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Level 3 Physics, 2016

91524 Demonstrate understanding of mechanical systems

2.00 p.m. Tuesday 15 November 2016
Credits: Six

Achievement	Achievement with Merit	Achievement with Excellence
Demonstrate understanding of mechanical systems.	Demonstrate in-depth understanding of mechanical systems.	Demonstrate comprehensive understanding of mechanical systems.

Check that the National Student Number (NSN) on your admission slip is the same as the number at the top of this page.

You should attempt ALL the questions in this booklet.

Make sure that you have Resource Booklet L3–PHYSR.

In your answers use clear numerical working, words and/or diagrams as required.

Numerical answers should be given with an SI unit, to an appropriate number of significant figures.

If you need more room for any answer, use the extra space provided at the back of this booklet.

Check that this booklet has pages 2–8 in the correct order and that none of these pages is blank.

YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Excellence

TOTAL 22

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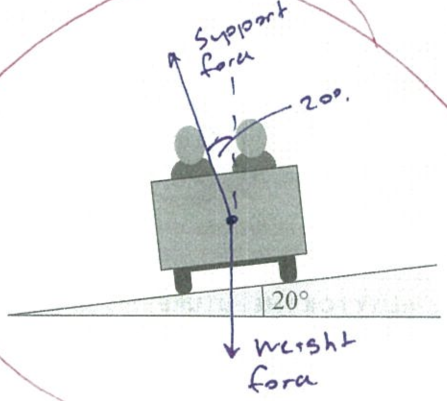
QUESTION ONE: CIRCULAR MOTION

Alice is in a car on a ride at a theme park. The car travels along a circular track that is banked, as shown in the diagram below.

The candidate correctly draws and labels two force vectors.



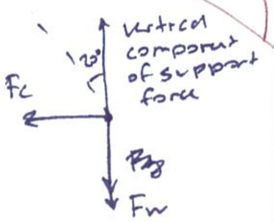
(a) On the diagram above, draw labelled vectors showing the two forces acting on the car.

You may assume that friction is negligible.

(b) The mass of the car and passengers is 9.60×10^2 kg. The track is banked at an angle of 20°.

Use a vector diagram to calculate the size of the centripetal force on the car.

Vector diagram:



$F_w = ma = 9.60 \times 10^2 \times 9.81$

$= 9417.6\text{N}$

$\tan 20 = \frac{F_c}{F_w}$

$F_c = F_w \times \tan 20$

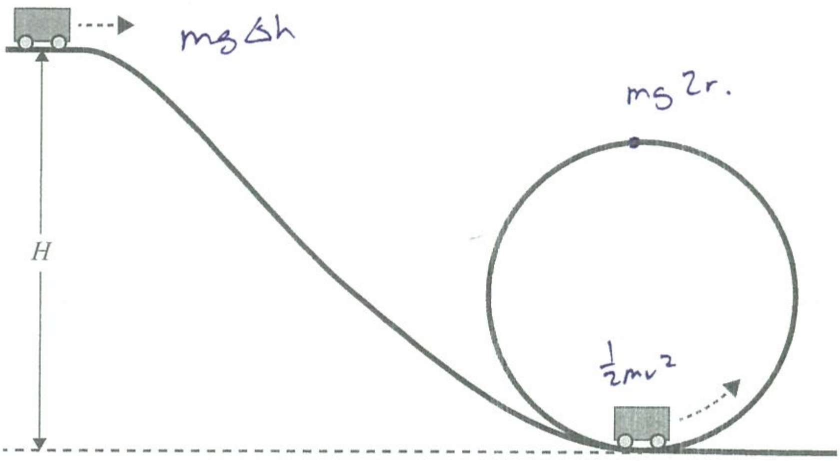
$= 3427.7$

$= 3430\text{N}.$

Correct understanding for the vector diagram and the correct working for the size of the centripetal force with correct answer.

The following diagram shows part of a roller coaster track with the car at two positions.

Position A



Position B

(c) Compare the force that the track exerts on the car when the car is at the top of the hill (Position A), with the force that the track exerts on the car when the car is at the bottom of the hill, entering the loop (Position B).

Explain your answer.

At position A the track exerts ~~an~~ an equal and opposite weight force $F=mg$ to the force ~~that~~ the car exerts on the track.

However at position B since the car is in circular motion there is centripetal force acting on the car. As the force that the track exerts on the car provides this centripetal force the force exerted on the car by the track is greater at position B since it also provides the additional centripetal force on top of ~~[illegible]~~ exerting an equal and opposite weight force of the car.

centripetal force acts upwards on the car at position B towards the centre of the loop

The candidate gives the complete answer for both positions with links between concepts.

