A2 Level Physics

Chapter 6 – Further Mechanics

6.4.1 Centripetal Force

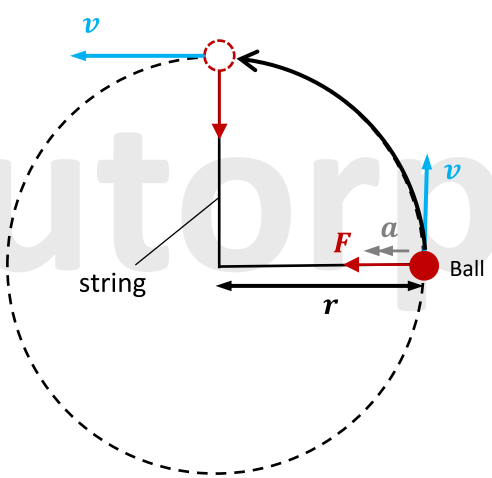
Notes

Centripetal Force and Acceleration

In the previous pack, we saw how a body can move at a constant speed around a circle, but the body also has a constant acceleration.

To understand this remember the definition of acceleration, which states the change in velocity per unit time. Since velocity, unlike speed, is a vector, even if an object moves in a circle at a constant speed, the continuous change in direction constitutes an acceleration.

Consider a ball attached to the end of a string and whirled in a horizontal circle at constant speed (v).



The velocity of the ball is always directed along the tangent to the circle (i.e. at $90°$ to the string).

The magnitude of the velocity remains constant because the speed is constant, but the direction of velocity is constantly changing.

Centripetal Force and Acceleration

Since a change in direction causes an acceleration, the ball has an acceleration which is directed towards the centre of the circular path.

This is the Centripetal Acceleration (a).

Newton's 1st law of motion states that unless there is a force acting on an object, its velocity will remain constant. Since an object travelling in a circle experiences centripetal acceleration, this acceleration must be caused by a force. This force is called the centripetal force (F) and acts towards the centre of the circular path.

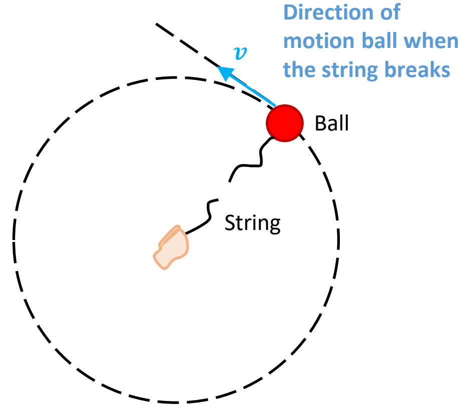
The centripetal force is provided by the tension in the string.

Remember:

Since the centripetal force is what keeps the object moving in a circle, if the string breaks, the ball will fly off at a tangent to the circle from the point where the force stopped acting.

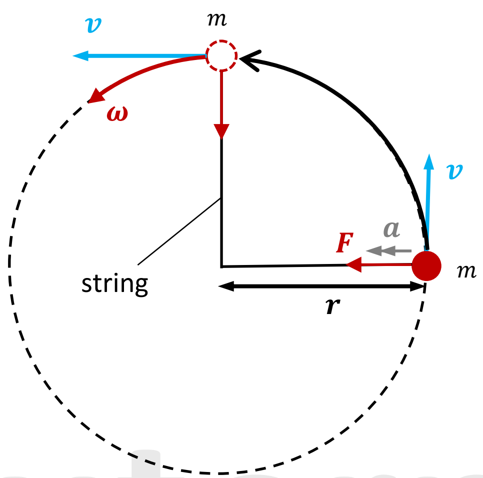
The centripetal acceleration and force are directed towards the centre of the circle (i.e. at a 90° angle to the ball's motion).

The centripetal force does no work on the object moving in a circular path. This is due to the fact that the force acts at right angles to the object's motion, so there is no actual motion in the force direction.



Centripetal Force and Acceleration

Centripetal Acceleration



The centripetal acceleration (a) of an object of mass (m) travelling at a constant speed (v) in a circular path of radius (r) is given by:

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

Where:

a = centripetal acceleration in ms^{-2}

v = magnitude of linear velocity in ms^{-1}

r = radius in m

However, we already know that $v = \omega r$ from the previous pack, so substituting this into the above equation gives us:

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

Centripetal Force and Acceleration

Therefore:

$$a = \omega^2 r$$

Where:

ω = angular speed in $rad\ s^{-1}$.

