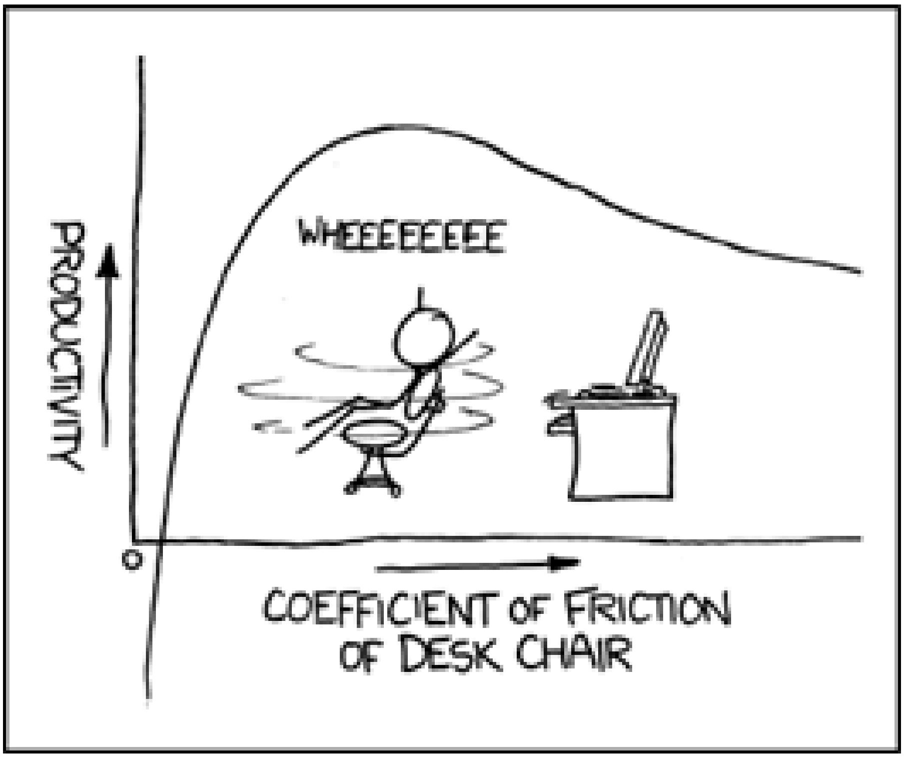
Advanced Higher Physics

Past Paper Questions

1.3 Rotational Dynamics



3. A student uses a solid, uniform circular disc of radius 290 mm and mass 0·40 kg as part of an investigation into rotational motion.

The disc is shown in Figure 3A.

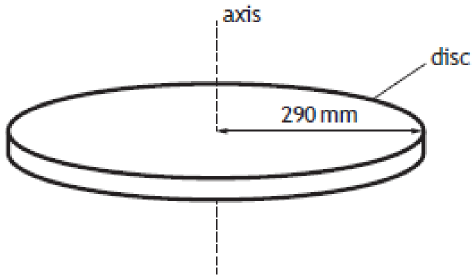


Figure 3A

(a) Calculate the moment of inertia of the disc about the axis shown in Figure 3A. 3

(b) The disc is now mounted horizontally on the axle of a rotational motion sensor as shown in Figure 3B.

The axle is on a frictionless bearing. A thin cord is wound around a stationary pulley which is attached to the axle.

The moment of inertia of the pulley and axle can be considered negligible.

The pulley has a radius of 7·5 mm and a force of 8·0 N is applied to the free end of the cord.

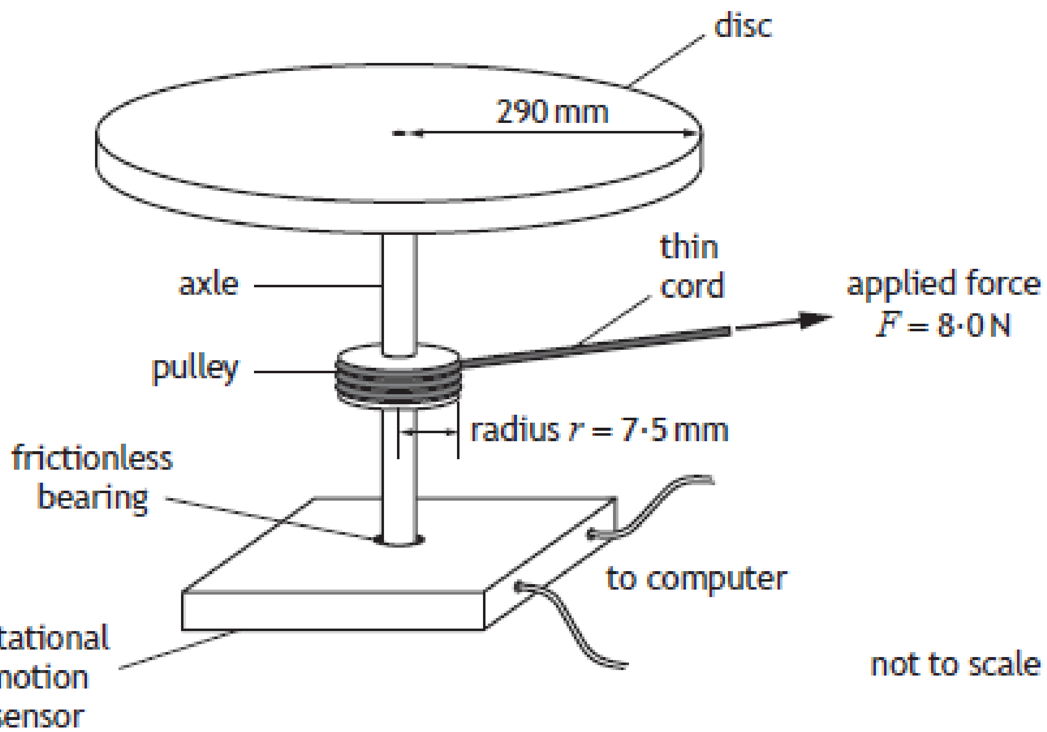


Figure 3B

(i) Calculate the torque applied to the pulley. 3

(ii) Calculate the angular acceleration produced by this torque. 3

(iii) The cord becomes detached from the pulley after 0·25 m has unwound.

By considering the angular displacement of the disc, determine its angular velocity when the cord becomes detached. 5

(c) In a second experiment the disc has an angular velocity of 12 rad s^{-1}.

The student now drops a small 25 g cube vertically onto the disc. The cube sticks to the disc.

The centre of mass of the cube is 220 mm from the axis of rotation, as shown in Figure 3C.

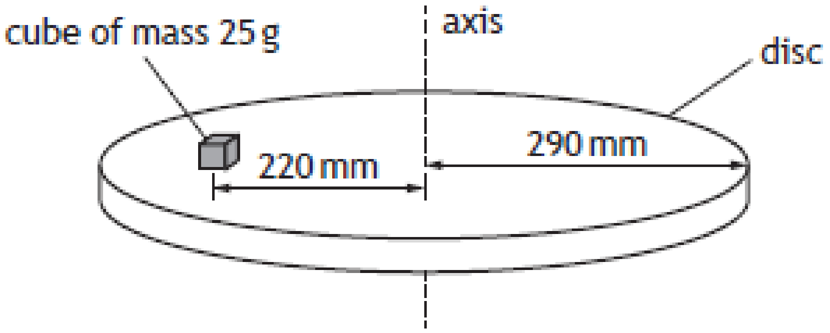


Figure 3C

Calculate the angular velocity of the system immediately after the cube was dropped onto the disc. 5

2. A disc of mass 6·0 kg and radius 0·50 m is allowed to rotate freely about its central axis as shown in Figure 2A.

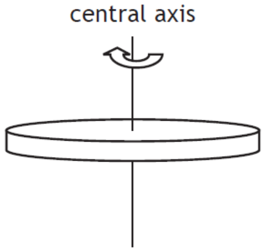
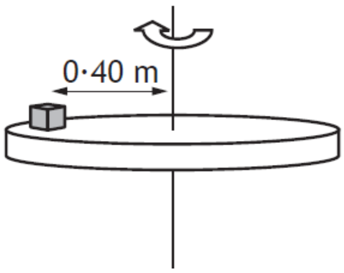


Figure 2A

(a) Show that the moment of inertia of the disc is 0·75 kg m^2. **2**

(b) The disc is rotating with an angular velocity of 12 rad s^{-1}. A cube of mass 2·0 kg is then dropped onto the disc. The cube remains at a distance of 0·40 m from the axis of rotation as shown in Figure 2B.



