IB Physics – Circular Motion Worksheet

Instructions

Topic A.2 (SL/HL): uniform circular motion, angular velocity, centripetal acceleration and centripetal force. Section A follows the Paper 1 multiple-choice format (12 marks); Section B follows the Paper 2 structured format (78 marks). Questions are original, written in IB exam style.

- Use $g = 9.8\ \text{m s}^{-2}$ unless stated otherwise.
- Show all working in Section B; give answers to an appropriate number of significant figures.
- Suggested time: Section A 18 min, Section B 95 min.

Data booklet relationships:

- $v = \omega r$
- $\omega = 2\pi/T = 2\pi f$
- $a = v^2/r = \omega^2 r = 4\pi^2 r/T^2$
- $F = mv^2/r = m\omega^2 r$

Section A — Paper 1 style (multiple choice)

Choose one answer for each question. [1 mark each]

1. A particle moves in a horizontal circle of radius 0.50 m at constant speed, completing 4.0 revolutions every second. What is its angular velocity?

- A. $4.0\ \text{rad s}^{-1}$
- B. $8.0\ \text{rad s}^{-1}$
- C. $25\ \text{rad s}^{-1}$
- D. $50\ \text{rad s}^{-1}$

2. A wheel of radius 0.30 m rotates with a frequency of 5.0 Hz. What is the linear speed of a point on its rim?

- A. $1.5\ \text{m s}^{-1}$
- B. $4.7\ \text{m s}^{-1}$
- C. $9.4\ \text{m s}^{-1}$

- D. 31 m s^{-1}

3. An object moving in a circle completes 30 revolutions in 12 s. What are the period T and the angular velocity ω?

- A. T = 0.40 s, ω = 16 rad s^{-1}
- B. T = 0.40 s, ω = 2.5 rad s^{-1}
- C. T = 2.5 s, ω = 2.5 rad s^{-1}
- D. T = 2.5 s, ω = 16 rad s^{-1}

4. An object undergoes uniform circular motion. Which statement is correct?

- A. Its velocity is constant.
- B. Its acceleration has constant magnitude and is directed towards the centre.
- C. The resultant force on it is zero.
- D. Its speed changes continuously.

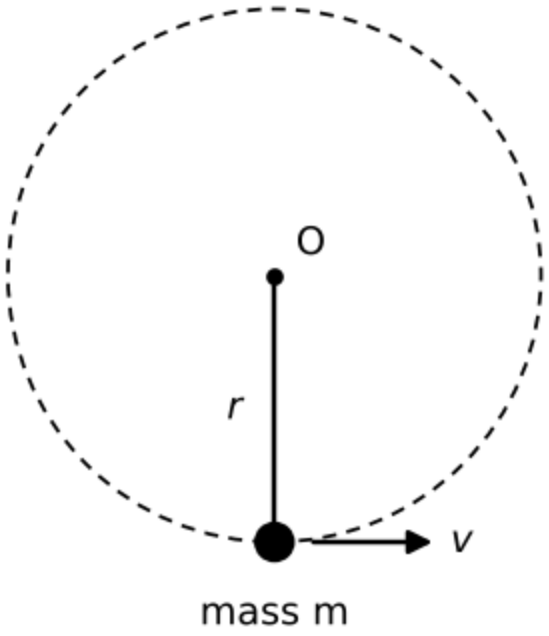
5. The speed of an object in circular motion is doubled and the radius of the circle is halved. By what factor does the centripetal acceleration change?

- A. 2
- B. 4
- C. 8
- D. 16

6. A car of mass 1200 kg travels round a flat bend of radius 50 m at 15 m s^{-1}. What is the frictional force required between the tyres and the road?

- A. 360 N
- B. 5400 N
- C. 12 000 N
- D. 18 000 N

7. A ball of mass m on a string moves in a vertical circle of radius r. At the lowest point its speed is v and the tension is T. Which expression gives T?

