(T + \frac{3}{5}T\right) = \frac{8T}{5mr} = \frac{8}{5m \times 3L} \times \frac{5}{4}mg = \frac{2g}{3L}$$

$$\omega = \sqrt{\frac{2g}{3L}}$$

(iv) $v = r\omega = 3L\sqrt{\dfrac{2g}{3L}} = \sqrt{6gL}$

(b) When the angular speed is increased, the centripetal force, provided by the tensions in the two portions of the string, required to keep the ring in circular motion increases.

The increase in tension results in a greater vertical component of the tension in the upper portion of the string. Hence there will be a resultant vertical force acting upwards on the ring, causing it to accelerate and rise.

Comments

(a) **(i)** Many students did not read the question carefully. The total length of the string (horizontal part + slope part) is $8L$.

(ii) Some students referenced the angle θ without indicating it in the diagram.

(iv) The final answer should be simplified, e.g., $L \times \dfrac{1}{\sqrt{L}}$ should be $\sqrt{L}$.

(b) Many students claimed that the horizonal component of T provides for centripetal force. They failed to realise that there is also tension in the horizontal part of the string. Hence the increase in centripetal force required is only due to an increase in tension, rather than a change in the angle θ.

Some students argued that the angle θ increases because $T\cos\theta = mg$ and T is increased. However, if the angle does indeed change, then the lower string is no longer horizontal and hence needs to be factored in the equation.

3 **(a)** The graph shows that the acceleration of the ball is a constant negative value when it is in mid-air with a sharp spike in acceleration when the ball hits the ground. This means that the magnitude and direction of the acceleration of the ball does not vary with displacement when the ball is in mid-air. There is only a momentary change in magnitude and the direction of the acceleration when the ball hits the ground.

For simple harmonic motion, the magnitude and direction of the object's acceleration changes such that its magnitude is directly proportional to its displacement and its direction is always opposite to that of displacement.

Hence the ball is not undergoing simple harmonic motion.

(b) **(i)** Total energy of system at higest point

$= E_P + E_K$

$= mg(\Delta h) + 0$ since potential energy is zero at lowest (eqm) point

$= 0.0040mg$ J

OR

Total energy of system

$= E_{P,\max}$ when $E_K = 0$

$= mg(\Delta h)$ since potential energy is zero at lowest (eqm) point

$= 0.0040mg$ J

(ii) Total energy $= E_{K,\max} = \frac{1}{2}mv_{\max}^2 = \frac{1}{2}m\omega^2 x_0^2$

