Access Tuition

A-Level Physics

Rotational Motion

Question Paper

Time available: 46 minutes
Marks available: 46 marks

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1. (a) State **one** function of a flywheel.

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(1)

(b) A student does an experiment to determine the frictional torque acting at the bearings of a steel flywheel. The flywheel has a radius of 0.075 m and is perfectly balanced.

The student places a small magnet of mass 0.020 kg at point **A** on the circumference of the flywheel on a horizontal line through the axis of rotation as shown in **Figure 1a**. The student releases the flywheel. The flywheel first comes to rest when it has moved through an angle of 3.00 rad (172°), with the magnet now in position **B** as shown in **Figure 1b**.

Figure 1a

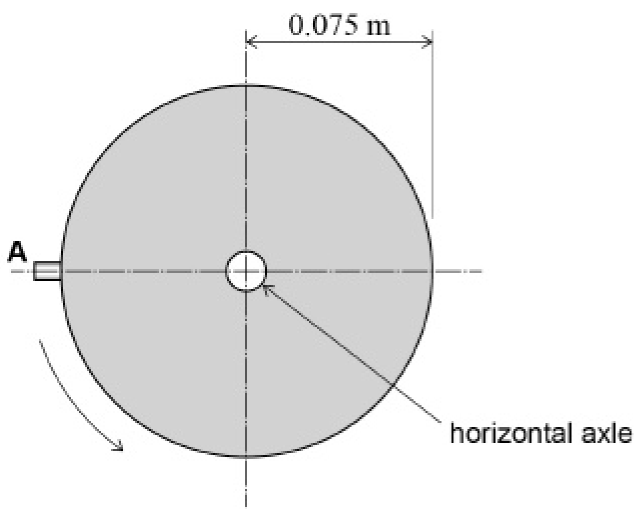
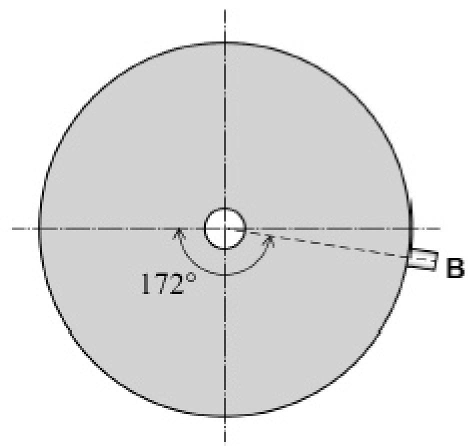


Figure 1b



The loss in gravitational potential energy of the magnet equals the work done against the frictional torque acting at the bearings.

Show that the frictional torque is about 7×10^{-4} N m

(3)

(c) The student goes on to determine the moment of inertia of the flywheel.
The magnet is removed and the flywheel is made to spin. Measurements show that the flywheel makes 573 rotations as its angular speed reduces uniformly from 25.0 rad s^{-1} to zero. Assume the frictional torque at the bearings is constant and the same as in question (b).

Determine the moment of inertia of the flywheel about its axis of rotation.

moment of inertia = ____________________ kg m^2

(3)

(Total 7 marks)

2. (a) State the condition necessary so that the law of conservation of angular momentum applies to a rotating system.

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(1)

A clutch is used to connect two rotating shafts together so that they rotate at the same speed.

(b) The figure shows two shafts, **A** and **B**, rotating freely about the same axis.
Table 1 gives information about the two shafts.

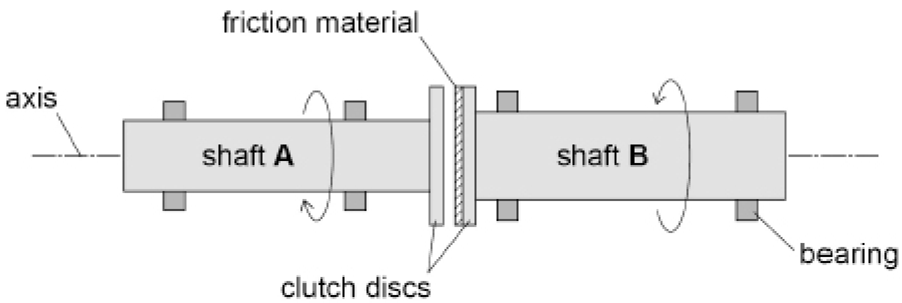


Table 1

	Shaft **A**	Shaft **B**
Angular speed / rad s^{-1}	95	45
Moment of inertia / kg m^2	7.2	11.5
Direction of rotation	Clockwise looking from left	Anticlockwise looking from left

The two shafts are connected by forcing the clutch discs together.
Friction acts between the discs and slipping occurs for a short time until both shafts rotate at a common angular speed.
The clutch is now said to be engaged.