Centripetal Force

According to Newton's 2nd law:

$$Force = mass \times acceleration$$
$$F = m\,a$$

So, we get the equation for the centripetal force by substituting the centripetal acceleration into the equation above:

$$F = \frac{mv^2}{r}$$

Or

$$F = m\omega^2 r$$

Where:

F = centripetal force in N

m = mass in kg

v = magnitude of linear velocity in ms^{-1}

r = radius in m

ω = angular speed in $rad\ s^{-1}$

Whirling Bung Experiment

A whirling bung can be used to study circular motion.

Apparatus:

- Rubber bung
- Glass tube about 15cm long
- A range of hanging masses
- 1.5m of nylon string
- Ruler
- Stop-watch

Method:

1) Measure the rubber bung's mass (m) and tie it to one end of the string before threading it though a short length of glass tube.

2) Attach a mass (M) weight to the other side of the string at a set distance apart. The hanging masses at the bottom of the vertical string will provide the tension in the string and thereby the centripetal force. You can calculate the centripetal force using $F = Mg$.

3) A paperclip should be attached near the glass tube. You can use the paperclip to keep a fixed length of string (i.e., radius) that you can measure.

4) While holding the glass tube, rotate the bung in a horizontal circle while keeping the radius of the bung's orbit constant (i.e., maintaining a fixed radius).

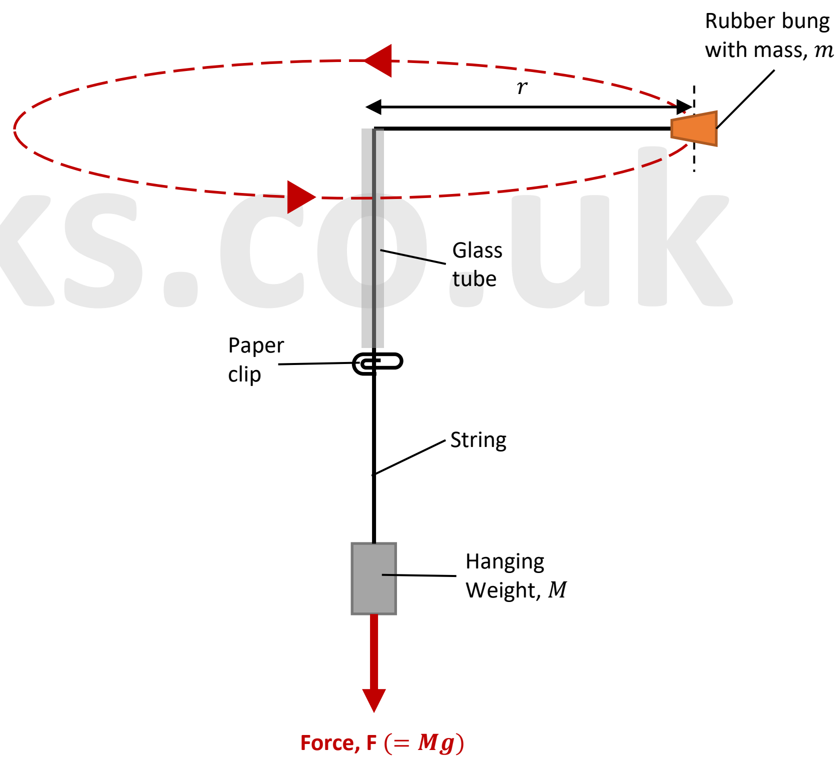
5) Time how long it takes to complete ten rotations. Then use $\omega = \frac{2\pi}{T}$ in order to calculate the angular velocity. Remember that T stands for time period, which is the time taken to complete a single spin. To calculate the time period, divide the time it takes to complete 10 rotations by ten to get the time it takes to complete one rotation.

Whirling Bung Experiment

6) Repeat the steps with a range of forces (i.e., different numbers of hanging masses) and then plot a graph of ω^2 against F.

$$F = mr\omega^2$$
$$\therefore \ \omega^2 = \frac{F}{mr}$$

When you plot ω^2 against F, you should get a straight best-fit line. This lines gradient will be $\frac{1}{mr}$.



Please see '6.4.2 Centripetal Force worked examples' pack for exam style questions.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.