SUPERVISOR'S USE ONLY

3

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 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.

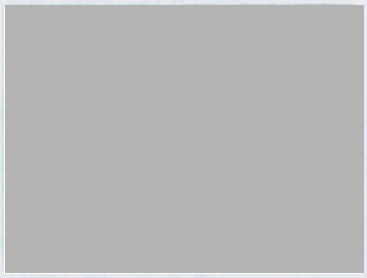
YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

Achievement

TOTAL 12

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.



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

Mass of Saturn: 5.68×10^{26} kg

Radius of Saturn: 5.82×10^{7} m

Mass of Titan: 1.35×10^{23} kg

~~Sat~~ 1.22×10^{9}

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

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

$$x_{com} = \frac{m_1x_1 + m_2x_2}{m_1+m_2} = \frac{0 + (1.35\times10^{23} \times 1.22\times10^{9})}{5.68\times10^{26} + 1.35\times10^{23}}$$

$$x_{com} = 2,89964.7887$$

$$= 2.90 \times 10^{5}\ \text{m} \quad (3sf)$$

(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.

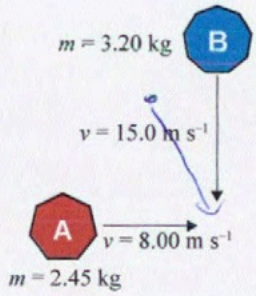
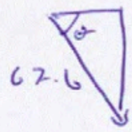


Diagram:



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.

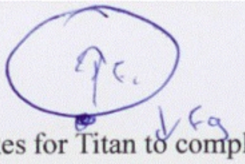
A diagram may assist your answer.

$P_{com} = (3.20 \times 15) + (2.45 \times 8) = 67.6$ kgms^{-1}

since momentum is conserved $P_i = P_f$ ∴ ~~P~~

P after when they are stuck together is also 67.6 kgms^{-1}

$P_i =$ ~~(3.20×15)~~ 67.6 kgms^{-1}



one orbit = 2π

(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.

$\cancel{F}$ $F_c = F_g$

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

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

$v^2 = gr$

$v = \sqrt{gr}$

$v = \sqrt{9.81 \times 1.22 \times 10^9}$

$v = 1.09 \times 10^5 \ ms^{-1}$

$v = r\omega$

$v/r = \omega$

$\frac{1.09 \times 10^5}{1.22 \times 10^9} = \omega$

$\omega = 8.97 \times 10^{-5} \ rads^{-1}$

$\omega = 2\pi f$

$f = \omega / 2\pi = \frac{8.97 \times 10^{-5}}{2\pi}$

$= 1.43 \times 10^{-5}$ Hz ~~rads~~

$T = \frac{1}{f} = 1/1.43 \times 10^{-5} = 70069$ seconds

$= 19.46$ hours

(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.

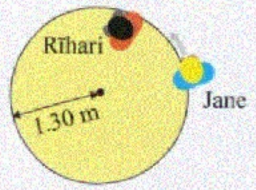
Explain why astronauts appear to be weightless yet can remain in orbit.

At the low earth orbit, Fc is the net force. The weight ~~gravity~~ force acts in the downwards direction whereas Fc acts in the upwards direction. In order to provide Fc, Fr, the reaction force, will have to overcome the Fw, weight force acting downwards, in order to be able to provide Fc and keep the international space station in the low earth orbit. Since Fws is what decides how "heavy" we feel, since it is overcome, we feel weightless but can remain in orbit.

QUESTION TWO: ROTATIONAL MOTION

Rīhari and Jane are playing on a roundabout (sometimes known as a merry-go-round) in the local playground. The roundabout has a radius of 1.30 m. Rīhari stands on the roundabout whilst Jane pushes on it to make it spin as shown in the diagram. Starting from rest Jane steadily accelerates the roundabout so that it takes 12.0 s to make 4.00 rotations.

https://www.findtheneedle.co.uk/companies/yates-playgrounds/products/playground-roundabout-design-and-manufacture1



(a) Show that the angular velocity of the roundabout after the 12.0 s is 4.19 rad s^{-1}.

$f = 1/3 = 0.333 Hz$

(b) Rīhari then drags his foot along the ground to bring the roundabout to a stop over 19.2 s.

