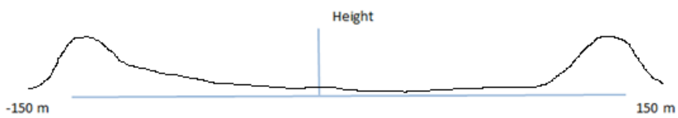
Q	Evidence	1–4 Below Schol	5–6 Scholarship	7–8 Outstanding
ONE (a)(i)	The restoring force must be directly proportional to the negative of the displacement.	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(a)(ii)	$\omega = \dfrac{2\pi}{T}$ $v_{\max} = A\omega = \dfrac{2\pi \times 150}{60} = 15.7079\ \text{m s}^{-1}$			
(b)	Total energy = $GPE_{\text{half way}} + KE_{\text{half way}}$ Total energy is found by $\dfrac{1}{2}mv^2 = mgh$ and that gives 12.58 m $Mg \times 12.58 = Mgh + \frac{1}{2} M (\omega^2 (150^2 - 75^2))$ Gives $h = 3.15$ m			
(c)(i)	 The profile is higher on each side (points A and C) with the shallowest region at point B. The profile is higher at A and C because the wagon, moving slowly at these points of the motion, spends more time at these locations. The sideways motion of the falling sand can be ignored if the distance fallen to the track is regarded as negligible.			
(ii)	Everything is constant apart from the total energy and force of the system.			
(d)	$R^2 = (R - 12.58)^2 + 150^2$ $R = \dfrac{150^2 + 12.58^2}{25.16} = 901\ \text{m}$ Angle the wagon moves through = $\sin^{-1}\left(\dfrac{150}{901}\right) = 9.6°$ This is close to the small angle limit so the motion should be acceptable to be treated as SHM.			

Q	Evidence	1–4 Below Schol	5–6 Scholarship	7–8 Outstanding
2 (a)	This system of two springs in series is equivalent to a single spring, of spring constant k. For spring 1, from Hooke's Law $F = k_1 x_1$ where x_1 is the deformation of spring. Similarly if x_2 is the deformation of spring 2 we have $F = k_2 x_2$ Total deformation of the system $x_1 + x_2 = \frac{F}{k_1} + \frac{F}{k_2}$ $\Rightarrow x_1 + x_2 = F\left(\frac{1}{k_1 + k_2}\right)$ Rewriting and comparing with Hooke's law we get: $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	$F_o = k\Delta x_2$ from Using part a $\frac{1}{k} = \frac{1}{k_1} + \frac{1}{k_2}$ – this rearranged gives the above expression.			
(c)	Different amplitudes, both masses will move in negative phase with each other because the centre of mass will stay at a constant position – overall motion is SHM.			
(d)	Energy conservation and momentum conservation. $k_{\text{effective}} = 3.3\frac{N}{m}$ using the expression in (a). Using the numbers provided ($F = 2N$ and k =3.3) implies that $\Delta x_2 = 0.6$ m. That extension produces the store of energy $= \frac{1}{2}k_{\text{eff}}x^2$ – that energy will be shared between the masses. When they are at max velocity (no stored elastic energy) – all energy will be kinetic therefore $\frac{1}{2}m_1 v_1^{\,2} + \frac{1}{2}m_2 v_2^{\,2} = \frac{1}{2}kx^2 = 0.6$ J and $m_1 v_1 = m_2 v_2$ due to conservation of momentum (or the fact that the centre of mass doesn't move). This gives $v_1 = \frac{3}{2}v_2$ substituting into the above energy equation and solving gives $v_2 = 0.4$ m s^{-1}			
(e)	The period of oscillation will alter and increase as there is more mass in system. The amplitude will be unchanged (since no E_k at end points). The maximum speed will decrease as overall E is constant. The centre of mass motion will be unchanged.			

<table>
<tr><th>Q</th><th>Evidence</th><th>1-4 marks</th><th>5-6 marks</th><th>7-8 marks</th></tr>
<tr><td>3 (a)</td><td>$f = \text{s}^{-1} \quad r = \text{m} \quad v_\text{w} = \text{m s}^{-1}$
$\text{St} = \frac{fr}{v_\text{w}} = \frac{\text{s}^{-1}\text{ m}}{\text{m s}^{-1}} = 1 \text{ (dimensionless)}$</td><td rowspan="6">Thorough understanding of these applications of physics.
OR
Partially correct mathematical solution to the given problems.
AND / OR
Partial understanding of these applications of physics.</td><td rowspan="6">(Partially) correct mathematical solution to the given problems.
AND / OR
Reasonably thorough understanding of these applications of physics.</td><td rowspan="6">Correct mathematical solution to the given problems.
AND
Thorough understanding of these applications of physics</td></tr>
<tr><td>(b)</td><td>If the tension increases, then effectively a mass element in the wire will experience a greater acceleration leading to a greater velocity. If the mass / length is lower, then the acceleration experienced will also be greater leading to a greater velocity. Overall the velocity will be proportional to the tension and inversely proportional to the mass / length.</td></tr>
<tr><td>(c)</td><td>$T = \frac{175 \times 9.81}{2} = 858 \text{ N}$
$\text{St} = \frac{fr}{v_\text{w}} \Rightarrow r = 10^{-2} \text{ m}$
$\mu = \pi \times (10^{-2})^2 \times 1 \times 8 \times 10^3 = 2.51 \text{ kg m}^{-1}$
$v = \sqrt{\frac{858}{2.51}} = 18.48 = 18 \text{ m s}^{-1}$</td></tr>
<tr><td>(d)(i)</td><td>$T_1 + T_2 = 175 \times \text{g} = 1716.75 \text{ N}$
$4 \ T_1 = 2 \times 100 \times \text{g} + 3 \times 75 \times \text{g}$
$T_1 = \frac{4169.25}{4} = 1042 \text{ N}$
$T_2 = 674.4375 \text{ N}$
$v_1 = \sqrt{\frac{T_1}{\mu}} = 20.365 \text{ m s}^{-1}$
$v_2 = \sqrt{\frac{T_2}{\mu}} = 16.381 \text{ m s}^{-1}$
$\text{Wavelength } 1 = \frac{v_1}{200} = 10.18 \text{ cm}$
$\text{Wavelength } 2 = \frac{v_2}{200} = 8.19 \text{ cm}$</td></tr>
<tr><td>(d)(ii)</td><td>Beats require slightly different frequencies. If the wind is to produce the frequency, then the wires have the same radius then this will not result. So one possibility is to slightly alter the radius of one of the wires.</td></tr>
</table>

