No part of the candidate evidence in this exemplar material may be presented in an external assessment for the purpose of gaining credits towards an NCEA qualification.

91524

915240

3

SUPERVISOR'S USE ONLY

NEW ZEALAND QUALIFICATIONS AUTHORITY
MANA TOHU MĀTAURANGA O AOTEAROA

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

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.

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Achievement

TOTAL 9

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.

m

r

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

Gravity force, acting towards the centre of Earth. //

The candidate correctly names the force and direction in which this force acts.

(b) Calculate the force acting on the satellite.

$$F_g = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 300}{(4.22 \times 10^7)^2}$$

$$= 67.1\text{N} \quad //$$

Correct working and answer.

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

$$F_g = F_c \Rightarrow F_c = \frac{mv^2}{r}$$

$$\Rightarrow 67.1 = \frac{300}{4.22 \times 10^7} \times v^2$$

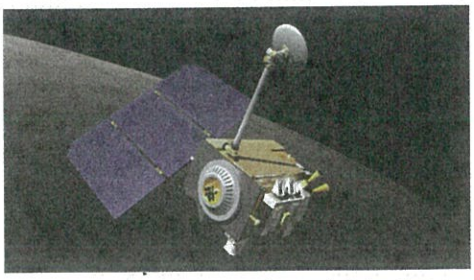
$$v^2 = 9.44 \times 10^6 \text{ms}^{-1}$$

$$v = 3.07 \times 10^3 \text{ms}^{-1} \quad //$$

Correct equation and evidence for calculating the speed of satellite.

(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.



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.

ASSESSOR'S USE ONLY

M5

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.

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.

if $a = -1.54 \times 10^{-6} y$, then at the start of the journey $y = 6.38 \times 10^6$ m and $a = -1.54 \times 10^{-6} \times 6.38 \times 10^6 = -9.83\text{ms}^{-2}$ this means the scales will read 0, as a is negative ($F = ma$)

X

To get an Achieved, the candidate needs to explain that the passenger and the bathroom scales are falling at the same rate, so there is no contact force between them.

(b) Calculate:

(i) The maximum acceleration of the elevator.

~~$a = -1.54 \times 10^{-6} \times$~~ $a = -1.54 \times 10^{-6} \times 6.38 \times 10^6$

~~=~~ $= -9.83\text{ms}^{-2}$

L

Correct working and answer.

(ii) The maximum linear velocity of the elevator.

$a = \frac{\Delta v}{t}$ ~~[illegible]~~ when $a = 0$ $v = \text{max}$

X

Incomplete working. For Achieved, the candidate needs to state a suitable equation of SHM to calculate the maximum linear velocity. For Merit, the candidate needs to have a correct equation with the correct answer.

(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

N2

QUESTION THREE: CATS AND GRAVITY

ASSESSOR'S USE ONLY

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, $I \propto mr^2$.

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.

the centre of mass of the cat is decelerating during its fall, if V_{com} is decreasing, then p is increasing ($p=mv$)//

X

Incorrect explanation. For a Achieved, the candidate needs to states that linear momentum increases because of the increase in cats velocity while falling or linear momentum increase due to an increase in vertical velocity. To get Merit candidate needs to explain that that the centre of mass accelerates downwards and linear momentum increases due to the external force (weight) causing an increase in vertical velocity.

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.

$L = I\omega \Rightarrow 3.24 \times 10^{-3} = I \times 1.20$

$\Rightarrow I = \dfrac{3.24 \times 10^{-3}}{1.20}$

$= 2.70 \times 10^{-3}$ //

✓

Correct working and answer.

$\dfrac{kg\,m^2}{s}$

$\dfrac{rad}{s}$

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.

The total angular momentum must equal zero or the cat will rotate around its centre of mass and it won't land on its feet.//

Incorrect explanation. For Achieved grade, candidate needs to state that no external torques act or Lrear = -Lfront . For Merit grade, candidate needs to explain that no external torques act so total angular momentum must be conserved so rear half of cat must rotates but in the opposite direction.

