A-Level Physics

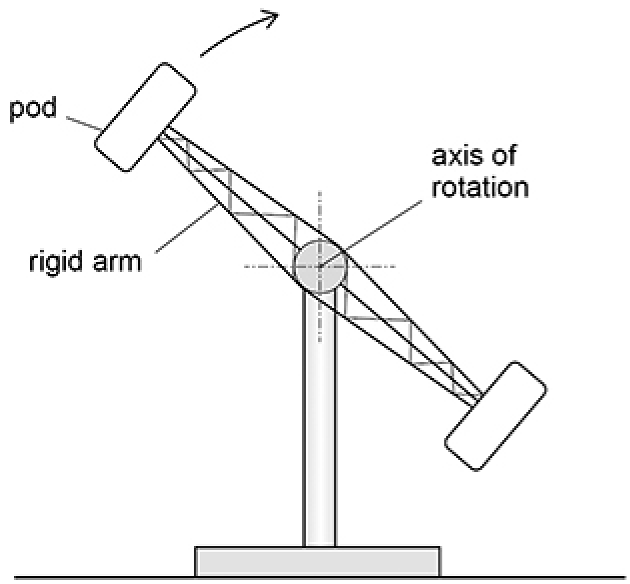
Angular Momentum

Question Paper

Time available: 78 minutes
Marks available: 44 marks

1. **Figure 1** shows a fairground ride.

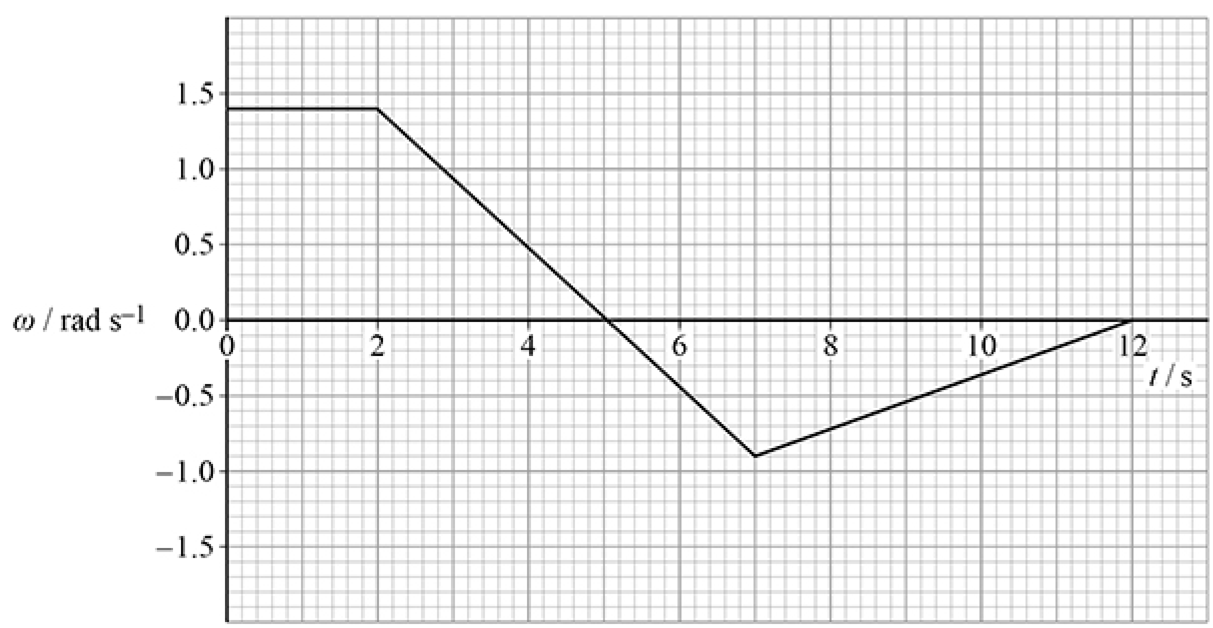
Figure 1



The ride consists of a rotor that rotates in a vertical circle about a horizontal axis.
The rotor has two rigid arms. A pod containing passengers is attached to each arm.
The rotor is perfectly balanced.
The direction of rotation of the rotor is reversed at times during the ride.

Figure 2 shows the variation of the angular velocity ω of the rotor with time t during a 12 s period.

Figure 2



(a) Determine the mean angular velocity of the rotor during the $12\ \text{s}$ period.

mean angular velocity = _______________ rad s^{-1}

(2)

The moment of inertia of the rotor about its axis of rotation is $2.1 \times 10^4\ \text{kg m}^2$.
A constant frictional torque of $390\ \text{N m}$ acts at the bearings of the rotor.

