A-LEVEL PHYSICS • EXERCISE SHEET

12.2 Centripetal acceleration

Name: ____________ Class: ________ Date: __________ **Total: 18 marks**

KEY WORDS centripetal acceleration 向心加速度 • centripetal force 向心力 • acceleration 加速度 • force 力 • friction 摩擦力

Objective

Build the skills to answer exam questions on **centripetal acceleration and force**.

You must be able to:

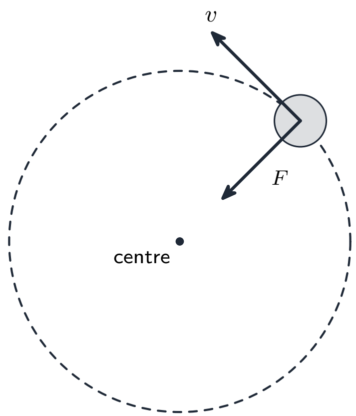
- describe uniform circular motion in terms of **velocity** and **acceleration**
- use $a = v^2/r = r\omega^2$ and $F = mv^2/r = mr\omega^2$
- identify the **real force** that provides the centripetal force (tension, friction, gravity, electric)

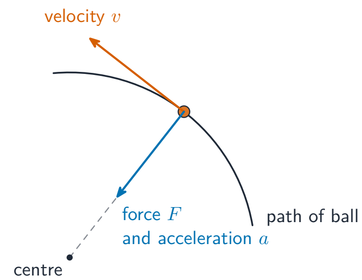
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

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:





Centripetal acceleration points to the centre

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

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}.

2 Practice

Now apply the methods above.

2.1 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. [3]

2.2 Write **two** forms of the centripetal acceleration equation. [2]

2.3 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**. [2]

2.4 State what provides the centripetal force for a car turning a **flat** corner. [1]

3 Exam-style questions

3.1 For an object in uniform circular motion, the centripetal force is directed: [1]

- **A** along the velocity
- **B** towards the centre
- **C** away from the centre
- **D** opposite to the velocity

3.2 A car of mass 900 kg turns a corner of radius 30 m at 15 m s^{-1}. Calculate the **centripetal force** needed. [3]

3.3 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. [1]

(b) Calculate the **speed** of the electron. [3]

3.4 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**. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

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

2.2

- $a = v^2/r$
- $a = r\omega^2$

2.3

- $m = 0.20$ kg, $v = 3.0$ m s^{-1}, $r = 0.50$ m
- $F = mv^2/r$

$$F = \frac{(0.20\text{ kg})(3.0\text{ m s}^{-1})^2}{0.50\text{ m}} = \mathbf{3.6}\text{ N}$$

2.4

- **friction** between the tyres and the road

3.1 B

- the centripetal force (and the acceleration) is directed **towards the centre**
- **A** is the tangent (velocity); **C** is the fictitious "centrifugal" direction; **D** would reverse the motion

3.2

- $m = 900$ kg, $v = 15$ m s^{-1}, $r = 30$ m
- $F = mv^2/r$

$$F = \frac{(900\text{ kg})(15\text{ m s}^{-1})^2}{30\text{ m}} = 6750\text{ N} \approx \mathbf{6.8 \times 10^3}\text{ N}$$

3.3

(a) its **velocity is changing direction**, and a changing velocity is an acceleration (towards the centre)

(b) the electric force is the centripetal force: $F = mv^2/r$, so $v = \sqrt{Fr/m}$

$$v = \sqrt{\frac{(8.2 \times 10^{-8}\text{ N})(5.3 \times 10^{-11}\text{ m})}{9.1 \times 10^{-31}\text{ kg}}} = \mathbf{2.2 \times 10^6}\text{ m s}^{-1}$$

3.4

- the **tension** in the string provides it

- if the string breaks the stone flies off along a **straight line (the tangent)**, since there is no longer a centripetal force