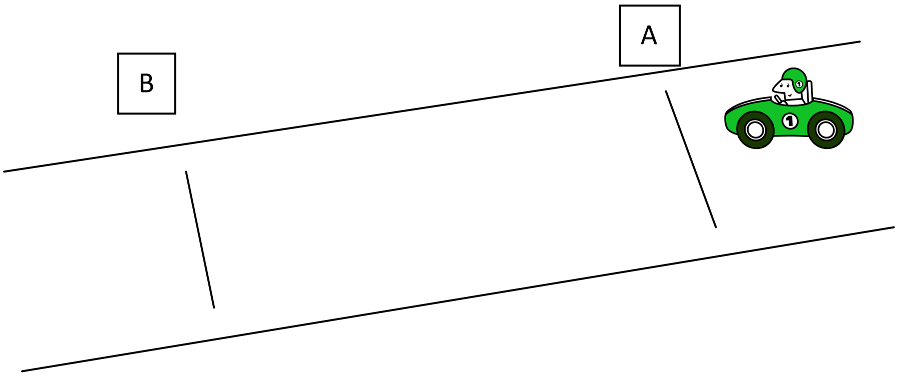
CfE Advanced Higher Physics

Rotational Motion & Astrophysics Past Paper Homework

1.Kinematic Relationships

1. The average acceleration of a radio controlled car is investigated by a student.

She marks distance AB on a straight track, as shown below and measures this distance using a measuring tape.



She places the car at A and uses the radio control to accelerate the car. The car starts from rest and accelerates in a straight line along the track to B. Using a stopwatch, the student measures the time for the car to travel the distance AB.

She repeats this several times and obtains the following results.
Distance AB = (3.54+/- 0.01)m.

Stopwatch readings: 2.53s, 2.29s, 2.34s, 2.36s, 2.65s, 2.53s.

(i) Starting with the appropriate equation of motion, show that the acceleration of the car is given by

$a = \frac{2s}{t^2}$ where the symbols have their usual meanings. 3

(ii) Calculate the average value of the car's acceleration. 2

(iii) Calculate the random uncertainty in the time measurement. 3

(iv) Calculate the percentage uncertainty in the average acceleration. 4

(v) Express the numberical result of her investigation in the form. 2

final value +/- absolute uncertainty. **(14)**

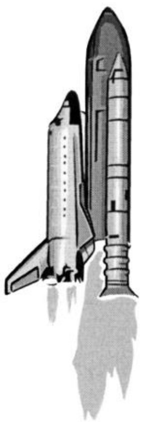
2. (a) A particle has displacement $s = 0$ at time $t = 0$ and moves with constant acceleration a.

The velocity of the object is given by the equation $v = u + at$, where the symbols have their usual meanings.

Using calculus, derive an equation for the displacement s of the object as a function of time t. 4

(4)

3 . Figure 1A shows a space shuttle shortly after take-off.



(a) Immediately after take off, the vertical displacement of the shuttle for part of its journey can be described using the equation

$$s = 3.1t^2 + 4.1t.$$

(i) Find, by differentiation, the equation for the vertical velocity of the shuttle.

2

(ii) At what time will the vertical velocity be $72 ms^{-1}$? 3

(iii) Calculate the vertical linear acceleration during this time. 2

(7)

Total Marks 25

CfE Advanced Higher Physics

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2. Angular Motion

1. (*a*) A turntable consists of a uniform disc of radius 0.15 m and mass 0.60 kg.

(i) Calculate the moment of inertia of the turntable about the axis of rotation shown. **3**

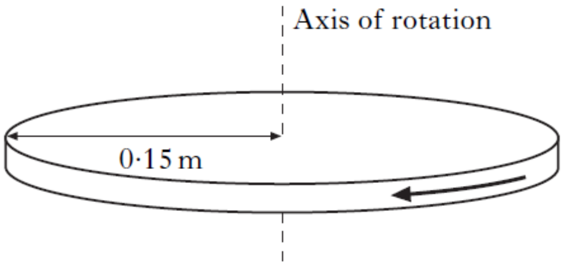


Figure 1

(ii) The turntable accelerates uniformly from rest until it rotates at 45 revolutions per minute. The time taken for the acceleration is 1.5 s.