(i) Determine the total moment of inertia of the disc and cube. **3**

(ii) Calculate the angular velocity of the disc after the cube lands. **3**

(iii) State **one** assumption you have made in your response to b(ii). **1**

(c) The cube is removed and the disc is again made to rotate with a constant angular velocity of 12 rad s^{-1}. A sphere of mass 2·0 kg is then dropped onto the disc at a distance of 0·40 m from the axis as shown in Figure 2C.

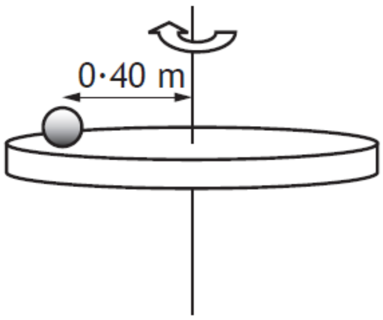


Figure 2C

State whether the resulting angular velocity of the disc is greater than, the same as, or less than, the value calculated in b(ii).

You must justify your answer. **2**

3. A student uses two methods to calculate the moment of inertia of a cylinder about its central axis.

(a) In the first method the student measures the mass of the cylinder to be 0·115 kg and the diameter to be 0·030 m.

Calculate the moment of inertia of the cylinder. **3**

(b) In a second method the student allows the cylinder to roll down a slope and measures the final speed at the bottom of the slope to be $1{\cdot}6\ \text{m s}^{-1}$. The slope has a height of 0·25 m, as shown in Figure 3.

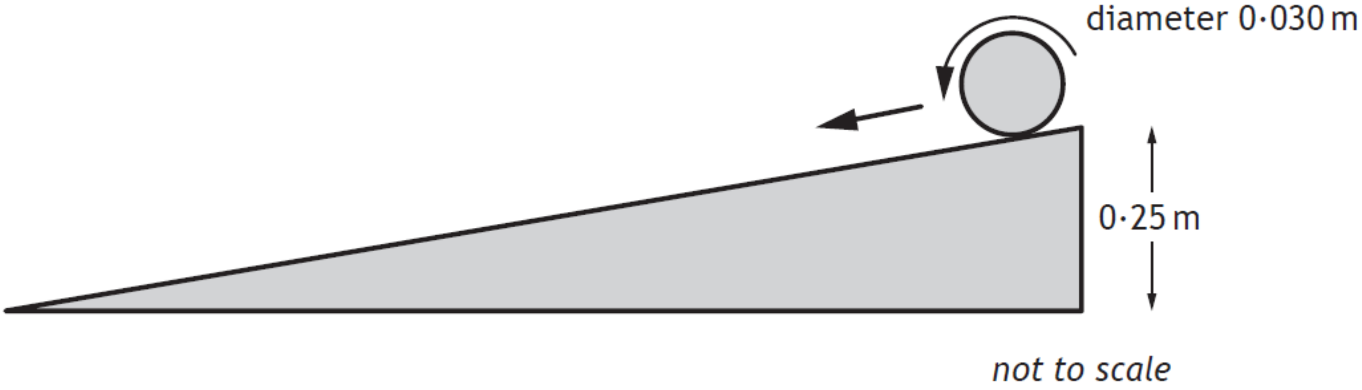


Figure 3

Using the conservation of energy, calculate the moment of inertia of the cylinder. **5**

(c) Explain why the moment of inertia found in part (b) is greater than in part (a). **1**

2. A disc of mass 6·0 kg and radius 0·50 m is allowed to rotate freely about its central axis as shown in Figure 2A.

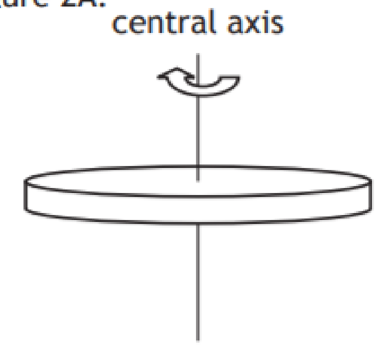


Figure 2A

(a) Show that the moment of inertia of the disc is 0·75 kg m^2. **2**

(b) The disc is rotating with an angular velocity of 12 rad s^{-1}. A cube of mass 2·0 kg is then dropped onto the disc. The cube remains at a distance of 0·40 m from the axis of rotation as shown in Figure 2B.

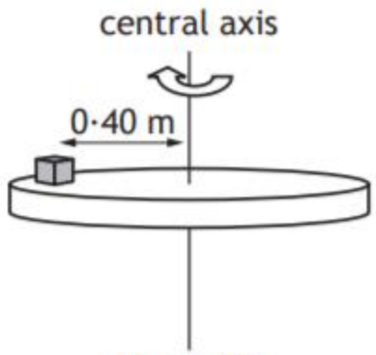


Figure 2B

(i) Determine the total moment of inertia of the disc and cube. **3**

(ii) Calculate the angular velocity of the disc after the cube lands. **3**

(iii) State **one** assumption you have made in your response to b(ii). **1**

(c) The cube is removed and the disc is again made to rotate with a constant angular velocity of 12 rad s^{-1}. A sphere of mass 2·0 kg is then dropped onto the disc at a distance of 0·40 m from the axis as shown in Figure 2C.

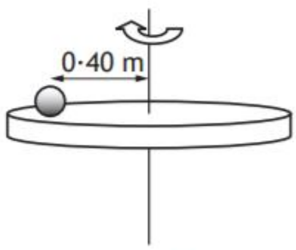


Figure 2C

State whether the resulting angular velocity of the disc is greater than, the same as, or less than, the value calculated in b(ii).

You must justify your answer. **2**

1. A flywheel consisting of a solid, uniform disc is free to rotate about a fixed axis as shown in Figure 1A. The disc has a mass of 16 kg and a radius of 0·30 m.

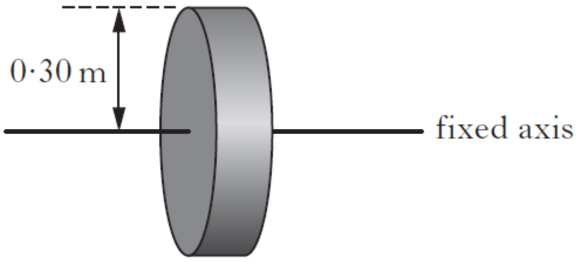


Figure 1A

(*a*) Calculate the moment of inertia of the flywheel. **2**

(*b*) A mass is attached to the flywheel by a light string as shown in Figure 1B.

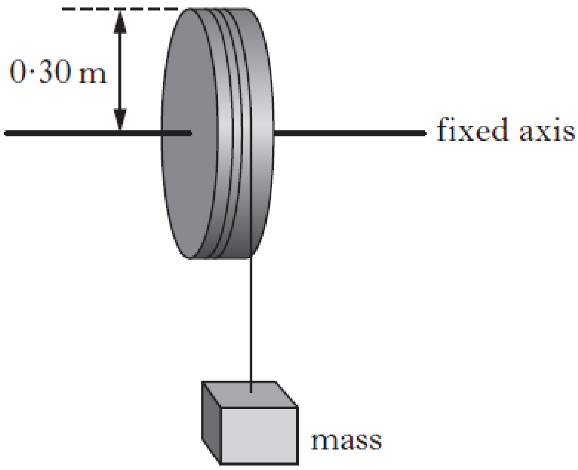


Figure 1B

The mass is allowed to fall and is found to be travelling at 3·0 m s^{-1} when the string leaves the flywheel. The flywheel makes 5 further revolutions before it comes to rest.

