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91524



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

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Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 3 Physics 2025

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 the margins (✂/✂/✂). 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

TOTAL 17

QUESTION ONE: MOMENTUM AND CIRCULAR MOTION

Titan is the largest of Saturn's moons. For the sake of this question, you can ignore the gravitational effects of the other moons of Saturn and the rest of the objects in the solar system, and assume that Titan is in a perfectly circular orbit.

Mass of Saturn: 5.68×10^{26} kg

Radius of Saturn: 5.82×10^7 m

Mass of Titan: 1.35×10^{23} kg

Distance between the centres of mass of Saturn and Titan: 1.22×10^9 m

https://science.nasa.gov/wp-content/uploads/2023/07/titan_carousel2.jpg

- (a) Show that the centre of mass of Saturn and Titan is 2.90×10^5 m from the centre of Saturn.

$$X_{\text{COM}} = \frac{m_1 x_1 + m_2 x_2}{m_1 + m_2}, \quad \text{IF SATURN AT } X=0,$$

$$X_{\text{COM}} = \frac{m_2 x_2}{m_1 + m_2} = \frac{1.35 \cdot 10^{23} \cdot 1.22 \cdot 10^9}{5.68 \cdot 10^{26} + 1.35 \cdot 10^{23}} \\ \approx 2.899 \cdot 10^5$$

- (b) Two ice particles around Saturn move toward each other, as shown below. Particle A has a mass of 2.45 kg and a velocity of 8.00 m s^{-1} ; particle B has a mass of 3.20 kg and a velocity of 15.0 m s^{-1} . The particles collide and stick together without losing any mass.

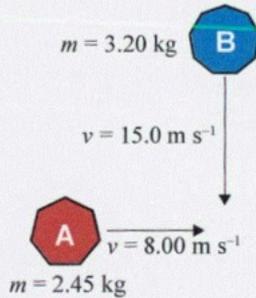
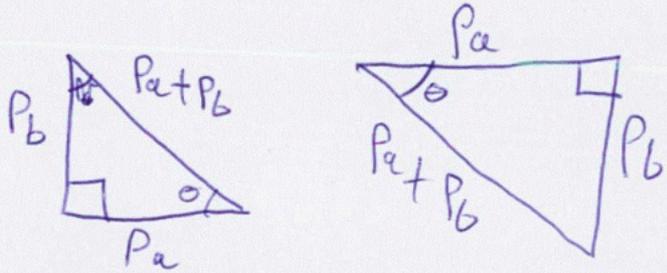


Diagram:



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

Calculate the size and direction of the momentum of the two particles when they are stuck together.

Determine the direction relative to the initial velocity of particle A.

A diagram may assist your answer.

AS MOMENTUM IS CONSERVED, $P_{AI} + P_{BI} = P_{A+P_Bf}$

$$P_{A+P_B} = \sqrt{P_A^2 + P_B^2} = \sqrt{(8 \cdot 2.45)^2 + (3.2 \cdot 15)^2} \\ \approx 51.8 \text{ KG M S}^{-1}$$

$$\theta = \sin^{-1}\left(\frac{P_B}{P_{A+P_B}}\right) \approx \cancel{67.9^\circ} 67.9^\circ$$

- (c) Calculate the time it takes for Titan to complete one orbit of Saturn.

You could begin by calculating the velocity of Titan in its orbit.

$$F_c = F_g \quad \text{so} \quad \frac{mv^2}{r} = \frac{GMm}{r^2}$$

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

$$v^2 = \frac{GM}{r}$$

$$v = \sqrt{\frac{GM}{r}} = \sqrt{\frac{6.67 \cdot 10^{-11} \cdot 5.68 \cdot 10^{26}}{1.22 \cdot 10^9}}$$

$$\approx 5.57 \cdot 10^4 \text{ m s}^{-1}$$

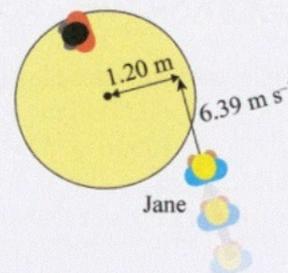
$$\omega = \frac{v}{r} = \frac{5.57 \cdot 10^4}{1.22 \cdot 10^9} = 4.57 \cdot 10^{-5} \text{ RAD s}^{-1}$$

- (d) Future manned missions to the solar system are most likely to be launched from space stations in low earth orbit, similar to the International Space Station. Astronauts on the International Space Station appear to be weightless, even though Earth's gravity is still acting on them.