Calculate the average torque exerted to slow the roundabout, if the roundabout and Rīhari have a rotational inertia of 430 kg m^2.

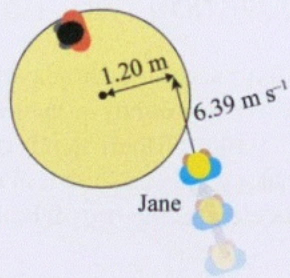
$T = I\alpha = Fr$ $\quad$ $\alpha = \Delta\omega / \Delta t$ $\quad$ $I = 430$

$T = 430 \times 0.218$ $\quad$ $= 4.19 / 19.2$ $\quad$ $t = 19.2$

$= 93.8938 \text{ Nm}^{-1}$ $\quad$ $= -0.218 \text{ rad s}^{-2}$

$= 93.8 \text{ Nm}^{-1}$ $\quad$ "-" indicates deceleration

(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 Rīhari 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.

$m = 52$, $v = 6.39$, $I = 430$, $r = 1.20$

~~$v = r\omega$~~
~~$\omega = v/r = 6.39/1.20$~~
~~$= 5.325 \text{ rads}^{-1}$~~
~~$= 5.33 \text{ rads}^{-1}$~~

~~$F = 52 \times 9.81$~~
~~$= 510.12 \text{ N}$~~
~~$= 510 \text{ N}$~~
~~$T = ~~I\alpha~~ Fr$~~
~~$T = 510 \times 1.20$~~
~~$= 612.144 \text{ Nm}^{-1} = 612 \text{ Nm}^{-1}$~~

~~$T = I\alpha$~~ $L = mvr$
$= (52 \times 6.39 \times 1.20)$
$= 398.736$
$= 399 \text{ kg}^2 \text{ms}^{-1}$

~~$L = I\omega =$~~
$\omega = L/I = 399/430 = ~~0.4~~$
$= 0.9273 \text{ rads}^{-2}$
$= 0.93 \text{ rads}^{-2}$

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

Rīhari moves inwards, towards the centre of the roundabout.

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

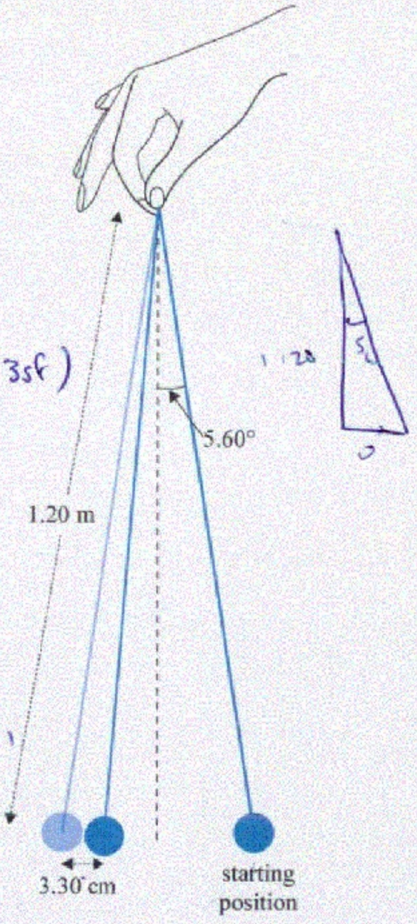
By moving inwards, the radius of the roundabout has essentially decreased. Since monetum is conserved due to no external torques acting on the system, and $L = I\omega$, if ~~radius~~ the rotatonial inertia is to decrease (this is caused from $I = mr^2$ as radius decreased), then the angular velocity must increase. As $Ek_{rot} = \frac{1}{2} I \omega^2$, the decrease in inertia is being overcome by the increase in angular velocity since it is being squared, hence the rotational energy of the system also increases.
(It is assumed that energy is conserved)

$\tan\theta = O/A$

$A \times \tan\theta =$

QUESTION THREE: SIMPLE HARMONIC MOTION

Rīhari 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.

