Angular speed and acceleration in a circle

90 marks

Hints online, answers free with an account: mathswariz.uk/worksheets/ocr-further-maths-mech-circular-basics/

Date

A Do Now

Quick questions to start.

A1 Needed today [2 marks]

Change $150°$ to radians, as a multiple of π.

Change 1.2 radians to degrees.

Answer .....

A2 From A-Level Maths [2 marks]

An arc of a circle of radius $2.5\ \text{m}$ subtends an angle of 0.8 radians at the centre. Find the length of the arc.

Answer .....

A3 From A-Level Maths [2 marks]

Forces of $10\ \text{N}$ and $4\ \text{N}$ act in opposite directions along a line on a particle of mass $0.4\ \text{kg}$. Find its acceleration.

Answer .....

A4 From chapter 1 [2 marks]

v is a speed and r is a length. Find the dimensions of $\dfrac{v^2}{r}$.

Answer .....

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Your teacher works each example with you (I do). You try the one beside it together (We do). Then practise that part on your own (You do).

PART 1 Angular speed, period and speed

EXAMPLE 1 · I DO

A turntable turns at a constant 45 revolutions per minute. Find its angular speed in $\mathrm{rad\,s^{-1}}$, and the time it takes for one revolution.

Hint One revolution is 2π radians. Change the minutes to seconds as well. The period is $T = \dfrac{2\pi}{\omega}$.

YOUR TURN · WE DO

B1 A drill turns at 300 revolutions per minute. Find its angular speed in $\mathrm{rad\,s^{-1}}$, the period of one revolution, and the angle in radians it turns through in 0.5 s. [3 marks]

Answer .....

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EXAMPLE 2 · I DO

A disc of radius $0.35\ \text{m}$ turns with angular speed $\dot{\theta} = 12\ \text{rad}\,\text{s}^{-1}$. Find the speed of a point on its rim, the speed of a point halfway from the centre to the rim, and the period.

Hint $\dot{\theta}$ is another way to write ω. Every point of the disc has the same ω; the speed $v = r\omega$ depends on how far it is from the centre.

YOUR TURN · WE DO

B2 A child on a roundabout moves in a circle of radius $3\ \text{m}$ at a constant speed of $7.5\ \text{m}\,\text{s}^{-1}$. Find $\dot{\theta}$ and the period. Find how far the child travels in $12\ \text{s}$, and how many revolutions that is. [4 marks]

Answer .....

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C1 A satellite moves in a circular orbit of radius $7.0 \times 10^{6}\ \mathrm{m}$ about the centre of the Earth. It takes 97 minutes to complete one orbit. Find the angular speed and the speed of the satellite. [3 marks]

Answer .....

C2 A bicycle wheel of radius $0.34\ \mathrm{m}$ turns at a constant 180 revolutions per minute. Find the angular speed of the wheel, the speed of a point on its rim, and the distance that point travels in $5\ \mathrm{s}$. [4 marks]

Answer .....

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PART 2 Acceleration towards the centre

EXAMPLE 3 · I DO

A particle moves in a horizontal circle of radius $0.6\ \text{m}$ with constant angular speed $5\ \text{rad}\,\text{s}^{-1}$. Find the magnitude and direction of its acceleration.

Hint The speed is constant but the direction of motion keeps changing, so the particle accelerates. The acceleration is $r\omega^2$, towards the centre of the circle.

YOUR TURN · WE DO

B3 A car drives round a horizontal circle of radius $5\ \text{m}$ at a constant $12\ \text{m}\,\text{s}^{-1}$. Find the magnitude and direction of its acceleration, and its angular speed. [3 marks]

Answer .....

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C3 A particle moves in a horizontal circle of radius $0.5\ \text{m}$ with angular speed $6\ \text{rad}\,\text{s}^{-1}$. Sam writes: "$a = \dfrac{\omega^2}{r} = \dfrac{36}{0.5} = 72\ \text{m}\,\text{s}^{-2}$, in the direction the particle is moving." Explain the two mistakes in Sam's answer, and find the acceleration correctly. [4 marks]

Answer .....

C4 The drum of a washing machine has radius $0.27\ \text{m}$ and spins at 1400 revolutions per minute. Find the speed of a point on the drum, and the magnitude of its acceleration. Give the acceleration as a multiple of g. [5 marks]

Answer .....

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C5 A light rod rotates in a horizontal plane about a fixed vertical axis through its end O, with constant angular speed. Points A and B on the rod are $0.4\ \text{m}$ and $1.0\ \text{m}$ from O. The speed of B is $3\ \text{m s}^{-1}$ more than the speed of A.

(a) Find the angular speed of the rod. [2 marks]

Answer .....