Explain why astronauts appear to be weightless yet can remain in orbit.

THE ONLY FORCE ACTING ON THE ISS IS GRAVITY.

- (c) Jane has a mass of 52.0 kg. She runs at 6.39 m s^{-1} and jumps onto the stationary roundabout, close to the edge, landing 1.20 m from the axis of rotation, as indicated in the diagram. This causes the roundabout to rotate slowly.



The roundabout and Rihari have a rotational inertia of 430 kg m^2 .

The rotational inertia of a point mass is $I = mr^2$.

Calculate the angular velocity of the roundabout after Jane has jumped on.

$$L_i = L_f, \text{ AS ANGULAR MOMENTUM IS CONSERVED}$$

- (d) Later, Rihari and Jane are both standing on the edge of the roundabout while it is rotating at a constant angular velocity.

Rihari moves inwards, towards the centre of the roundabout.

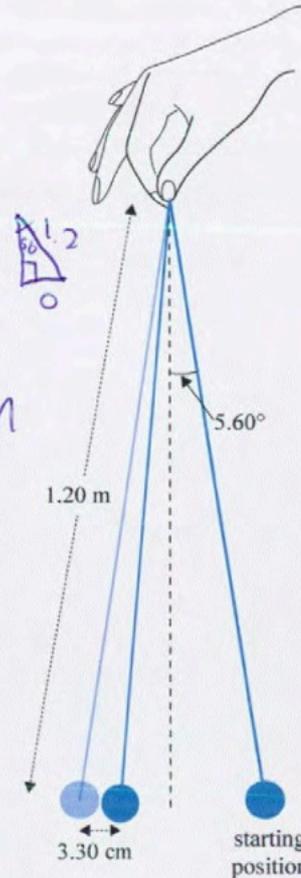
Explain the effect this has on the rotational energy of the system.

AS THIS MAKES ~~THE~~ RADIUS SHORTER, HIS ~~ROTATIONAL~~ I IS ALSO DECREASED. AS ANGULAR MOMENTUM IN $L = I\omega$ IS CONSERVED, THIS MEANS THE ω MUST INCREASE.

IN $E_{k(\text{rot})} = \frac{1}{2} I\omega^2$, I IS DECREASED, HOWEVER ω IS INCREASED SQUARED, SO THE $E_{k(\text{rot})}$ MUST ALWAYS INCREASE, SO MORE ENERGY IN THE SYSTEM.

QUESTION THREE: SIMPLE HARMONIC MOTION

Rihari is playing with a ball on a string and lets it swing as a pendulum. It is 1.20 m from the fixed point of the string to the centre of mass of the ball. The top of the string is held, and the ball is released from the starting position at an angle of 5.60° from the vertical. The mass of the string is insignificant compared to the mass of the ball.



- (a) Show that the maximum displacement of the ball is 0.117 m.

$$\sin(\theta) = \frac{d}{L}, \text{ so } 0 = \sin(\theta) \cdot L$$

$$0 = \sin(5.60^\circ) \cdot 1.2 \approx 0.1171 \text{ m}$$

- (b) Show that the angular frequency of the ball's motion is 2.86 rad s^{-1} .

$$T = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{1.2}{9.81}}$$

$$\approx 2.220$$

$$\omega = 2\pi f = 2\pi \frac{1}{T} = 2\pi \cdot \frac{1}{2.220}$$

$$\approx 2.860 \text{ RAD S}^{-1}$$

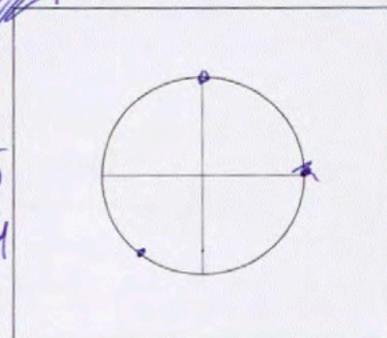
- (c) After the ball is released from the starting position, calculate the time it will take for the ball to reach a point 3.30 cm before its next stationary position, as shown on the diagram.

