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Level 3 Physics 2021

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 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.

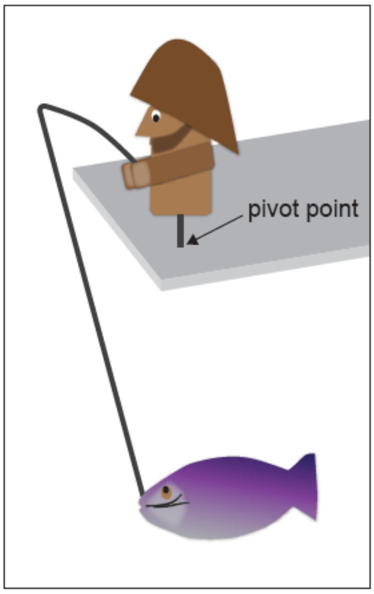
Do not write in any cross-hatched area ( ). This area may be cut off when the booklet is marked.

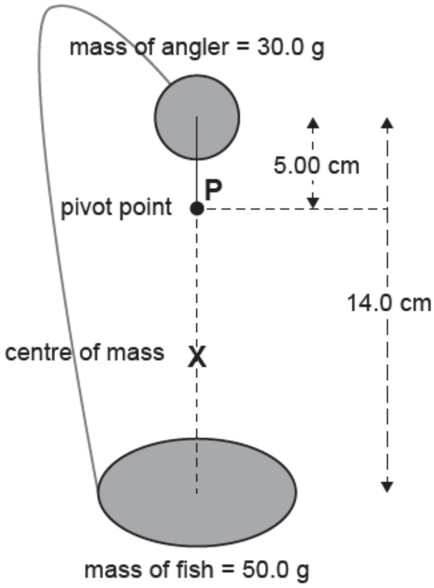
YOU MUST HAND THIS BOOKLET TO THE SUPERVISOR AT THE END OF THE EXAMINATION.

QUESTION ONE: FISHING TOY

A simple balancing toy can be made by joining two masses with a rigid wire. The 'Balancing Angler' toy below is an example.

It can be approximated to two masses, joined by wire, as shown in the diagram. The distance between the centres of mass of the angler and the fish is 14.0 cm. The pivot point is at the bottom of the pole under the angler, and is 5.00 cm below the centre of mass of the angler.

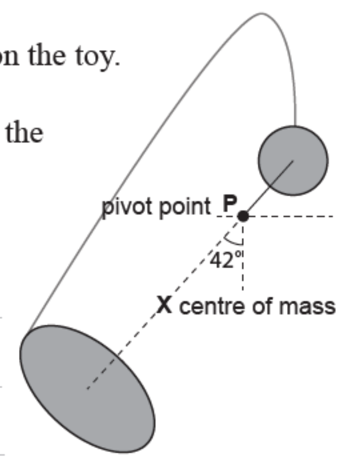




(a) Assuming that the wire has no mass, show that the centre of mass (X) of the system is 3.75 cm (3.75×10^{-2} m) below the pivot point (P), along the line joining the angler and the fish.

(b) (i) When the toy is rotated about the pivot, a torque due to gravity acts on the toy.

Show that when the toy is rotated by 42°, as shown, the torque about the pivot point is 0.0197 N m.

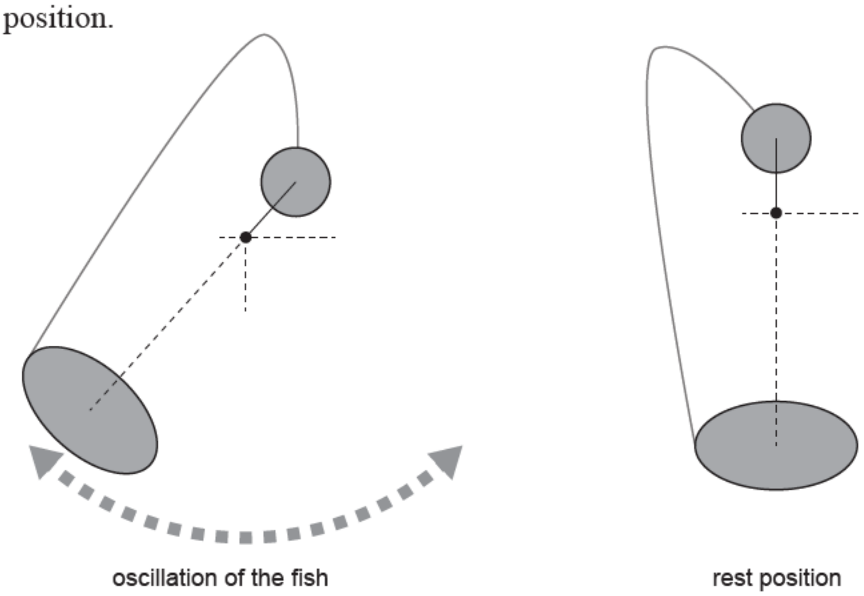


(ii) The rotational inertia for the whole toy is the sum of rotational inertia of each mass. The rotational inertia, I, of each mass can be estimated by treating each as a point mass, for which $I = mr^2$, where m is the mass of the object and r is its distance from the pivot.

Use the information given to estimate the rotational inertia of the toy about its pivot point, and hence its angular acceleration when it is released from the position shown in part (i).

(c) When the toy is released, it oscillates but eventually ends up stationary, in the rest position shown below.

Discuss the energy transfers that occur while the toy is oscillating, and explain why it always stops in that exact position.



