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Level 3 Physics, 2018

91524 Demonstrate understanding of mechanical systems

2.00 p.m. Tuesday 20 November 2018
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 2–12 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

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QUESTION ONE

Mass of the Earth	$= 5.97 \times 10^{24}$ kg
Radius of the Earth	$= 6.37 \times 10^{6}$ m

The Electron Rocket developed by New Zealand company Rocket Lab has begun commercial launches of satellites from the Mahia Peninsula in Hawke's Bay. The rocket can carry a satellite of mass 1.50×10^{2} kg to a stable, circular orbit 5.00×10^{5} m above the Earth's surface.

(a) Show that the force due to gravity on the satellite in this orbit is 1270 N.

(b) The rocket, the satellite, and any space debris at the same altitude in stable, circular orbits, will all travel at the same speed.

Show that this is always true by deriving the formula for orbital velocity:

$v_{\text{orbit}} = \sqrt{\frac{GM}{r}}$, and use this to determine the orbital velocity of the satellite.

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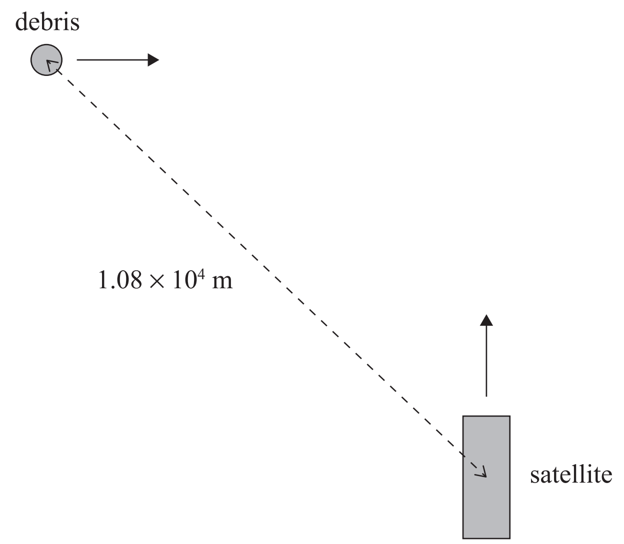
A 20.0 kg piece of space debris is travelling at the same altitude and speed as the satellite but in a direction that is 90° to the satellite's velocity. At the moment shown in the diagram below, the debris and the satellite are 1.08×10^4 m apart.

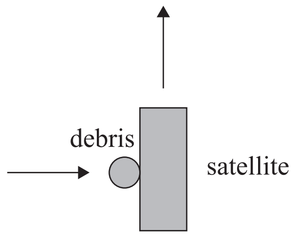


(c) (i) Calculate the distance between the centre of mass of the system and the satellite.

(ii) Describe the motion of the centre of mass of the system as the debris and satellite continue to move along their paths.

Justify your response.

(d) The debris collides and becomes embedded in the satellite.



Calculate the speed and direction (relative to the initial direction of the satellite) of the satellite and embedded debris.

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QUESTION TWO

Weather satellites can be launched into orbits that circle around the North and South poles. This enables the satellite's camera to view the whole of the Earth's surface as the Earth spins underneath. The orbital period of a typical weather satellite is 101 minutes.

www.metoffice.gov.uk/learning/making-a-forecast/first-steps/obs-from-space

(a) Show that in order to keep the camera pointed towards the Earth's surface, the satellite must spin at an angular velocity of 1.04×10^{-3} rad s^{-1}.

This angular velocity is achieved by firing two 5.00 N thrusters attached on opposite sides of the satellite's 1.60 m diameter.

(b) Explain why two thrusters must be used rather than simply one on one side of the satellite with double the thrust force.

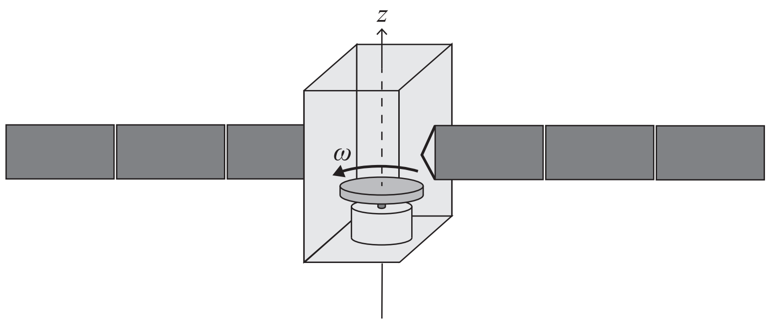
(c) The thrusters are fired for 6.48×10^{-3} s to set the satellite rotating at the required angular velocity.