Show that the common angular speed of the two shafts immediately after the clutch is engaged is about 9 rad s^{-1}.

State whether the direction of the common angular speed is clockwise or anticlockwise when viewed from the left.

direction when viewed from the left = _______________

(3)

(c) **Table 2** gives information about two clutches, **C** and **D**.
C and **D** provide different constant frictional torques during slipping at the clutch discs.

Table 2

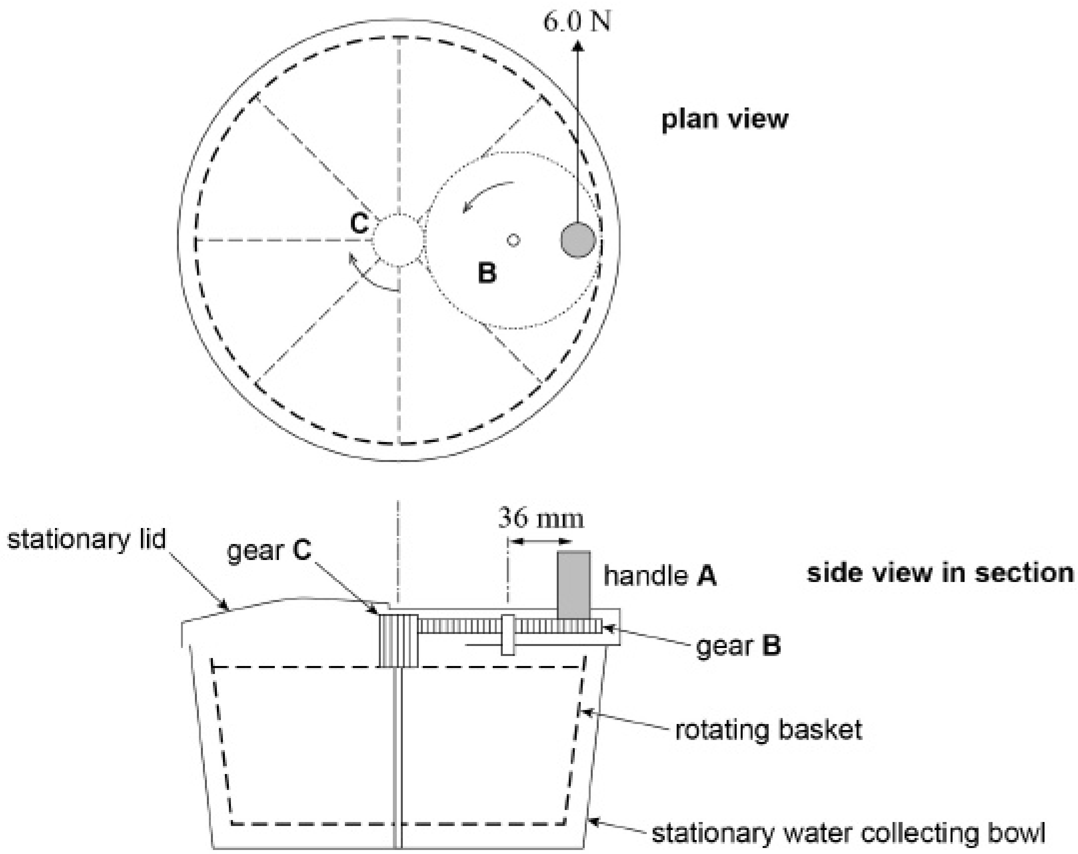
Clutch	**Frictional torque during slipping / N m**
C	600
D	320

The slipping time is to be kept between 1.0 s and 2.0 s with the same initial conditions shown in **Table 1**, and the same final common angular speed.

Deduce whether either or both clutches allow this.

(3)
(Total 7 marks)

3. The diagram shows the basic principle of operation of a hand-operated salad spinner used to dry washed salads.



The salad is placed in the basket and the lid is attached.

When handle **A** is turned the basket and its contents spin rapidly. Water on the salad is driven through holes in the basket into the stationary water collecting bowl. The pivot for gear **B** is fixed to the lid. This pivot and the lid do not move. When gear **B** rotates, gear **C** also rotates but at a greater angular speed. Gear **C** is fixed to the basket and rotates it.

A force of 6.0 N is applied to handle **A** as shown. Handle **A** is at a radius of 36 mm from its centre of rotation.