(i) Calculate the angular acceleration of the flywheel after the string leaves the flywheel. **3**

(ii) Calculate the frictional torque acting on the flywheel. **2**

(*c*) The experiment is repeated with a flywheel made from a more dense material with the same physical dimensions. The string, falling mass and all frictional forces are the same as in part (*b*).

As the string detaches from the flywheel, is the speed of the falling mass greater than, the same as or less than 3·0 m s^{-1}?

You must justify your answer. **2**

(*d*) A Kinetic Energy Recovery System (KERS) is used in racing cars to store energy that is usually lost when braking.

One of these systems uses a flywheel, as shown in Figure 1C, to store the energy.

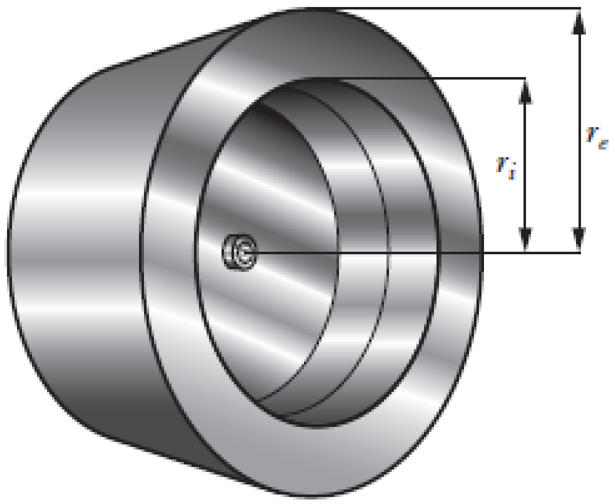


Figure 1C

Data for this KERS flywheel is given below.

Internal radius r_i = 0·15 m

External radius r_e = 0·20 m

Mass of flywheel M = 6·0 kg

Maximum rate of revolution = $6{\cdot}0 \times 10^4$ revolutions per minute

(i) Using the expression

$$I = \tfrac{1}{2} M(r_i^2 + r_e^2)$$

determine the moment of inertia of the flywheel. **1**

(ii) Calculate the maximum rotational kinetic energy that can be stored in the flywheel. **3**

(13)

2. A student uses two methods to calculate the moment of inertia of a cylinder about its central axis.

(*a*) In the first method the student measures the mass of the cylinder to be 0·115 kg and the diameter to be 0·030 m.

Calculate the moment of inertia of the cylinder. **2**

(*b*) In a second method the student allows the cylinder to roll down a slope and measures the final speed at the bottom of the slope to be 1·6 m s^{-1}. The cylinder has a diameter of 0·030 m and the slope has a height of 0·25 m, as shown in Figure 2.

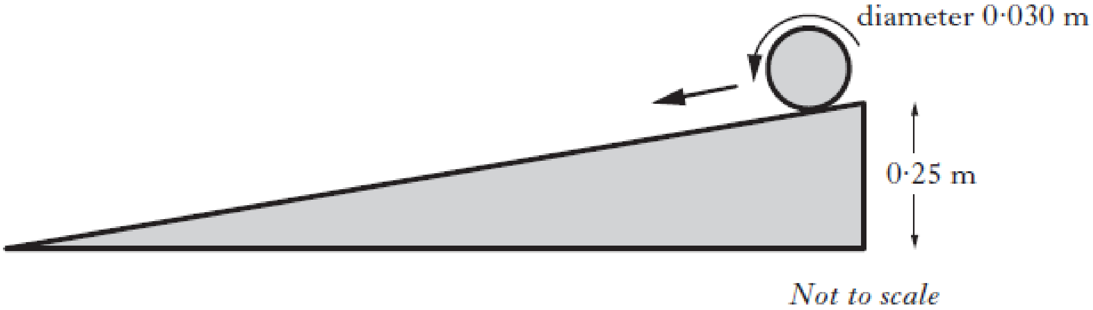


Figure 2

Using the conservation of energy, calculate the moment of inertia. **4**

(*c*) Explain why the moment of inertia found in part (*b*) is greater than in part (*a*). **1**

(7)

Traditional Advanced Higher 2014

1. A flywheel consisting of a solid, uniform disc is free to rotate about a fixed axis as shown in Figure 1A. The disc has a mass of 16 kg and a radius of 0·30 m.

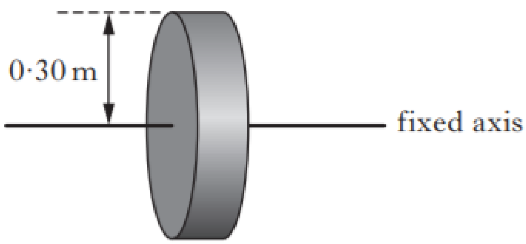


Figure 1A

(*a*) Calculate the moment of inertia of the flywheel. **2**

(*b*) A mass is attached to the flywheel by a light string as shown in Figure 1B.

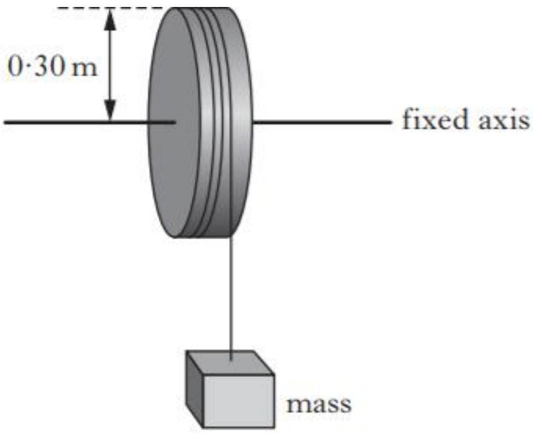


Figure 1B

The mass is allowed to fall and is found to be travelling at $3{\cdot}0\,\mathrm{m\,s^{-1}}$ when the string leaves the flywheel. The flywheel makes 5 further revolutions before it comes to rest.

(i) Calculate the angular acceleration of the flywheel after the string leaves the flywheel. **3**

(ii) Calculate the frictional torque acting on the flywheel. **2**

(*c*) The experiment is repeated with a flywheel made from a more dense material with the same physical dimensions. The string, falling mass and all frictional forces are the same as in part (*b*).

As the string detaches from the flywheel, is the speed of the falling mass greater than, the same as or less than $3{\cdot}0\,\mathrm{m\,s^{-1}}$?

You must justify your answer. **2**

(*d*) A Kinetic Energy Recovery System (KERS) is used in racing cars to store energy that is usually lost when braking.

One of these systems uses a flywheel, as shown in Figure 1C, to store the energy.

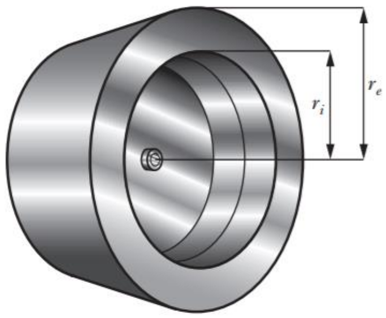
Data for this KERS flywheel is given below.

Internal radius r_i = 0·15 m

External radius r_e = 0·20 m

Mass of flywheel M = 6·0 kg

Maximum rate of revolution = $6{\cdot}0 \times 10^4$ revolutions per minute



(i) Using the expression

$$I = \tfrac{1}{2} M(r_i^2 + r_e^2)$$

determine the moment of inertia of the flywheel. **1**

(ii) Calculate the maximum rotational kinetic energy that can be stored in the flywheel. **3**

(13)

Marks

3. To test a springboard a diver takes up a position at the end of the board and sets up an oscillation as shown in Figure 3A. The oscillation approximates to simple harmonic motion. The board oscillates with a frequency of 0·76 Hz. The end of the board moves through a vertical distance of 0·36 m.

