3

91524

915240

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

QUALIFY FOR THE FUTURE WORLD
KIA NOHO TAKATŪ KI TŌ ĀMUA AO!

SUPERVISOR'S USE ONLY

Level 3 Physics, 2015

91524 Demonstrate understanding of mechanical systems

9.30 a.m. Friday 20 November 2015
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.

TOTAL

ASSESSOR'S USE ONLY

ASSESSOR'S USE ONLY

QUESTION ONE: SATELLITES

Mass of Earth = 5.97×10^{24} kg

Universal gravitational constant = 6.67×10^{-11} N m^2 kg^{-2}

Digital television in New Zealand can be accessed by using a satellite dish pointed at a satellite in space. The satellite used to transmit the signals appears to stay still above the equator.

The satellite, with a mass of 300 kg, is actually travelling around the Earth in a geostationary orbit at a radius of 4.22×10^7 m from the centre of the Earth.

(a) Name the force that is keeping the satellite in this circular orbit, and state the direction in which this force is acting.

(b) Calculate the force acting on the satellite.

(c) Show that the speed of the satellite is 3.07×10^3 m s^{-1}.

ASSESSOR'S USE ONLY

(d) Kepler's law states that, for any orbiting object, $T^2 \propto r^3$, where r is the radius of the orbit, and T is the time period for the orbit.

NASA uses a robotic spacecraft to map the Moon. The Lunar Reconnaissance Orbiter orbits the Moon at an average height of 50.0×10^3 m with a period of 6.78×10^3 s. The Moon has a radius of 1.74×10^6 m.

For copyright reasons, this resource cannot be reproduced here.

https://upload.wikimedia.org/wikipedia/commons/9/95/Lunar_Reconnaissance_Orbiter_001.jpg

Use Kepler's law to estimate the mass of the Moon.

In your answer you should:

- use the relevant formulae to derive Kepler's law
- use Kepler's law to determine the mass of the Moon.

QUESTION TWO: GRAVITY ELEVATORS

ASSESSOR'S USE ONLY

Earth's average radius = 6.38×10^6 m.

In the 2012 science fiction movie *Total Recall*, a gravity-powered elevator called "The Fall" is used to transport passengers between the Northern and Southern hemispheres, straight through the Earth. If a straight tunnel could be dug through the Earth from the North Pole to the South Pole, protected from the heat inside the Earth and the journey unaffected by friction, an elevator could be used, harnessing the gravity of the planet.

Once dropped, the elevator would accelerate downwards and then decelerate once it had passed through the midpoint and – in the absence of friction – would just arrive at the far side of the Earth.

For copyright reasons, this resource cannot be reproduced here.

Adapted from: http://www.killerasteroids.org/impact.php

An equation can be used to summarise acceleration of the elevator.

$a = -1.54 \times 10^{-6}\,y$, where y = distance from the midpoint

(a) One of the passengers on the elevator stands on bathroom scales at the start of the journey.

Describe why the bathroom scales read zero.

(b) Calculate:

(i) The maximum acceleration of the elevator.

(ii) The maximum linear velocity of the elevator.

(c) Explain how the equation given shows that the elevator is undergoing simple harmonic motion.

(d) Calculate the time the journey from the North Pole to the South Pole would take.

ASSESSOR'S USE ONLY

QUESTION THREE: CATS AND GRAVITY

Cats have the ability to orient themselves in a fall, allowing them to avoid many injuries even when dropped upside down. Cats can do this even without tails to help them and they do not need to be rotating first.

The sequence of events for a typical 3.00 kg cat:

- The cat determines which way is up (by rotating its head).
- The cat exerts internal forces to twist the front half of its body to face down (by twisting its spine around its centre of mass and aligning its rear legs).
- Then the cat exerts internal forces to twist the back half of its body to face down (by arching its back).
- The cat lands safely.

The cat can be modelled as a pair of equal mass cylinders (the front and back halves of the cat) linked at the centre of mass of the cat. The moment of inertia, $I \propto mr^2$.

For copyright reasons, this resource cannot be reproduced here.

https://catsnco.files.wordpress.com/2013/02/falling_cat03.jpg

(a) Describe the motion of the centre of mass of the cat during its fall, and explain why the linear momentum of the cat is increasing.

Considering only the first half of the fall:

With the cat's legs tucked in, the front half of the cat can be modelled as a cylinder of radius 0.060 m.

During the first part of the fall the cat uses its muscles to twist its front legs around quickly to reach an angular velocity of 1.20 rad s^{-1}.

(b) If the angular momentum of the front half of the cat is 3.24×10^{-3} kg m^2 s^{-1}, calculate the rotational inertia of the front half of the cat.

ASSESSOR'S USE ONLY

(c) The cat is able to twist the front half of its body, even though the total angular momentum of the cat must remain zero.

Explain why the total angular momentum of the cat must remain zero, and explain what must happen to the rear of the cat's body.

(d) During the first half of its fall, the cat stretches out its rear legs. The rear half of the cat can be modelled as a cylinder of radius 0.120 m.

Explain how the cat can rotate the front and rear of its body at different speeds.

In your answer you should:

- calculate the angular momentum of the rear half of the cat
- explain why there is a difference in rotational speed between the front half of the cat and the rear half of the cat
- calculate the angular velocity of the rear of the cat.

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

QUESTION NUMBER

ASSESSOR'S USE ONLY

91524