No part of the candidate's evidence in this exemplar material may be presented in an external assessment for the purpose of gaining an NZQA qualification or award.

SUPERVISOR'S USE ONLY

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91524

915240

Draw a cross through the box (☒) if you have NOT written in this booklet

Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Physics 2023

91524 Demonstrate understanding of mechanical systems

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 appropriate SI unit.

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 2–12 in the correct order and that none of these pages is blank.

Do not write in any cross-hatched area (DO NOT WRITE IN THIS AREA). This area will be cut off when the booklet is marked.

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

Merit 15

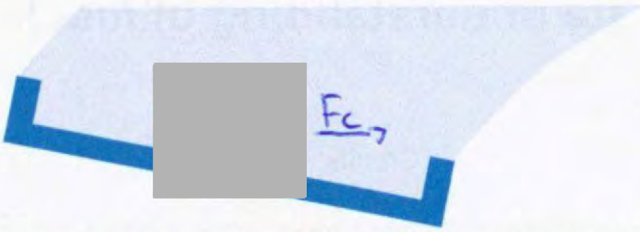
QUESTION ONE: HORIZONTAL AND VERTICAL CIRCLES

Tane has a toy car track set. Part of the track is a horizontal banked curve and part of it has a vertical loop. For this question, assume that sideways friction on the tyres is negligible. The toy car has a mass of 0.120 kg.

Source: www.walmart.ca/en/ip/hot-wheels-massive-loop-mayhem-track-set-multi/6000203404407

(a) On the diagram below, draw a vector diagram to identify the net force that is responsible for the car going in a horizontal circle along the banked curve. Label the net force.

0.75



If you need to redraw your response, use the diagram on page 9.

Source: www.shutterstock.com/image-vector/red-sports-car-front-view-156275714

(b) The banked curve of the car track has a radius of 0.750 m.

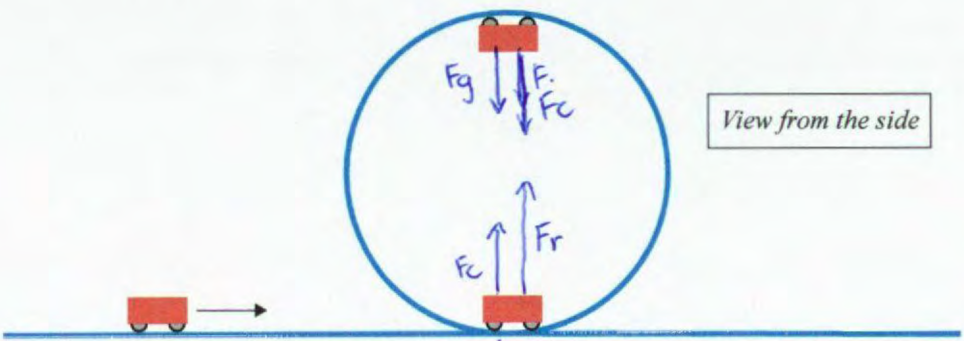
Calculate the angle of banking when there is no sideways friction on the wheels of the car as it goes around the banked curve at 1.55 m s^{-1}.

~~$0.12 \times 9.81 = 1.1772 = F_g$~~ $0.12 \times 9.81 = 1.1772 = F_g$

~~$\tan^{-1}\left(\frac{0.75}{1.177}\right) = 29.9°$~~ $F_c = \frac{0.12 \times 1.55^2}{0.75} = 0.3844$

$\tan^{-1}\left(\frac{0.384}{1.1772}\right) = 18.1°$

The diagram below is a simplified version of the vertical circular loop that makes up part of the car track.



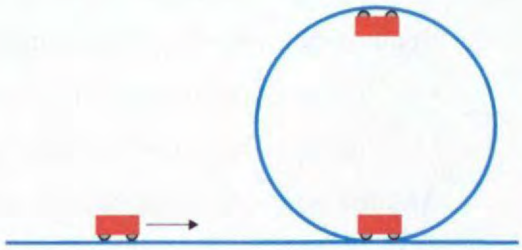
If you need to redraw your response to part (c), use the diagram on page 9.