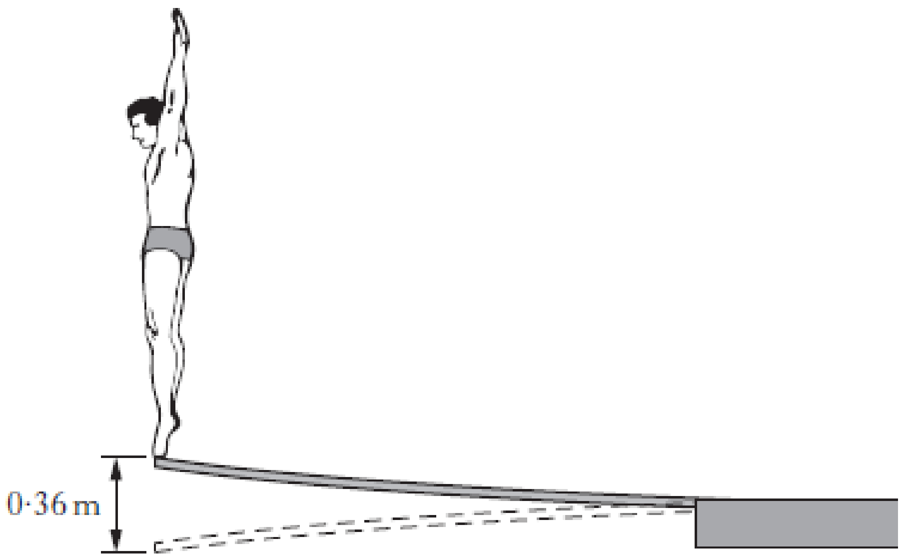


Figure 3A

(*a*) (i) Write an expression for the vertical displacement *y* of the end of the board as a function of time *t*. Include appropriate numerical values. **2**

(ii) The diver increases the amplitude of the oscillation. The frequency remains constant. Show that the amplitude when the diver just loses contact with the board is 0·43 m. **1**

(*b*) A sport scientist analyses a dive. At one point during the dive, shown in Figure 3B, he approximates the diver's body to be two rods of equal mass rotating about point G. One rod has a length of 0·94 m the other of 0·90 m. The diver has a mass of 66·0 kg

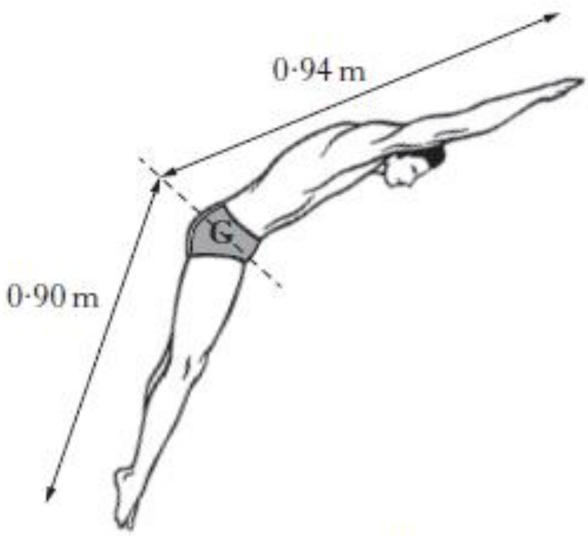


Figure 3B

(i) Calculate the approximate moment of inertia of the diver. **3**

(ii) The diver's true moment of inertia about point G is found to be $10{\cdot}25\ \text{kg m}^2$. Account for any difference between the value calculated in part (i) and the true value. **1**

(iii) In the position shown in Figure 3B, the diver has an initial angular velocity of $0{\cdot}55\ \text{rad s}^{-1}$. He changes his position to that shown in Figure 3C. The diver now has a moment of inertia of $7{\cdot}65\ \text{kg m}^2$. Calculate the angular velocity of the diver in this new position. **2**

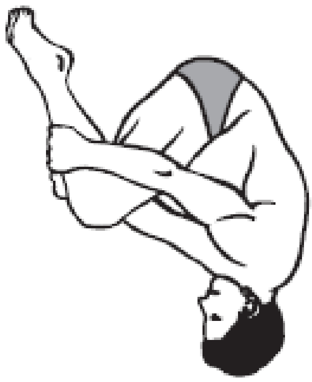


Figure 3C

c) (i) Calculate the change in rotational kinetic energy between these two positions. **2**

(ii) Account for the difference in rotational kinetic energy. **1**

(12)

Marks

2. The front wheel of a racing bike can be considered to consist of 5 spokes and a rim, as shown in Figure 2A.

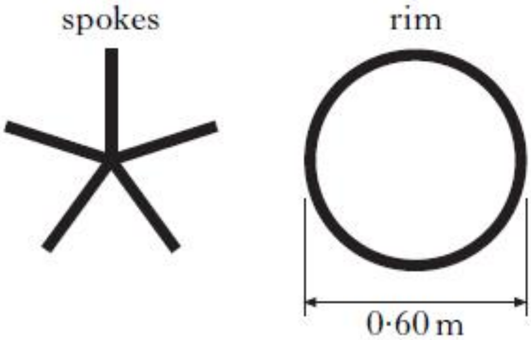


Figure 2A

The mass of each spoke is 0·040 kg and the mass of the rim is 0·24 kg. The wheel has a diameter of 0·60 m.

(*a*) (i) Each spoke can be considered as a uniform rod. Calculate the moment of inertia of a spoke as the wheel rotates. **2**

(ii) Show that the total moment of inertia of the wheel is $2{\cdot}8 \times 10^{-2}\,\text{kg m}^2$. **2**

(*b*) The wheel is placed in a test rig and rotated as shown in Figure 2B.

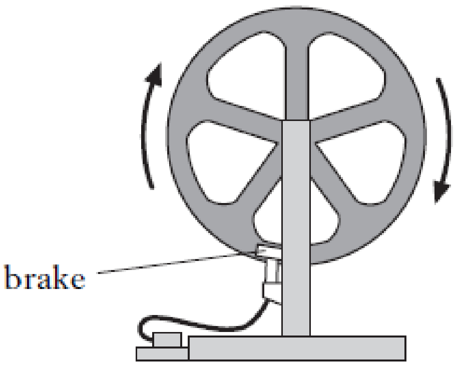


Figure 2B

(i) The tangential velocity of the rim is $19{\cdot}2\,\text{m s}^{-1}$. Calculate the angular velocity of the wheel. **2**

(ii) The brake is now applied to the rim of the wheel, bringing it uniformly to rest in 6·7 s.

(A) Calculate the angular acceleration of the wheel. **2**

(B) Calculate the torque acting on the wheel. **2**

(10)

3. A mass of 2·5 kg is attached to a string of negligible mass. The string is wound round a flywheel of radius 0·14 m. A motion sensor, connected to a computer, is placed below the mass as shown in Figure 3A.

