

# Centripetal acceleration and gravity in orbit

## AP Physics 1 (algebra-based) · Worksheet

Name: \_\_\_\_\_ Date: \_\_\_\_\_ Class: \_\_\_\_\_

These twenty problems build circular motion and gravitation skills in the style of AP Physics 1 unit 2. They start with direction and scaling reasoning, move to calculations with  $a = v^2/r$  and  $F = G m_1 m_2 / r^2$ , and end with free-response tasks that mix equations with written justification.

Use  $g = 9.81 \text{ m/s}^2$ ,  $G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$  and show every substitution. Where a problem asks you to explain, write full sentences that link forces to the acceleration.

**Level:** AP Physics 1 (algebra-based) · **Curriculum:** AP P1 Unit 2

### Problem 1 Direction check (easy)

Answer about an object moving at constant speed on a horizontal circle.

1. State the direction of its acceleration.
2. State the direction of the net force on it.
3. Explain why its speed stays constant even though it accelerates.

### Problem 2 Track cycling (easy)

Bilal in Lahore rides at a steady 7.2 m/s round a circular track of radius 24 m. The total mass of Bilal and the bicycle is 80 kg.

1. Calculate his centripetal acceleration.
2. Calculate the net force on him.
3. Calculate the time for one lap.

### Problem 3 Record player (easy)

A small mark sits 0.12 m from the centre of a record turning at 45 revolutions per minute.

1. Calculate the period in seconds.
2. Calculate the speed of the mark.
3. Calculate its centripetal acceleration.

### Problem 4 Scaling the pull (easy)

The gravitational force between two planets is  $F$ . State the new force in terms of  $F$  when:

1. the distance between them is halved.
2. one mass is tripled and the distance is tripled.
3. both masses are doubled and the distance is doubled.

### Problem 5 Two cargo ships (easy)

Two cargo ships, each of mass  $5.0 \times 10^7 \text{ kg}$ , lie 200 m apart in a calm harbour. Use  $G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$ .

1. Calculate the gravitational force between them.
2. Explain why the ships do not drift together.

### Problem 6 Real forces only (easy)

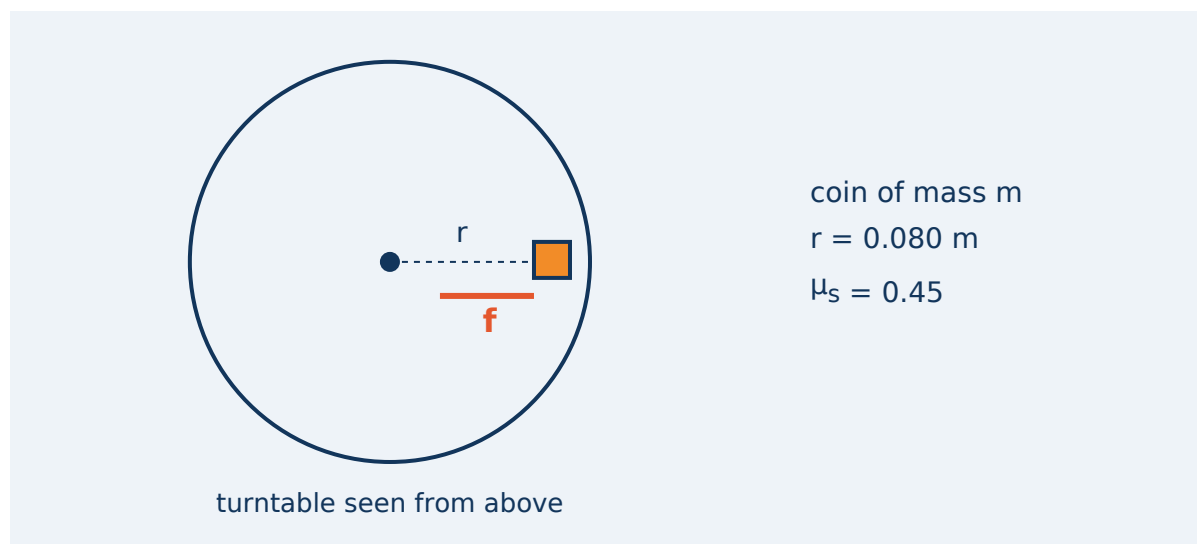
Name the single real force, or the combination of forces, that provides the centripetal force in each case.