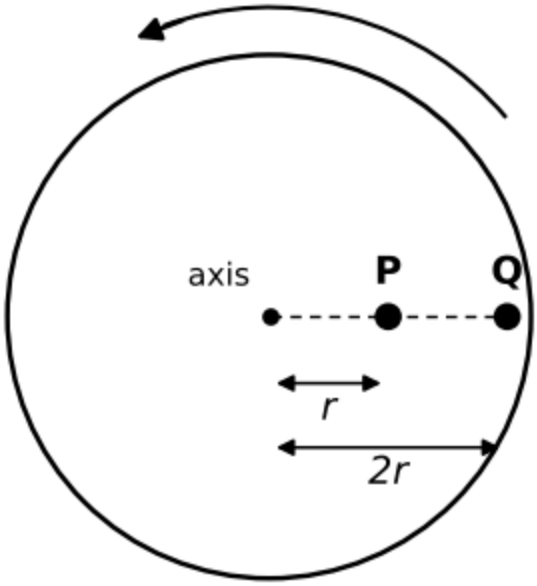


- A. mv^2/r
- B. $mg - mv^2/r$
- C. $mg + mv^2/r$
- D. $mv^2/r - mg$

8. A small mass on a string moves in a vertical circle of radius 0.80 m. What is the minimum speed at the top of the circle for the string to remain taut?

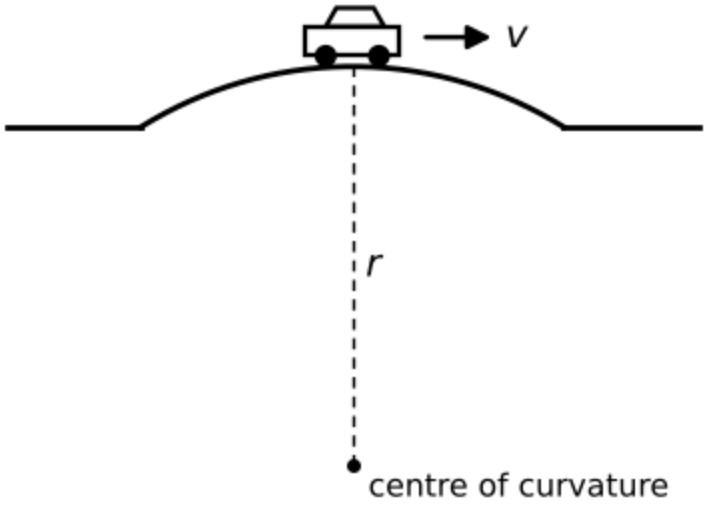
- A. 1.4 m s^{-1}
- B. 2.8 m s^{-1}
- C. 7.8 m s^{-1}
- D. 8.9 m s^{-1}

9. Points P and Q lie on a disc rotating at constant angular velocity. P is at distance r from the axis and Q at distance 2r. Which is correct?



- A. P and Q have the same speed and the same acceleration.
- B. P and Q have the same angular velocity; the acceleration of Q is twice that of P.
- C. P and Q have the same angular velocity; the acceleration of Q is four times that of P.
- D. P and Q have the same speed; the acceleration of Q is half that of P.

10. A car of mass m passes over the top of a hump-backed bridge of radius r at speed v. What is the normal force exerted by the road on the car?



- A. mg
- B. $mg + mv^2/r$

- C. $mg - mv^2/r$
- D. mv^2/r

11. An object moves in a circle of radius 2.0 m with a period of 4.0 s. What is its centripetal acceleration?

- A. 0.79 m s^{-2}
- B. 3.1 m s^{-2}
- C. 4.9 m s^{-2}
- D. 9.9 m s^{-2}

12. A child stands still on a horizontal roundabout that rotates at constant angular velocity. Which force provides the centripetal force on the child?

- A. The weight of the child
- B. The normal reaction from the roundabout
- C. Static friction from the roundabout, directed towards the centre
- D. An outward centrifugal force