Show that the rotational inertia of the satellite is 50.0 kg m^2.

(d) Instead of using two thrusters to adjust the angular velocity of a satellite, it is often preferable to use a "reaction wheel" system. When the wheel begins to turn in one direction, the satellite will turn in the opposite direction.

The wheel is solid and has rotational inertia given by $I = \frac{1}{2}mr^2$.

The radius of the wheel is 0.200 m and the mass of the wheel is 5.00 kg.



Adapted from: http://www.conceptualdynamics.com/files/rbmo/rbmo_rp8.png

Calculate the angular velocity of the wheel required to keep the camera pointed at the Earth.

State any assumptions.

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QUESTION THREE

When astronauts return to Earth, a spring under their seat reduces the force during the landing. The astronaut's kinetic energy is converted to spring potential energy as the spring is compressed. If friction is negligible, this will set the astronaut into simple harmonic motion.

(a) State the conditions required for the astronaut's motion to be considered simple harmonic motion.

During a landing, an astronaut and seat had a combined mass of 80.0 kg and were set into a simple harmonic motion with an amplitude of 0.150 m and a period of 0.940 s.

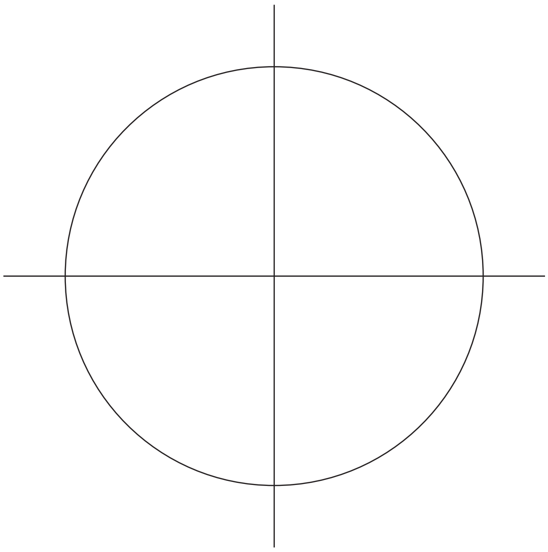
(b) Determine:

(i) the spring constant of the spring

(ii) the amount of energy stored in the spring at maximum displacement.

(c) Using a reference circle or otherwise, determine the velocity of the astronaut when the astronaut is 0.100 m above the equilibrium position.

(Assume the motion is un-damped).



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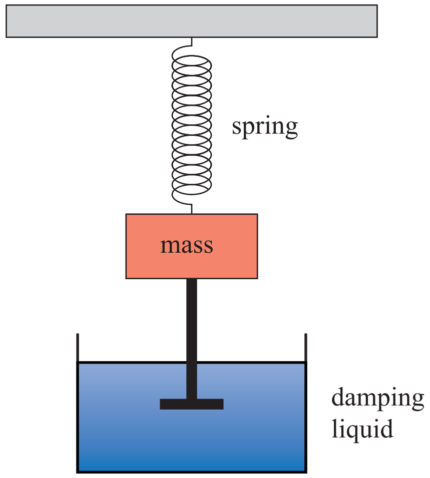
(d) The motion of the astronaut is quickly brought to rest by a damping system on the spring. Damped harmonic motion can be modelled in the laboratory with a mass, spring, and beaker of water as shown.



adapted from: https://brilliant.org/practice/deriving-exponential-decay-from-damping-forces/

Discuss how damping will affect the amplitude and period of the harmonic motion of the mass on the spring.

Your discussion should include:

- a description of what is meant by damping
- a description of the damping force in the laboratory model and how this will impact the motion
- a sketch of a graph of the position of the mass versus time starting at the moment the mass is released from the maximum downward displacement.

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

QUESTION NUMBER

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