1. A coin riding on a turntable without slipping.
2. A conker swung round on a string above the head.
3. A satellite orbiting the Earth.
4. A rider pressed against the wall of a spinning drum.

### Problem 7 Coin on a turntable (medium)

A coin rests on a horizontal turntable at 0.080 m from the axis, as shown. The coefficient of static friction is 0.45. Use  $g = 9.81 \text{ m/s}^2$ .

1. State which force provides the centripetal force.
2. Show that the greatest speed without slipping is  $v = \sqrt{\mu_s g r}$  and calculate it.
3. Calculate the greatest rate of turning in revolutions per minute.



Top view: friction  $f$  on the coin points toward the axis.

### Problem 8 Rover on Mars (medium)

Mars has mass  $6.42 \times 10^{23} \text{ kg}$  and radius  $3.39 \times 10^6 \text{ m}$ . Use  $G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$ . A rover of mass 180 kg stands on the surface.

1. Calculate the gravitational field strength at the surface of Mars.
2. Calculate the weight of the rover on Mars.

3. Compare that weight with its weight on Earth.

### Problem 9 Orbit of Europa (medium)

The moon Europa moves on a nearly circular orbit of radius  $6.71 \times 10^8$  m around Jupiter, mass  $1.90 \times 10^{27}$  kg. Use  $G = 6.67 \times 10^{-11}$  N m<sup>2</sup>/kg<sup>2</sup>.

1. Calculate its orbital speed.
2. Calculate its period in days.
3. State how the answers would change for a moon of twice the mass at the same radius.

### Problem 10 Swinging a bucket (medium)

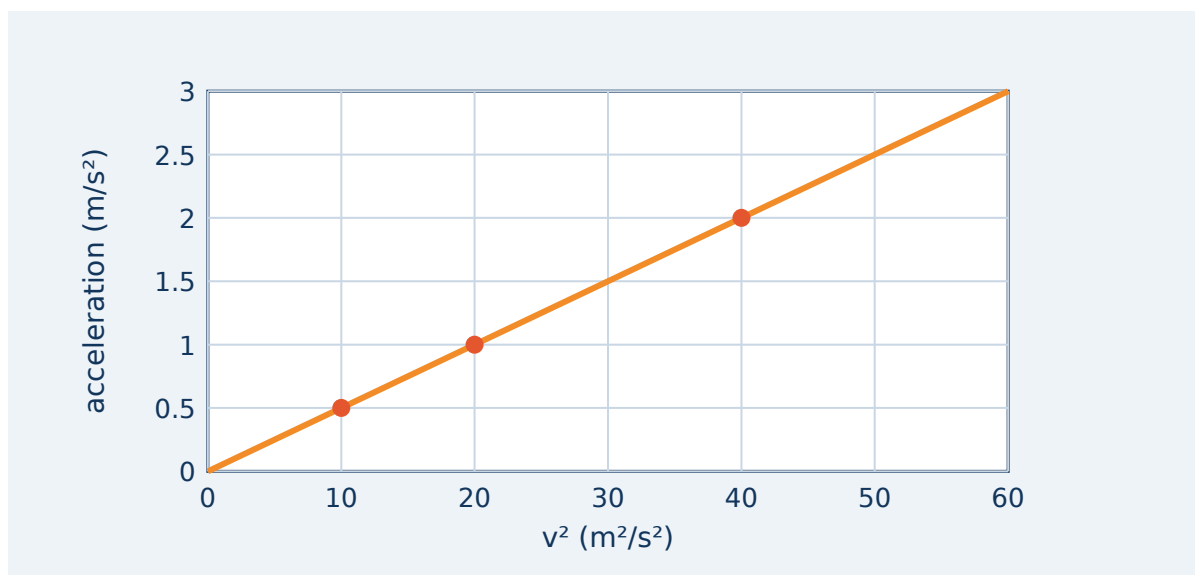
Wanjiru in Nairobi swings a 1.5 kg bucket of water in a vertical circle of radius 0.90 m. Use  $g = 9.81$  m/s<sup>2</sup>.