$$0.0040mg = \frac{1}{2}m\omega^2 x_0^2$$

$$0.0040mg = \frac{1}{2}m \times \frac{g}{L} \times x_0^2$$

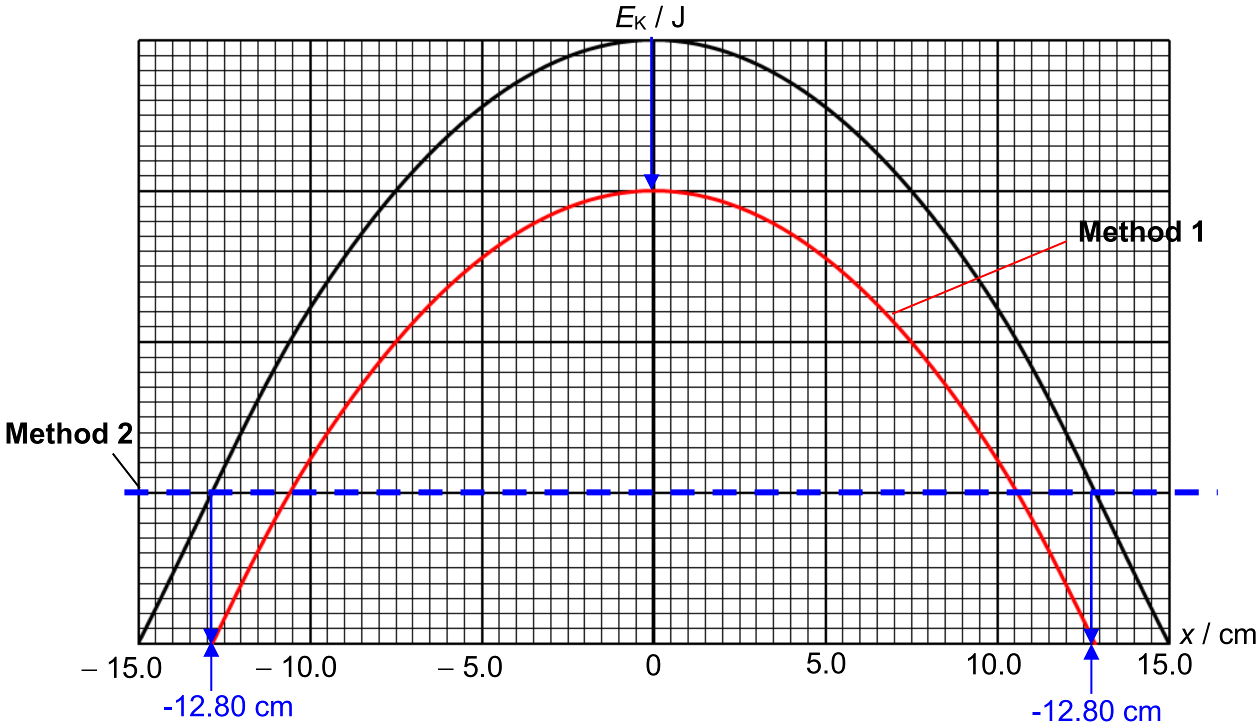
$$L = \frac{x_0^2}{0.0080}$$

$$= \frac{(0.15)^2}{0.0080}$$

$$= 2.8125 = 2.81 \text{ m}$$

(iii) When the pendulum is raised vertically by 0.30 cm, its total energy (maximum E_K) would be ¾ of the total energy when it is raised by 0.40 cm.

Method 1:
Hence the E_K graph will shift downwards such that the maximum E_K shifts downwards by 1 large square.



Evidence showing graph profile translating down by 1 large square
Evidence of extrapolating value of new amplitude from original graph at ¼ of maximum E_K

Method 2:
Drawing a horizontal line across at ¼ of the original total energy. Determine the corresponding value of *x*.

New amplitude = 12.80 cm

Comments

(a) For full credit, the definition of SHM must be present in the answer (both points have to be mentioned), reference must be made to Fig. 3.2 to explain why SHM is not shown (reference to acceleration being constant – same value, same direction always) and the correct conclusion must be stated.

Most students could articulate the 2 points that define an object's motion as simple harmonic. However, some inaccurate phrases include stating 'distance' instead of 'displacement'. These two quantities are not the same. Using the term 'force' instead of 'acceleration'. Benefit of doubt was given in this second case, assuming that the students meant the net force on the object.
When using the term 'displacement', it should be more accurately described as 'displacement from a fixed point'. Some students simply stated the equation $a = -\omega^2 x$ without any explanation of the equation, or definition of the terms.

Some reference to Fig. 3.2 had to be made, or at the very least, some discussion about the observations from the graph. Those who simply said that the ball's motion is not SHM because the acceleration is 9.81 m s^{-2} were not given full credit as there was no reference to the graph.

Many students stated that the graph needs to be 'a straight line with a constant gradient passing through zero'. This is inaccurate. The horizontal line given in Fig 3.2 is a straight line with a constant gradient (of zero). A horizontal line along the x-axis or vertical line along the y-axis would also satisfy the description. What needs to be stated is that the line must be downwards sloping and cutting through the origin. It is also insufficient to only state that the line needs to be 'linear'.

(b) **(i)** Conservation of energy is not a complex concept, but the explanations given for this part of the question were often incomplete and flawed. Most students could get the answer for this, but lost the mark for the explanation.

Many answers wrote 'Loss in G.P.E. = Gain in K.E.' without any clear indication of where the start and end points of reference are.

Simply stating "Total energy = Loss in G.P.E." without further explanation is incorrect. Total energy is the amount of energy at a particular position, while the loss in G.P.E. refers to a change between 2 positions. We should not equate them without any explanation. Firstly, it should be articulated that we are considering the loss in G.P.E. from the point of release (the amplitude) to the equilibrium position. Since K.E. is zero at the amplitude and G.P.E. is zero at the equilibrium, we can then conclude that Total energy = Loss in G.P.E.

Some answers implied that the pendulum gained G.P.E. and lost K.E. while it is being displaced from the equilibrium position to the amplitude before releasing it. This is incorrect as the pendulum was not swinging freely when it was raised to a height of 0.40 cm. During this part, it is the work done by external force to raise it that is equal to the increase in G.P.E.

Lastly, the SI unit for energy 'J' was given. Hence, the height must be stated in SI units as well. So there was a need to convert 0.40 cm to 0.0040 m.

(ii) Several students were careless and omitted the power 2 for the amplitude when using the equation for total energy ($E = \frac{1}{2} m\omega^2 x_o{}^2$)

The amplitude of the motion is 15 cm (mazimum horizontal displacement read off from the graph) and not 0.40 cm, which is the vertical height.

