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91524



915240



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## 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.**

**Not Achieved**

**TOTAL**

**6**

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# QUESTION ONE: SATELLITES

Mass of Earth =  $5.97 \times 10^{24}$  kg

Universal gravitational constant =  $6.67 \times 10^{-11}$  N m<sup>2</sup> kg<sup>-2</sup>

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  $4.22 \times 10^7$  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.

Gravity is keeping the satellite in orbit and this force will be acting towards earth. ||

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

- (b) Calculate the force acting on the satellite.

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

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

Correct working and answer.

~~$$F_g = 67.1 \text{ N}$$~~

$$F_g = 67.1 \text{ N (3sf)} ||$$

- (c) Show that the speed of the satellite is  $3.07 \times 10^3$  m s<sup>-1</sup>.

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

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

$$283162000 = 300v^2 \quad 9438733.3 = v^2$$

$$v = 3.07 \times 10^3 \text{ m s}^{-1} ||$$

Correct equation and evidence for showing the speed of satellite.

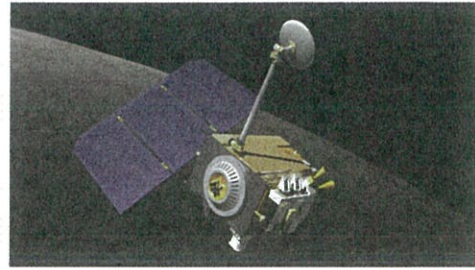
- (d) Kepler's law states that, for any orbiting object,  $T^2 \propto r^3$ , where  $r$  is the radius of the orbit, and  $T$  is the time period for the orbit.

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

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.



[https://upload.wikimedia.org/wikipedia/commons/9/95/Lunar\\_Reconnaissance\\_Orbiter\\_001.jpg](https://upload.wikimedia.org/wikipedia/commons/9/95/Lunar_Reconnaissance_Orbiter_001.jpg)

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ms



## QUESTION TWO: GRAVITY ELEVATORS

Earth's average radius =  $6.38 \times 10^6$  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.

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

- (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.

Because the elevator is in mid air and there is nothing beneath it all the way to other side of earth. The scales can't read the weight ???

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.

$$a = (-1.54 \times 10^{-6}) \times (6.38 \times 10^6) \text{ m/s}^2$$

- (ii) The maximum linear velocity of the elevator.

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

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

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No



### 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,  $I \propto mr^2$ .

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 starts higher up, as its legs are turned upwards but as it rotates the C.O.M moves lower down the cat, as there is now more weight at the bottom of the cat.  $P = mv$  and as the cat falls its velocity increases therefore meaning its linear momentum will also increase.   
 $\otimes$  making it more balanced/safe when it lands

[https://catsnco.files.wordpress.com/2013/02/falling\\_cat03.jpg](https://catsnco.files.wordpress.com/2013/02/falling_cat03.jpg)

Considering only the first half of the fall:

When 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  $1.20 \text{ rad s}^{-1}$ .

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

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



- (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.

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QUESTION  
NUMBER

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