(a) Calculate the input torque.

torque = ____________________ N m

(1)

(b) Gear **C** rotates four times for every one revolution of gear **B**.

Deduce whether it is possible for the torque on gear **C** to be greater than one quarter of the input torque.

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(2)

(c) It takes 2.1 s for the empty basket to reach an angular speed of 76 rad s^{-1}.
The torque on gear **C** is a constant 0.054 N m during this time. Frictional losses are negligible.

Calculate the moment of inertia of the basket about its axis of rotation.

moment of inertia = ____________________ kg m^2

(2)

(d) The gears are made from polymer (plastic). An early version of this salad spinner suffered from damaged gear teeth.

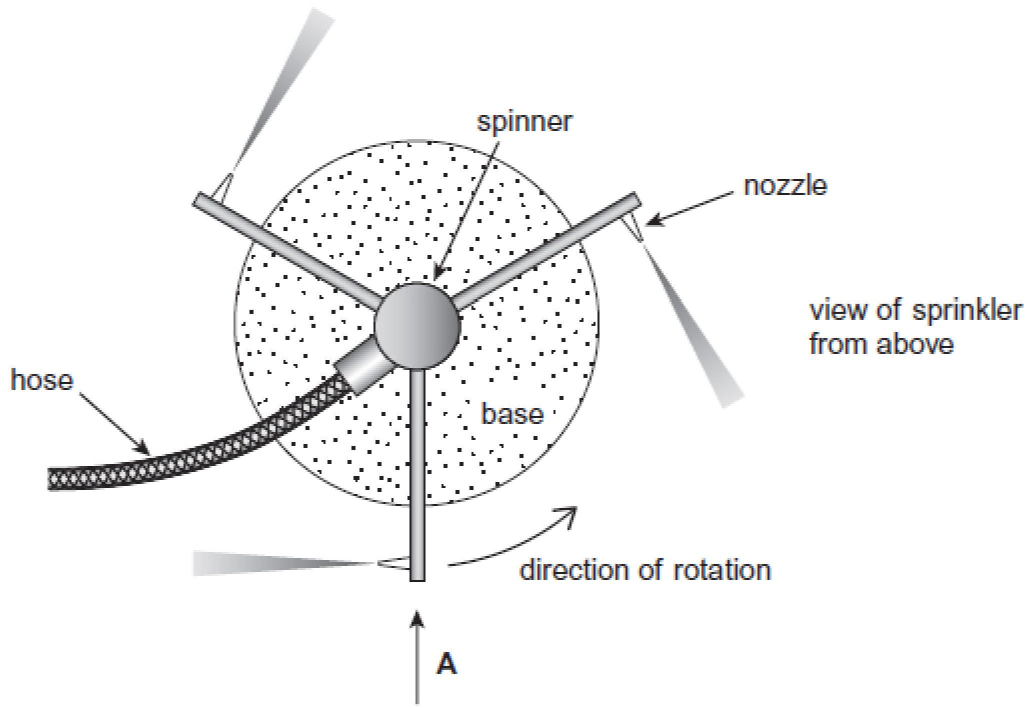
Explain with reference to angular impulse why a great force is put on the gear teeth if the user tries to stop the loaded basket too quickly using the handle.

(3)

(Total 8 marks)

4. A garden sprinkler consists of a fixed base and a rotating spinner having three arms as shown in **Figure 1**.

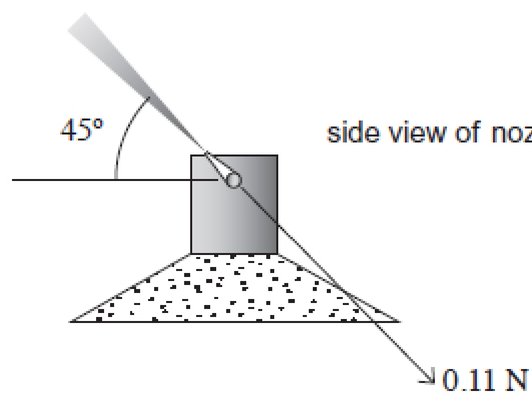
Figure 1



At the end of each arm is a nozzle at 90° to the arm and inclined at 45° to the horizontal. Water flows in jets at a constant rate from these nozzles when the hose water tap is turned on.

Figure 2 shows a side view of one of the nozzles viewed in the direction of arrow **A** in **Figure 1**.