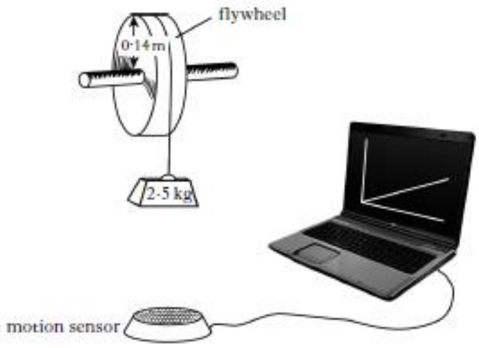
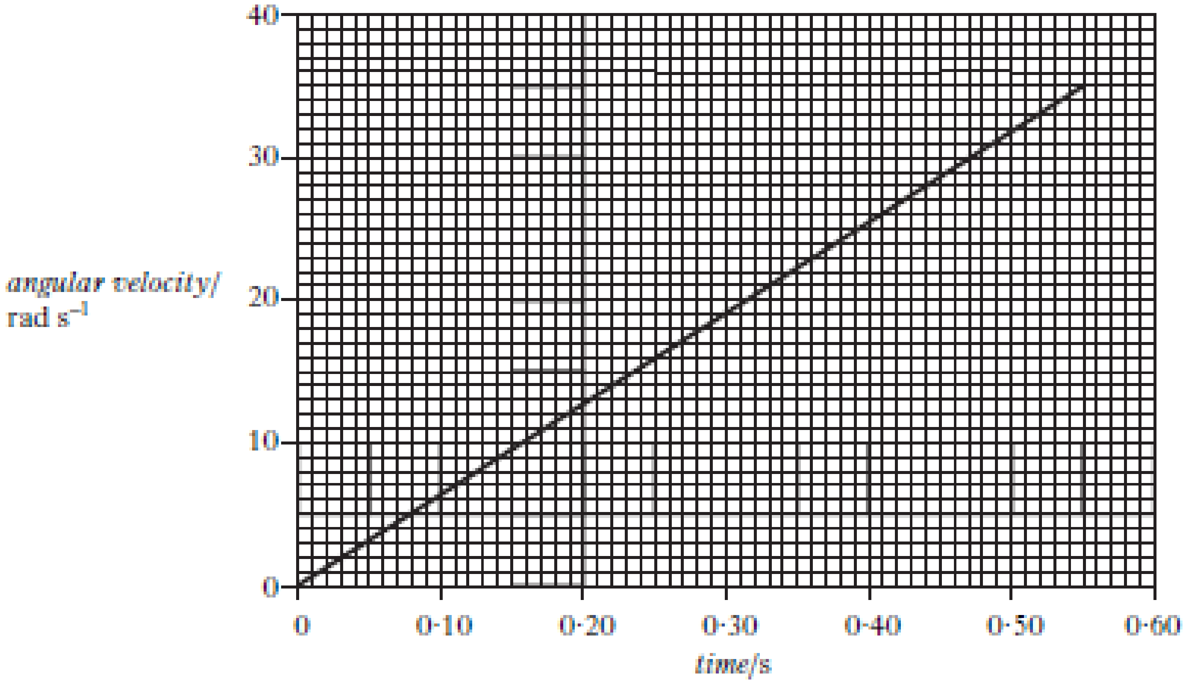


Figure 3A

The mass is released from rest. The computer calculates the linear velocity of the mass as it falls and the angular velocity of the flywheel.

The graph of the angular velocity of the flywheel against time, as displayed on the computer, is shown in Figure 3B.



(*a*) Calculate the angular acceleration of the flywheel. **2**

(*b*) Show that the mass falls a distance of 1·3 m in the first 0·55 seconds. **3**

(*c*) Use the conservation of energy to calculate the moment of inertia of the flywheel. Assume the frictional force to be negligible. **4**

(9)

(b) (continued) *Marks*

(ii) As the student rotates, she grasps a 2·5 kg mass from a stand as shown in Figure 4B.

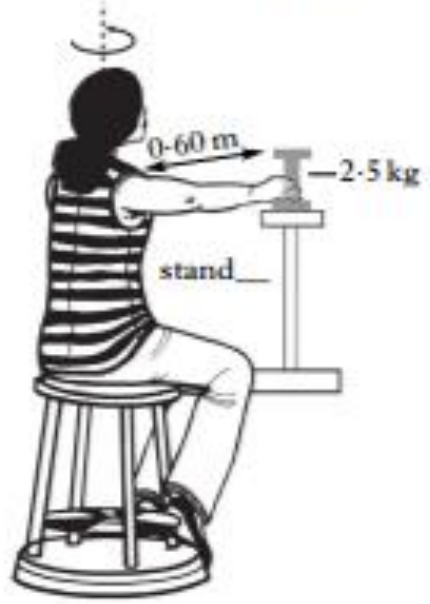


Figure 4B

Calculate the angular velocity of the student and platform just after the mass has been grasped. **3**

(iii) The student then pulls the mass towards her body.

Explain the effect this has on the angular velocity of the student and the platform. **2**

(c) In another investigation the student and platform rotate at $1{\cdot}5\,\text{rad}\,\text{s}^{-1}$. The student puts one foot on the floor as shown in Figure 4C.

Figure 4C

The frictional force between the student's shoe and the floor brings the student and platform to rest in 0·75 seconds. The new moment of inertia of the student and platform is $4{\cdot}5\,\text{kg}\,\text{m}^2$.

Calculate the average frictional torque. **3**

2. (continued)

(*b*) The rotating part of the anemometer is made up of a central cylinder and three arms as shown in Figure 2C.

Plan view of rotating parts of anemometer

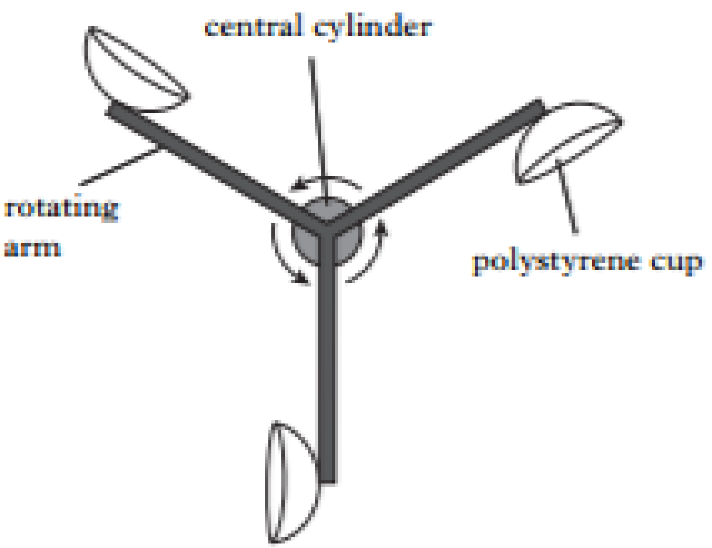


Figure 2C

Each arm consists of a rod of length 76 mm and mass 11 g with a polystyrene cup of negligible mass on the end of the rod. One arm of the anemometer is shown in Figure 2D.

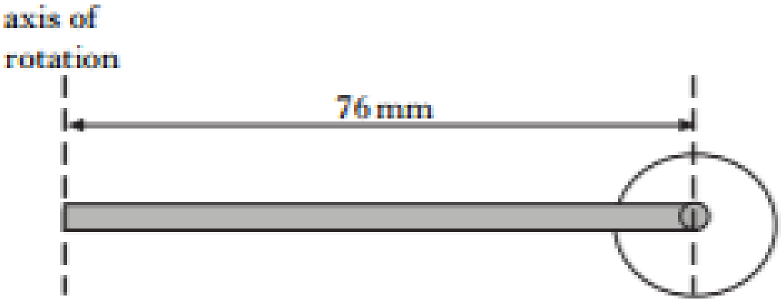


Figure 2D

(i) Calculate the moment of inertia of the rod about the axis shown. **2**

(ii) The moment of inertia of the central cylinder is $1 \cdot 1 \times 10^{-6}\,\text{kg m}^2$. Calculate the total moment of inertia of all the rotating parts. **2**

(*c*) Calculate the average torque acting on the rotating system during the **second** test. **2**

(*d*) The anemometer is set up at a field site to record wind speed. Freezing rain deposits a layer of ice evenly over the cups. Explain the effect this might have on the motion of the arm. **2**

(12)

Marks

3. (continued)

(*b*) On setting 2, the brush head can be considered to oscillate with simple harmonic motion with amplitude A as shown in Figure 3C.