(d) At the top of the circular loop the force that the track exerts on the car is zero.

Using energy considerations, calculate the height H, of the hill if the radius of the loop is 5.00 m.

You may assume that friction is negligible.

On top of the hill the car has $E_p = mgH$ and ~~[illegible]~~ at the top of the circular loop has $E_p = mg2r$ and $E_k = \frac{1}{2}mv^2$. Since energy is conserved because friction is negligible, the two energy values must equal.

$mgH = mg2r + \frac{1}{2}mv^2$

~~$H=2r$~~ ~~(2×5)~~ ~~$(r=5m)$~~

~~[illegible]~~ $F_c = F_g$

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

$v^2 = gr$

$\therefore mgH = mg2r + \frac{1}{2}mgr$

~~$H = g2r + \frac{1}{2}mgr$~~ ~~mg~~

~~$= 9.8 \times 2 \times 5 + \frac{1}{2} \times 9.8 \times 5^2 \times$~~

$H = 2r + \frac{1}{2}r$

$= \frac{5}{2}r$

$= \frac{5}{2} \times 5$

$= 12.5\text{ m}$

Correct working and answer.

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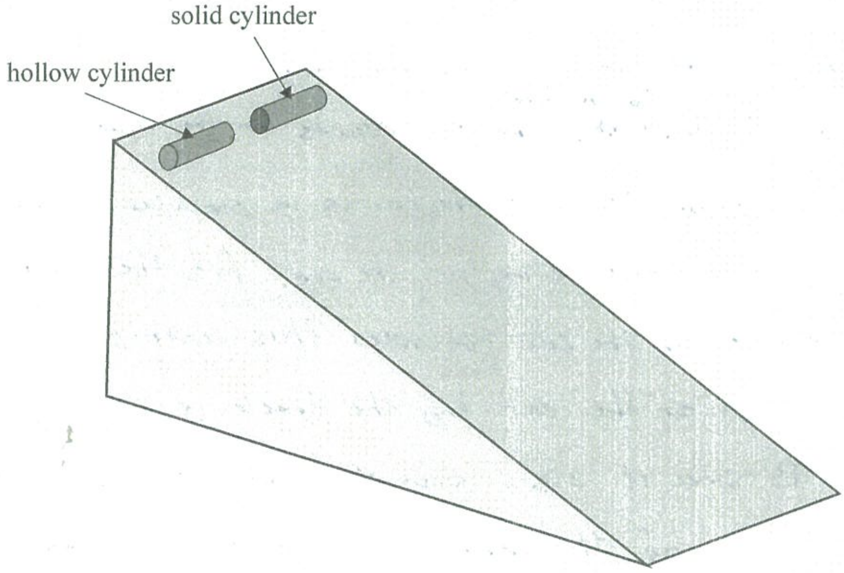
QUESTION TWO: ROTATIONAL MOTION

A solid cylinder and a hollow cylinder of the same shape and mass are rolled down a slope.



(a) State the energy changes that take place as the cylinders roll down the slope.

You may assume that there is negligible heat and sound energy produced.

As the cylinders roll down the slope gravitational potential energy is converted into both rotational kinetic energy and linear kinetic energy.

Correct explanation.

(b) The hollow cylinder has a radius of 0.058 m. It rolls down the slope, and reaches a speed of 0.250 m s^{-1} at the bottom.

The rotational inertia of the hollow cylinder is 0.140 kg m^2.

Calculate the rotational kinetic energy of the hollow cylinder at the bottom of the slope.

$E_{k(ROT)} = \frac{1}{2} I \omega^2$

$v = r\omega$

$\omega = \frac{v}{r} = \frac{0.25}{0.058} = 4.31 \text{ rad s}^{-1}$

$E_{k(ROT)} = \frac{1}{2} \times 0.14 \times 4.31^2$

$= 1.3 \text{ J}$

Correct equation and evidence for calculating the rotational kinetic energy.

(c) The hollow cylinder starts from rest and has an angular acceleration of 1.72 rad s^{-2}.

Calculate the time taken to complete the first full rotation.

$\omega_i = 0$ $\alpha = 1.72\ rad\,s^{-2}$ $\theta = 2\pi\ rad$ $t = ?$

$\omega_f^2 = \omega_i^2 + 2\alpha\theta$

$\omega_f = \sqrt{\omega_i^2 + 2\alpha\theta}$

$= \sqrt{0 + 2\times1.72\times2\pi} = 4.65\ rad\,s^{-1}$

$\omega_f = \omega_i + \alpha t$

$t = \frac{\omega_f - \omega_i}{\alpha} = \frac{4.65 - 0}{1.72} = 2.7s.$

Correct equation and evidence for calculating the time taken to complete the first full rotation.