1. Calculate the least speed at the top for the water to stay in the bucket.
2. Calculate the force in the rope at the bottom when the speed there is 5.0 m/s.

### Problem 11 Reading a straight line (medium)

A student measures centripetal acceleration for several speeds on one fixed circle and plots the graph.

1. Explain why the graph is a straight line through the origin.
2. Use the gradient to find the radius of the circle.
3. Predict  $a_c$  when  $v = 8.0$  m/s.



Centripetal acceleration against  $v^2$  for one fixed circle.

### Problem 12 Comparing two orbits (medium)

Satellite B orbits the same planet as satellite A, at four times the orbital radius. Both are in circular orbits. Give each ratio B : A.

1. Orbital speed.

2. Period.
3. Centripetal acceleration.

**Problem 13 Spot the slip** (medium)

A student writes: "A 900 kg car takes a bend of radius 50 m at 20 m/s, so the centripetal force is  $m v / r = 900 \times 20 \div 50 = 360 \text{ N}$ ."

1. Identify the mistake.
2. Calculate the correct force.

**Problem 14 Floating in orbit** (medium)

A space station orbits 400 km above the surface of the Earth. Use  $G M = 3.98 \times 10^{14} \text{ m}^3/\text{s}^2$  and Earth radius  $6.37 \times 10^6 \text{ m}$ .

1. Calculate the gravitational field strength at the station.
2. Express it as a percentage of the surface value, 9.81 N/kg.
3. Explain why astronauts nevertheless float.

**Problem 15 Tractor on a farm track** (medium)

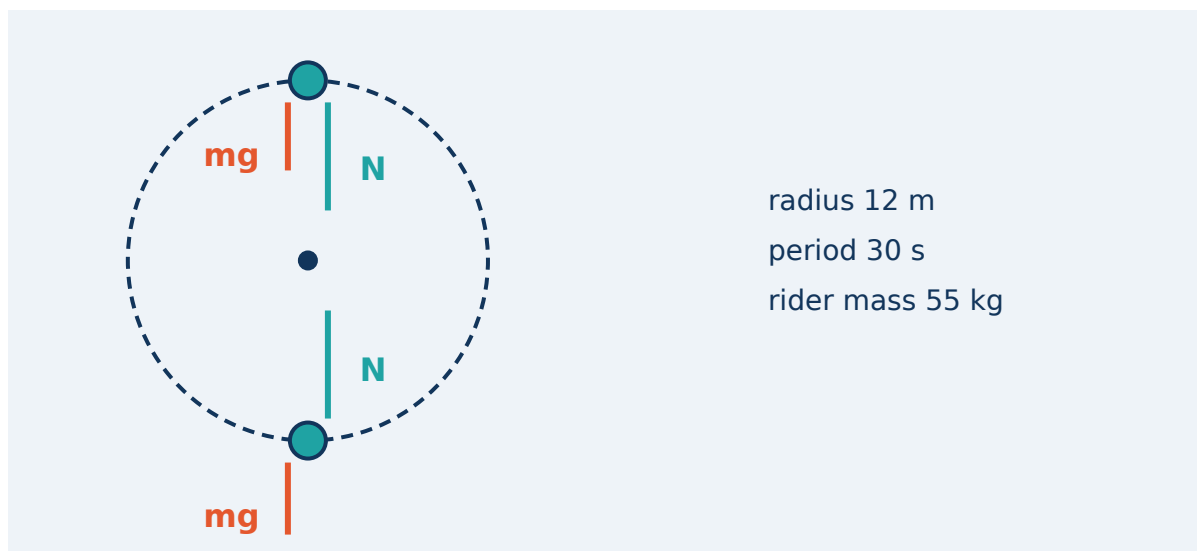
A tractor takes a level, curved farm track of radius 35 m. Use  $g = 9.81 \text{ m/s}^2$ .

1. Calculate the greatest speed on dry soil, where  $\mu_s = 0.60$ .
2. Calculate the greatest speed after rain, where  $\mu_s = 0.25$ .
3. Explain, using forces, why the safe speed falls.