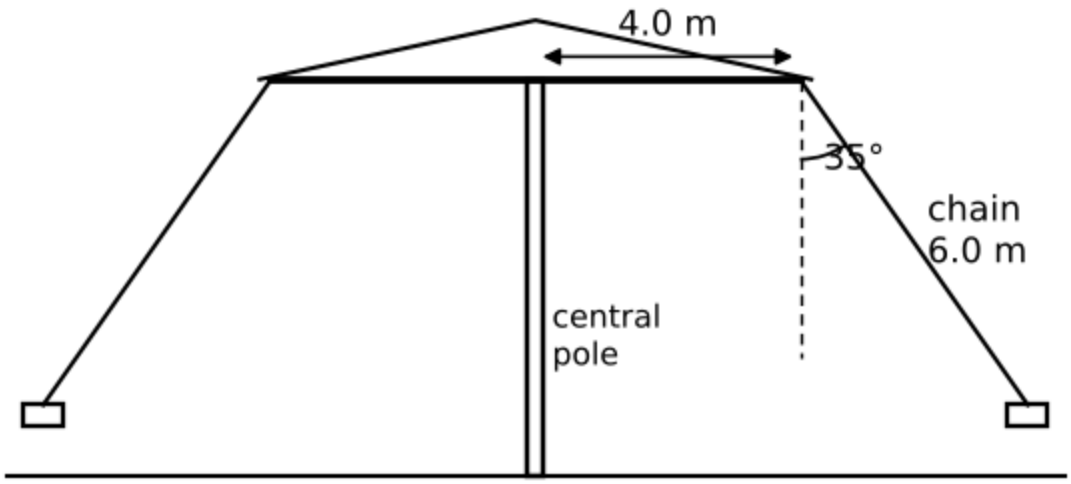
Section B — Paper 2 style (structured)

Answer all questions. Marks are shown in brackets.

13. A wind turbine has three blades, each of length 40 m. In a steady wind the blades rotate at 15 revolutions per minute.

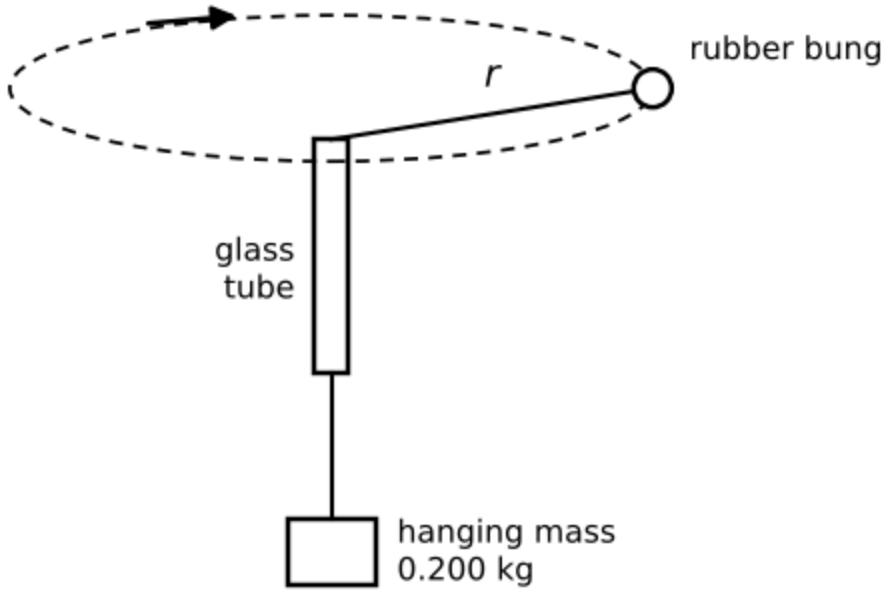
- (a) Calculate the angular velocity of the blades. Include an appropriate unit for your answer. [1]
- (b) Show that the speed of a blade tip is about 63 m s^{-1}. [1]
- (c) Calculate the period and the frequency of rotation. [1]
- (d) A sensor of mass 2.0 kg is fixed to the tip of one blade. Calculate the centripetal force acting on the sensor. [2]
- (e) Sketch a graph to show how the centripetal acceleration of a point on a blade varies with its distance r from the axis of rotation. [2]
- (f) A second sensor is fixed halfway along the same blade. Compare its angular velocity and its linear speed with those of the sensor at the tip. [2]
- (g) In a stronger wind the blades rotate at 20 revolutions per minute. Calculate the new centripetal force on the sensor at the tip. [1]

14. A fairground swing ride has seats hanging from chains of length 6.0 m. The top of each chain is attached to the rim of a horizontal rotating frame of radius 4.0 m. When the ride rotates at constant speed, each chain makes an angle of 35° to the vertical. A seat and its rider have a total mass of 85 kg. Ignore the mass of the chain.