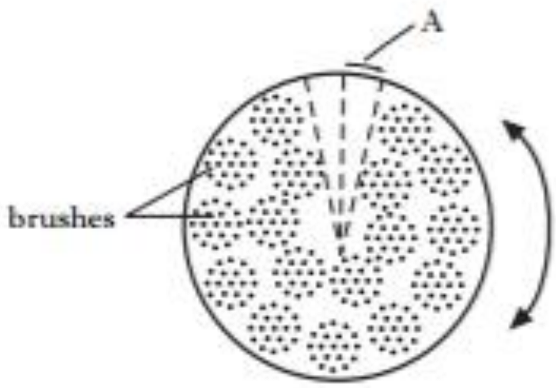


Figure 3C

The velocity, in $m\,s^{-1}$, of a point on the circumference of the head can be given by the equation

$$v = 9{\cdot}2 \times 10^{-2} \cos 77t.$$

Calculate the amplitude of the oscillation on setting 2. **2**

(*c*) A particle of toothpaste of mass $2{\cdot}5 \times 10^{-6}$ kg on the outer edge of the brush head is shown in Figure 3D.

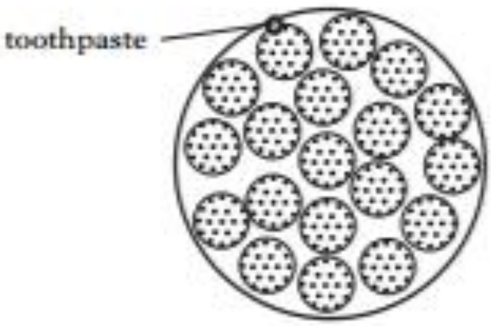


Figure 3D

The switch is on setting 2.

(i) Calculate the maximum kinetic energy of the particle of toothpaste. **2**

(ii) Sketch a graph of the kinetic energy of the particle of toothpaste against its displacement. Appropriate numerical values are required on both axes. **2**

(10)

Marks

1. A centrifuge is used to separate out small particles suspended in a liquid. Figure 1 shows the rotating part of the centrifuge which includes two test tubes containing the liquid.

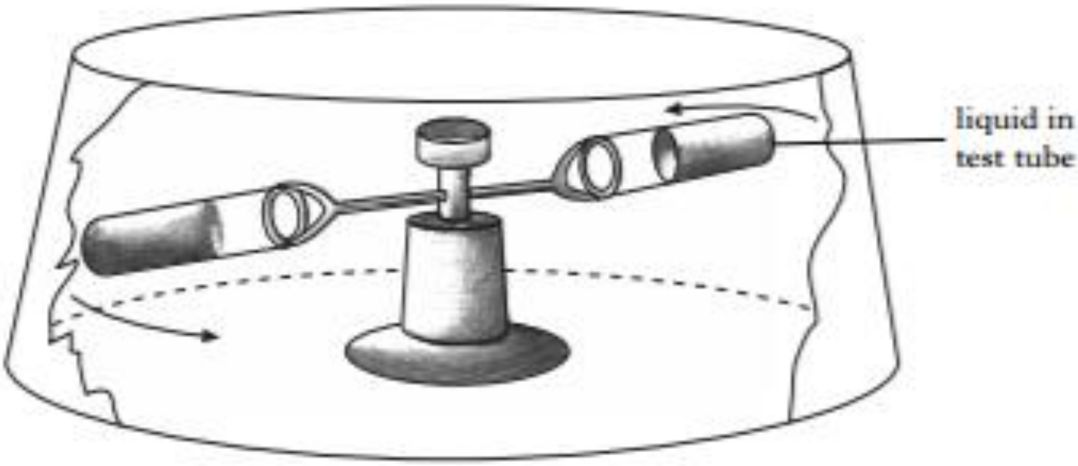


Figure 1

The rotating part starts from rest and reaches a maximum angular velocity of 1200 rad s^{-1} in a time of 4 seconds.

The average moment of inertia of the rotating part is $5{\cdot}1 \times 10^{-4}$ kg m^2.

(*a*) (i) Calculate the angular acceleration of the rotating part. **2**

(ii) Calculate the average unbalanced torque applied during this time. **2**

(iii) How many **revolutions** are made during this time? **3**

(*b*) Figure 2 shows an overhead view of the rotating part.

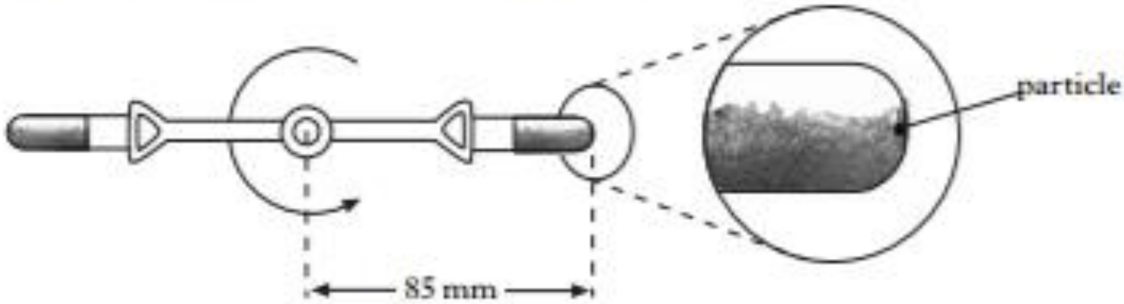


Figure 2

The expanded view shows the position of a single particle of mass $5{\cdot}3 \times 10^{-6}$ kg.

(i) Calculate the central force acting on the particle at the maximum angular velocity. **2**

(ii) What provides the central force acting on this particle? **1**

1. (continued)

(*c*) At rest the test tubes in the centrifuge are in a vertical position as shown in Figure 3.

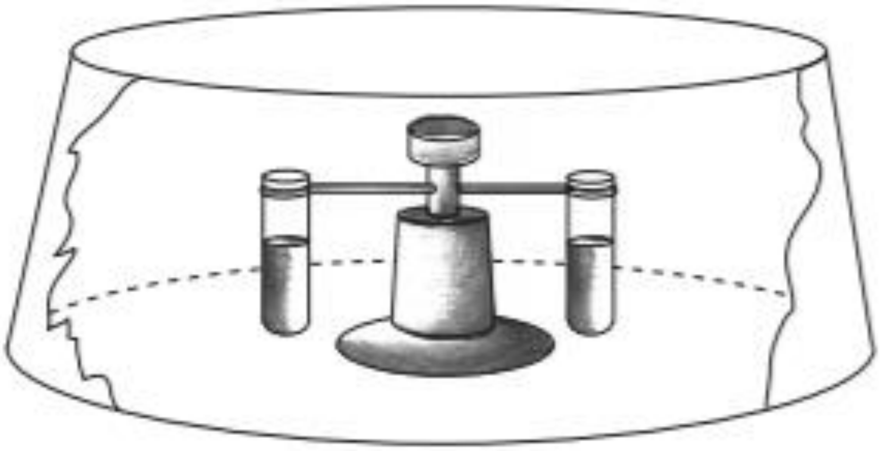


Figure 3

Does the moment of inertia of the rotating part increase, decrease, or stay the same during the acceleration of the rotating part? Justify your answer. **2**

(12)

Marks

2. A circular metal disc is mounted horizontally on the axle of a rotational motion sensor as shown in Figure 3.

The axle is on a frictionless bearing.