ECF was awarded from (b)(ii).

(iii) Not many students could do this part. Those who showed understanding in their constructions that raising the pendulum by 0.30 cm meant that the maximum K.E. would be three quarters of the original (i.e. peak of the new graph would be 3 large squares) were given credit for that.

4 **(a)** Polarisation of an electromagnetic wave occurs when the oscillations of the electric field is restricted to one direction only and this direction is perpendicular to the direction of energy transfer.

(b) **(i)** Since $I \propto A^2$,

$$\frac{I_Q}{I_0} = \frac{\left(\frac{A_0}{3}\right)^2}{A_0^2}$$

$$I_Q = \frac{1}{9} I_0$$

(ii) Using Malus' law, $I_{transmitted} = I_{incident} \cos^2 \theta$

$$\frac{1}{9} I_0 = I_0 \cos^2 \theta$$

$$\cos \theta = \frac{1}{3}$$

$$\theta = 70.529° = 70.5° \text{ or } 71°$$

(iii) Maximum intensity of the light beam is obtained when the polarising axes of polarisers P and Q are parallel to each other.

Hence, first intensity maximum occurs when Q is further rotated by an angle of $180° - 71° = 109°$ and second intensity maximum occurs when it is further rotated by an angle of $180° + 109° = 289°$.

Comments

(a) Full credit is given to those who managed to recall and write the definition of polarisation in respect of electromagnetic wave.

Many students mentioned that polarisation of an electromagnetic wave as the oscillations of particles being restricted to one direction when it should have been the oscillations of the electric field (vectors) of the electromagnetic wave.

In addition, the oscillations of the electric field (vectors) is perpendicular to the direction of energy propagation of the electromagnetic wave and not perpendicular to the direction of wave travel or propagation.

(b) **(i)** No credit given to those who merely stated their answer as $I = I_0 \cos^2 \theta$ as it does not meet the requirement of question i.e. to express intensity in terms of I_0 only.

Many students were vague in their worked solution to this part and was unclear in arriving at their answer. Such students receive only partial credit.

(ii) A common mistake here is to apply Malus' law in terms of the amplitude i.e. $\frac{A_0}{3} = A_0 \cos^2 \theta$ which will obviously lead to the wrong answer.

(iii) Some students stated only one angle when they should have stated two as required by the question. No credit is given if only one correct angle is stated.

No credit given to students who stated their answers as 180° and 360°, as these angles are not taken with reference to the angle calculated in (b)(ii) as required by the question.

Many students failed to give a precise explanation in their answers. Many wrote that to achieve the two consecutive maxima, polariser Q must be rotated such that it is parallel to polariser P. This is incorrect as the planes of polarisers P and Q are always parallel. It should have been that the polarising axes of both polarisers must be aligned or parallel to each other.

5 (a) (i) A **transverse** wave is one in which its particles **oscillate** in a direction **perpendicular** to the direction of **energy** transfer.

A **longitudinal** wave is one in which its particles **oscillate** in a direction **parallel** to the direction of **energy** transfer.

(ii) Particles to the left of C are displaced to the right and those to the right of C are displaced to the left.

Hence, point C has the highest pressure.

(b) (i) When the sound wave from the loudspeaker reaches piston P, it gets reflected. The **incident** wave and the **reflected** sound waves, having the **same amplitude**, frequency and speed but travelling along the same line in opposite directions, undergo superposition to form a stationary wave such that
an **antinode is at Q** and a **node is at P** (or the length of the tube is an odd number of quarter-wavelength).

(ii) 1.

1st resonance: $\frac{1}{4}\lambda = 0.15 + c$ ----- (1)

2nd resonace: $\frac{3}{4}\lambda = 0.47 + c$ ----- (2)

(2) – 3×(1): $c = 0.01$ m

2.

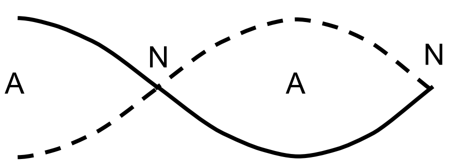
Between 2 consecutive nodes or antinodes: $\frac{\lambda}{2} = 0.47 - 0.15 = 0.32$ m

$\lambda = 0.64$ m

Or, from equation (1), $\lambda = 4(0.15 + 0.01) = 0.64$ m

$f = \frac{v}{\lambda} = \frac{330}{0.64} = 515.625 = 516$ or 520 Hz

(iii)



*Draw ¾λ with both envelopes, where antinode ends at or outside of Q.
*Label As and Ns at the correction positions.
*Distance between neighbouring A and N should be 1/3 of the length of the tube.