X

(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.

if $L_{total} = 0$, then L of the rear of the cat $= -$ ~~[illegible]~~ $3.24 \times 10^{-3}\ kgm^2s^{-1}$ //

The candidate correctly states the angular momentum of the rear half of the cat. To gain higher grades, they need to explain that the cat can change the rotational inertia of both parts its body independently, cat can change the speed for both parts by changing its mass distribution, tucking in the legs distributes more of the cats' mass close to the axis of rotation so angular velocity is greater since angular momentum is conserved or vise versa. Correct calculation for the angular velocity of the rear of the cat is required.

/

N2

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Achievement

TOTAL 10

ASSESSOR'S USE ONLY

ASSESSOR'S USE ONLY

QUESTION ONE: SATELLITES

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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.

The force keeping the satellite in orbit is gravitational force, which is acting in the direction of the centre of the Earth //

The candidate correctly names the force and direction in which this force acts.

(b) Calculate the force acting on the satellite.

$F_g = GMm/r^2$

$= 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 300 / (4.22 \times 10^7)^2$

$= 67.1$ N //

$= 70.0$ N

Correct working and answer.

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

~~$F_c = m$~~

~~$F_c = mv^2/r$~~

~~$F_g = F_g$~~

~~$F_c = 67.08053503$~~

$F_c = mv^2/r$

~~$67.1 = m$~~

$67.1 = 300 \times v^2 / 4.22 \times 10^7$

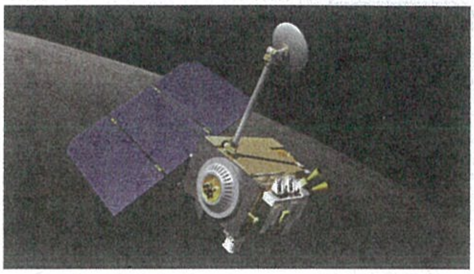
$v = 3071.8065$

$= 3.07 \times 10^3$ m s^{-1} //

Correct equation and evidence for showing the speed of satellite.

(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.



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.

ASSESSOR'S USE ONLY

M5

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ASSESSOR'S USE ONLY

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

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

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

(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.

The bathroom scales are falling at the same speed as the passenger, and no force is being exerted onto the scales.

The answer clearly describes why the bathroom scales read zero.

(b) Calculate:

(i) The maximum acceleration of the elevator.

$a = -1.54 \times 10^{-6}\,y$

$= -1.54 \times 10^{-6} \times 6.38 \times 10^{6}$

$= -9.8252$

$= 9.83\ \text{ms}^{-2}$

Correct working and answer.

(ii) The maximum linear velocity of the elevator.

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

ASSESSOR'S USE ONLY

During simple harmonic motion (shm) the velocity of the system is at it's maximum when at the midpoint. Since $a = -1.54 \times 10^{-6} y$, when $y = 0$, $a = 0$. This is because at the midpoint v is at its maximum so there is no acceleration. //

X

For Achieved , the candidate needs to reference SHM equation. For Merit, complete explanation that acceleration or restoring force is proportional to the displacement and acts in the opposite direction to each other with reference to SHM equation is required.

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

A3

QUESTION THREE: CATS AND GRAVITY

ASSESSOR'S USE ONLY

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.

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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, $I \propto mr^2$.

(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.

As the cat is ~~falling~~ falling, it's velocity increases due to its acceleration due to gravity. Since $p = mv$ and v is increasing but its mass, m, stays the same, the linear momentum of the cat is increasing.

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

Correctly states that linear momentum increases because of the increase in cats velocity while falling. To get Merit candidate needs to explain that that the centre of mass accelerates downwards and linear momentum increases due to the external force (weight) causing an increase in vertical velocity.

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(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.

$L = I\omega$

$I = L/\omega$

$= 3.24 \times 10^{-3} / 1.20 = 0.0027 = 2.70 \times 10^{-3}$ kgm^2

Correct working and answer.

(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.

ASSESSOR'S USE ONLY

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.

If the total angular momentum of the cat is zero, then it is able to control the movement of its body. The rear of the cat's body must not twist in order to keep the total angular momentum at zero. //

X

Incorrect explanation. For Achieved grade, candidate needs to state that no external torques act or Lrear = -Lfront . For Merit grade, candidate needs to explain that no external torques act so total angular momentum must be conserved so rear half of cat must rotates but in the opposite direction.

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- 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.

~~Since L = mvr~~ L = mvr and the two halves have different radius, r //

X

Incorrect explanation

N2