(A) Show that the angular velocity after 1.5 s is 4.7 rad s^{-1}. **2**

(B) Calculate the angular acceleration of the turntable. **3**

(iii) When the turntable is rotating at 45 revolutions per minute, its motor is disengaged. The turntable continues to rotate freely with negligible friction. **3**

A small mass of 0.20 kg is dropped onto the turntable at a distance of 0.10m from the centre, as shown in Figure 2. The mass remains in this position on the turntable due to friction, and the turntable and mass rotate together.

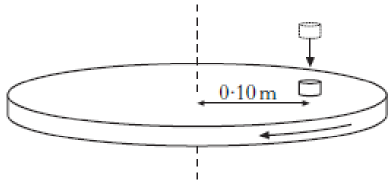


Figure 2

Calculate the new angular velocity of the turntable and mass. 2

(13)

2. A child's toy consists of a model aircraft attached to a light cord. The aircraft is swung in a vertical circle **at constant speed** as shown in Figure 1.

X is the highest point and Y the lowest point in the circle.

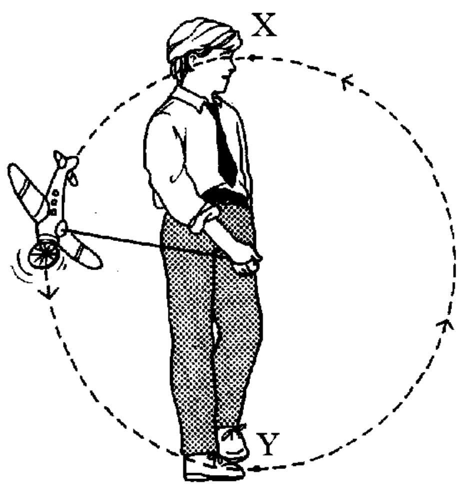


Figure 1

(*a*) The time taken for the aircraft to complete 20 revolutions is measured five times.

The mass of the aircraft and the radius of the circle are also measured. The following data is obtained.

Time for 20 revolutions: 10·05 s; 9·88 s; 10·30 s; 9·80 s; 9·97 s.
Radius of circle = 0·500 ± 0·002 m.
Mass of aircraft = 0·200 ± 0·008 kg.

(i) (A) Calculate the average period of revolution of the aircraft. 3

(B) Assuming that the scale reading uncertainty and the calibration uncertainty of the timer are negligible, calculate the absolute uncertainty in the period. 3

(ii) Show that the centripetal force acting on the aircraft is 15·8 N. 4

(iii) Calculate the absolute uncertainty in this value for the centripetal force. Express your answer in the form

$$F = (15{\cdot}8 \pm \qquad)\,\text{N}.$$ 3

(iv) Draw labelled diagrams to show the forces acting on the aircraft:

(A) at position X; 2

(B) at position Y. 2

(v) Calculate the minimum tension in the cord. 3

(23)

3 A compact disc (CD) stores information on the surface as shown in Figure 1.

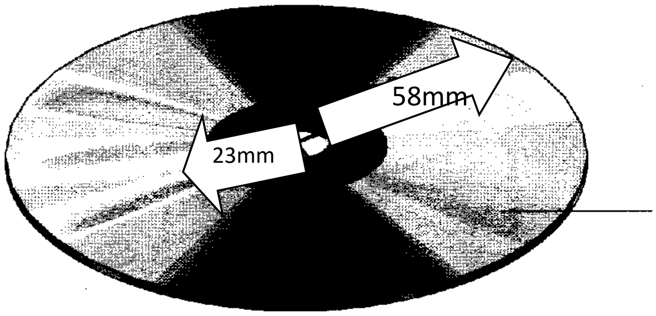


Figure 1

The information is retrieved by an optical reader which moves outwards as the CD rotates, as shown in Figure 2.

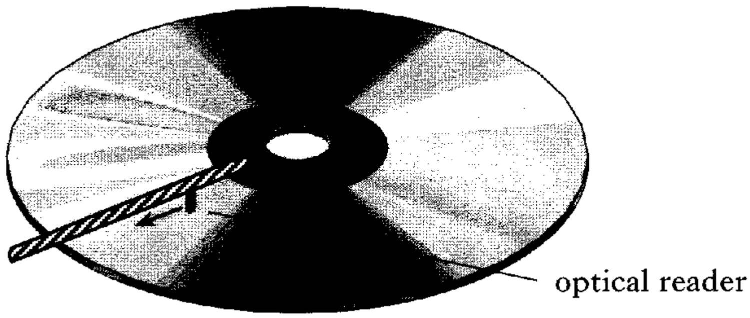


Figure 2

The part of the CD below the reader must always have a tangential speed of $1{\cdot}30\,\text{m}\,\text{s}^{-1}$.