<u>Comments</u>

(a) **(i)** Particles only “oscillate”, not “move”, “travel” or “propagate”. Cambridge only accepts direction of “energy”, not “wave”.

Note that longitudinal and tranverse waves can also be progressive and stationary waves too. Hence, students should not confuse the two sets of terms in their explanations.

(ii) Many students wasted time and space by repeating parts of the questions, like stating “positive displacement means rightward motion” or “highest pressure means compression”. They also explained unnecessariliy which point is a rarefaction or at atmospheric pressure, which is not what the question wants. If any parts of their answer contradict or showed misconception, marks will be deducted.

Answers should not refer to “front/back of C” or “before/after C” as the question clearly refers to “left/right” direction.

As this is a progressive wave, answers that refered to “nodes” and “antinodes” will be penalised.

Note that if the explanation is incorrect, the answer, even if correct, will not be awarded any marks.

(b) **(i)** Students are expected to answer in the context of the question, and not provide generic statements that are unrelated to the question.

Although the two waves that meet head-on are coherent, it is insufficient to explain the formation of a stationary wave.

(ii) **1.** As the same sound source is used, the frequency is constant and there is no 1^{st} and 3^{rd} harmonics.

Students should label and show their working clearly, instead of just showing numerical working without any statement or explanation. BOD is not awarded when marker is unable to figure out the steps.

2. ECF cannot be awarded if students used a different working or value for wavelength or frequency from (b)(ii)1.

(iii) Weaker students mixed up the meaning of nodes and antinodes.

Section C

6 **(a)** **(i)** The gravitational potential at a point in a gravitational field is defined as the work done per unit mass by an external force in bringing a small test mass from infinity to that point.

(ii) Gravitational potential at infinity is zero.

Since gravitational force is attractive, to bring a mass from infinity to a point in the gravitational field, the direction of the external force is opposite to the direction of displacement of the mass.

This results in negative work done by the external force.

Hence, based on its definition, gravitational potential has a negative value.

(b) **(i)** at $r = 8.0 \times 10^8$ m, $\phi = -1.6 \times 10^8$ J kg^{-1}

$\phi = -\dfrac{GM}{r}$ where M is the mass of the planet

$$M = -\frac{\phi r}{G}$$
$$= -\frac{\left(-1.6 \times 10^8\right)\left(8.0 \times 10^8\right)}{6.67 \times 10^{-11}}$$
$$= 1.9190 \times 10^{27} = 1.9 \times 10^{27} \text{ kg (2 s.f.)}$$

*Should show the before rounded off value then the final answer in 2 s.f.

(ii) **1.** Gravitational force on the object provides the centripetal force.
Let m be the mass of the object.

$$\frac{GMm}{r^2} = m\frac{v^2}{r}$$
$$v = \sqrt{\frac{GM}{r}}$$
$$= \sqrt{\frac{\left(6.67 \times 10^{-11}\right)\left(1.9190 \times 10^{27}\right)}{2.0 \times 10^8}}$$
$$= 2.5297 \times 10^4 = 2.53 \times 10^4 \text{ m s}^{-1}$$

2. from the graph,
at point X: $r_X = 8.0 \times 10^8$ m, $\phi_X = -1.6 \times 10^8$ J kg^{-1}
at point Y: $r_Y = 2.0 \times 10^8$ m, $\phi_Y = -6.3 \times 10^8$ J kg^{-1}

Consider the motion from point X to point Y to determine the speed of the stone when it reaches point Y.

increase in K.E. = decrease in G.P.E.

$$\frac{1}{2}mv_Y^2 - \frac{1}{2}mv_X^2 = m(\phi_X - \phi_Y)$$

$$v_Y = \sqrt{2\left[(\phi_X - \phi_Y) + \frac{1}{2}v_X^2\right]}$$

$$= \sqrt{2\left[(-1.6-(-6.3))\times 10^8 + \frac{1}{2}(3.5\times 10^4)^2\right]}$$

$$= 4.6529\times 10^4 = 4.65\times 10^4 \text{ m s}^{-1}$$

Since the <u>speed of the space stone at point Y is not equal to the speed of an object in circular orbit</u> at that same distance as found in (b)(ii)1., the space stone will not orbit around the planet.

