

Angular velocity, centripetal force and circular paths

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet

Name: _____ Date: _____ Class: _____

These twenty problems practise the language of rotation: angular velocity, period, linear speed and centripetal acceleration. They then apply Newton's second law to cars on flat and banked bends, conical pendulums and vertical circles, always asking which real force points to the centre.

They suit A Level, IB physics and CBSE Class 11 students. Draw a free-body diagram first, take the direction to the centre as positive, and use $g = 9.81 \text{ N/kg}$.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** A Level 3.6

Problem 1 Key relationships (easy)

Write each relationship.

1. Angular velocity in terms of the period T .
2. Linear speed in terms of ω and the radius r .
3. Centripetal acceleration in two forms.
4. Centripetal force in terms of m , v and r .

Problem 2 Angles and rates (easy)

Convert each quantity.

1. 180° to radians.
2. 120 revolutions per minute to rad/s.
3. A frequency of 0.50 Hz to ω .
4. 120 rpm to the period in seconds.

Problem 3 Fan blade tip (easy)

A fan blade has a tip radius of 0.18 m and turns at 1500 rpm.

1. Calculate ω in rad/s.
2. Calculate the speed of the blade tip.

Problem 4 Rotation of the Earth (easy)

The Earth turns once in 86 400 s. Its equatorial radius is $6.37 \times 10^6 \text{ m}$.

1. Calculate its angular velocity.

- Calculate the speed of a person standing on the equator.

Problem 5 Toy on a string (easy)

A toy of mass 0.25 kg is whirled on a string in a horizontal circle of radius 0.60 m at 3.0 m/s.

- Calculate its centripetal acceleration.
- Calculate the tension in the string.

Problem 6 What supplies the force (easy)

Name the force that supplies the centripetal force in each case.

- A car turns on a flat road.
- A satellite orbits the Earth.
- A conker whirls on a string.
- A rider is pinned to the wall of a spinning drum.

Problem 7 Roundabout on a bicycle (medium)

Aarav cycles around a flat roundabout of radius 15 m at 6.0 m/s. The mass of the rider and bicycle is 70 kg.

- Calculate the centripetal force needed.
- Calculate the minimum coefficient of friction needed.
- The road is wet and $\mu = 0.20$. Calculate the greatest safe speed.

Problem 8 Maximum speed on a bend (medium)

A car travels round a flat bend of radius 45 m.

- Calculate the greatest speed on dry road where $\mu = 0.65$.
- Calculate the greatest speed on a wet road where $\mu = 0.25$.
- Explain why the mass of the car does not matter.

Problem 9 Whirling a bung (medium)

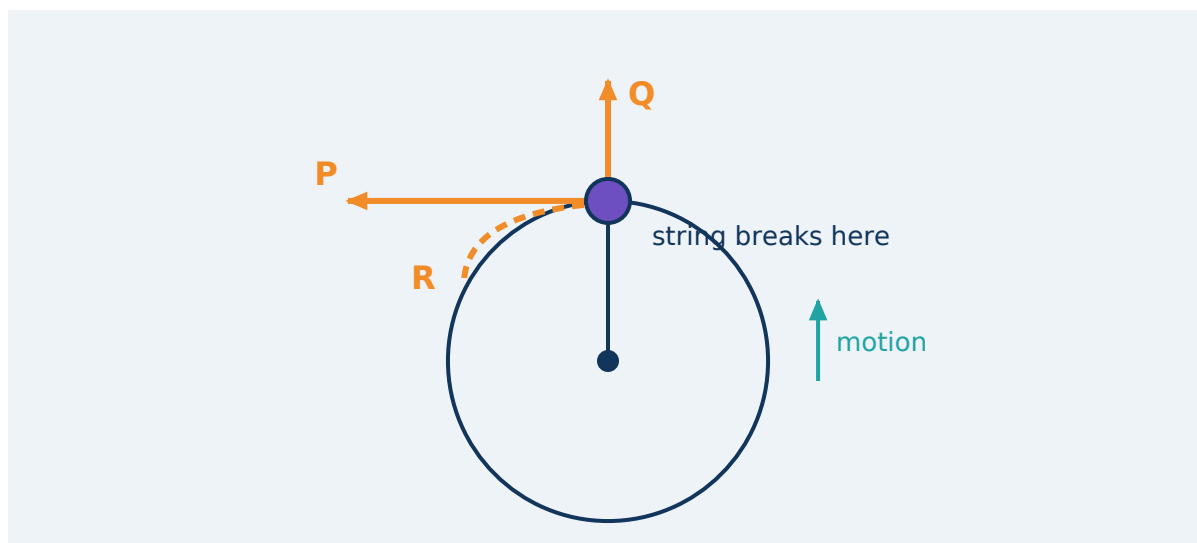
A student whirls a bung of mass 0.20 kg in a horizontal circle of radius 0.50 m and measures the tension.

