Module 5 Newtonian World & Astrophysics

Module 5: Newtonian world and astrophysics

The aim of this module is to show the impact Newtonian mechanics has on physics. The microscopic motion of atoms can be modelled using Newton's laws and hence provide us with an understanding of macroscopic quantities such as pressure and temperature. Newton's law of gravitation can be used to predict the motion of planets and distant galaxies. In the final section we explore the intricacies of stars and the expansion of the Universe by analysing the electromagnetic radiation from space. As such, it lends itself to the consideration of how the development of the scientific model is improved based on the advances in the means of observation (HSW1, 2, 5, 6, 7, 8, 9, 11).

In this module, learners will learn about thermal physics, circular motion, oscillations, gravitational field, astrophysics and cosmology.

Module 5 Newtonian World & Astrophysics

Unit 2 Circular Motion

5.2 Circular motion

There are many examples of objects travelling at constant speed in circles, e.g. planets, artificial satellites, charged particles in a magnetic field, etc. The physics in all these cases can be described and analysed using the ideas developed by Newton. The concepts in this section have applications in many contexts present in other sections of this specification, such as planetary motion in section 5.4.3 (HSW1, 2, 5, 9).

This section provides knowledge and understanding of circular motion and important concepts such as centripetal force and acceleration.

Module 5 – Newtonian world and astrophysics

5.1 Thermal physics

You are here! 5.2 Circular motion

5.3 Oscillations

5.4 Gravitational fields

5.5 Astrophysics and cosmology

Module 6 – Particles and medical physics

6.1 Capacitors

6.2 Electric fields

6.3 Electromagnetism

6.4 Nuclear and particle physics

6.5 Medical imaging

5.2 Circular Motion

- 5.2.1 Kinematics of Circular Motion
- 5.2.2 Centripetal Force

5.2.1 Kinematics of Circular Motion

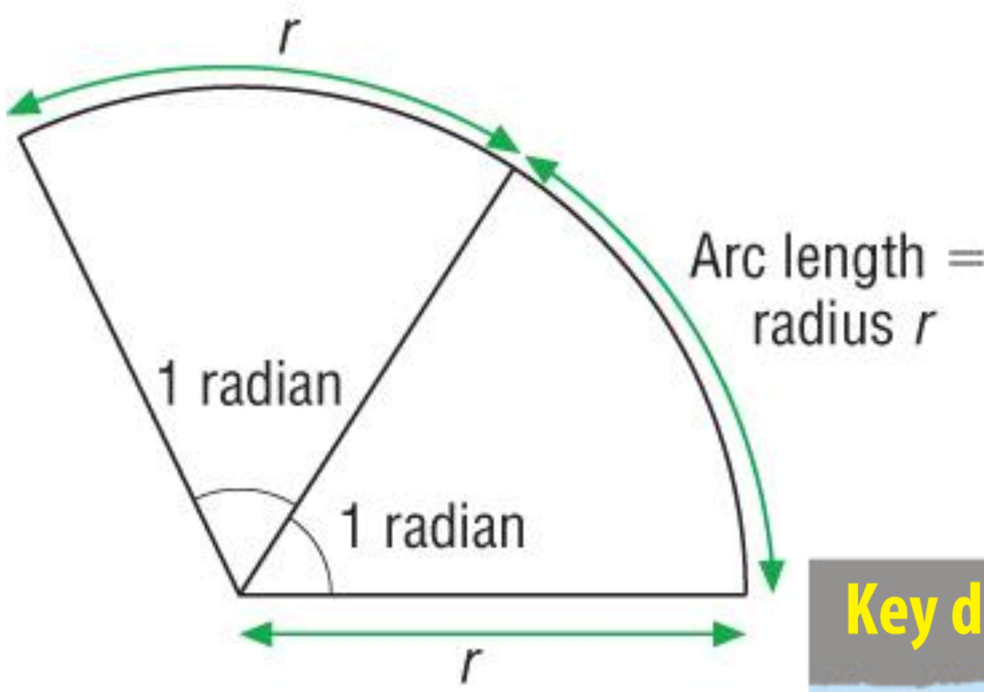
5.2.1 Kinematics of circular motion

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	the radian as a measure of angle
(b)	period and frequency of an object in circular motion
(c)	angular velocity ω, $\omega = \dfrac{2\pi}{T}$ or $\omega = 2\pi f$

Ever heard of radians? Nope, me neither!