(*a*) The reader starts at a radius of $23{\cdot}0\,\text{mm}$ from the centre of the CD. Calculate the angular velocity of the CD at the start. **3**

(*b*) Show that the CD rotates at $22{\cdot}4\,\text{rad}\,\text{s}^{-1}$ when the reader reaches the outer edge of the disc. **2**

(*c*) Explain why the angular velocity of the CD decreases as the CD plays. **2**

(*d*) The CD makes a total of $2{\cdot}80 \times 10^4$ revolutions from start to finish.

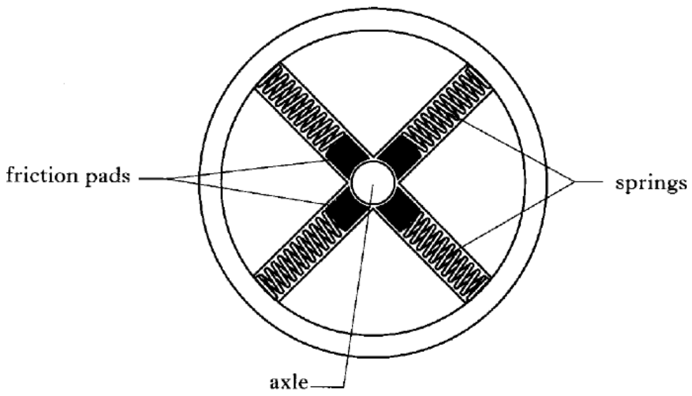
(i) Show that the total angular displacement of the CD is $1{\cdot}76 \times 10^5$ radians. **1**

(ii) Calculate the average angular acceleration of the CD as the disc is played from start to finish. **3**

(iii) Calculate the total playing time of the CD. **3**

(14)

4. One type of yo-yo has four friction pads inside each disc. Each friction pad is held in place by a spring which exerts a force of 5.00N. At low angular velocities the friction pads grip the axle as shown below.

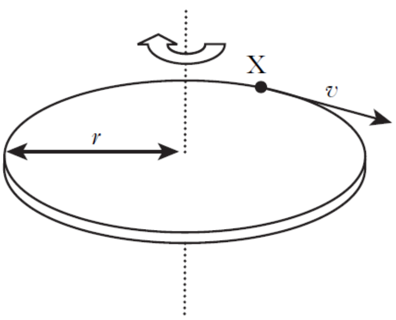


At higher angular velocities the pads move away from the axle and compress the springs. This releases the axle and allows the discs to spin freely.

(a) Explain why the friction pads move away from the axle. 1

(b) Each friction pad can be considered as a point mass of 12.0 g at a radius of 10.0mm from the centre of the axle.
Calculate the minimum angular velocity at which the axle is released from the friction pads. **(4)** 3

5. A turntable, radius *r*, rotates with a constant angular velocity ω about an axis of rotation. Point X on the circumference of the turntable is moving with a tangential speed *v*, as shown in Figure 1A.



(*a*) Derive the relationship: 3

$$v = rw.$$

(b) Data recorded for the turntable is shown below.

Angle of rotation	$(3{\cdot}1 \pm 0{\cdot}1)$ rad
Time taken for angle of rotation	$(4{\cdot}5 \pm 0{\cdot}1)$ s
Radius of disk	$(0{\cdot}148 \pm 0{\cdot}001)$ m

(i) Calculate the tangential speed *v*. 3

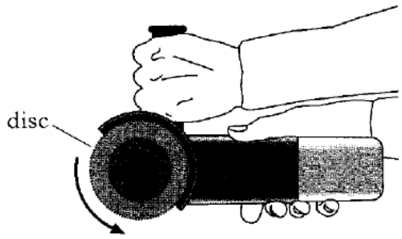
(ii) Calculate the percentage uncertainty in this value of *v*. 3

(iii) As the disk rotates, *v* remains constant.

(A) Explain why point X is accelerating. 1

(B) State the direction of this acceleration. **(11)** 1

6. A grinder is used for cutting paving slabs.
The grinder has a motor and a disc with an abrasive edge as shown below.



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 30s.