- (a) Draw a free-body diagram for the seat and rider. [2]
- (b) Explain, with reference to Newton's laws, why the chains cannot remain vertical when the ride is rotating. [2]
- (c) Show that the radius of the circle travelled by the seat is about 7.4 m. [1]
- (d) Determine the tension in the chain. [2]
- (e) Determine the period of rotation of the ride. [3]
- (f) A child of smaller mass sits on another seat. State and explain whether the angle of the child's chain to the vertical is different. [2]

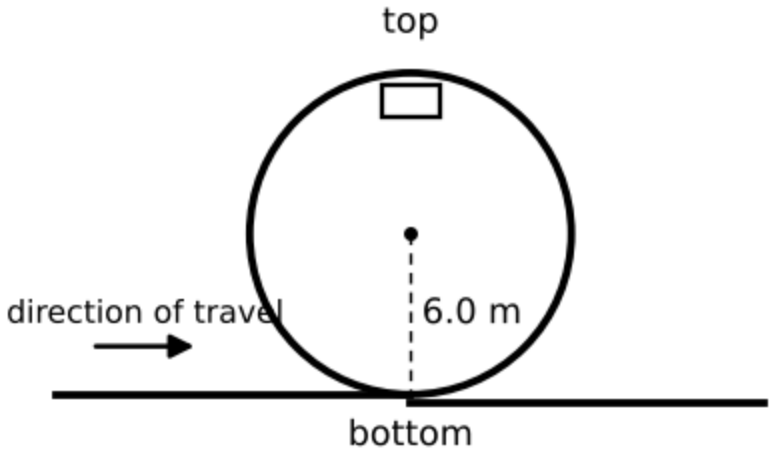
15. A student investigates circular motion using a rubber bung on a string. The string passes through a vertical glass tube and a hanging mass of 0.200 kg is attached to its lower end. The student whirls the bung in a horizontal circle so that the hanging mass stays at rest, and records the time for 20 revolutions for different radii r. The uncertainty in each time is ± 0.2 s; the uncertainty in r is negligible.



r / m	Time for 20 revolutions / s
0.40	9.0
0.60	11.0
0.80	12.7
1.00	14.2

- (a) Suggest why the student timed 20 revolutions rather than one. [1]
- (b) Calculate the period T, with its absolute uncertainty, for r = 0.80 m. [2]
- (c) Show that, if the tension equals the weight W of the hanging mass, $T^2 = (4\pi^2 m / W)\, r$, where m is the mass of the bung. [2]
- (d) The student plots T^2 against r. Predict the shape of the graph and determine its gradient using the data for r = 1.00 m. [2]
- (e) Determine the mass of the bung and its absolute uncertainty using the data for r = 1.00 m. [3]
- (f) Suggest one reason why the tension in the string at the bung may differ from W. [1]

16. A roller-coaster cart of total mass 250 kg travels round a vertical circular loop of radius 6.0 m.

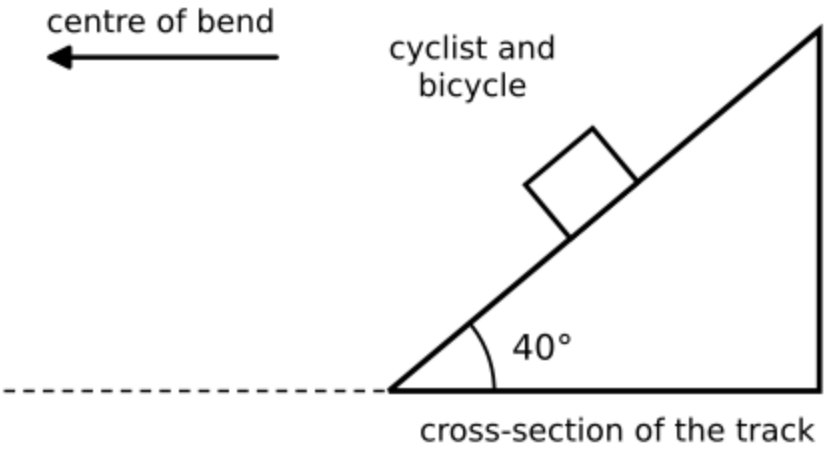


- (a) Show that the minimum speed at the top of the loop for the cart to stay on the track is about 7.7 m s^{-1}. [2]
- (b) The cart passes the top of the loop at 9.0 m s^{-1}. Calculate the normal force exerted by the track on the cart at the top. [2]
- (c) The cart passes the bottom of the loop at 17 m s^{-1}. Calculate the normal force exerted by the track on the cart at the bottom. [2]
- (d) Calculate the ratio of the normal force at the bottom to the weight of the cart. [1]
- (e) Explain why riders feel heavier at the bottom of the loop and lighter at the top. [2]
- (f) Many real loops are tear-drop shaped, with a smaller radius at the top than at the bottom. Outline one advantage of this shape for the riders. [2]

17. A communications satellite of mass 1500 kg moves in a circular orbit of radius 4.22×10^7 m around the Earth with a period of 24 hours.