(b) Find the magnitudes of the accelerations of A and of B. [3 marks]

Answer .....

(c) A small bead of mass $0.05\ \text{kg}$ is fixed to the rod at B. Find the magnitude of the horizontal force the rod exerts on the bead. [2 marks]

Answer .....

Total for C5: 7 marks

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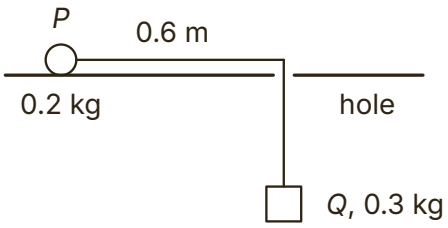
PART 3 Strings that pull a particle round

EXAMPLE 4 · I DO

Particle P of mass $0.2\ \text{kg}$ moves on a smooth horizontal table in a circle of radius $0.6\ \text{m}$. A light inextensible string joins P to particle Q of mass $0.3\ \text{kg}$. The string passes through a small smooth hole at the centre of the circle, and Q hangs at rest below the hole. Find the angular speed and the speed of P.



Hint Q is at rest, so the tension equals the weight of Q. The same tension pulls P towards the hole. The weight of P is vertical, so it plays no part in the horizontal equation.

YOUR TURN · WE DO

B4 Particle P of mass $0.3\ \text{kg}$ moves on a smooth horizontal table, joined by a light string through a small smooth hole to particle Q of mass $0.45\ \text{kg}$, which hangs at rest. P moves in a circle with centre the hole at a speed of $4.2\ \text{m s}^{-1}$. Find the radius of the circle and the angular speed of P. [4 marks]

Answer .....

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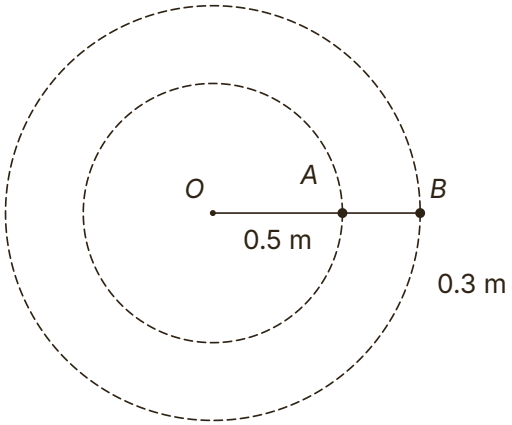
EXAMPLE 5 · I DO

Particles A of mass $0.2\ \text{kg}$ and B of mass $0.1\ \text{kg}$ lie on a smooth horizontal table. Light strings join O to A and A to B, with $OA = 0.5\ \text{m}$ and $AB = 0.3\ \text{m}$. The particles move in circles with centre O, with O, A and B always in a straight line, at $4\ \text{rad}\,\text{s}^{-1}$. Find the tension in each string.



Hint Both particles have the same ω. Start with B: only AB pulls it. A is pulled in by OA and out by AB. B moves on a circle of radius $0.8\ \text{m}$, not $0.3\ \text{m}$.

YOUR TURN · WE DO

B5 Particles A of mass $0.3\ \text{kg}$ and B of mass $0.2\ \text{kg}$ lie on a smooth horizontal table, joined by light strings OA of length $0.4\ \text{m}$ and AB of length $0.4\ \text{m}$, where O is fixed. They move in circles with centre O, with O, A and B in a straight line, at $5\ \text{rad}\,\text{s}^{-1}$. Find the tension in each string. [4 marks]

Answer .....

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C6 A particle of mass $0.2\ \text{kg}$ moves in a circle on a smooth horizontal table, on the end of a light string of length $0.9\ \text{m}$ fixed at the centre. The tension in the string is $7.2\ \text{N}$. Find the speed of the particle and the number of revolutions it makes per minute. [4 marks]

Answer .....