(b) Calculate the power output of the driving mechanism during the first $2\ \text{s}$ shown in **Figure 2**.

power output = _______________ W

(1)

(c) Calculate the maximum torque applied by the driving mechanism to the rotor during the 12 s period.

maximum torque = _______________ N m

(3)

(d) Calculate the magnitude of the angular impulse on the rotor between t = 2.0 s and t = 7.0 s.

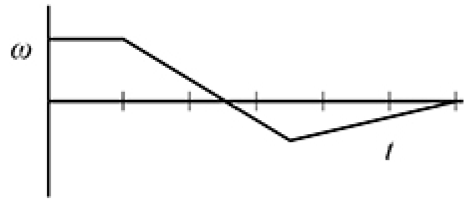
angular impulse = _______________ N m s

(1)

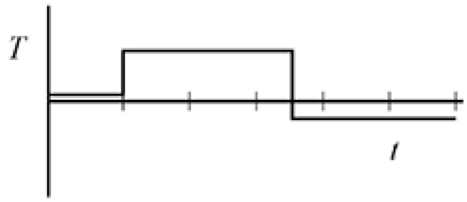
(e) Which graph best shows the variation of the torque T applied to the rotor for the 12 s period?

Tick (✓) **one** box.

A copy of **Figure 2** is provided to help you.



copy of **Figure 2**



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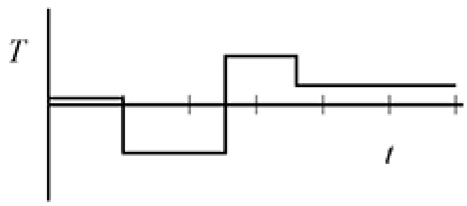

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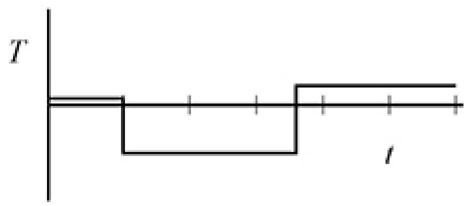

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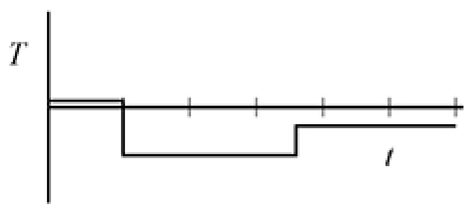

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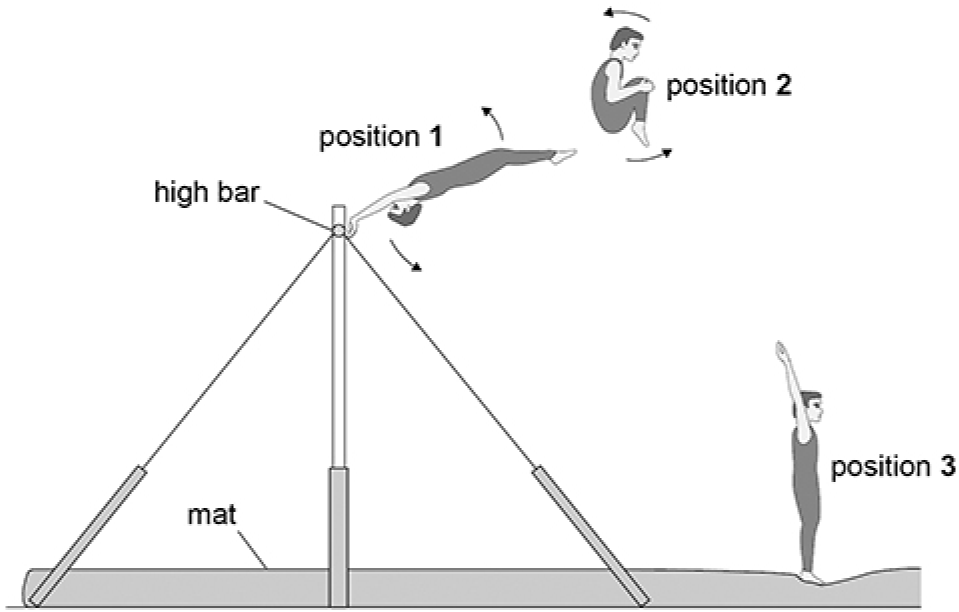
(1)
(Total 8 marks)

2. A gymnast dismounts from an exercise in which he swings on a high bar. The gymnast rotates in the air before landing.

The figure below shows the gymnast in three positions during the dismount.



The arrows show the direction of rotation of the gymnast.

In position **1** the gymnast has just let go of the bar. His body is fully extended.