A reference circle may be used to calculate your answer.

$$x = A \cos(\omega t)$$

$$= 0.117 \cos(2.86 t)$$

IF YOU START PLACING IT, THEN
MAX DISPLACEMENT IS LEFT US
TAKA CH, AND NEED TO FIND
HOW CH, SO $x = 0.117 \cos(\omega t)$
- $0.117 \cos(\omega t) = 0.117 \cos(\omega t)$
IN BACK

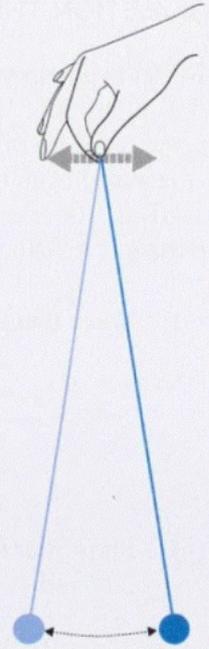


If you need to redraw your response, use the diagram on page 9.

- (d) Rīhari holds the end of the string between his fingers, and moves his hand horizontally from side to side. He notices that at a certain frequency of movement, the ball will oscillate with a very large amplitude.

Explain why this occurs.

Your answer should include both force and energy considerations.



SPARE DIAGRAMS

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

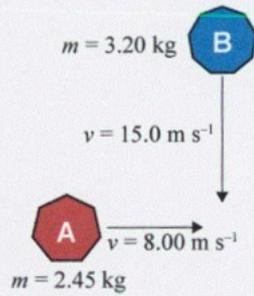
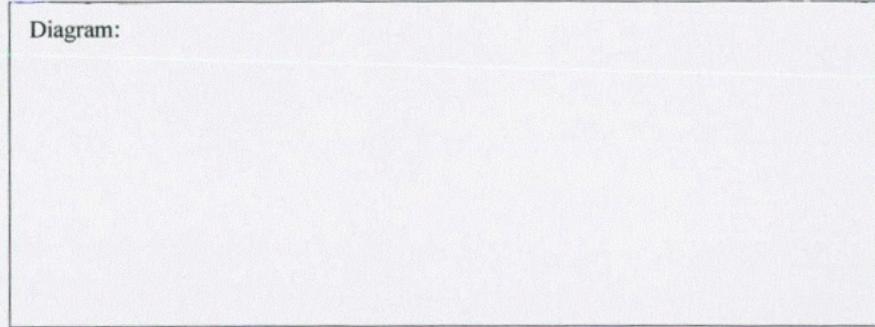
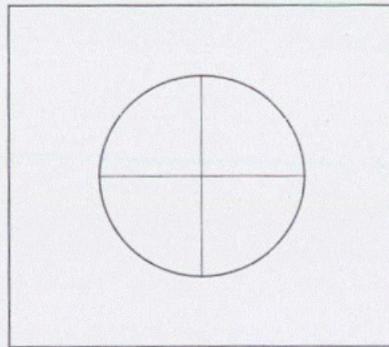


Diagram:



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



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

QUESTION
NUMBER

3c

$$y = A \cos \omega t$$

$$= 0.117 \cos(2.86t)$$

POINT IS 3.3 CM FROM LEFT, OR
8.4 CM FROM CENTER, AND LEFT
SO -8.4 CM OR -0.084 M

$$\text{SO } y = -0.084,$$

$$0.117 \cos(2.86t) = -0.084$$

$$t \approx 0.83 \text{ s}$$

Merit

Subject: L3 Physics

Standard: 91524

Total score: 17

Q	Grade score	Marker commentary
One	5	<p>(a) The candidate used correct formulae and distances to show value.</p> <p>(b) The candidate correctly solved for momentum and angle from A.</p> <p>(c) The candidate correctly solved for velocity. Did not calculate time period.</p> <p>(d) The candidate identified gravity as a force acting on the space station is insufficient to identify why the astronaut feels “weightless”. This needed to link at least to F_g providing the F_c required to remain in orbit.</p>
Two	5	<p>(a) The candidate did not recognise the object was accelerating.</p> <p>(b) The candidate calculated torque using angular acceleration.</p> <p>(c) The candidate recognised that the momentum is conserved based on $L_i = L_f$.</p> <p>(d) The candidate was able to describe the relationship between inertia, angular velocity and rotational energy. Did not explain why either momentum is conserved (no net torque) or why inertia decreases (moving towards axis of rotation).</p>
Three	7	<p>(a) The candidate recognised this as a trig solution.</p> <p>(b) The candidate recognised the need to calculate the time period, and then used a second step to calculate angular frequency.</p> <p>(c) The candidate showed clear understanding of how to solve a SHM calculation of time from a set displacement.</p> <p>(d) The candidate did not recall information regarding resonance and natural frequency.</p>