# Teacher Delivery Guide Mechanics: Circular Motion

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| **Y421 MECHANICS MAJOR: CIRCULAR MOTION (b)****Y415 MECHANICS b: CIRCULAR MOTION**  |
| The language of circular motion | Mr1 | Understand the language associated with circular motion. | The terms: tangential, radial and angular velocity; radial component of acceleration. |  for angular velocity. or . | Angular velocity as a vector. |
| Modelling circular motion | r2 | Identify the force(s) acting on a body in circular motion. | Learners will be expected to set up equations of motion. |  |  |
| r3 | Be able to calculate acceleration towards the centre of circular motion. | Using the expressions  and . |  |  |
| Circular motion with uniform speed | r4 | Be able to model situations involving circular motion with uniform speed in a horizontal plane. | E.g. a conical pendulum, a car travelling horizontally on a cambered circular track. |  |  |

***DISCLAIMER***

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| **Specification** | **Ref.** | **Learning outcomes** | **Notes** | **Notation** | **Exclusions** |
| Circular motion with non-uniform speed | r5 | Be able to model situations involving circular motion with non-uniform speed. | E.g. rotation in a horizontal circle with non-uniform angular velocity. |  |  |
|  | r6 | Be able to calculate tangential acceleration. | Tangential component of acceleration .Use of Newton’s 2nd law, , in the tangential direction. |  |  |
|  | r7 | Be able to model situations involving motion in a vertical circle. | The use of conservation of energy, and of  in the radial and tangential directions.E.g. sliding on the interior or exterior surface of a sphere. |  |  |
|  | r8 | Identify the conditions under which a particle departs from circular motion. | E.g. when a string becomes slack, when a particle leaves a surface.Questions may ask about the subsequent motion. |  |  |

# Thinking Conceptually

### General approaches

First one needs to introduce the notions of angular velocity (ω = v/r) and its unit (radians/second) and the idea of period of motion.

Newton’s Second Law then requires a force towards the centre of the circle in order that the velocity vector changes direction. Students are not required to know a proof that the acceleration towards the centre equals *v*2/*r* but students at this level will usually find it helpful to understand the derivation.

It is perhaps best to start by applying this principle to horizontal circle motion, as this is more straightforward than motion in a vertical circle. Starting with motion in a horizontal plane with no vertical forces, one can then extend this to, for example, motion in a conical pendulum, or a banked track, where the vertical components of forces are in equilibrium.

Vertical circle motion questions are usually tackled using the following approach: first, find the velocity using a conservation of energy calculation; second, investigate forces towards the centre using Newton’s Second Law, applied towards the centre of the circular motion. Whilst the context, initial conditions and variables of problems will vary, the method of solution is common to all problems, so that learners, who might initially struggle to combine the different ideas, should, with practice, be able to tackle these types of problems with confidence.

### Common difficulties learners may have

Angular velocity may be a relatively new concept to learners; radian measure is required for *v* = *rω* to be valid.

*a*

**

*a*

*a* cos**

*h*= *a* – *a* cos**

*h*

A common element of vertical circle questions is the geometry of calculating the difference in vertical height between points on the circumference, as in this example.

Force diagrams require learners to think carefully about which direction the forces act in. For example, it is instructive to compare a particle rotating in a vertical circle when attached to a light rod, and when attached to an inextensible string. Although the forces in a general position are similar, the rod can be either in tension or in thrust, and so the resulting central force can be either positive or negative, whereas a string can only be in tension. The conditions for completing complete circles will in each case be different.

Many vertical circle problems require the learner to calculate a contact force in a general position, and then to set this force to zero in order to find out when a particle leaves vertical circle motion.

### Common misconceptions learners may have

It is important that learners fully understand the difference between a linear velocity and an angular velocity.

People sometimes talk of the ‘centrifugal force’, which is a force felt away from the centre of the circle. This feeling is due to inertia, which would tend to keep the object moving in a straight line – see <http://www.physicsclassroom.com/class/circles/Lesson-1/The-Forbidden-F-Word>

Velocity and acceleration need to be regarded as vector quantities: when travelling in a horizontal circle, the *speed* may well be constant, but the *velocity* is not!

Problems in vertical circle motion require the use of conservation of energy. But why is energy conserved in this context, whereas in another, such as collisions, energy is not conserved? This is, of course, because the centripetal force is doing no work, as it is at right angles to the direction of motion. It is important that learners appreciate these details before applying these physical principles.

### Conceptual links to other areas of the specification

This topic has links with vectors, radian measure, Newton’s 2nd Law (applied towards the centre), kinetic and potential energy, and conservation of energy.

# Thinking Contextually

The concept of centripetal acceleration has many applications to familiar physical experiences: the playground roundabout, cornering when running, cycling or motoring, throwing a hammer, the wall of death, etc. In practice, it is quite difficult to measure the velocity, acceleration and forces experimentally, but identifying the centripetal forces in a range of such contexts can help to motivate and reinforce the theory. It can also help to ensure that learners draw forces correctly on force diagrams, and apply Newton’s Second Law correctly.