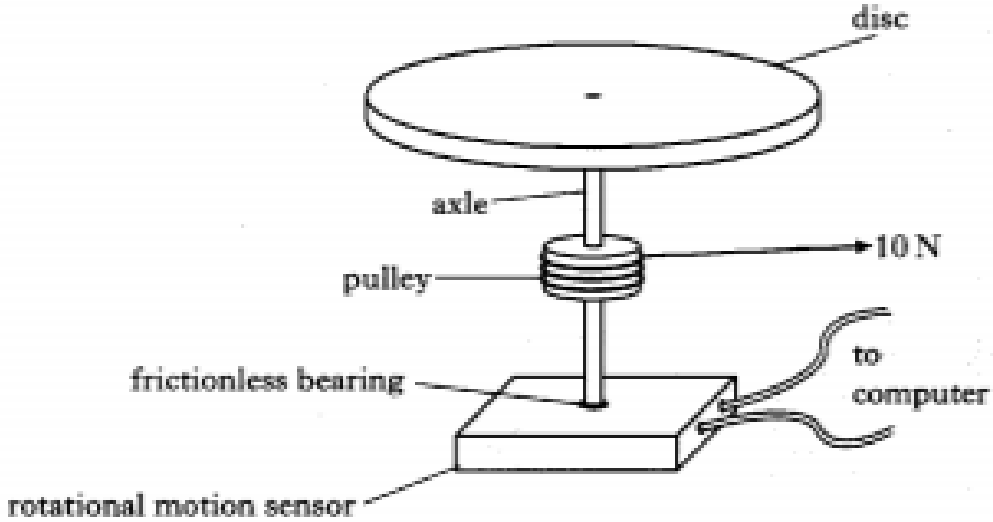


Figure 3

A thin cord is wound round a light pulley which is attached to the axle. The pulley has a radius of 20 mm and a force of 10 N is applied to the free end of the cord.

The cord fully unwinds from the pulley in a time of 3·0 s.

The rotational motion sensor is interfaced to a computer which is programmed to display a graph showing the variation of the angular velocity of the metal disc with time.

The graph displayed on the monitor is shown in Figure 4.

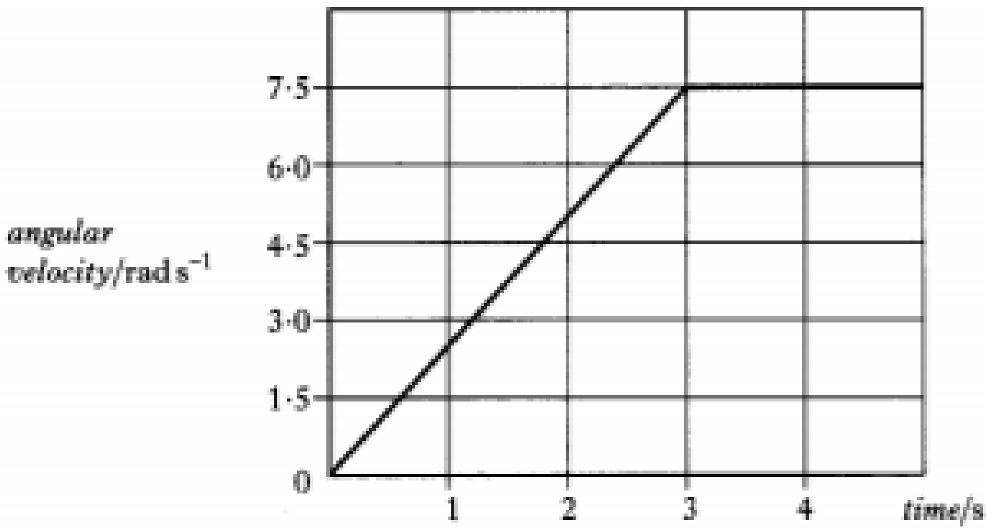


Figure 4

(*a*) (i) Calculate the torque exerted by the cord. **2**

(ii) Using information from the graph, determine the angular acceleration of the disc. **2**

(iii) Calculate the moment of inertia of the disc. **2**

2. (continued)

(*b*) After the cord is fully unwound, a second uniform disc with mass 3·2 kg and radius 0·12 m is gently dropped on top of the original disc as shown in Figure 5.

Both discs now rotate with a new angular velocity.

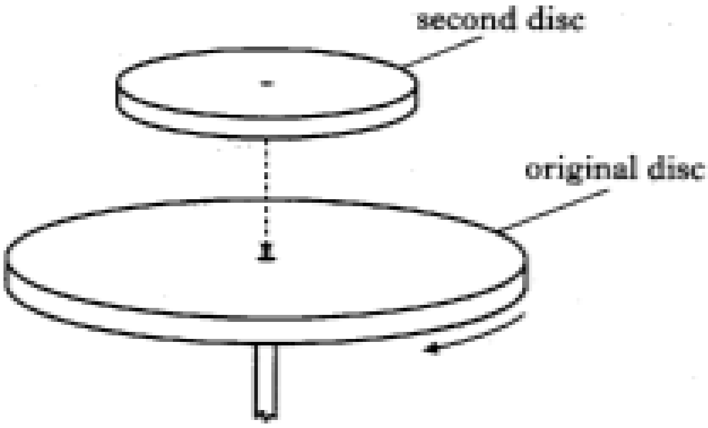


Figure 5

(i) Calculate the moment of inertia of the second disc. **2**

(ii) Calculate the new angular velocity of the discs. **2**

(*c*) The experiment is repeated, except that a **ring**, with the same mass and diameter as the second disc, is gently dropped on top of the original disc as shown in Figure 6.

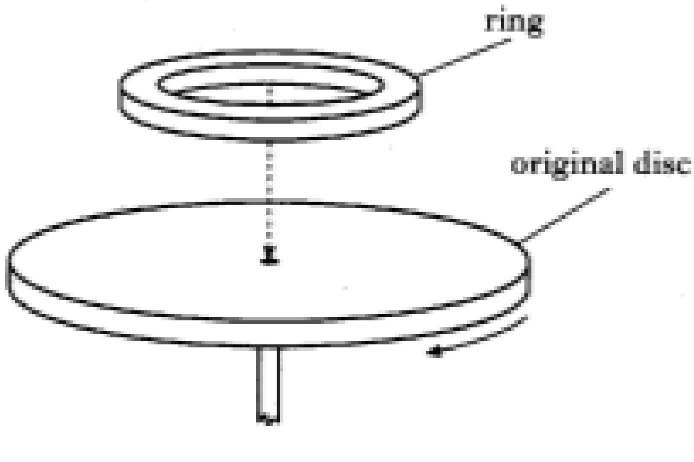


Figure 6

State whether the resulting angular velocity is greater than, less than or the same as that calculated in (*b*)(ii).

You must justify your answer. **2**

(12)

[Turn over

2. A playground roundabout has a radius of 2·0 m and a moment of inertia of 500 kg m^2 about its axis of rotation. A child of mass 25 kg runs tangentially to the stationary roundabout and jumps on to its outer edge, as shown in Figure 3.

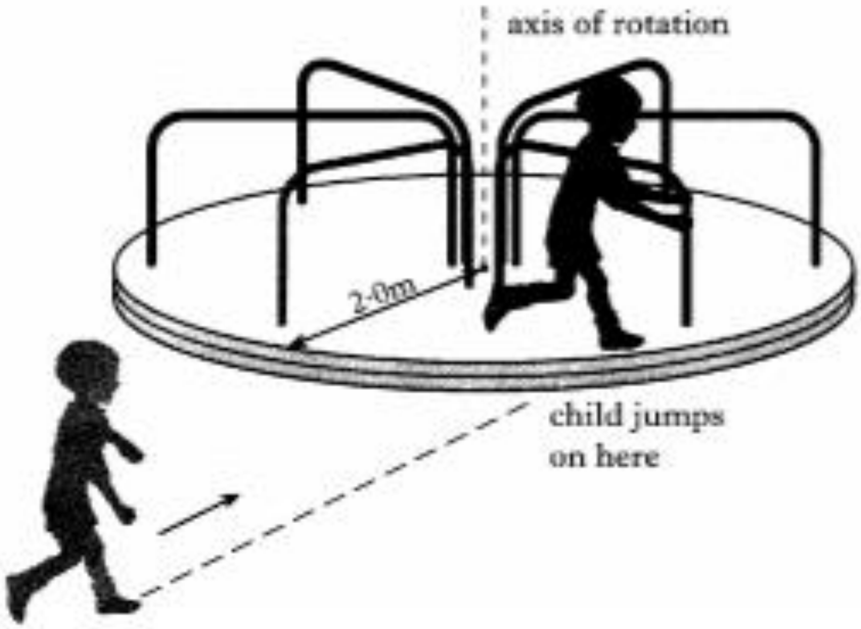


Figure 3

(*a*) Show that, with the child at the outer edge, the combined moment of inertia of the roundabout and child is 600 kg m^2. **2**

(*b*) State what is meant by *conservation of angular momentum*. **1**

(*c*) At the point of jumping on to the roundabout, the tangential speed of the child is 2·4 m s^{-1}. At this **point**, calculate:

(i) the linear momentum of the child; **1**

(ii) the angular momentum of the child about the axis of rotation of the roundabout. **1**

(*d*) Calculate the angular velocity of the roundabout and child just after the child jumps on. **2**

(*e*) Calculate the loss of kinetic energy as the child jumps on to the roundabout. **2**

(*f*) The roundabout with the child onboard makes half a complete revolution before coming to rest.