Question	Evidence	1-4 marks	5-6 marks	7-8 marks
4 (a)	Force on an object mass m due to gravity = $\frac{GMm}{R^2}$ $M = \frac{4}{3}\pi R^3 \rho$ (where ρ is the density of the planet, assumed constant) $F = \frac{4}{3}\pi \rho G m R$ The force of gravity is in the opposite direction to the displacement R measured from the centre of the planet. $F = -\frac{4}{3}\pi \rho G m R$ $F = ma$ $a = -\frac{4}{3}\pi \rho G R$ Acceleration is proportional to – R (since the other terms are constants). This is the condition for SHM.	Thorough understanding of these applications of physics. OR Partially correct mathematical solution to the given problems. AND / OR Partial understanding of these applications of physics.	(Partially) correct mathematical solution to the given problems. AND / OR Reasonably thorough understanding of these applications of physics.	Correct mathematical solution to the given problems. AND Thorough understanding of these applications of physics.
(b)	$a_{max} = \omega^2 A$ (This expression means that a candidate can work out this answer without having managed part (a) by assuming $a_{max} = 9.81$) $T = \frac{2\pi}{\omega} = \frac{2\pi}{\sqrt{\frac{4}{3}\pi \times 5.5\times 10^3 \times 6.67\times 10^{-11}}}$ $T = 5.069\times 10^3$ s			
(c)	Work out the period of the satellite using $\frac{4\pi^2 R}{T^2} = \frac{GM_E}{R^2}$ and spot that the two periods are the same; or recognise that the LEO represents the reference circle for the SHM.			
(d)	The falling object would be subject to a Coriolis force, which would make the object collide with the side of the tube continuously as it fell. The object would start with a tangential velocity at right angles to the radius it is falling along. Deeper parts of the hole will not have as great a tangential velocity, and so the object will be going faster (towards the East) than the hole is going. The object will bang into the east wall of the hole – all the way down.			

FIVE (a)	For a horizontal displacement x: The force of compression from spring 2 is $-kx$. The force of extension from spring 1 is $-kx$. The total force on the mass is $-2kx$. This is a restoring force proportional to the displacement. The condition for SHM.	Shows some understanding of the underlying physics. AND / OR (Partially) correct mathematical solution to given problem.	A reasonable understanding of the underlying physics. AND (Partially) correct mathematical solution to given problem.	Correct mathematical solution to the given problem. AND Thorough understanding of the underlying physics.
(b)	The springs are attached to supports, which are anchored to the ground. As the springs alter the momentum of the moving masses, they also alter the momentum of the supports (and the Earth). The system of the springs and oscillating masses is NOT a closed system and so the law of conservation of momentum does not apply. In the larger system, including the Earth, momentum is conserved.			
(c)(i)	Momentum is conserved so: $M.v_I = (M+m) . v_F$ $v_F = \frac{M.v_1}{(M+m)}$ Initial energy (E) = ½ $M . v_I^2$ Final energy (F) = ½ $(M+m) . v_F^2$ Substitute for v_F $F = \frac{\frac{1}{2}(M+m).M^2.v_1^2}{(M+m)^2}$ Cancel $(M+m)$. Replace ½ $M . v_I^2$ with E $F = \frac{M}{M+m}.E$ Final energy is a factor of $\frac{M}{(M+m)}$ of the initial Energy.			
(c)(ii)	There is no change in the energy of the system. All the initial energy is potential energy in the springs. This does not change when the mass is added. So the total energy stays the same.			
(d)	$F = \mu mg$ is the maximum frictional force on mass m. If ma (the accelerating force) is greater than the maximum frictional force, then the mass "m" will slip. So "a" must be less than or equal to μg a_{MAX} of the SHM = $A\omega^2$ $2kx = F = (M+m)a$ $a_{MAX} = \frac{2kA}{(M+m)}$ $\omega^2 = \frac{2k}{(M+m)}$ m will slip when $m\omega^2 A = \mu mg$ when $A = \mu g \frac{(M+m)}{2.k}$			