- (a) Outline why the satellite is accelerating even though its speed is constant. [1]
- (b) State the force that provides the centripetal force on the satellite. [1]
- (c) Calculate the angular velocity of the satellite. [1]
- (d) Calculate the orbital speed of the satellite. [1]
- (e) Calculate the centripetal acceleration of the satellite. [1]
- (f) Calculate the centripetal force acting on the satellite. [1]
- (g) Explain why the speed of the satellite does not change even though a resultant force acts on it. [2]

18. A velodrome track is banked at 40° to the horizontal on a bend of radius 25 m. A cyclist and bicycle have a total mass of 80 kg. Assume there is no sideways friction between the tyres and the track.

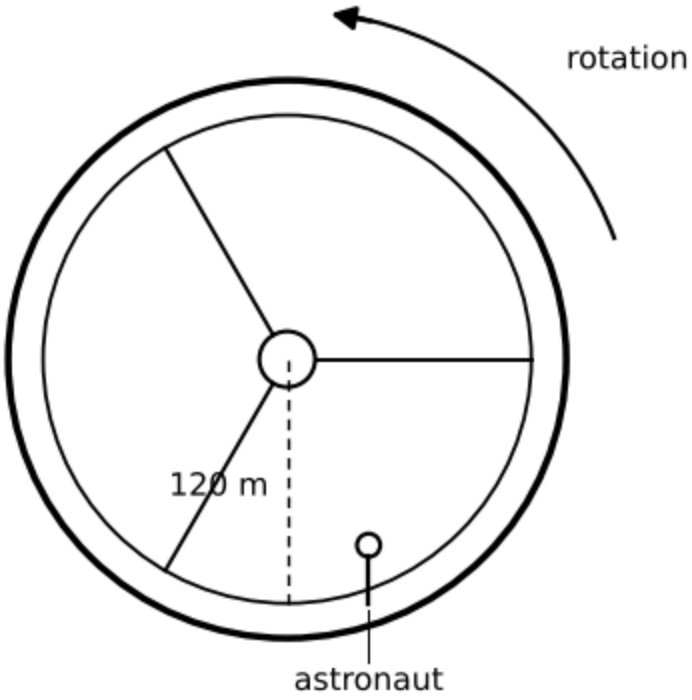


- (a) Draw a free-body diagram for the cyclist and bicycle on the bend. [2]
- (b) Explain how the normal force can provide the centripetal force on the cyclist. [2]
- (c) Show that the speed at which the cyclist can ride round the bend is about 14 m s^{-1}. [3]
- (d) Calculate the normal force exerted by the track on the cyclist. [1]
- (e) The cyclist rides round the bend more slowly than this speed. State and explain which way she tends to slide. [2]

19. In the hammer throw, an athlete swings a hammer of mass 7.3 kg on a wire in a circle of radius 1.8 m. Just before release the hammer moves at 25 m s^{-1}.

- (a) Calculate the centripetal force on the hammer just before release. [2]
- (b) Calculate how many times greater this force is than the weight of the hammer. [1]
- (c) Calculate the angular velocity and the period of the hammer just before release. [2]
- (d) The wire breaks if the tension exceeds 3000 N. Determine the maximum speed of the hammer for this radius. [2]
- (e) Describe the path of the hammer immediately after release, as seen from above. [1]

20. A proposed space station is a large ring of radius 120 m that rotates about its central axis to create artificial gravity for astronauts standing on the inside of the rim.



- (a) Calculate the angular velocity needed for an astronaut on the rim to experience an acceleration equal to 9.8 m s^{-2}. [2]
- (b) Calculate the period of rotation. [1]
- (c) Explain, with reference to the forces acting, why the astronaut feels a weight while standing on the rim. [2]
- (d) The astronaut climbs a ladder towards the centre to a point 60 m from the axis. Determine the ratio of the apparent weight there to the apparent weight on the rim. [1]
- (e) On the rim, the astronaut releases a ball from rest relative to her hand, 1.5 m above the floor. Discuss, from the point of view of an observer outside the station, why the ball does not land exactly below the point of release. [2]