Angular Measurement

- The SI unit for an angle is the radian.



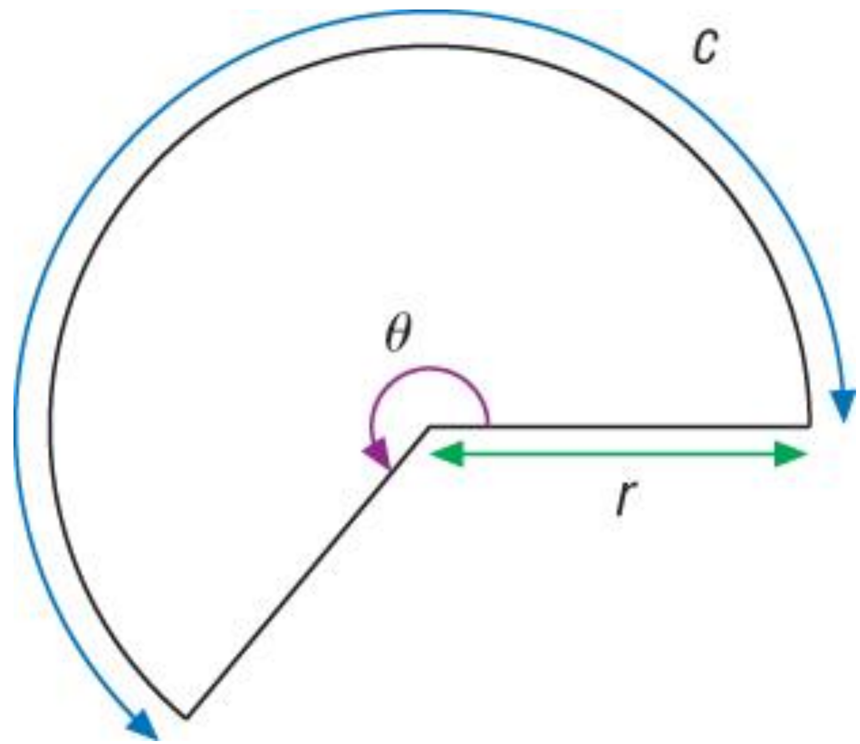
Key definition

One **radian** is the angle subtended at the centre of a circle by an arc of length equal to the circle's radius.

Radians

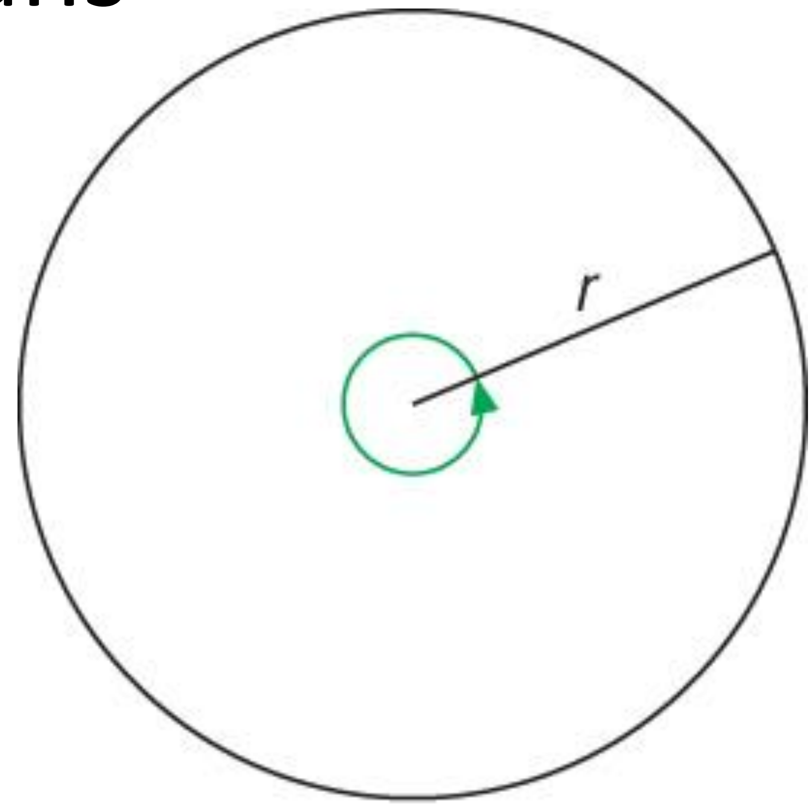
- Any angle measured in radians can be calculated by dividing the curved arc distance (c) by the radius (r) of a circle.