(c) Explain why the person sitting in a car on an actual roller coaster would feel heavier at the bottom of the loop compared to the top of the loop.

Begin your answer by drawing labelled vectors in the diagram at the bottom of the opposite page, to represent the forces acting on the car when it is at the top of the loop AND when it is at the bottom of the loop.

At the bottom of the loop, $F_c = F_r - F_g$, so the reason a person would feel heavier is because the reaction force must be greater than the F_g in order to contribute to the F_c. At the top, a person would not feel heavy, as there is minimal/no reaction force, and so $F_c = F_g$ at the top of the loop.

(d) The toy car of mass 0.120 kg approaches the vertical circular loop of radius 0.250 m.



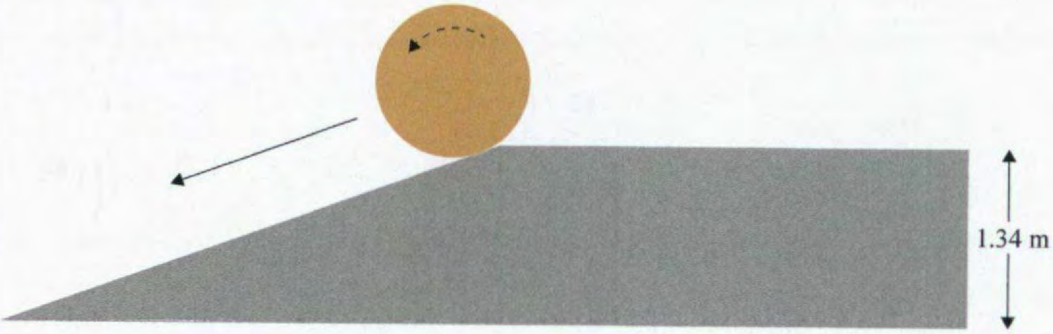
Calculate the speed with which the car must approach the bottom of the loop to be able to go around the vertical circular loop, such that the car seems weightless at the top of the loop.

$v = \sqrt{gr}$ so $\sqrt{9.81 \times 0.25}$

$v = 1.57\ ms^{-1}$

QUESTION TWO: ROTATIONAL MOTION

Tane works weekends unloading barrels. In one instance he rolls an empty barrel of mass 5.50 kg and radius 0.280 m, down a ramp that is 1.34 m high. The linear speed of the barrel when it reaches the bottom of the ramp is 3.40 m s^{-1}.



(a) Describe the energy changes that take place as the barrel rolls down the ramp.

$E_{(grav.pot.)} \rightarrow E_{K\,lin} + E_{K\,ROT}$

(b) Calculate the rotational inertia of the barrel.

Begin your answer by calculating:

- the gravitational potential energy at the top
- the angular velocity of the barrel as it reaches the bottom of the ramp.

Assume no energy is lost due to friction.

~~I ≠ ½m~~ $I = mr^2$

$E_p = mgh$ so $5.5 \times 9.81 \times 1.34 = 72.3\,J$

$\omega = \frac{v}{r}$ so $3.4 \div 0.28 = 12.1\,rads^{-1}$

$I = E_K \div \frac{1}{2}\omega^2$ ~~so I~~ =

Since friction is negligable, $E_p = E_K$

$72.3 \div (\frac{1}{2} \times 12.1^2) = 0.988\,kgm^2$

Tane then sits on a swivelling stool, holding a full bottle of water in each hand. He notices that when he holds the bottles with his arms outstretched, he tends to spin more slowly, as compared to when he brings his arms inwards, close to his body.

Source: www.exploratorium.edu/snacks/momentum-machine

(c) Explain the reason for this observation.