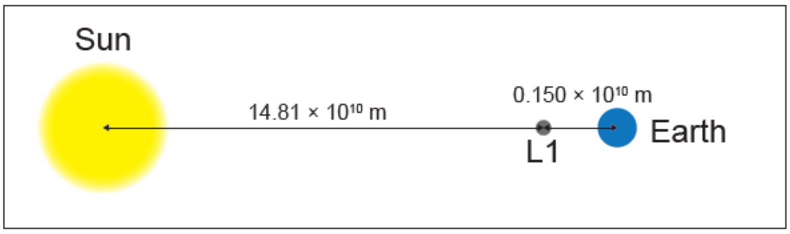
QUESTION TWO: A SATELLITE IN AN UNUSUAL ORBIT

Mass of the Sun = 1.99×10^{30} kg

Mass of the Earth = 5.97×10^{24} kg

The Deep Space Climate Observatory satellite is in a very unusual orbit of the Sun, at the L1 point. In this position the satellite is attracted to both the Sun and the Earth, and it is in a stable orbit around the Sun with the same period as the Earth, keeping it always between the Sun and the Earth.

The satellite is 14.81×10^{10} m from the Sun and 0.150×10^{10} m from the Earth.



Simplified diagram (not to scale) showing the position of the L1 point relative to the Sun and Earth.

(a) A magazine article states that the L1 point is where the gravitational forces of the Sun and the Earth are balanced.

Explain why this cannot be true if the satellite is moving in a stable circular orbit.

(b) The satellite, due to its L1 position between the Earth and the Sun, is under the influence of the gravitational field of the Sun as well as that of the Earth.

Show that the net gravitational field strength, g, at position L1 on the satellite, if it is moving in a circular orbit and is consistent with it having a period of an Earth year (3.1536×10^7 s), is 5.88×10^{-3} N kg^{-1}.

(c) The satellite has special cameras pointing at the Sun and at the Earth, so it has to spin with a period of one Earth year to keep in line with these objects as it orbits the Sun. The solar panels on the satellite could be moved closer or further from the satellite to adjust the spin period.

Explain how moving the solar panels further from the satellite would affect its angular velocity.

Adapted from: https://en.wikipedia.org/wiki/Deep_Space_Climate_Observatory#/media/File:DSCOVR_spacecraft_model.png

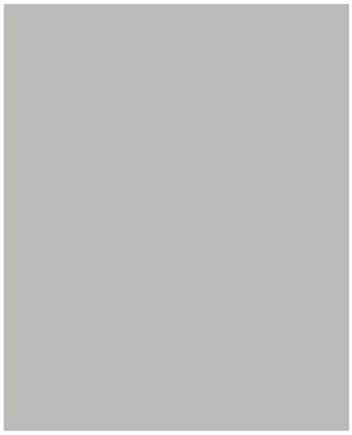
(d) A small fragment of an icy comet hits the spacecraft and sticks to one of the solar panels at a distance of 1.42 m from the axis of rotation. The fragment has a mass of 0.780 kg and it increases the angular velocity of the satellite by 0.0124 rad s^{-1}. The satellite (with the fragment) is estimated to have a rotational inertia of 179 kg m^2.

Determine the impact speed of the fragment (relative to the satellite).

QUESTION THREE: CAR SUSPENSION

A simple car suspension system rests the weight of the car onto four springs – each attached to a wheel. The car has a mass of 893 kg.

Jon sits on the roof, in the middle of the car, then slides off, careful to quickly release his weight from the car without pushing down on it. He watches the car oscillate up and down. It completes one oscillation in 1.14 s.



https://educalingo.com/zh/dic-de/einzelradaufhangung

Adapted from: www.seekpng.com/ipng/u2r5t4a9a9q8a9r5_side-view-of-the-car-hd-car-side/

(a) Show that the spring constant for the combined four-spring system is 2.71×10^4 N m^{-1}.

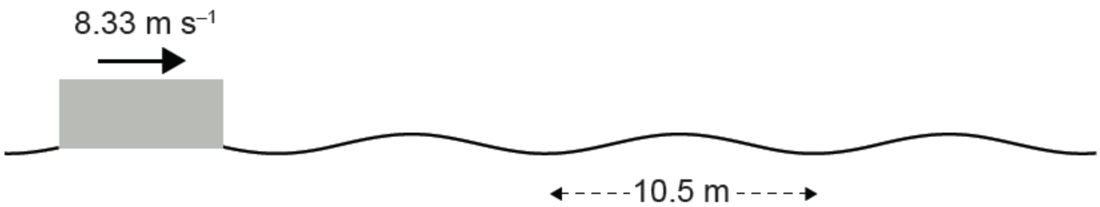
(b) Jon wonders whether the car body is moving with simple harmonic motion (SHM).

State the conditions for SHM.

(c) Jon has a mass of 103 kg, and while he sat on the roof, his weight was supported by each of the four wheels equally.

Determine the initial amplitude of the oscillation, and hence the maximum acceleration of the car as it oscillates.

(d) Jon and his friend Rick ride in the car together. Speed bumps in the road are 10.5 m apart. When they are travelling at 8.33 m s^{-1}, the car builds up large vertical oscillations.



Adapted from: www.seekpng.com/ipng/u2r5t4a9a9q8a9r5_side-view-of-the-car-hd-car-side/

Explain why this happens, and determine Rick's mass.

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

QUESTION NUMBER

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