(a) Calculate the maximum angular velocity of the disc in $rads^{-1}$. 2

(b) Calculate the angular acceleration of the disc as it slows. 3

(c) How many revolutions does the disc make during this time? 5

(d) The moment of inertia of the disc is 2.16×10^{-3} kg m^{2}. 2

Calculate the torque acting on the disc as it slows. **(12)**

Total Marks 77

CfE Advanced Higher Physics

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3. Rotational Dynamics

1. A yo-yo consists of two discs mounted on an axle. A length of string is attached to the axle and wound round the axle.
   With the string fully wound, the yo-yo is suspended from a horizontal support as shown below:

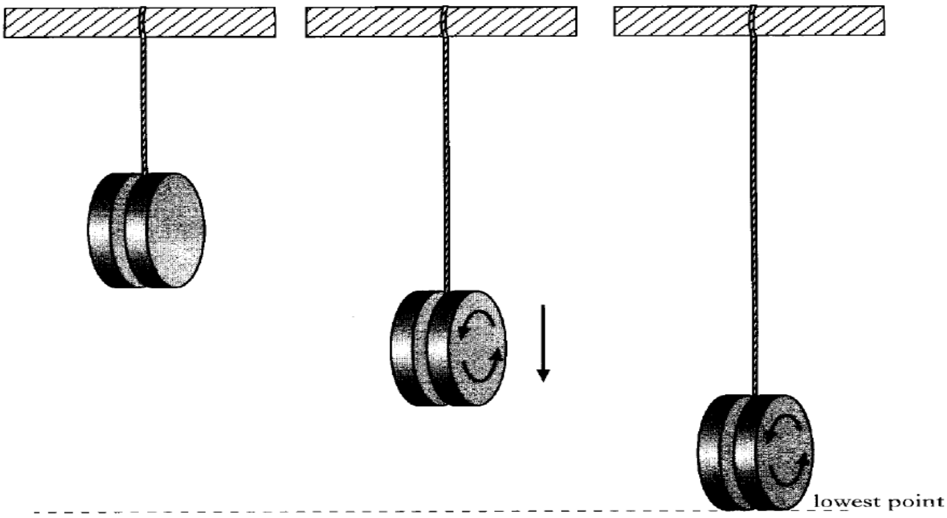


Figure 1(*a*) Figure 1(*b*) Figure 1(*c*)

The yo-yo is released from rest and rotates as it falls, as shown in Figure 1(b).
The string is fully unwound at the yo-yo's lowest point, as shown in Figure 1 (c).
The yo-yo then rises, rewinding the string.

(a) State the type(s) of energy which the yo-yo has when it is at the position shown in

  (i) Figure 1 (b) **3**

  (ii) Figure 2 (c) **1**

(b) Each disc has a mass *m* of 0.100 kg and a radius *r* of 0.050m.
The moment of inertia of a disc is given by ½ mr^2. The moment of inertia of the axle is negligible. Calculate the moment of inertia of the yo-yo. **3**

(c) When the yo-yo is at the position shown in Figure 1 (c) it has an angular velocity of 120 rads. **3**
Calculate the maximum height to which the yo-yo could rise as it rewinds the string.

(10)

2. A playground roundabout has a radius of 2.0m and a moment of inertia of 500 kgm^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.

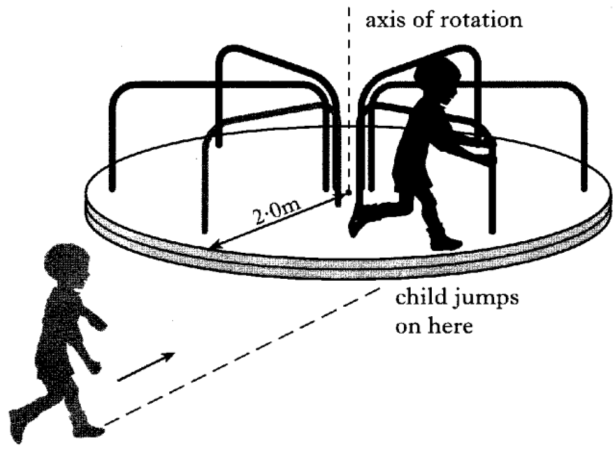


Figure 3

(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. **4**

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

(c) At the point of jumping onto the roundabout, the tangential speed of the child is 2.4 ms^{-1}. At this point, calculate :

(i) the linear momentum of the child; **2**

(ii) the angular momentum of the child about the axis of rotation of the roundabout, **2**

(d) Calculate the angular velocity of the roundabout and the child just after the child jumps on. **3**

(e) Calculate the loss in kinetic energy as the child jumps onto the roundabout. **4**

(f) The roundabout with the child onboard makes half a complete revolution before coming to rest.
Calculate the frictional torque acting on the roundabout. **4**

(20)

3. A circular metal disc is mounted horizontally on the side of a rotational motion sensor as shown in Figure 4.
The axle is on a frictionless bearing.