Position **2** shows the rotating gymnast a short time later. His knees have been brought close to his chest into a ‘tuck’.

Position **3** is at the end of the dismount as the gymnast lands on the mat. His body is once again fully extended.

(a) Explain why the moment of inertia about the axis of rotation decreases when his knees are moved towards his chest.
Go on to explain the effect this has on his angular speed.

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(3)

The table below gives some data about the gymnast in position **1** and in position **2**.

Position	**Moment of inertia / kg m^2**	**Angular speed / rad s^{-1}**
1	13.5	ω
2	4.1	14.2

(b) Calculate the angular speed ω of the gymnast in position **1**.

ω = _______________ rad s^{-1}

(1)

(c) The gymnast stays in the tuck for 1.2 s.

Determine the number of **complete** rotations performed by the gymnast when in the tuck during the dismount.

number of complete rotations = ________________

(2)

(d) The gymnast repeats the exercise. The height of the bar remains unchanged.

State and explain **two** actions the gymnast can take to complete more rotations during the dismount.

1 ____

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2 ____

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(4)

(Total 10 marks)

3. (a) State the law of conservation of angular momentum.

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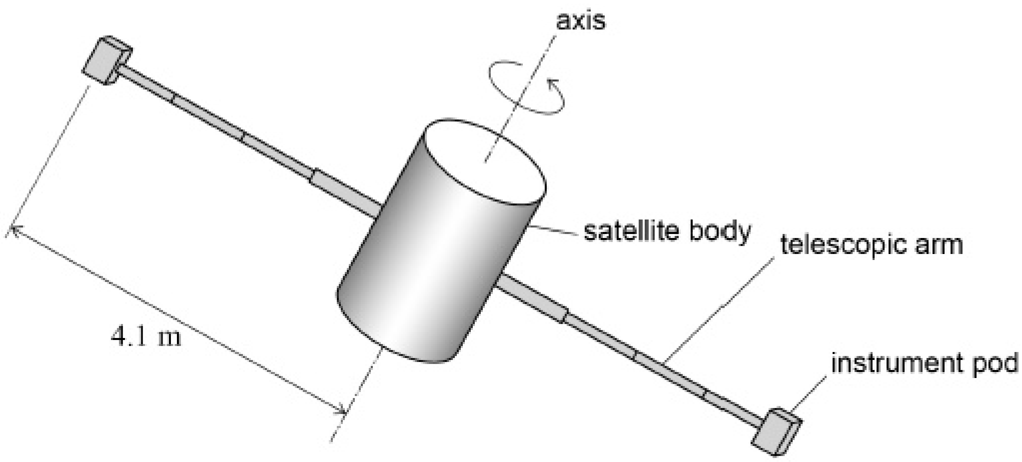
(1)

(b) The diagram shows an orbiting satellite fitted with two small instrument pods attached to the ends of telescopic arms. The arms can be extended or retracted by a motor in the body of the satellite.



With the telescopic arms fully extended, the centre of mass of each instrument pod is at a radius of 4.1 m from the axis of rotation.

moment of inertia of satellite body about axis = 71 kg m2

mass of each instrument pod = 5.0 kg

The mass of the telescopic arms is negligible.

Show that the total moment of inertia of the satellite with the arms fully extended is 240 kg m^2

(2)

(c) The satellite is initially rotating slowly about its axis with the arms fully extended. The arms are slowly retracted so that the instrument pods move closer to the body of the satellite.

State and explain the change in the angular speed of the satellite as the arms are retracted.

(3)

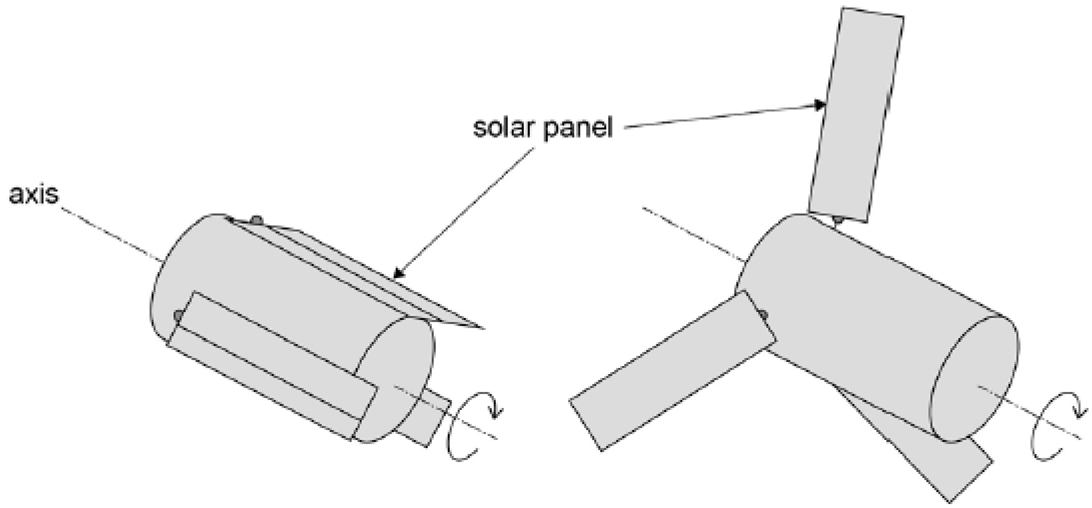
(d) The satellite is initially rotating at 1.3 rad s^{-1} with the telescopic arms fully extended. When fully retracted the instrument pods are at a radius of 0.74 m from the axis. The satellite contains sensitive equipment that may be damaged if the rotational speed exceeds 4.2 rad s^{-1}

