Exercise walk-through

Centripetal acceleration ▪ 12.2

eXercise

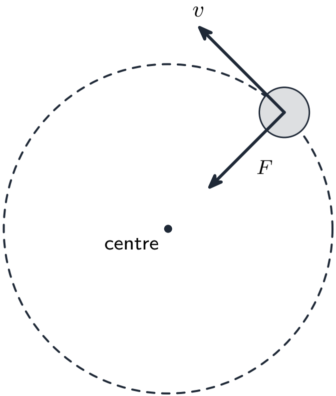
You must be able to

- describe uniform circular motion in terms of **velocity** and **acceleration**
- use $a = v^2/r = r\omega^2$ and $F = mv^2/r = mr\omega^2$
- identify the **real force** that provides the centripetal force (tension, friction, gravity, electric)

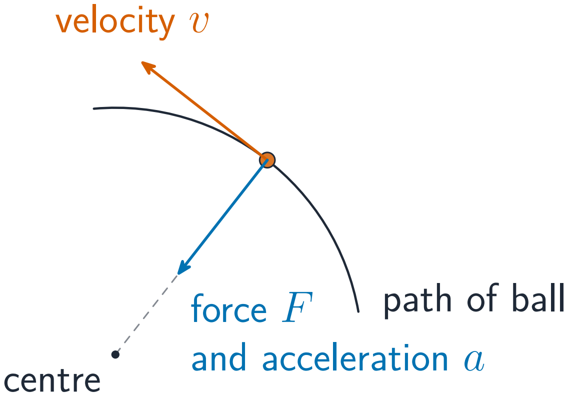
Method — Centripetal acceleration

In a circle at constant speed, the **speed** is constant but the **velocity** keeps changing direction — so there is an acceleration, directed **towards the centre**, perpendicular to v:

$$a = \frac{v^2}{r} = r\omega^2.$$



Method — Centripetal acceleration



Centripetal acceleration points to the centre

Method — Centripetal force

$$F = ma = \frac{mv^2}{r} = mr\omega^2.$$

This is **not a new force** — it is provided by a **real** force acting towards the centre: **tension** (string), **friction** (a car cornering), **gravity** (a satellite or planet), or the **electric force** (an electron orbiting a nucleus).

Worked example. A 0.20 kg ball whirled on a string in a 0.50 m horizontal circle at 3.0 m s^{-1}: the string tension provides $F = \dfrac{0.20 \times 3.0^2}{0.50} = 3.6$ N.

Worked example (orbit). If an electric force of 8.2×10^{-8} N keeps an electron (mass 9.1×10^{-31} kg) in a circle of radius 5.3×10^{-11} m, that force is the centripetal force: $v = \sqrt{\dfrac{Fr}{m}} = \sqrt{\dfrac{(8.2 \times 10^{-8})(5.3 \times 10^{-11})}{9.1 \times 10^{-31}}} = 2.2 \times 10^6$ m s^{-1}.

Practice 2.1 ▪ 3 marks

A car drives round a roundabout at a steady 12 m s^{-1}. Explain why the car is **accelerating** even though its speed never changes, and state the direction of that acceleration.

Solution 2.1

Method: Centripetal acceleration

Worked steps

Velocity is a **vector**, so it changes whenever the **direction** of travel changes, even at constant speed **B1**; a changing velocity means the car is accelerating **B1**. That acceleration is directed towards the **centre** of the roundabout, at right angles to the velocity **B1**.

Practice 2.2 ▪ 2 marks

Write **two** forms of the centripetal acceleration equation.

Solution 2.2

Method: Centripetal acceleration

Worked steps

$a = \dfrac{v^2}{r}$ and $a = r\omega^2$ **B1** **B1**.

Practice 2.3 ▪ 2 marks

A 0.20 kg ball is whirled in a horizontal circle of radius 0.50 m at 3.0 m s^{-1}. Find the **centripetal force**.

Solution 2.3

Method: Centripetal force

Worked steps

$$F = \frac{mv^2}{r} = \frac{0.20 \times 3.0^2}{0.50} = 3.6 \text{ N} \quad \boxed{\textbf{M1}}\boxed{\textbf{A1}}.$$

Practice 2.4 ▪ 1 mark

State what provides the centripetal force for a car turning a **flat** corner.

Solution 2.4

Method: Centripetal force

Worked steps

Friction between the tyres and the road B1.

Exam-style 3.1 ▪ 1 mark

For an object in uniform circular motion, the centripetal force is directed:

A along the velocity

B towards the centre

C away from the centre

D opposite to the velocity

Solution 3.1

Method: Centripetal acceleration

A along the velocity

B towards the centre ✓

C away from the centre

D opposite to the velocity

Worked steps

B — towards the centre.

Exam-style 3.2 ▪ 3 marks

A car of mass 900 kg turns a corner of radius 30 m at 15 m s^{-1}. Calculate the **centripetal force** needed.

Solution 3.2

Method: Centripetal force

Worked steps

$$F = \frac{mv^2}{r} = \frac{900 \times 15^2}{30} \quad \text{M1} \; \text{M1} \quad = 6750 \text{ N} \approx 6.8 \times 10^3 \text{ N} \quad \text{A1}.$$

Exam-style 3.3 ▪ 1 mark

An electron of mass 9.1×10^{-31} kg moves in a circle of radius 5.3×10^{-11} m. The electric force on it is 8.2×10^{-8} N and provides the centripetal force.
(a) State why the electron is **accelerating** even though its speed is constant.
(b) Calculate the **speed** of the electron.

Solution 3.3

Method: Centripetal force

Worked steps

(b) The electric force is the centripetal force: $F = \dfrac{mv^2}{r}$, so $v = \sqrt{\dfrac{Fr}{m}} = \sqrt{\dfrac{(8.2 \times 10^{-8})(5.3 \times 10^{-11})}{9.1 \times 10^{-31}}}$ **M1** **M1** $= 2.2 \times 10^{6}$ m s^{-1} **A1**.

Exam-style 3.4 ▪ 2 marks

A stone is whirled on a string in a horizontal circle. State what provides the centripetal force, and describe its motion **if the string breaks**.

Solution 3.4

Method: Centripetal force

Worked steps

The **tension** in the string provides it **B1**; if the string breaks the stone flies off along a **straight line (the tangent)**, since there is no longer a centripetal force **B1**.