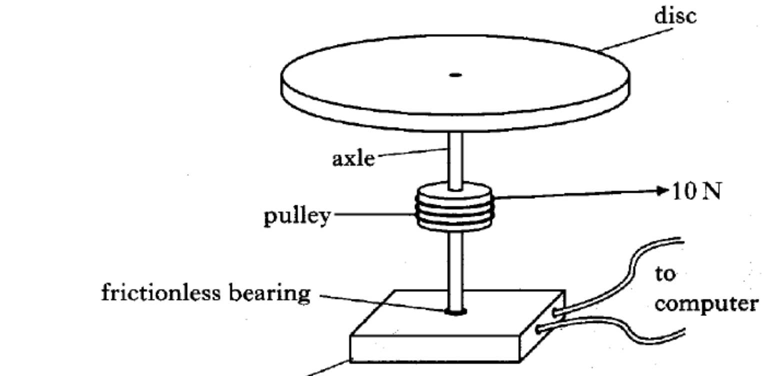


Figure 4.

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 5.

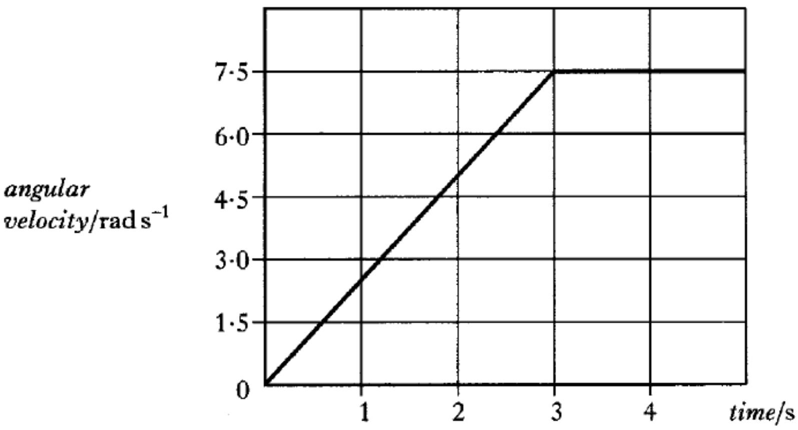


Figure 5.

(a) (i) Calculate the torque exerted by the cord. 3

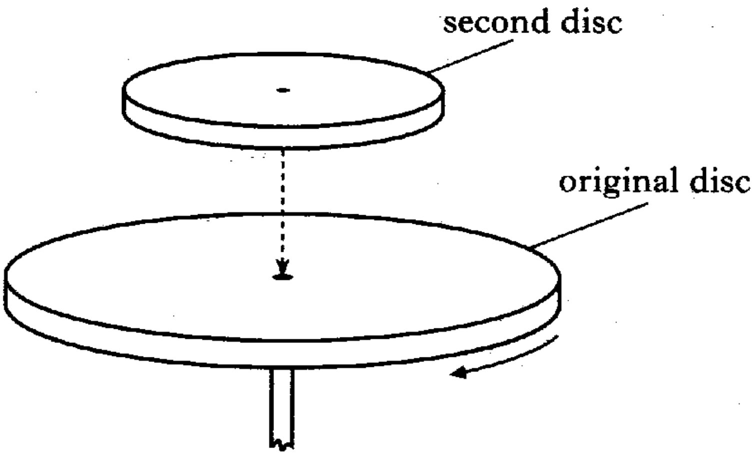
(ii) Using information from the graph, determine the angular acceleration of the disc. 3

(iii) Calculate the moment of inertia of the disc. 3

(b) After the cord is fully unwound, a second uniform disc with mass of 3.2 kg and radius 0.12m is gently dropped on top of the original disc as shown in Figure 6.

Both discs now rotate with a new angular velocity.

Figure 6.