# Resources

| **Title** | **Organisation** | **Description** | **Ref** |
| --- | --- | --- | --- |
| [Circular Motion Demonstration with Sparkler](https://www.youtube.com/watch?v=ID0R43My4Co) | Alom Shaha | Short video clip of a couple of simple circular motion demonstrations to show students that the instantaneous velocity of an object moving in uniform circular motion is at a tangent to the circle. | r1, r2, r3 and r4 |
| [3.1 Circular motion, speed and velocity](https://www.stem.org.uk/rxvpz) | Nuffield | Activity 3.1, on page 37, is a theoretical activity but could involve some simple modelling. The activity links to 3.2. | r1, r2, r3 and r4 |
| [3.2 Vector equations of circular motion](https://www.stem.org.uk/rxvpz) | Nuffield | Activity 3.2, on page 38. Hints on page 143, answers on page 163. Follows on from activity 3.1. | r1, r2, r3 and r4 |
| [3.3 using equations of circular motion](https://www.stem.org.uk/rxvpz) | Nuffield | Activity 3.3, page 40, provides an opportunity to use the equations of circular motion Hints on page 143, answers on page 163 | r1, r2, r3 and r4 |
| [7.1 Force diagrams for circular motion](https://www.stem.org.uk/rxvq2) | Nuffield | Activity 7.1, page 102, provides an opportunity to practice drawing force diagrams. | r1, r2, r3 and r4 |
| [7.2 Problems involving circular motion](https://www.stem.org.uk/rxvq2) | Nuffield | Activity 7.2, page 104, begins with a focus on the Universal Law of Gravitation. | r1, r2, r3 and r4 |
| [3.2 Communications Satellites](https://www.stem.org.uk/rxyt3) | The Spode Group | Communication satellites, page 59, consolidates understanding of circular motion | r1, r2, r3 and r4 |
| [The conical pendulum 1](https://www.stem.org.uk/rxtgk) | Mechanics in Action Project | The conical pendulum 1, page 122, provides a practical activity introducing the dynamics of circular motion. Links with the Conical pendulum 2 activity. | r1, r2, r3 and r4 |
| [The conical pendulum 2](https://www.stem.org.uk/rxtgk) | Mechanics in Action Project | The conical pendulum 2, page 127, provides a practical activity introducing the dynamics of circular motion. Links with the Conical pendulum 1 activity. | r1, r2, r3 and r4 |
| [Motion on a banked track](https://www.stem.org.uk/rxtgk) | Mechanics in Action Project | Motion on a banked track is a practical activity investigating forces in this context. | r1, r2, r3 and r4 |
| [Uniform Circular Motion](https://www.youtube.com/watch?v=kLN9W73ASrQ) | Matt Anderson | 9 minute video introduction lecture to circular motion, developing the formula for acceleration towards the centre of circular motion | r3 |
| [Circular Motion – Plane on a string Part 1](https://www.youtube.com/watch?v=LQN4DqqKR9o)[Circular Motion – Plane on a string Part 2](https://www.youtube.com/watch?v=0FbvgtiaQAs) | Mike Richardson | 6 minute video reviewing a question on a toy plane moving in a circle on a string (conical pendulum) Video Part 1 covers question part a, video part 2 covers question part b | r4 |
| [Uniform Circular Motion](https://www.stcharlesprep.org/01_parents/vandermeer_s/Useful%20Links/Honors%20Physics/pdf%20lectures/Circular%20Motion.pdf) | Southern Polytechnic State University | Set of slides on theory and applications in context, both horizontal and vertical examples | r4 and r7 |
| [Non uniform circular motion](https://www.youtube.com/watch?v=6QcbngODHiM) | Matt Anderson | 7 minute video lecture  | r5 |
| [7.1 The Assault course](https://www.stem.org.uk/rxvq2) | Nuffield | Activity 7.1, page 85, investigates how the tension in a rope varies as it swings under load.  | r5, r6 and r7 |
| [7.2 Validating the answer](https://www.stem.org.uk/rxvq2) | Nuffield | Activity 7.2, page 87 is a practical activity where the model, introduced in activity 7.1, is validated  | r5, r6 and r7 |
| [7.4 Looping the loop](https://www.stem.org.uk/rxvq2) | Nuffield | Activity 7.4, page 91, is a practical activity. | r5, r6 and r7 |
| [Motion in a vertical circle - particle on a string](https://www.youtube.com/watch?v=zI4D2pkAeZY) | Exam Solutions | 12 minute review of exam question using energy considerations. | r7 |
| [Cake tin](https://www.stem.org.uk/rxtgk) | Mechanics in Action | Cake tin, page 138, task sheet 40 involves rolling a marble around the outside of a smooth cylinder and investigating the point at which the marble loses contact with the tin. | r8 |

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