3. Total energy of the space stone is the sum of its G.P.E. and K.E.
When space stone is at point X:

$$E_T = E_P + E_K$$

$$= \phi_X m + \frac{1}{2}mv_X^2$$

$$= (-1.6\times 10^8)(1.5\times 10^5) + \frac{1}{2}(1.5\times 10^5)(3.5\times 10^4)^2$$

$$= 6.7875\times 10^{13} = 6.79\times 10^{13} \text{ J}$$

OR

When space stone is at point Y:

$$E_T = E_P + E_K$$

$$= \phi_Y m + \frac{1}{2}mv_Y^2$$

$$= (-6.3\times 10^8)(1.5\times 10^5) + \frac{1}{2}(1.5\times 10^5)(4.6529\times 10^4)^2$$

$$= 6.7871\times 10^{13} = 6.79\times 10^{13} \text{ J}$$

4. Since the total energy of the space stone is <u>more than zero (or positive)</u>, the space stone <u>will escape</u> the gravitational field of the planet.

<u>Comments</u>

(a) (i) The first part of the definition for gravitational potential is strictly ‘work done per unit mass by an external force’. ‘Work done per unit mass’ comes as a phrase as this implies that the units for potential is J kg^{-1}. The force that does the work needs to be clearly stated as ‘external force’. This needs to be clear as there is also gravitational force present in the field.

(ii) The explanation is given in the lecture notes. It is necessary that students understand why gravitational potential is negative and be able to explain using the key phrases. Key phrases and key words related to the concepts applied in the explanations are important in exhibiting clear understanding.

Quite a number of students implied that work done has a direction, which is incorrect. Work done is a scalar quantity and does not have a direction. Work done is negative because the directions of the force and the displacement are opposite (force and displacement are both vector quantities and thus have directions). It is also incorrect to replace ‘displacement’ with ‘distance’. Students have to make an effort to distinguish between scalar and vector quantities and be precise in the way they use and address these quantities.

(b) **(i)** Do pick a point on the graph that lies exactly along the horizontal and vertical grid lines instead of picking a point that is in between grid lines where you need to estimate the cooridnates.

For all show questions, do process the working using a calculator and write down the more precise value (i.e. the value written to more s.f.) for the final answer before rounding it off to the value given in the question. The examiners have explicitly stated that it is necessary to do this.

Marks were not deducted this time but it may be deducted in future.

(ii) **1.** The explanation ‘gravitational force provides the centripetal force’ must always be stated before equating the formula for gravitational force to the centripetal force in a mathematical equation.

Students need to define any symbols (e.g. F_g and F_c) used that are not defined in the question or are not in the list of symbols stated in the syllabus document.

All numerical substitution of values need to be shown clearly in detail.

2. Potential values at specific points in the field can be read off directly from the given potential-distance graph, instead of calculating these values, which can be time consuming.

Many students need to improve in writing the conservation of energy equation, which should be:

increase in K.E. = decrease in G.P.E.
final K.E. – initial K.E. = initial G.P.E. – final G.P.E.

(Note that ‘increase’ and ‘decrease’ implies positive values, so it has to be strictly the larger value minus the smaller value on both sides of the equation.)

OR

initial K.E. + initial G.P.E. = final K.E. + final G.P.E.

OR

Change in K.E. = – change in G.P.E.

(Note that ‘change’ strictly implies ‘final – initial’. Therefore, there must be a minus sign in front of the ‘change in G.P.E.’ to indicate that the G.P.E. has actually decreased i.e the final value is smaller than the initial value.)

Take note that each G.P.E. value or term is negative.

Relevant calculations and reference to the answer in (b)(ii)1. were essential as these were stated in the question.

Read the question carefully and answer the question directly. The question asked to explain why the stone will not move in a circular orbit and did not ask to explain if the stone will escape the field or not.

Also, many students did not read the question carefully and used the wrong distances and speeds at points X and Y.

Reading and understanding the question is very important so that you can answer in the context of the question.

3. The total energy of the stone remains constant throughout its motion. Students can consider the K.E. and G.P.E. at either point X or point Y.

Students cannot use $E_K = \frac{1}{2}\frac{GMm}{r}$ and $E_T = -\frac{1}{2}\frac{GMm}{r}$ to calculate the kinetic and total energies respectively. This is because the stone is not in orbit around the planet. These expressions for kinetic and total energies were derived by equating the gravitational force on an orbiting object to centripetal force, for bounded systems. Besides, these equations usually need to be derived before we use them.

Common mistakes are again, mixing up the values of the distances and speeds for points X and Y and missing out the 'square' of the speed when calculating K.E.

4. The question asked to 'deduce' which implies using evidence from the earlier parts or stating facts that are sufficiently substantiated.