$\tan 5.60 \times 1.20 = 0.117661 = 0.117\text{ m}$ (3sf)

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

$T = 2\pi\sqrt{\frac{l}{g}} = 2\pi\sqrt{\frac{(1.20)}{(9.81)}}$

$T = 2.1975$ sec $= 2.20$ sec

$w = 2\pi/T = 2\pi/2.20 = 2.8591 = 2.86\text{ rads}^{-1}$

(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.

$117 - 3.30 = 113.7\text{ cm} = 0.1137\text{ m}$

~~$\cos\theta = 0.117/0.137$~~

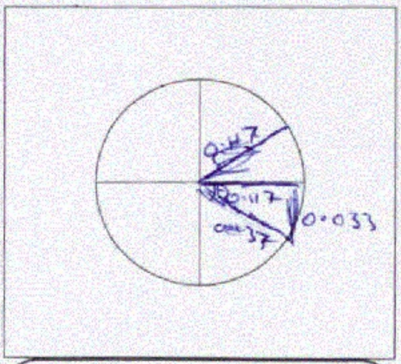
$wt = \theta = 15.8°$

$\tan\theta = 0.033/0.117$

$w = 2.86\text{ rads}^{-1}$

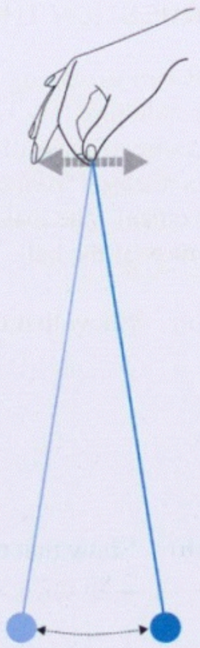
$\theta = 15.75° = 15.8°$

$\therefore t = \theta/w = 15.8/2.86 = 5.51$ sec



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.

This certain frequency is the resonance frequency. At this resonant frequency, when a force is applied onto the ball, it will be in the same motion as the ball, hence there is very minimal energy losses due to external forces such as friction, ~~as a result~~, ~~so~~ Since there is less energy lost and more energy applied to the ball, the ball will have a much larger amplitude.

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.

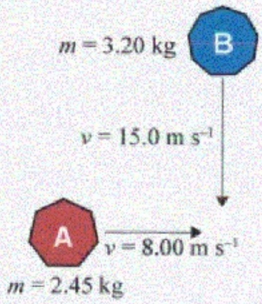
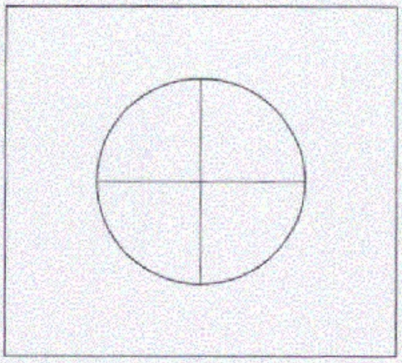


Diagram:

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.



Achievement

Subject: L3 Physics

Standard: 91524

Total score: 12

Q	Grade score	Marker commentary
One	4	(a) The candidate has correctly shown how to determine centre of mass. (b) The candidate determined the total initial momentum but has not been able to use momentum in 2 dimensions to solve the problem. (c) The candidate has shown understanding of the method required to determine orbital velocity but has used the wrong radius. (d) The candidate has confused reaction force, centripetal force and gravitational force and has not realised the significance of reaction force in terms of "feeling weight".
Two	5	(a) The candidate could not use kinematic equations to solve for angular velocity. (b) The candidate successfully calculated torque by first solving for angular acceleration. (c) The candidate recognised the conservation of momentum, but was unable to recognise that the inertia of the roundabout was initially zero. (d) The candidate was able to show the relationship between radius reduction, hence inertia reduction for Merit criteria, but for Excellence criteria, needed to recognise the significance of moving towards the axis of rotation.
Three	3	(a) The candidate did not use trigonometry to solve for amplitude. (b) The candidate determined the time period to then calculate angular velocity. (c) The candidate was unable to determine the correct displacement or draw a phasor diagram to demonstrate understanding and did not use the correct angular displacement. (d) The candidate could identify resonance as the physics phenomena, but did not use an in-depth knowledge to explain either the impact of the driving force or identify the conversion of energy supplied by the hand movement to add kinetic energy, and hence gravitational potential energy for Merit.