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(d) The solid and the hollow cylinders are both released at the same time from the top of the slope.

Explain why the solid cylinder reaches the bottom of the slope first.

Since the ~~ho~~ hollow cylinder has a greater proportion of its mass distributed further from its centre of rotation compared to the solid cylinder it has a greater rotational inertia since $I \propto r^2$ (distance of mass from the centre of rotation). Therefore, the ~~h~~ hollow cylinder gains a higher proportion of rotational kinetic energy from gravitational potential and so less linear kinetic energy. As it gains ~~a~~ less linear kinetic energy its speed at the bottom of the slope will be smaller than that of the solid cylinder, meaning it has less (linear) acceleration. Hence, the hollow cylinder reaches the bottom of the slope later than the solid cylinder as it has a smaller (linear) acceleration.

The candidate correctly links two ideas by stating that hollow cylinder has greater rotational inertia since it has all its mass further away from the centre and then correctly links two ideas to conservation of energy.

QUESTION THREE: SIMPLE HARMONIC MOTION

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A toy bumble bee hangs on a spring suspended from the ceiling in the laboratory. Tom pulls the bumble bee down 10.0 cm below equilibrium and releases it. The bumble bee moves in simple harmonic motion.

(a) State the two conditions necessary for simple harmonic motion.

Acceleration must be proportional to displacement.

Acceleration must always act in the opposite direction to displacement i.e. towards the equilibrium position.

Two conditions stated correctly.

(b) The bumble bee's oscillation has a period of 1.57 s.

Calculate the bumble bee's acceleration at time t = 0.25 s after Tom releases the bumble bee from the lowest point.

$\omega = \frac{2\pi}{T} = \frac{2\pi}{1.57} = 4 \text{ rads}^{-1}$

$a = -A\omega^2 \cos \omega t$

$= -0.1 \times 4^2 \times \cos(4 \times 0.25)$

$= -0.86 \text{ ms}^{-2}$ or ~~0.86ms⁻¹~~ 0.86 ms^{-2} towards equilibrium position.

Correct working and answer for the bumble bee's acceleration.

(c) Tom pushes the toy bumble bee with a very small force at regular intervals of time (periodically), so that eventually it is moving up and down with a very large amplitude.

State the name of this phenomenon.

Explain how the bumble bee's motion develops a very large amplitude.

(d) Tom stops pushing the bumble bee when its displacement is 20 cm.

Using the axes given below, draw a graph of displacement against time for three complete oscillations, starting from $y = +20$ cm.

Include appropriate values on both axes.