v (m/s)	2.0	3.0	4.0	5.0	6.0
F (N)	1.6	3.6	6.4	10.0	14.4

- Calculate $F \div v^2$ for each column.
- State what graph of F against v^2 shows and its gradient.
- Use the gradient to confirm the mass of the bung.

Problem 10 String breaks (medium)

A ball is whirled anticlockwise on a string. The string breaks when the ball is at the top of the circle shown.



A ball whirled anticlockwise on a string, seen from above.

1. State which path, P, Q or R, the ball follows.
2. Explain your choice using Newton's first law.
3. State the direction of the force that was acting on the ball just before the string broke.

Problem 11 Rotor ride (medium)

In a fairground rotor ride in Texas, riders of mass 65 kg stand against the wall of a cylinder of radius 3.0 m. The floor drops away. The coefficient of friction between the rider and the wall is 0.40.

1. Explain why the normal reaction N equals $m v^2 \div r$.
2. Calculate the least speed at which a rider does not slip down.
3. Calculate the corresponding number of revolutions per minute.

Problem 12 Hammer throw (medium)

An athlete whirls a hammer of mass 7.26 kg on a wire in a circle of radius 1.8 m. It leaves her hands at 25 m/s.

1. Calculate the force the wire exerts at release.
2. Compare it with the weight of the hammer.

Problem 13 Ball at the bottom (medium)

A ball of mass 0.50 kg is swung on a string of length 1.2 m in a vertical circle. At the bottom it moves at 5.0 m/s.

1. Calculate the tension at the bottom.
2. Calculate the minimum speed at the top for the string to stay taut.

Problem 14 Railway curve (medium)

A railway curve of radius 900 m is banked so that the track exerts no sideways force at 30 m/s.

1. Show that $\tan \theta = v^2 \div (r g)$.
2. Calculate the banking angle.

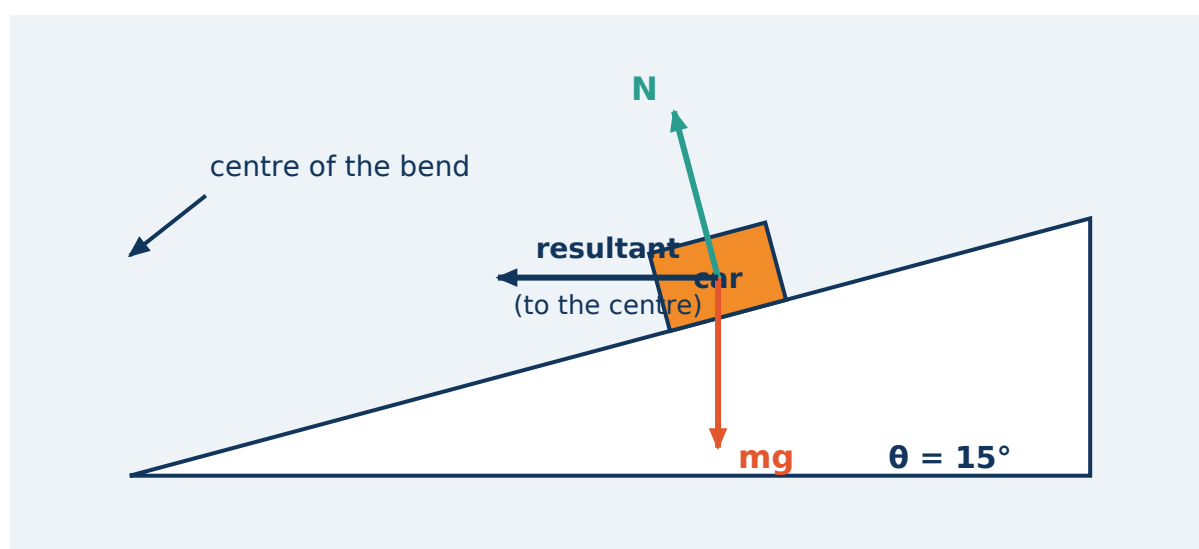
Problem 15 Centrifugal force myth (medium)

A passenger of mass 80 kg in a car feels pushed against the door when it turns a bend of radius 30 m at 12 m/s.