- $\theta = c/r$



Radians

- The angle of a complete revolution, in radians, is 2π.



Radius $= r$

Circumference $= 2\pi r$

$\therefore$ Angle $= \dfrac{2\pi r}{r} = 2\pi$ rad

Some conversions

Radians	Degrees	Right angles	Revolutions
$2\pi = 6.283$ rad	360	4	1
π	180	2	½
$\pi/2$	90	1	¼
$\pi/3$	60	⅔	1/6
$\pi/4$	45	½	1/8
$\pi/6$	30	⅓	1/12
$\pi/180$	1	1/90	1/360
1	$360/2\pi = 57.3°$	$2/\pi$	$1/2\pi$

Just remember: 2π radians = 360º

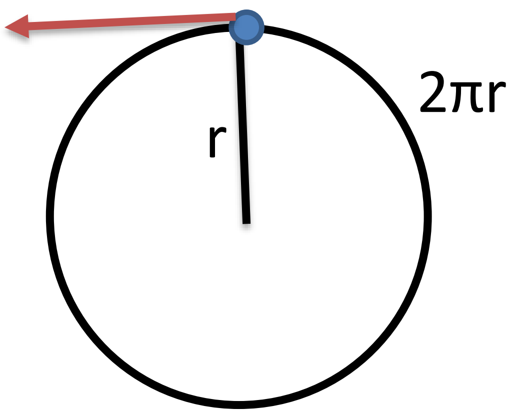
Why use radians? We're used to degrees.

- Three reasons:
  - The radian has no units.
    - It is a distance divided by a distance.
    - Sometimes the "unit" of rad is given just to ensure we know what the number refers to.
  - 360 degrees for a revolution is a strange number to use. Why 360?
  - Physicists measure the rate of rotation of an object, or angular velocity, in radians per second – not revs per minute like car manufacturers do.

What is Angular Velocity?

Circular Motion

- For an object travelling in a circular orbit with a constant speed, the time taken to complete one revolution is called the Period, T.



The speed of the object (v) is related to the radius (r) and the period T:

Speed = Distance/Time = Circumference/Period

Or

$v = 2\pi r/T$ (This is called the linear velocity)

Angular Velocity

- To describe an object moving in a circular path (rotating/orbiting), physicists mainly measure the angular velocity.
- Angular velocity is the rate of change of the angle about the point of rotation.

$$\omega = \frac{\theta}{t}$$

If we take the time to be the Period, T, the angle rotated will be one full rotation, 2π.

$$\omega = \frac{2\pi}{T}$$

What is the unit of angular velocity? **Rad.s^{-1}**

Another way of looking at it…

- Since frequency is the reciprocal of period:

$$f = \frac{1}{T}$$

- Angular velocity can also be written as:

$$\omega = 2\pi f$$

Summary

- So now we have:

$$\omega = \frac{\theta}{t} \qquad\qquad \omega = \frac{2\pi}{T}$$

$$\omega = 2\pi f$$

There are many alternative units for angular velocity (degrees per second, revs per minute). For this course, stick to **radians per second**.