7 (a) (i)

$$s = ut + \frac{1}{2}at^2$$

$$5220 = 0 + \frac{1}{2}a\left(1.0 \times 60\right)^2$$

$$a = 2.9 \text{ m s}^{-2}$$

(ii) Estimate constant speed from 1.6 min to 3.0 min since during this period $\frac{\Delta s}{\Delta t} = \frac{\Delta s}{0.2 \times 60}$ is approximately constant at 261 m s^{-1}.

Before this time period, $\frac{\Delta s}{\Delta t}$ is increasing implying the pod is still accelerating.

Hence time take to accelerate to constant speed is approximately 1.6 min.

OR

$$v = \frac{35220 - 13310}{(60)(3.0 - 1.6)}$$

$$= 260.83 \text{ m s}^{-1}$$

$$t = \frac{v - u}{a}$$

$$= \frac{260.83 - 0}{2.9} = 89.943 \text{ s} = 1.499 \text{ min} = 1.50 \text{ min}$$

(iii) By Newton's second law, $F_{resultant} = ma$, it implies that at a greater acceleration, a greater resultant force acts on the passengers which may injure them or cause discomfort.

(b) (i) 1. Box directly below where it was dropped.

2. Parabolic path from where box was dropped to the position in (b)(i)1., with initial path horizontal

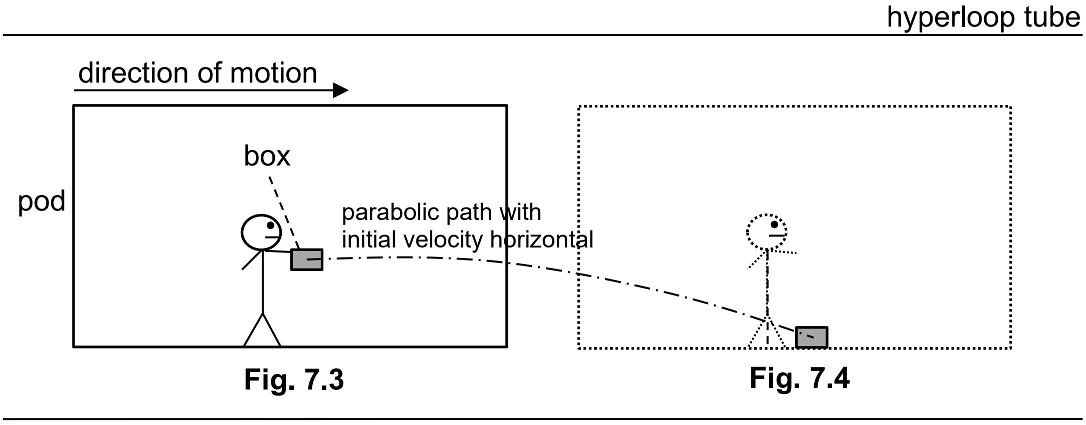


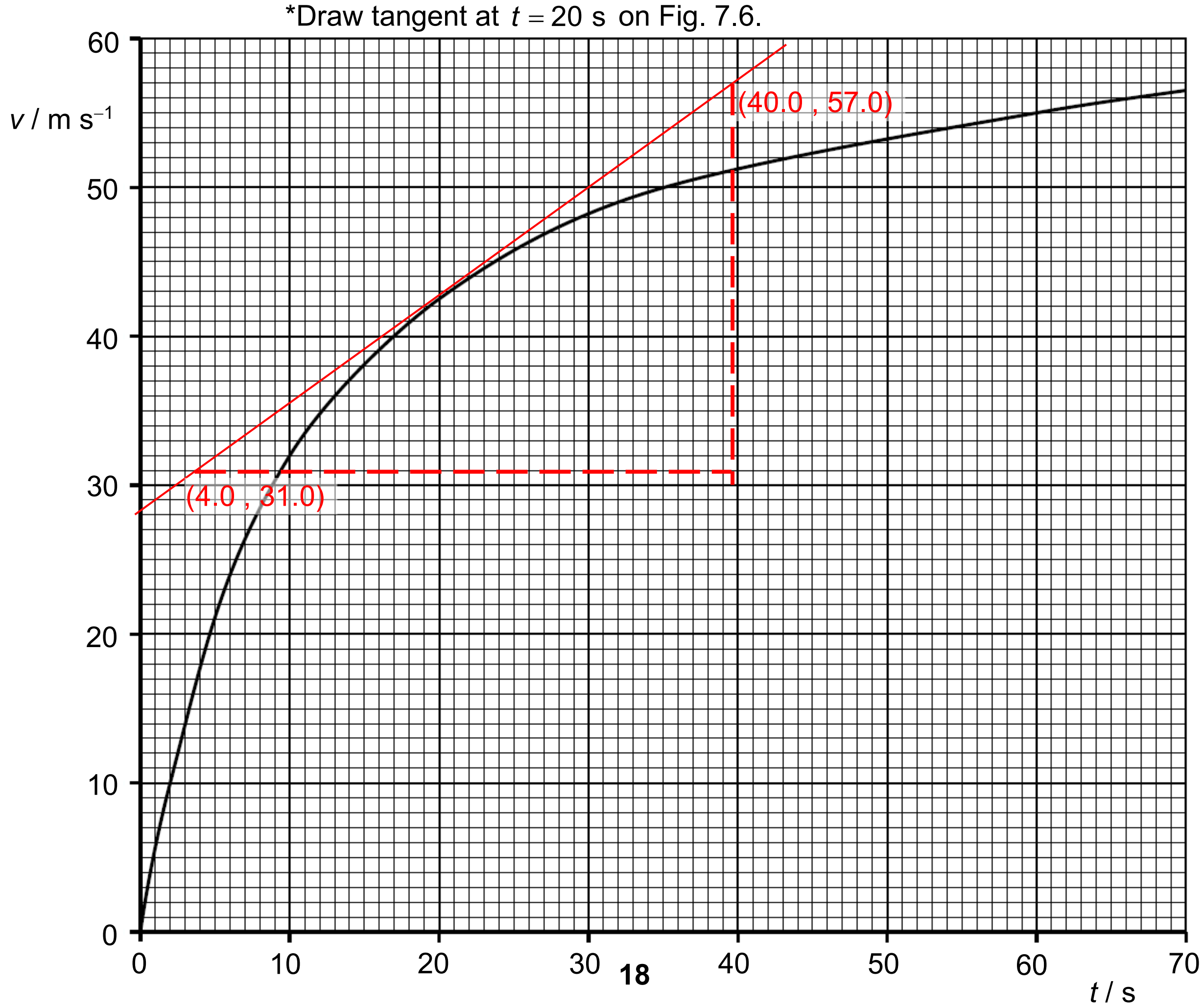
Fig. 7.3 **Fig. 7.4**

(ii) The passenger will oberve the box to accelerate (fly) forward away from him and hit the floor further in front of him compared to in (b)(i)1. where the box hit the floor right in front of him.

(c) (i) 1.

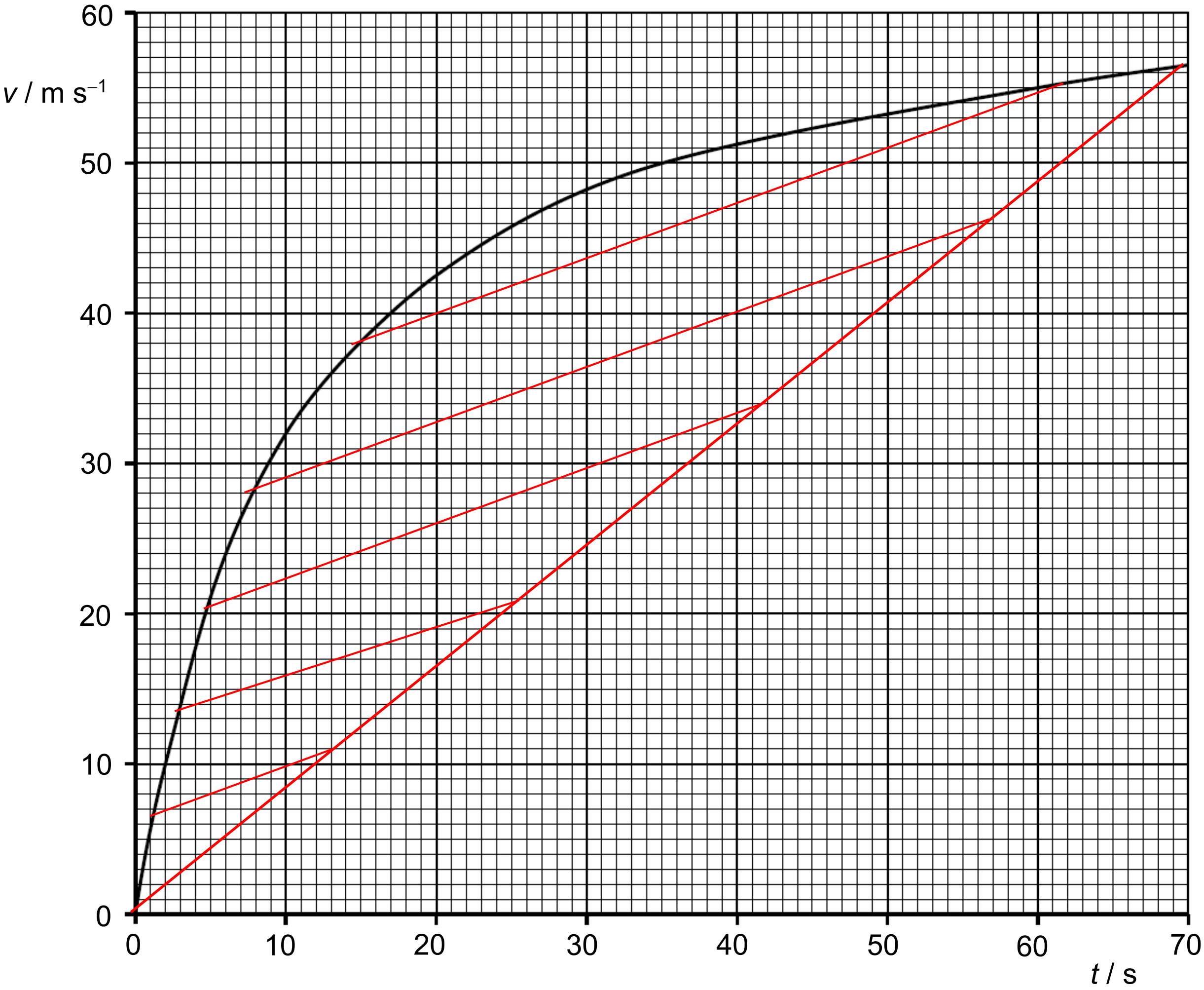
$$\text{acceleration} = \text{gradient} = \frac{57.0 - 31.0}{40.0 - 4.0} = \frac{26.0}{36.0} = 0.722 \text{ m s}^{-2}$$