(i) Calculate the moment of inertia of the second disc. 3

(ii) Calculate the new angular velocity of the disc. 3

(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 7.

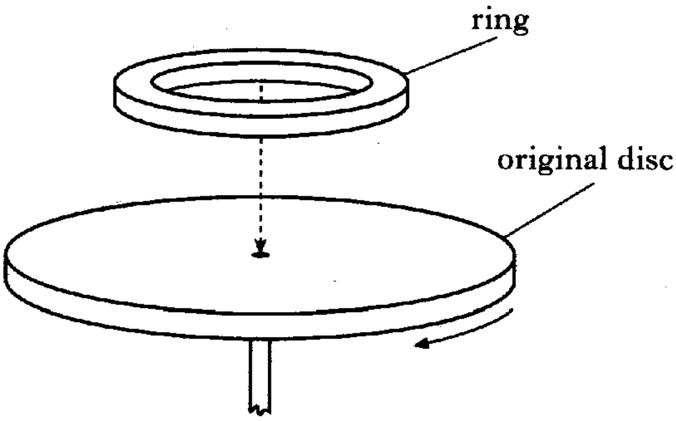


Figure 7.

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

(17)

4. (a) A turntable consists of a uniform disc of radius 0.15 m and mass 0.60 kg.

(i) Calculate the moment of inertia of the turntable about the axis of rotation shown in Figure 8. 3

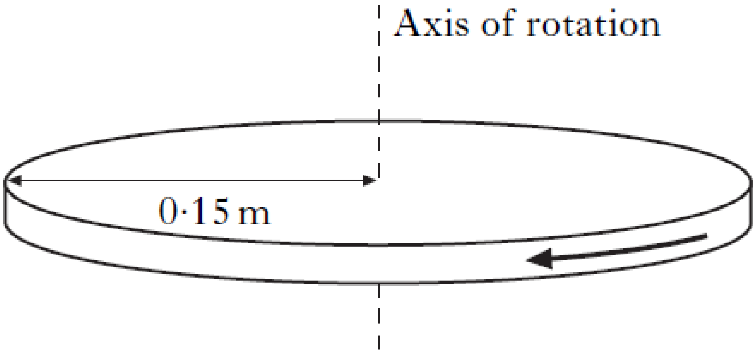


Figure 8.

(ii) The turntable accelerates uniformly from rest until it rotates at 45 revolutions per minute. The time taken for the acceleration is 1·5 s.

(A) Show that the angular velocity after 1·5 s is 4·7 rad s^{-1}. 2

(B) Calculate the angular acceleration of the turntable. 3

(iii) When the turntable is rotating at 45 revolutions per minute, its motor is disengaged. The turntable continues to rotate freely with negligible friction.

A small mass of 0·20 kg is dropped onto the turntable at a distance of 0·10 m from the centre, as shown in Figure 9

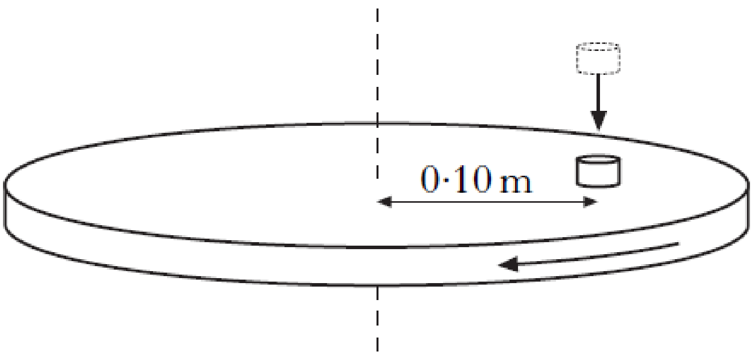


Figure 9.

The mass remains in this position on the turntable due to friction, and the turntable and mass rotate together.

Calculate the new angular velocity of the turntable and mass. 5

4 (a) (continued)

(iv) The experiment is repeated, but the mass is dropped at a distance greater than $0{\cdot}10\,\text{m}$ from the centre of the turntable. The mass slides off the turntable.

Explain why this happens. **2**

(*b*) An ice-skater spins with her arms and one leg outstretched as shown in Figure 10a She then pulls her arms and leg close to her body as shown in Figure 10b

Figure 10 (a)

Figure 10 (b)

State what happens to her angular velocity during this manoeuvre.

Justify your answer. **3**

(18)

Total Marks - 65