Tane is decreasing his rotational inertia by bringing mass closer to his rotational axis. Since $r\downarrow$, $I\downarrow$ $I = mr^2$
Since angular momentum is conserved, angular velocity increases due to $\downarrow I = \frac{L}{\omega}\uparrow$, and so Tane spins faster, e.g. more angular velocity

(d) Tane spins with an angular velocity of 3.00 rad s^{-1} when his arms are outstretched. When he brings his arms in, he reaches an angular velocity of 7.00 rad s^{-1} in a time of 4.50 s.

Calculate:

- his angular acceleration
- the number of revolutions made in this time.

$\Delta w = 4 \text{ rads}^{-1}$ $\quad \alpha = \frac{4.00}{4.50}$ $\quad \alpha = 0.889 \text{ rads}^{-2}$

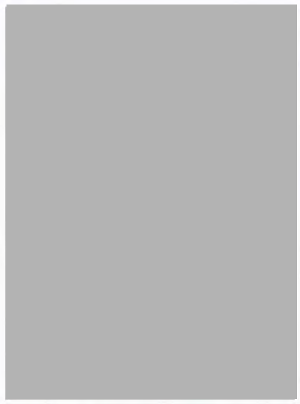
$\Delta w = \alpha \Delta t$ so $0.889 \times 0.45 = 4.00$

$4.00 \div 2\pi = f = 0.637 \text{ Hz}$

$T = \frac{1}{0.637}$ $\quad T = 1.57\text{s}$

$4.50 \div T = 2.86$ revolutions in 4.50s

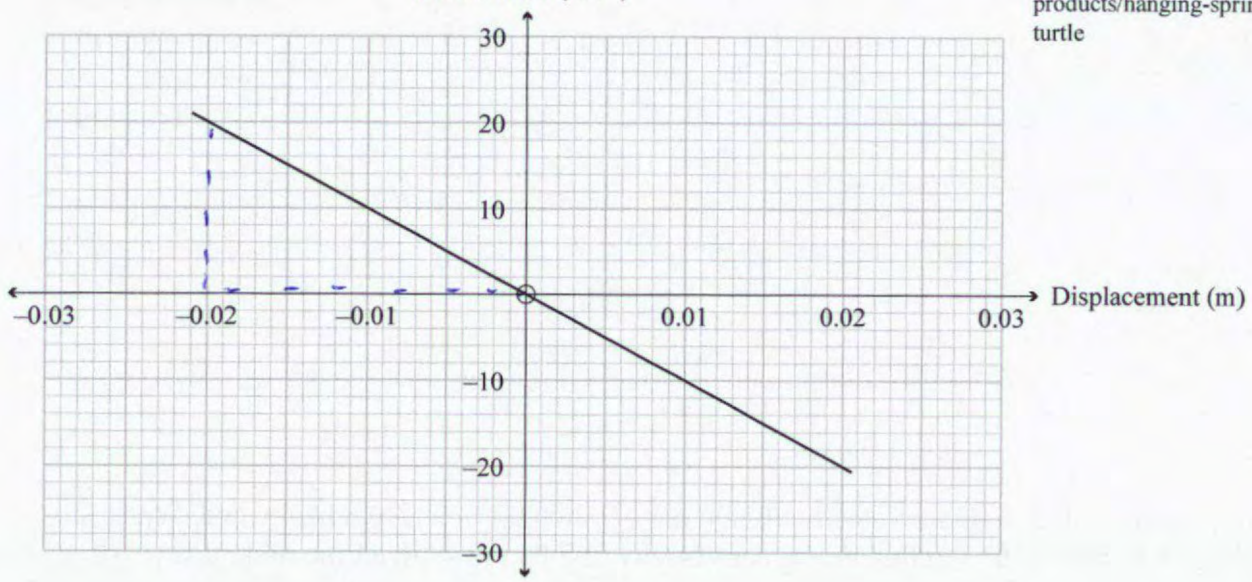
QUESTION THREE: SIMPLE HARMONIC MOTION



Source: www.ponylane.co.nz/products/hanging-spring-toy-turtle

Tanya is studying the motion of a toy bouncing up and down at the end of a spring that is hanging from the ceiling. The spring has a spring constant of 24.6 N m^{-1}.