*Draw tangent at $t = 20$ s on Fig. 7.6.



2. From Fig. 7.6, at $t = 20$ s, $v = 42.5$ m s^{-1}
From Fig. 7.5, at $v = 42.5$ m s^{-1}, $F_R = 215$ N
By Newton's second law,
$F_{\text{drive}} - F_{\text{R}} = ma$
$390 - 215 = m(0.722)$
$m = 242.38 = 242$ kg

(ii) **1.**



*Draw straight line from v at $t = 0$ s to $t = 70$ s
*Shade area between straight line and curve

2. The student's statement is correct.
Average acceleration is given by $\frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t}$ which is the same for both pods in the first 70 s.

Comments

(a) **(i)** Well attempted, but a handful of candidates did not give the answer to a greater number of s.f. before rounding off to 2 s.f. as required.

(ii) Many candidates just stated 1.5 min or 1.6 min without any working. This does not warrant any mark as the question clearly stated "Explain your working".

Most candidates are able to get the mark for calculating the constant speed and stating the correct time taken. However, to get full credit, a comparison must be made before and after that stated time to show that the speed was still increasing before the stated time.

(iii) Well attempted. Some candidates mentioned "friction", but the context is the pod is "hovering" in "vacuum" so this is not accepted.

(b) **(i)** **1.** Many candidates think the box would land at the back, which is incorrect. Relative to the passenger, he is releasing the box from rest, though both are moving forward with the same constant speed. Hence, relative to the passenger, the box should just drop vertically down and land at his foot.

2. Many candidates had the following mistakes:
Drop vertically downwards
Straight diagonal across
Parabolic backwards
Parabolic forward but doesn't hit the final position of box

The question asked for the path of the box as seen by an observer outside the pod. From outside the pod, since the oberserver is stationary, he will see the box moving forward with a horizontal velocity, together with the pod and passenger, while accelerating downwards due to gravity. Hence, the path he observes will be a parabolic one with a initial horizontal velocity.

(ii) Since the passenger is decelerating, the passenger is slowing down while the box continues to move forward with constant velocity. Hence the passenger, will observe the box as accelerating forward, relative to him, landing way in front of his foot.

(c) **(i)** **1.** Many candidates did not draw the gradient at $t = 20$ s, but elsewhere and this affects the gradient significantly as the graph curves a lot in that region.

2. Many candidates read the resistive force wrongly (many wrote 50 N).

(ii) **1.** Well attempted, but some left blank either due to carelessness or ran out of time.

2. Very well attempted.