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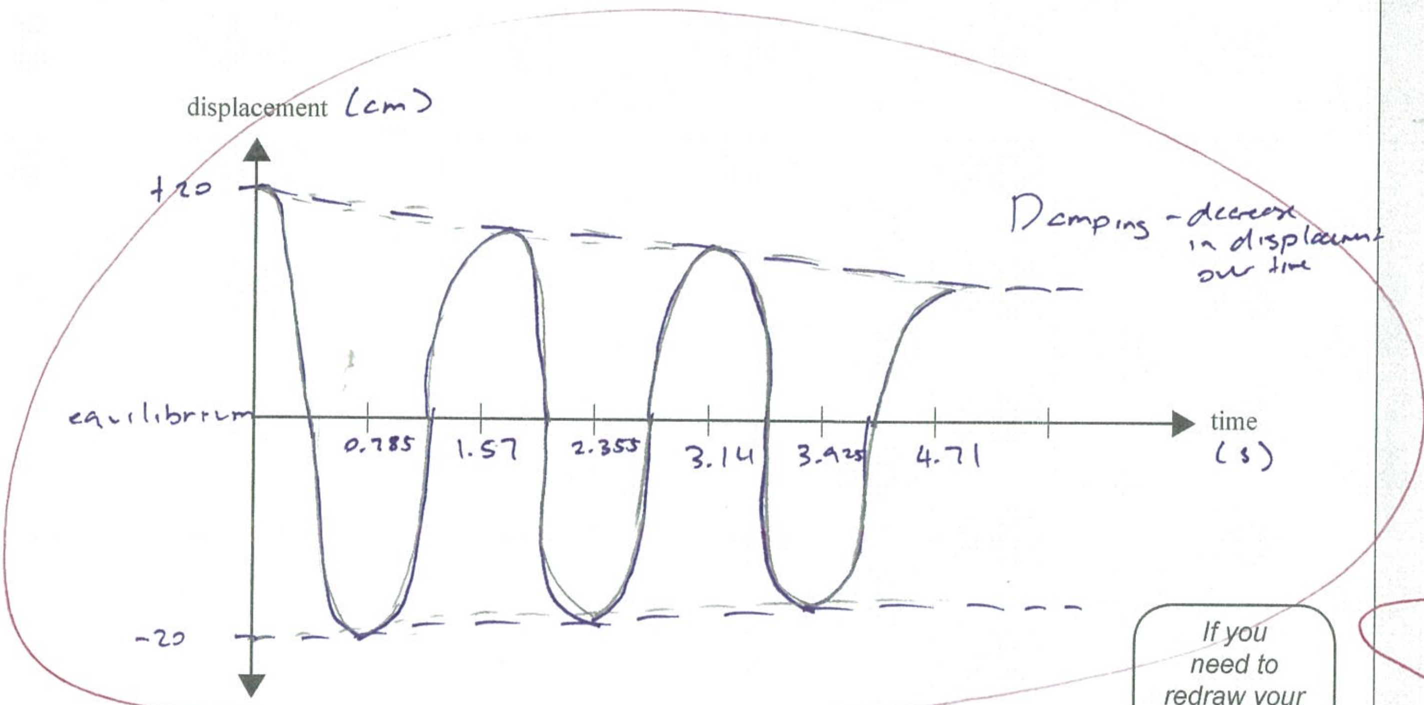
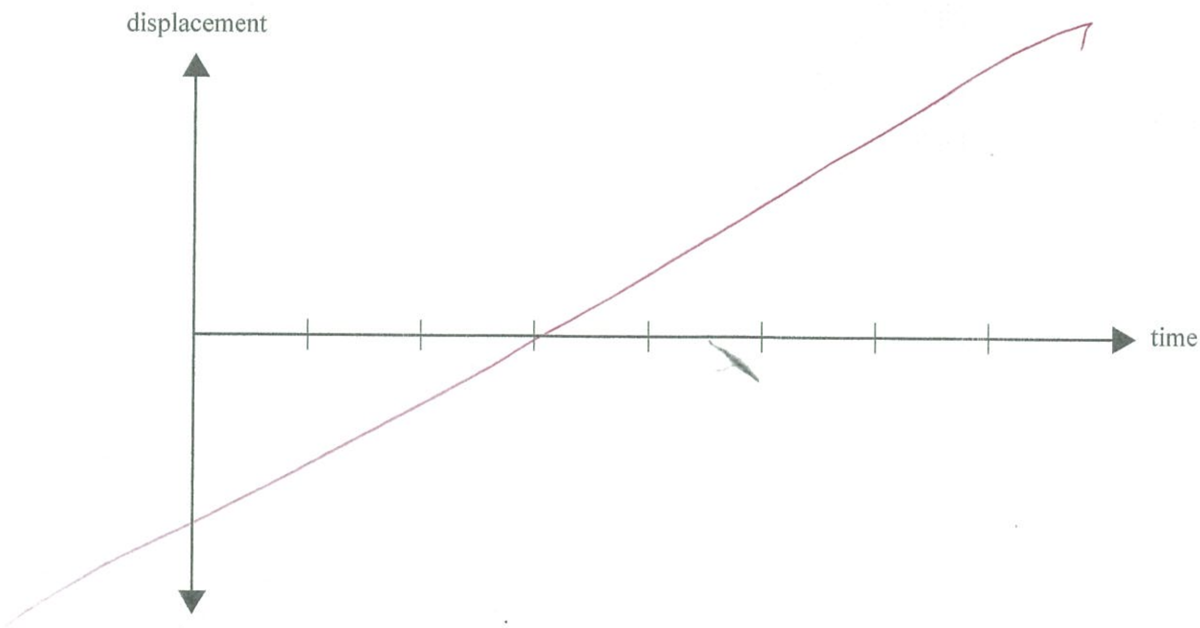


Correctly draws damped shape for 3 complete cycle starting at +20cm, has a constant period and includes appropriate values on both the axes.

If you need to redraw your response, use the diagram below.

SPARE DIAGRAM

If you need to redraw your response to Question Three (d), use the diagram below. Make sure it is clear which answer you want marked.



Extra paper if required.
Write the question number(s) if applicable.

QUESTION NUMBER

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