Tanya draws an acceleration against displacement graph, as shown below, of the toy on the spring that is bouncing up and down in simple harmonic motion.



(a) Given the equation relating to simple harmonic motion as $a = -\omega^2 y$, describe how the gradient of the graph line relates to the frequency of oscillation.

$\frac{a}{y}$ = gradient so $-\omega^2$ is gradient = angular ~~freq~~ frequency

gradient is negative because ω acts in opposite direction

(b) By calculating the gradient of the graph, show that the period of oscillation is $T = 0.199$ s, and hence determine the mass of the toy hanging on the spring.

$20 \div -0.02 = -1000$ so $-1000 = -\omega^2 \cancel{y}$ so

$1000 = \omega^2$ so $\omega = 31.6$

$\omega / 2\pi = f$ so $f = 5.03$ Hz

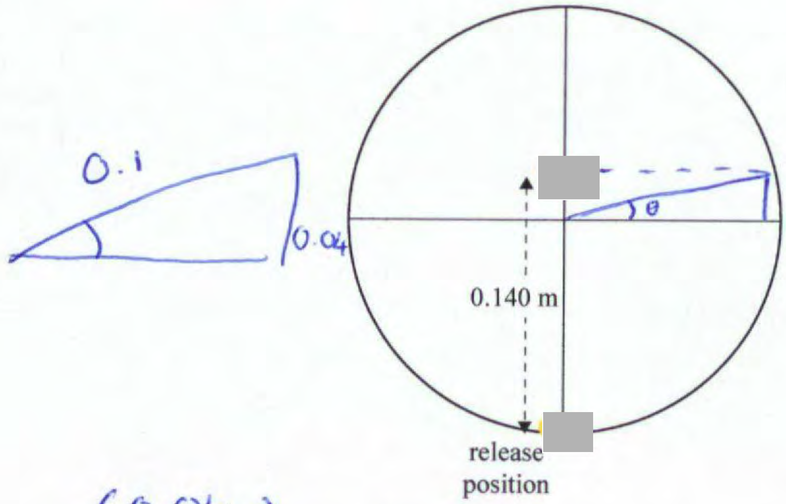
$T = \frac{1}{5.03}$ so $T = 0.199$ s

$(T^2 K) \div 4\pi^2 = m$

$m = 0.025$ kg

(c) Tanya then pulls the spring of period $T = 0.199$ s **down** through a distance of 0.100 m from the equilibrium position, and then releases it so that the toy bounces up and down in simple harmonic motion.

By using a reference circle or otherwise, calculate the time the toy on the spring would take to travel a distance of 0.140 m up from its release position.



If you need to redraw your response, use the diagram on page 9.