5.2.1 Kinematics of Circular Motion (review)

5.2.1 Kinematics of circular motion

	Learning outcomes
	Learners should be able to demonstrate and apply their knowledge and understanding of:
(a)	the radian as a measure of angle
(b)	period and frequency of an object in circular motion
(c)	angular velocity ω, $\omega = \dfrac{2\pi}{T}$ or $\omega = 2\pi f$

5.2.2 Centripetal Force

5.2.2 Centripetal force

Learning outcomes

Learners should be able to demonstrate and apply their knowledge and understanding of:

(a) a constant net force perpendicular to the velocity of an object causes it to travel in a circular path

(b) constant speed in a circle; $v = \omega r$

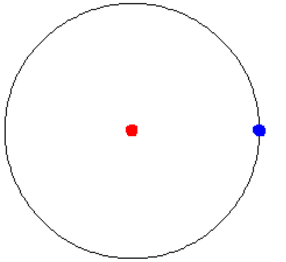
(c) centripetal acceleration; $a = \frac{v^2}{r}$; $a = \omega^2 r$

(d) **(i)** centripetal force; $F = \frac{mv^2}{r}$; $F = m\omega^2 r$

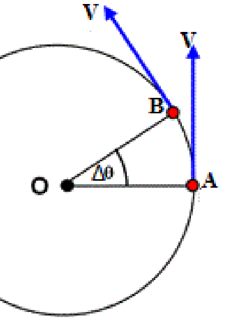
(ii) techniques and procedures used to investigate circular motion using a whirling bung.

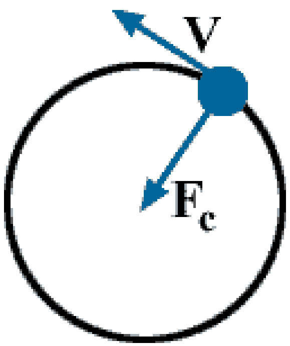
Centripetal or
centrifugal force?
(one doesn’t exist)

Centripetal Force

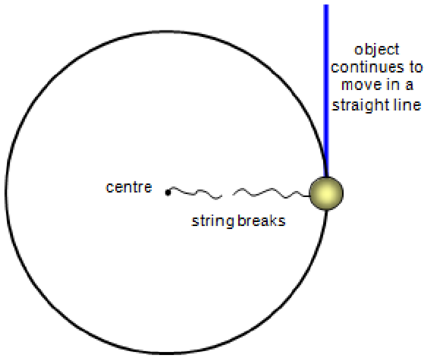


- An object moving in a circular path is constantly changing direction.
- It must therefore be accelerating (even if its speed is constant).
- An accelerating object has to be subject to a resultant force (f=ma).
- This force is towards the centre of the circular path.
- This force is called the centripetal force (meaning centre-seeking in Greek).

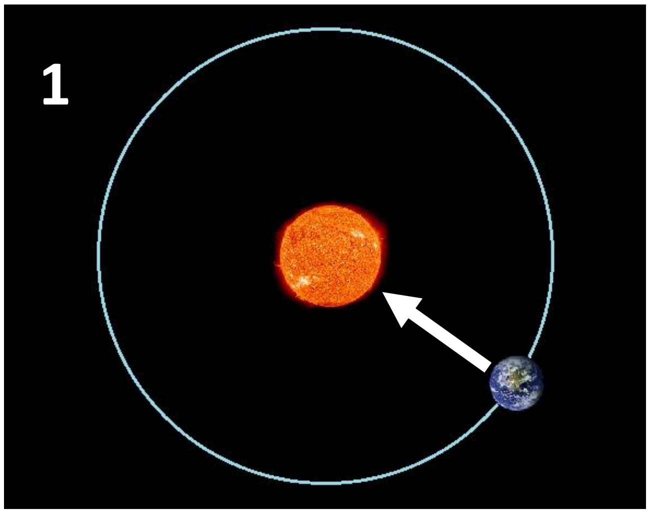




- What happens to an object moving in a circle if the centripetal force is suddenly removed?
- It continues but in a straight line.



