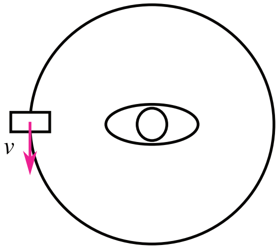
18 Moving in a Circle ♡

I swing a bung around in a horizontal circle above my head using a string. From above, it looks like this, and we can ignore the effect of gravity.



There is a force from the string acting on the bung (not shown in the diagram) acting towards the centre of the circle. Redraw the diagram above in your book to include this force.

The bung is neither speeding up nor slowing down, yet there is an unbalanced force acting on it. This force must therefore be changing the direction of the bung's motion.

- The bung's direction is changing so that it can go round in a circle.
- This means that its velocity is changing, so it must be accelerating.
- This acceleration requires a force.

Any force which causes something to go round in a circle can be labelled as a centripetal force. Three factors which affect the centripetal force are:

- mass of the object;
- its speed;
- the radius of the circle.

Formulae:

$$\text{centripetal acceleration} = \frac{\text{speed}^2}{\text{radius}} \qquad a = \frac{v^2}{r}$$

$$\text{centripetal force} = \text{mass} \times \text{acceleration} \qquad F = \frac{mv^2}{r}$$

The orbit of the Earth around the Sun is approximately circular. The force holding the Earth in this motion is the gravitational force, which acts as a centripetal force in this case.

Draw another arrow on the diagram in your book to show where the bung would go next if the string were cut whilst the bung is at the position shown.

18.1 A 0.50 kg object travels in a 1.4 m radius circle at a speed of 2.0 m/s.

(a) Calculate the force needed to keep it in this motion.

(b) Calculate the force needed for a circle of twice the radius with the same speed. What do you notice?

(c) Calculate the force needed for a speed twice as great for the original circle. What do you notice?

18.2 (a) Rearrange your 'centripetal acceleration' formula to make speed the subject.

(b) How fast are you travelling around a 4.0 m radius circle if the centripetal acceleration is 10 m/s^2?

18.3 What force is needed to enable a $1\,525$ kg car travelling at 20 mph (8.9 m/s) to go round a roundabout with an 8.0 m radius?

18.4 On a fairground ride, the passengers stand against a railing 5.3 m from the centre of a large wheel. If the wheel rotates once every 2.3 s, what is the acceleration of the riders? *[Hint: calculate the speed of the riders first.]*

18.5 A 200 kg satellite is going to orbit the Earth at a distance of $6\,600$ km from the Earth's centre. At this height (200 km from the surface), the gravitational field strength of the Earth is roughly the same as on the surface of the Earth (10 N/kg).

(a) Calculate the weight of the satellite in newtons.

(b) Calculate the speed at which the satellite will need to travel if the centripetal force is to be equal to its weight.

(c) Repeat (a) and (b) for a 120 kg satellite orbiting at the same height.

(d) Repeat (a) and (b) for a 100 kg satellite orbiting at a height of $1\,000$ km above the Earth's surface. At this height the gravitational field strength is 7.3 N/kg.

(e) Calculate the circumference of both the original orbit and the orbit in (d). For these circumferences, work out the time each satellite would take to orbit once.

18.6 A road over a humped-back bridge can be represented as a sector of a circle of radius 30 m. How fast could you travel over the top of the bridge before your wheels lifted off the ground there?

18.7 The formula for the gravitational field strength g (in N/kg) at distance r (in metres) from the Earth's centre is:

$$g = \frac{k}{r^2}$$

where $k = 4.0 \times 10^{14}$ N m^2/kg

(a) Calculate the orbital speed of a satellite orbiting in a circle of radius 4.0×10^7 m around the Earth.

(b) Calculate the time taken for this satellite to orbit once.

(c) Derive a formula for the time for one orbit of a satellite around the Earth in terms of the radius of its orbit. Use k rather than a numeric value in your formula.

(d) At what radius of orbit will a satellite orbit once every 24 hours? Such a satellite is called a geostationary satellite.

(e) The satellites which provide us with satellite TV are geostationary. Why are the TV companies willing to spend the extra money to put a satellite so far away from the Earth, when a nearer one would be much cheaper?

$^{13}/_{17}$