**Problem 16 Ferris wheel rider** (hard)

Mei rides a Ferris wheel of radius 12 m that turns once every 30 s at constant speed. Her mass is 55 kg. Use  $g = 9.81 \text{ m/s}^2$ .

1. Calculate her speed and centripetal acceleration.
2. Calculate the normal force from the seat at the top.
3. Calculate the normal force at the bottom.
4. Explain, using the free-body diagrams, why she feels lightest at the top.



Ferris wheel: weight  $mg$  and normal force  $N$  at the top and at the bottom of the circle.

### Problem 17 Satellite that stays overhead (hard)

A communications satellite stays above one point on the equator. Its period is  $24 \text{ h} = 86\,400 \text{ s}$ . Use  $G M = 3.98 \times 10^{14} \text{ m}^3/\text{s}^2$  and Earth radius  $6.37 \times 10^6 \text{ m}$ .

1. Derive  $T^2 = 4\pi^2 r^3 / (G M)$  from the force equation.
2. Calculate the orbit radius.
3. Calculate its height above the surface and its speed.

### Problem 18 Bigger planet, same mass (hard)

A planet has the same mass as the Earth but twice the radius.

1. Predict qualitatively whether the surface gravity is greater or smaller than on Earth.
2. Derive the ratio  $g_{\text{planet}} / g_{\text{Earth}}$  from  $g = G M / r^2$ .
3. Derive the ratio of the speeds of satellites skimming each surface.
4. Write a short paragraph arguing which world needs the greater launch speed to reach a skimming orbit, and why.

### Problem 19 Design: force against period (hard)

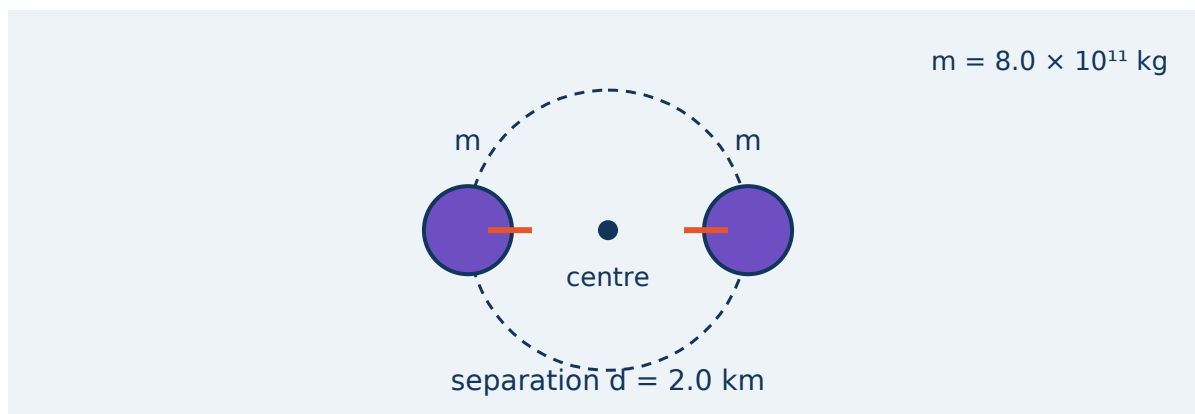
Design an experiment to test the relationship between the tension in a string and the period of a rubber bung of mass  $0.200 \text{ kg}$  swung in a horizontal circle of radius  $0.50 \text{ m}$ . Write answers for:

1. The independent and dependent variables and two controls.
2. The measurements and equipment.
3. The graph to plot so that the relationship is a straight line, and what its gradient should equal.
4. One source of error and how to reduce it.

### Problem 20 Double asteroid (hard)

Two asteroids, each of mass  $8.0 \times 10^{11} \text{ kg}$ , orbit the midpoint between them while their centres stay  $2.0 \text{ km}$  apart. Use  $G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$ .

1. State the radius of each orbit.
2. Show that the speed of each asteroid is  $v = \sqrt{(G m / (2d))}$ .
3. Calculate that speed and the period in hours.



*Two asteroids orbit the midpoint between them. Each moves on a circle of radius  $d/2$ .*