What provides the centripetal force?



Gravity

Friction

The drum

Angular Velocity v Linear Velocity

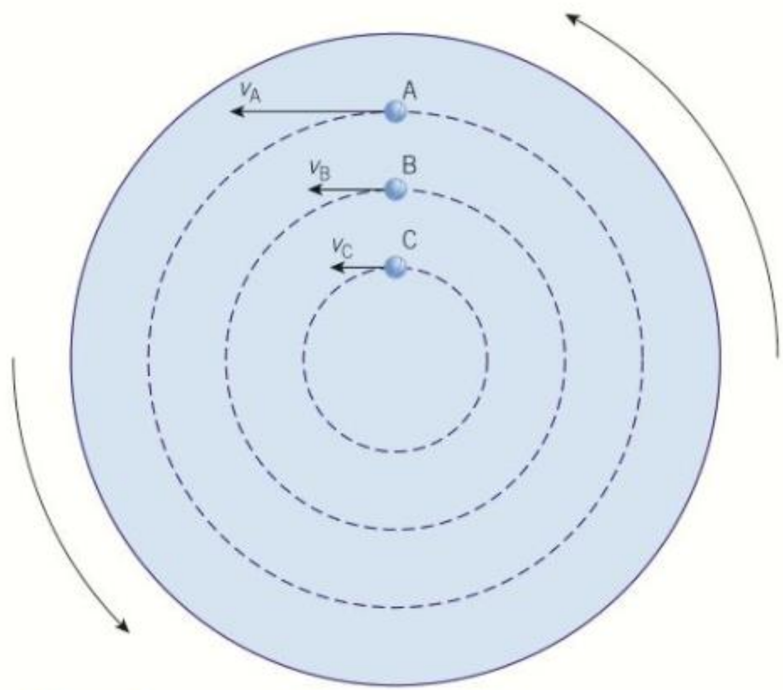
- Linear velocity:
  - Always at a tangent to the circular path (perpendicular to radius).
  - v = Distance Travelled / Time Taken
  - In 1 rotation, $v = 2\pi r/T$
- Angular velocity:
  - $\omega = 2\pi/T$

Combining these equations: $v = r\omega$

Angular Velocity v Linear Velocity

- Objects with the same angular velocity orbit at the same rate as each other.
- However, their linear velocities are proportional to their radius.

$$v = r\omega$$



▲ Figure 4 *As the radius of the path followed by the object increases, the linear velocity also increases*

Double the radius and the linear velocity will double

Centripetal Acceleration

- Centripetal acceleration is the acceleration which leads to the change in velocity of an object travelling in a circular path
- It always acts towards the centre of the circle.
- Centripetal acceleration, a, depends on the linear velocity, v, and the radius, r.

$$a = \frac{v^2}{r} \quad \text{or} \quad a = \omega^2 r$$

Extension: To know the derivation of these equations see p.307 (optional)

Centripetal Force

- Since: $F = ma$
- And: $a = \frac{v^2}{r}$ $\quad a = \omega^2 r$
- Then: $\mathrm{F} = \frac{mv^2}{r}$ $\quad \mathrm{F} = m\omega^2 r$

Investigating circular motion

- Practical:
  - Use a bung on a string attached to masses to investigate:
    - How linear velocity is related to centripetal force
    - How radius is related to centripetal force.

- Questions:
  - The Centrifuge
    - Complete the tasks on p.310

Describe:

- The forces acting on you while riding a loop-the-loop rollercoaster.
  - How do you travel in a circular path?
  - What does your bodyweight feel like at the top and at the bottom of the loop.

5.2.2 Centripetal Force (review)

5.2.2 Centripetal force

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Complete! → 5.2 Circular motion

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Module 6 – Particles and medical physics

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