$\sin^{-1}\left(\frac{0.04}{1.00}\right) = 23.58°$

$\frac{1}{4}T = \frac{1}{4} \times 1.99 = 0.4975\,s$

$360 \div 23.58 = 15.27\%$ of 360

$0.1527 \times 1.99 = 0.304\,s$

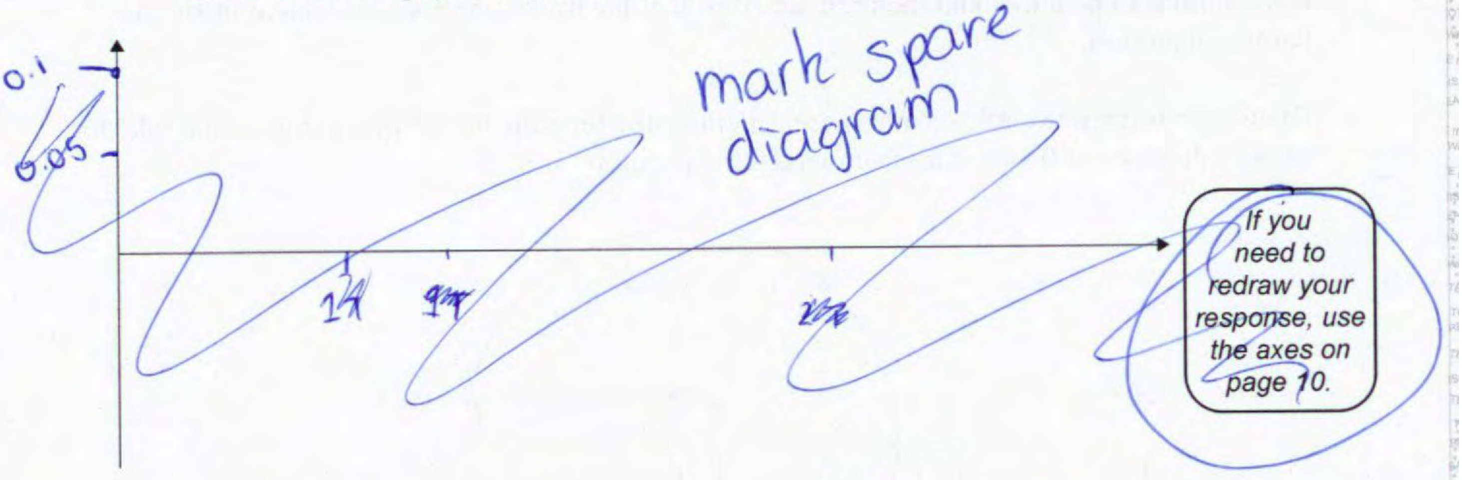
$0.304\,s + 0.4975\,s = t$

$t = 0.801\,s$

Question Three continues on the following page.

(d) Tanya notices that once she has pulled down the toy on the spring by 0.100 m and set it oscillating in simple harmonic motion with a period of $T = 0.199$ s, the amplitude gradually decreases with time, and eventually the toy on the spring stops oscillating.

- State the name of this phenomenon, and explain what causes a decrease in amplitude.
- Using the axes below, draw a graph of amplitude against time for **three complete oscillations**.
- Label axes with physical quantities, units, and values.



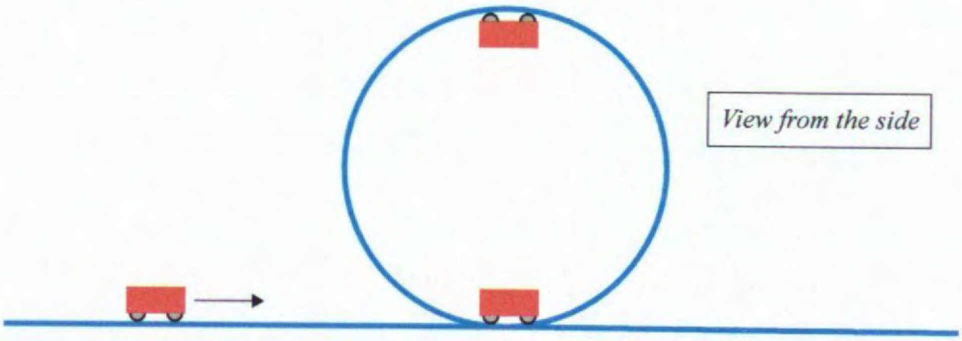
If you need to redraw your response, use the axes on page 10.