Calculate the frictional torque acting on the roundabout. **3**

(12)

Marks

3. A grinder is used for cutting paving slabs.

The grinder has a motor and a disc with an abrasive edge as shown in Figure 3.

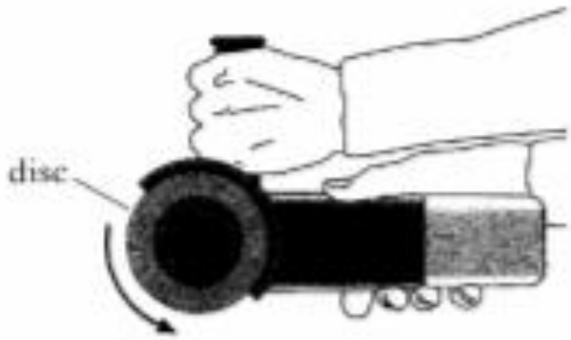


Figure 3

The motor is switched on and the disc reaches a maximum angular velocity of 600 revolutions per minute.

The motor is switched off and the disc slows uniformly to rest in 30 s.

(*a*) Calculate the maximum angular velocity of the disc in rad s^{-1}. **1**

(*b*) Calculate the angular acceleration of the disc as it slows. **2**

(*c*) How many revolutions does the disc make during this time? **3**

(*d*) The moment of inertia of the disc is $2{\cdot}16 \times 10^{-3}$ kg m^2.
Calculate the torque acting on the disc as it slows. **2**

(*e*) The disc is replaced by a disc of **half** the radius and **double** the mass. The motor is switched on and this disc also reaches a maximum angular velocity of 600 revolutions per minute. The grinder is switched off and a torque equal to that in part (*d*) acts on the disc.

Explain whether this disc comes to rest in a time greater than, equal to or less than 30 s.

The moment of inertia of a disc is given by $\frac{1}{2}mr^2$. **2**

(10)

8. (*a*) A student investigating the force on a current-carrying conductor placed perpendicularly to a uniform magnetic field obtains the following readings.

Length of conductor	= (0·050 ± 0·001) m				
Current	= (2·50 ± 0·01) A				
Force readings	3·8 mN	3·4 mN	3·3 mN	3·7 mN	3·3 mN

(i) Calculate the magnetic induction B, in Tesla, using the equation $F = BIl$.

(ii) Calculate the **absolute** uncertainty in this value.

(iii) Suggest **one** improvement that would reduce the uncertainty in the value obtained for the magnetic induction. **Justify your answer.** **7**

(*b*) The rectangular coil, PQRS, of a model motor consists of 20 turns of wire. PQ = 50 mm and QR = 40 mm.

The coil is placed horizontally between two magnets as shown in Figure 6.

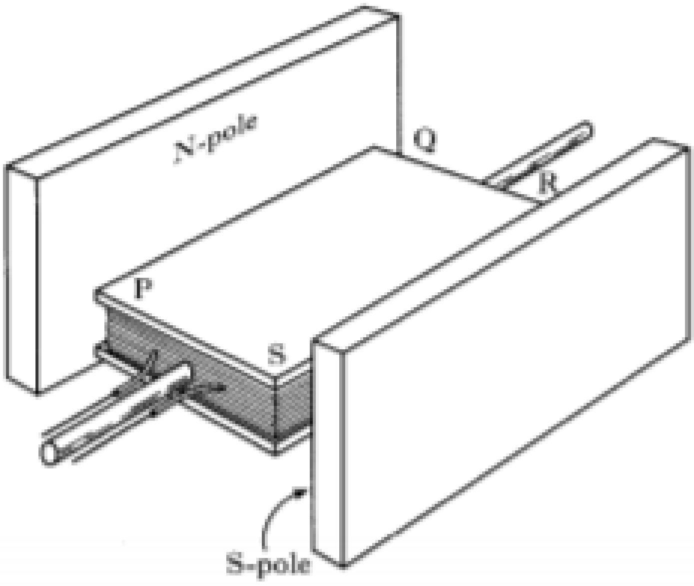


Figure 6

The magnets produce a uniform horizontal field of magnetic induction 0·1 T. The current in the coil is 2·2 A.

(i) Explain why the force on the wire on side QR is zero.

(ii) Calculate the torque on the coil.

(iii) The coil starts to rotate. What happens to the torque? Give a reason for your answer. **6**

(13)

Marks

2. A flywheel is made from two large discs joined in the middle by a smaller disc of radius 20 mm.

The flywheel is free to rotate about a fixed axis through the centres of the discs. A thin, light cord is coiled 8 times round the inner disc, as shown in Figures 3 and 4.

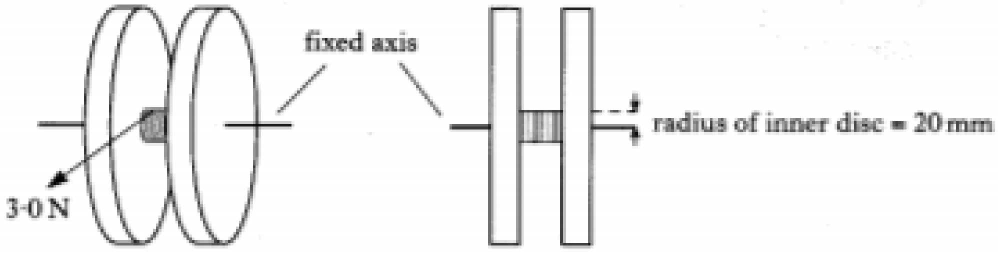


Figure 3 Figure 4

The flywheel is initially at rest.

A steady force of 3·0 N is applied to the end of the cord.

The cord takes 6·0 seconds to unwind fully.

(*a*) (i) Show that the angular acceleration of the flywheel is 2·8 rad s^{-2}.

(ii) Calculate the maximum angular velocity of the flywheel. **4**

(*b*) There is a constant frictional torque of 0·010 N m acting on the moving flywheel.

(i) Calculate the moment of inertia of the flywheel.

(ii) When the cord is fully unwound, it detaches from the flywheel.

Calculate:

(A) the angular deceleration of the flywheel;

(B) the time taken for the flywheel to stop rotating. **6**

(*c*) The thin cord is now replaced with a thicker cord of the **same length**. This thicker cord has to overlap itself when it is wound on the inner disc of the flywheel, as shown in Figures 5 and 6.

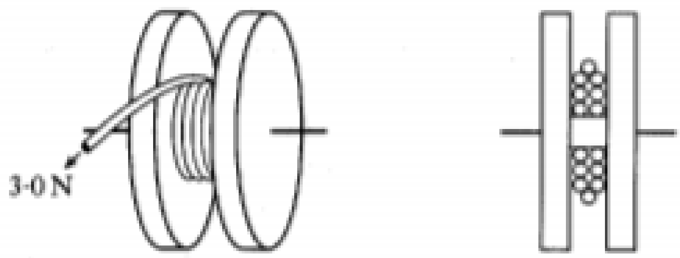


Figure 5 Figure 6

A constant force of 3·0 N is applied to the cord as before.

Will the time taken by the thicker cord to unwrap be longer, shorter or the same as the thin cord? **Explain your answer**.

Neglect the mass of the thicker cord. **2**

(12)