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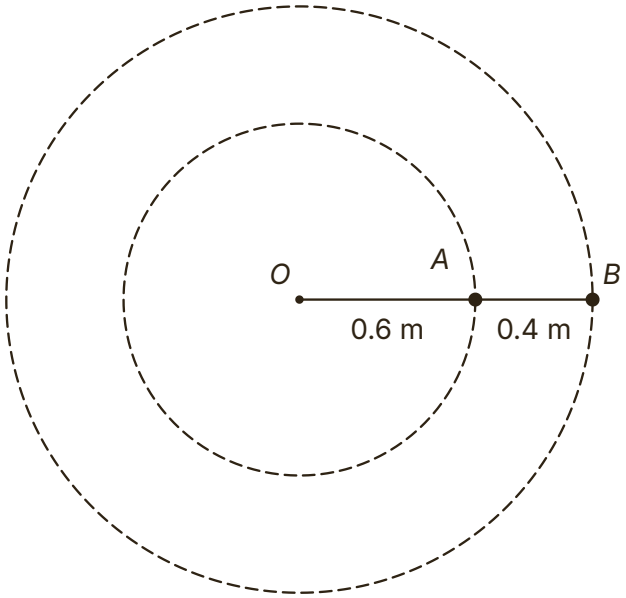
C7 Particle A of mass $0.4\ \text{kg}$ and particle B lie on a smooth horizontal table. A light string of length $0.6\ \text{m}$ joins a fixed point O to A, and a light string of length $0.4\ \text{m}$ joins A to B. The particles move in circles with centre O, with O, A and B always in a straight line. The tension in OA is $21\ \text{N}$ and the tension in AB is $15\ \text{N}$.



(a) Show that the angular speed of the particles is $5\ \text{rad}\,\text{s}^{-1}$. [3 marks]

(b) Find the mass of B. [2 marks]

Answer .....

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(c) Find the speed of B and the time for one revolution. [3 marks]

Answer .....

(d) Explain why the tension in OA must be greater than the tension in AB. [2 marks]

Total for C7: 10 marks

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D1

> Priya says: “The particle moves at a constant speed, so it has no acceleration and the string is not needed to keep it moving.”

A particle of mass $0.15\ \text{kg}$ moves on a smooth horizontal table in a circle, on the end of a light inextensible string of length $1.2\ \text{m}$ whose other end is fixed at the centre. It completes one revolution every $0.9\ \text{s}$.

(a) Explain why Priya is wrong. [2 marks]

(b) Find the tension in the string. [3 marks]

Answer .....

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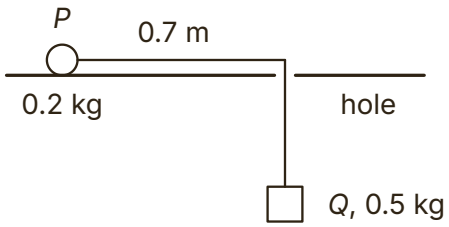
(c) The string will break if the tension exceeds $12\ \mathrm{N}$. Find the shortest possible time for one revolution. [3 marks]

Answer .....

Total for D1: 8 marks

D2 Particle P of mass $0.2\ \mathrm{kg}$ moves on a smooth horizontal table in a circle of radius $0.7\ \mathrm{m}$. A light inextensible string joins P to particle Q of mass $0.5\ \mathrm{kg}$. The string passes through a small smooth hole at the centre of the circle, and Q hangs at rest below the hole.

(a) State the tension in the string, giving a reason. [2 marks]



Answer .....

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(b) Find the angular speed and the speed of P. [4 marks]

Answer .....

(c) Q is replaced by a particle of mass $0.8\ \text{kg}$, which also hangs at rest. P moves with the same speed as before. Find the radius of its new circle. [3 marks]

Answer .....

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(d) State two modelling assumptions about the hole and the string that you have used. [2 marks]

Total for D2: 11 marks

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E Extension

Stretch

No route is given. The hints are at the end of the sheet. Use one at a time.

E1 [8 marks]

Particles P and Q move in the same sense round horizontal circles with the same centre O. P moves on the circle of radius $2\ \text{m}$ at $1.2\ \text{rad}\,\text{s}^{-1}$, and Q moves on the circle of radius $3\ \text{m}$ at $0.8\ \text{rad}\,\text{s}^{-1}$. At time $t = 0$, O, P and Q lie on one straight line, with P and Q on the same side of O. Find the first two times at which $PQ = 4\ \text{m}$. Find the greatest possible distance between P and Q, and the first time it happens.

Answer .....

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Extension hints

Cover these with paper. Uncover one at a time.

E1

Hint 1 P gains on Q by $1.2 - 0.8$ radians every second. What is the angle POQ at time t?

Hint 2 Use the cosine rule in triangle OPQ, with sides 2 and 3 and the angle between them.

Hint 3 The angle $0.4t$ can be more than π; $\cos 0.4t = -0.25$ has a second solution before 2π. When are P and Q on opposite sides of O?

How did it go?

Colour one circle on each line: not yet, nearly, yes.

I can change between rev/min and $\mathrm{rad\,s^{-1}}$, and find the period from ω. ○ ○ ○

I can use $v = r\omega$ and $a = r\omega^2 = \dfrac{v^2}{r}$, with the acceleration towards the centre. ○ ○ ○

I can find the tension in a string that keeps a particle moving in a horizontal circle. ○ ○ ○

I can explain why a particle moving at constant speed in a circle is accelerating. ○ ○ ○

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