1. Explain the sensation using Newton's first law and without a centrifugal force.
2. Calculate the inward force the door exerts on the passenger.

Problem 16 Banked bend with a car (hard)

A bend of radius 100 m is banked at 15° to the horizontal. Use $g = 9.81 \text{ N/kg}$. A car of mass 1200 kg drives round it with no friction.

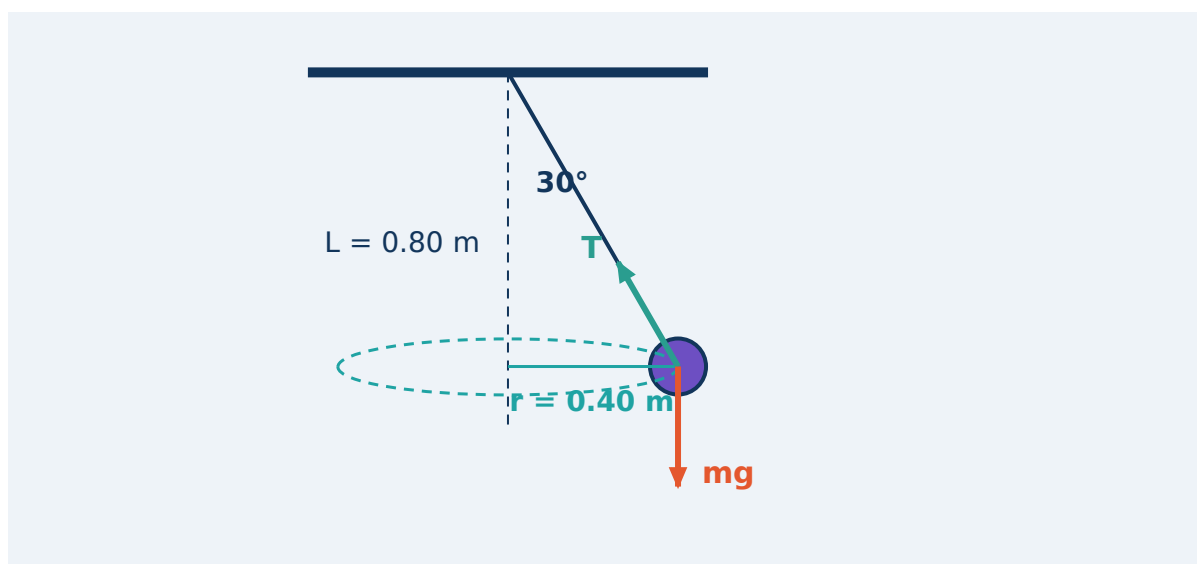


Cross-section of the banked bend.

1. Calculate the design speed.
2. Calculate the normal reaction at the design speed.
3. Show that the horizontal component of N equals the centripetal force needed.

Problem 17 Conical pendulum (hard)

A bob of mass 0.15 kg hangs on a string of length 0.80 m and moves in a horizontal circle with the string at 30° to the vertical.



A conical pendulum seen from the side.

1. Show that the radius of the circle is 0.40 m.
2. Calculate the tension in the string.
3. Calculate the angular velocity and the period.

Problem 18 Loop-the-loop (hard)

A roller-coaster car goes round a vertical loop of radius 8.0 m. Use $g = 9.81 \text{ N/kg}$.

1. Calculate the minimum speed at the top if the car stays on the track.
2. Use energy conservation to find the speed at the bottom if the top speed is this minimum.
3. Calculate the force of the seat on a 60 kg rider at the bottom, and express it in multiples of the rider's weight.

Problem 19 Leaning motorcycle (hard)

A motorcyclist turns a flat bend of radius 40 m at 15 m/s. The resultant of the normal reaction and friction passes through the centre of mass, so the angle θ of lean from the vertical satisfies $\tan \theta = v^2 \div (r g)$.

1. Calculate the lean angle.
2. Calculate the minimum coefficient of friction needed.
3. Calculate the lean angle at 20 m/s and comment.

Problem 20 Laboratory centrifuge (hard)

A centrifuge spins a sample tube at 3000 rpm. The sample is 0.10 m from the axis. The sample has mass 12 g.

1. Calculate ω .
2. Calculate the centripetal acceleration and express it in multiples of g .
3. Calculate the force needed on the sample.
4. State the effect on the acceleration of doubling the speed of rotation.