8 On the move

8.1 Speed and velocity

Learning objectives:

- How does displacement differ from distance?
- What is the difference between instantaneous speed and average speed?
- When is it necessary to consider velocity rather than speed?

Specification reference: 3.2.1

Hint

1 km = 1000 m; 1 hour = 3600 s;
108 km h^{-1} = 30 m s^{-1}

Figure 1

Speed

Displacement is distance in a given direction.

Speed is defined as change of distance per unit time.

Velocity is defined as change of displacement per unit time. In other words, velocity is speed in a given direction.

Speed and distance are scalar quantities. Velocity and displacement are vector quantities.

The unit of speed and of velocity is the metre per second (m s^{-1}).

Motion at constant speed

An object moving at a constant speed travels equal distances in equal times. For example, a car travelling at a speed of 30 m s^{-1} on a motorway travels a distance of 30 m every second or 1800 m every minute. In 1 hour, the car would therefore travel a distance of 108 000 m or 108 km. So 30 m s^{-1} = 108 km h^{-1}.

For an object which travels distance s in time t at constant speed,

$$\text{speed } v = \frac{s}{t}$$

$$\text{distance travelled } s = vt$$

For an object moving at constant speed on a circle of radius r, its speed

$$v = \frac{2\pi r}{T}$$

where T is the time to move round once and $2\pi r$ is the circumference of the circle.

Motion at changing speed

There are two types of speed cameras. One type measures the speed of a vehicle as it passes the camera. The other type is linked to a second speed camera and a computer, which works out the average speed of the vehicle between the two cameras. This will catch drivers who slow down for a speed camera then speed up again!

For an object moving at changing speed that travels a distance s in time t,

$$\text{average speed} = \frac{s}{t}$$

In a short time interval Δt, the distance Δs it travels is given by $\Delta s = v\Delta t$, where v is the speed at that time (i.e. its instantaneous speed). Rearranging this equation gives:

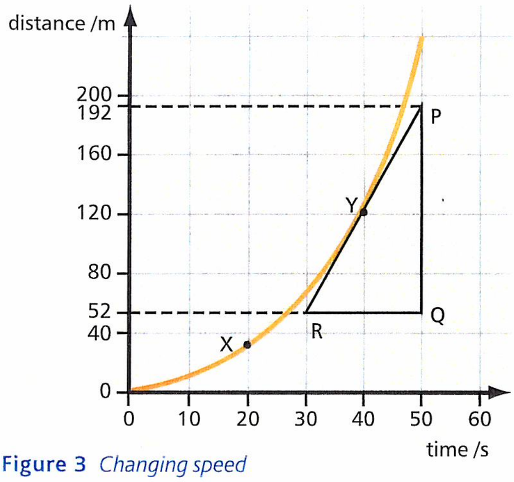
$$v = \frac{\Delta s}{\Delta t}$$

Distance–time graphs

For an object moving at **constant speed**, its graph of distance against time is a straight line with a constant gradient.

$$\text{The speed of the object} = \frac{\text{distance travelled}}{\text{time taken}} = \text{gradient of the line}$$

For an object moving at **changing speed**, the gradient of the line changes. The gradient of the line at any point can be found by drawing a tangent to the line at that point and then measuring the gradient of the tangent. This is shown in Figure 3 where PR is the tangent at point Y on the line. Show for yourself that the speed at point X on the line is $2.5\,\text{m}\,\text{s}^{-1}$.



$$\text{Speed at Y} = \frac{PQ}{QR} = \frac{192-52}{20}$$

$$= 7\,\text{m}\,\text{s}^{-1}$$

Figure 3 *Changing speed*

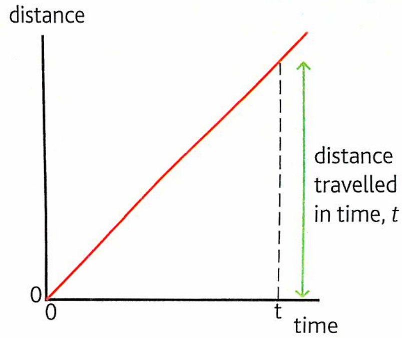


Figure 2 *Constant speed*

Velocity

An object moving at **constant velocity** moves at the same speed without changing its direction of motion.

If an object changes its direction of motion or its speed or both, its velocity changes. For example, the velocity of an object moving on a circular path at constant speed changes continuously because its direction of motion changes continuously.

Displacement–time graphs

An object travelling along a straight line has two possible directions of motion. To distinguish between the two directions, we need a direction code where positive values are in one direction and negative values in the opposite direction.

For example, consider an object thrown vertically into the air. The direction code is + for upwards and – for downwards. Figure 4 shows how its displacement changes with time. The object has an initial positive velocity and a negative return velocity. The displacement and velocity are both positive when the object is ascending. However, when it is descending, its velocity is negative and its displacement is positive until it returns to its initial position. We will consider displacement–time graphs in more detail in Topic 8.5.

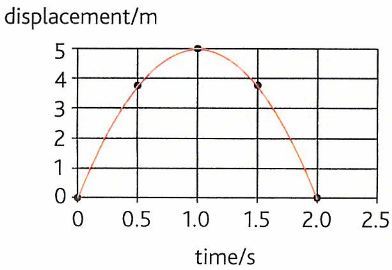


Figure 4 *A displacement–time graph*

Summary questions

1 kilometre (km) = 1000 m.

1 A car travels a distance of 60 km in 45 min at constant speed. Calculate its speed in:
a $\text{km}\,\text{h}^{-1}$, b $\text{m}\,\text{s}^{-1}$.

2 A satellite moves round the Earth at constant speed on a circular orbit of radius 8000 km with a time period of 120 min. Calculate its orbital velocity in a $\text{km}\,\text{h}^{-1}$, b $\text{m}\,\text{s}^{-1}$.

3 A vehicle joins a motorway and travels at a steady speed of $25\,\text{m}\,\text{s}^{-1}$ for 30 min then it travels a further distance of 40 km in 20 min before leaving the motorway. Calculate a the distance travelled in the first 30 min, b its average speed on the motorway.

4 a Explain the difference between speed and velocity.

b A police car joins a straight motorway at Junction 4 and travels for 12 km at a constant speed for 400 s. It then leaves at Junction 5 and rejoins on the opposite side and travels for 8 km at a constant speed for 320 s to reach the scene of an accident. Calculate i the displacement from Junction 4 to the accident, ii the velocity of the car on each side of the motorway.

c Sketch a displacement–time graph for the journey.