Figure 2



The water jets produce reaction forces that act on the arms which cause the spinner to rotate. The base remains fixed in position. In operation, the spinner rotates at a constant rate of 240 rev min^{-1}. The nozzles rotate in a horizontal circle of radius 120 mm.

(a) Each water jet exerts a constant force of 0.11 N on its arm at 45° to the horizontal.

Show that the torque exerted on the spinner by the jets of water is about 3×10^{-2} N m.

(2)

(b) (i) Explain why, when the water tap is turned on, the spinner accelerates initially but then reaches a constant angular speed.
Assume that, when the tap is turned on, the flow-rate of the water from the jets is constant.

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(2)

(ii) Calculate the power dissipated by the frictional torque acting between the spinner and the fixed base when the sprinkler is rotating at 240 rev min^{-1}.

power = ____________________ W

(2)

(c) When the water is suddenly turned off all the kinetic energy of the spinner and arms is dissipated as heat due to work done by the frictional torque and the spinner makes a further 13 rotations before coming to rest. Assume uniform deceleration.

(i) Calculate the time taken for the spinner to come to rest.

time = ____________________ s

(2)

(ii) Show that the kinetic energy of the spinner when rotating at its operating speed is about 2 J.

(1)

(iii) Determine the moment of inertia of the spinner about its axis of rotation.

moment of inertia = ____________________ kg m^2

(1)

(Total 10 marks)

5. A roundabout in a fairground requires an input power of 2.5 kW when operating at a constant angular velocity of 0.47 rad s^{-1}.

(a) Show that the frictional torque in the system is about 5 kN m.

(3)

(b) When the power is switched off, the roundabout decelerates uniformly because the frictional torque remains constant. The roundabout takes a time of 34 s to come to rest.

(i) Calculate the moment of inertia of the roundabout.
Give an appropriate unit for your answer.

moment of inertia ____________________ unit __________

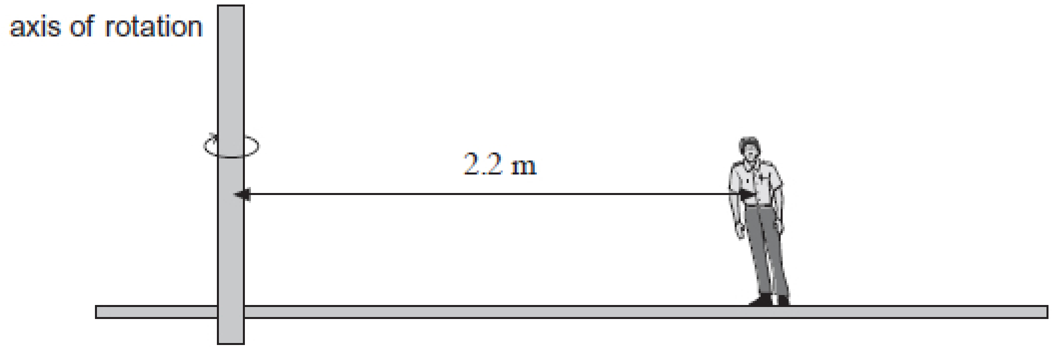
(3)

(ii) Calculate the number of revolutions that are made before the roundabout comes to rest.

number of revolutions ____________________

(3)

(c) An operator of mass 65 kg is standing on the roundabout when the roundabout is rotating at an angular velocity of 0.47 rad s^{-1}. His centre of mass is 2.2 m from the axis of rotation. The diagram shows that his body leans towards the centre of the path.



(i) Calculate the centripetal force needed for the operator to remain at this radius on the roundabout.

centripetal force ____________________ N

(2)

(ii) State the origin of this centripetal force and suggest why the operator has to incline his body towards the centre of rotation to avoid falling over.

You may draw the forces that act on the operator in the diagram to help your answer.

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(2)

(iii) While the roundabout is moving, the operator drops a coin.

Which statement correctly describes and explains what happens to the coin?
Tick (✓) the correct answer in the right-hand column.

	Tick (✓)
There is no longer a centripetal force acting, so the coin falls vertically downwards and lands on the roundabout directly below the point at which it was dropped.	
The centripetal force causes the coin to have a horizontal component of velocity towards the centre of the roundabout, so that it follows a trajectory towards the centre of the roundabout.	
There is no longer a centripetal force acting, so there is a horizontal component of the coin's velocity directed away from the centre of the roundabout and it follows a trajectory directly away from the centre.	
There is no longer a centripetal force acting, so the coin has a horizontal component of its velocity tangential to its original path on the roundabout and it follows a trajectory along this tangent.	

(1)
(Total 14 marks)