This is called damping, which is when amplitude is lost to elastic potential energy

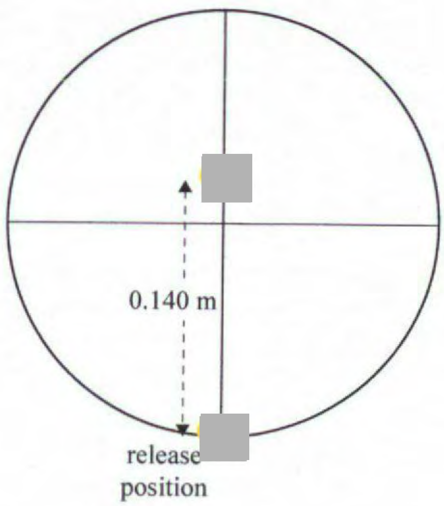
SPARE DIAGRAMS

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

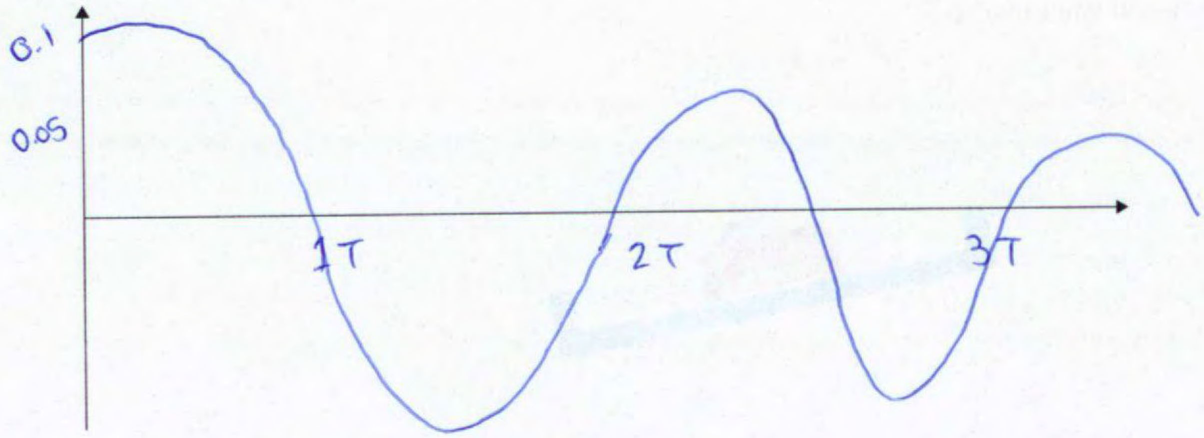
If you need to redraw your response to Question One (c), use the diagram below. Make sure it is clear which answer you want marked.



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



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



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

QUESTION NUMBER

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

QUESTION NUMBER

91524

<table>
<tr><td>Standard</td><td>91524</td><td></td><td></td><td>Total score</td><td>15</td></tr>
<tr><td>Q</td><td>Grade score</td><td colspan="4">Marker commentary</td></tr>
<tr><td>1</td><td>M6</td><td colspan="4">a. Fc labelled.
b. Correctly calculates angle.
c. Identifies Fc=Fr-Fg at the bottom of the loop to explain why they feel heavier at the bottom. And explains feeling of weightlessness at the top. For excellence needed an accurate vector diagram, Fg is shown to vary between top and bottom.
d. Calculates v at top of the loop. For merit needed to determine total energy at the top of the loop. For excellence needed to then use this to determine v at the bottom.</td></tr>
<tr><td>2</td><td>M5</td><td colspan="4">a. Appropriate energy transformations.
b. Determines I based on rotational energy gain only. Ignores linear kinetic energy. For excellence needed to use GPE at start → Ek(lin) + Ek(rot) and subtract Ek (lin) appropriately before calculating I.
c. Uses general formulae to justify the change in velocity.
d. Calculates angular acceleration only. For merit needed to work out the angle of displacement too. For excellence needed to calculate total number of revolutions.</td></tr>
<tr><td>3</td><td>A4</td><td colspan="4">a. Incorrect response. For achieved needed to state graph is linear/gradient is constant then the frequency must be constant or express this in terms of appropriate formulae.
b. Both answers correct.
c. Correct angle from reference circle. For Merit needed to determine total angle and for excellence then determine the time taken.
d. States damping as the phenomena. For Merit needed two more of: correctly shaped cosine curve, labelled axis and source of energy loss. For excellence needed all points.</td></tr>
</table>