Deduce whether the arms can be retracted fully without the satellite exceeding its maximum permitted angular speed.

(3)
(Total 9 marks)

4. **Figure 1** shows a satellite with three solar panels folded in close to the satellite's axis for the journey into space in the hold of a cargo space craft.

Figure 1 **Figure 2**



Just before it is released into space, the satellite is spun to rotate at 5.2 rad s^{-1}. Once released, the solar panels are extended as shown in **Figure 2**.

moment of inertia of the satellite about its axis with panels folded = 110 kg m^2

moment of inertia of the satellite about its axis with panels extended = 230 kg m^2

(a) State the law of conservation of angular momentum.

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(1)

(b) The total mass of the satellite is 390 kg and the solar panels each have a mass of 16 kg.

State what is meant by moment of inertia and explain why extending the solar panels changes the moment of inertia of the satellite by a large factor.

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(3)

(c) Calculate the angular momentum of the satellite when it is rotating at 5.2 rad s^{-1} with the solar panels folded. State an appropriate unit for your answer.

angular momentum = ____________________ unit __________

(2)

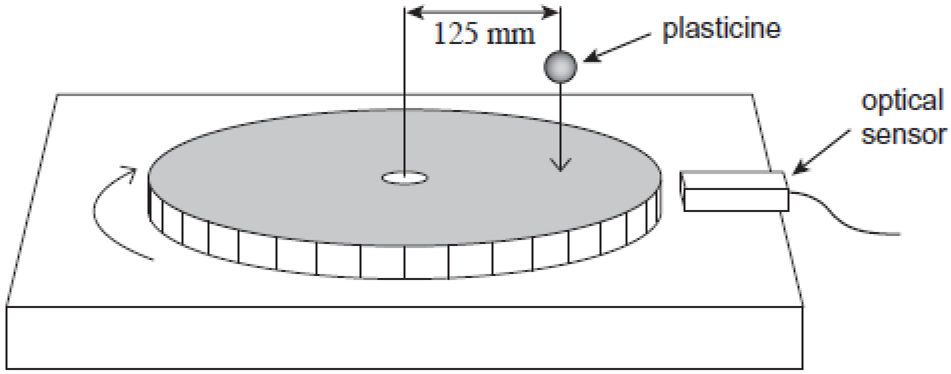
(d) Calculate the angular speed of the satellite after the solar panels have been fully extended.

angular speed = ____________________rad s^{-1}

(2)

(Total 8 marks)

5. A student carries out an experiment to determine the moment of inertia of a turntable. The diagram shows the turntable with a small lump of plasticine held above it. An optical sensor connected to a data recorder measures the angular speed of the turntable.



The turntable is made to rotate and then it rotates freely. The lump of plasticine is dropped from a small height above the turntable and sticks to it. Results from the experiment are as follows.

mass of plasticine = 16.0 g
radius at which plasticine sticks to the turntable = 125 mm
angular speed of turntable immediately before plasticine is dropped = 3.46 rad s^{-1}
angular speed of turntable immediately after plasticine is dropped = 3.31 rad s^{-1}

The student treats the plasticine as a point mass.

(a) Explain why the turntable speed decreases when the plasticine sticks to it.

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(3)

(b) Use the results of the experiment to determine the moment of inertia of the turntable.

Give your answer to an appropriate number of significant figures.

moment of inertia ____________________ kg m^2

(3)

(c) (i) Calculate the change in rotational kinetic energy of the turntable and plasticine from the instant before the plasticine is dropped until immediately after it sticks to the turntable.

change in kinetic energy ____________________ J

(2)

(ii) Explain the change in rotational kinetic energy.

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(1)

(Total 9 marks)