Lesson 1: Velocity

Vector and scalar quantities

Quantities that have size and direction are *vectors* and those with only size are *scalars*; all quantities are either vectors or scalars. It will be apparent why it is important to make this distinction when we add displacements together.

Scalar
A quantity with magnitude only.

Vector
A quantity with magnitude and direction.

Example

Consider two displacements one after another as shown in Figure 1.23.

Starting from A walk 4 km west to B, then 5 km north to C.

The total displacement from the start is not 5 + 4 but can be found by drawing a line from A to C.

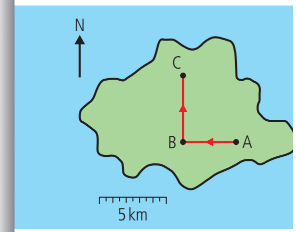


Figure 1.23 Displacements shown on a map.

Instead, the displacement can be found using Pythagoras's theorem: $\sqrt{5^2 + 4^2} = 6.4\,km$.

Check your understanding
1 Can you give some other examples of scalar quantities?
2 Can you give some other examples of vector quantities?
3 If someone walks 500 m east and then 200 m south, what is the distance they have walked? Calculate their displacement using Pythagoras's theorem.

Vectors in one dimension

In this course we will often consider the simplest examples where the motion is restricted to one dimension, for example a train travelling along a straight track. In examples like this there are only two possible directions – forwards and backwards. To distinguish between the two directions,we give them different signs (forward + and backwards –). Adding vectors is now simply a matter of adding the magnitudes, with no need for complicated triangles.

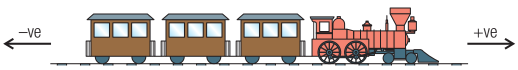


Figure 1.30 The train can only move forwards or backwards.

Worked example

If a train moves 100 m forwards along a straight track then 50 m back, what is its final displacement?

Solution

Figure 1.3 shows the vector diagram.

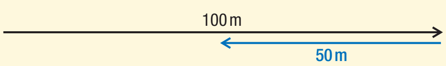


Figure 1.32 Adding vectors in one dimension.

The resultant is clearly 50 m forwards.

Displacement and distance

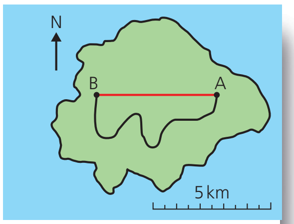


Figure 2.1.

It is important to understand the difference between distance travelled and displacement. To explain this, consider the route marked out on the map shown in Figure 1.4.

Displacement is the shortest path moved in a particular direction.

The unit of displacement is the metre (m).

Displacement is a vector quantity.

On the map, the displacement is the length of the straight line from A to B, a distance of 5 km west. (Note: since displacement is a vector you should always say what the direction is.)

Distance is how far you have travelled from A to B.

The unit of distance is also the metre.

Distance is a scalar quantity.

In this example, the distance travelled is the length of the path taken, which is about 10 km.

Sometimes this difference leads to a surprising result. For example, if you run all the way round a running track you will have travelled a distance of 400 m but your displacement will be 0 m.

In everyday life, it is often more important to know the distance travelled. For example, if you are going to travel from Paris to Lyon by road you will want to know that the distance by road is 450 km, not that your fin al displacement will be 336 km SE. However, in physics, we break everything down into its simplest parts, so we start by considering motion in a straight line only. In this case it is more useful to know the displacement, since that also has information about which direction you have moved.

Check your understanding

4 Explain the difference between distance and displacement.

5 Under what conditions are the distance and displacement of a journey the same?

Velocity and speed

Both speed and velocity are a measure of how fast a body is moving, but velocity is a vector quantity and speed is a scalar.

Velocity is defined as the displacement per unit time.

$$\textbf{velocity} = \frac{\textbf{displacement}}{\textbf{time}}$$

The unit of velocity is $m\,s^{-1}$.

Velocity is a vector quantity.

Speed is defined as the distance travelled per unit time.

$$\textbf{speed} = \frac{\textbf{distance}}{\textbf{time}}$$

The unit of speed is also $m\,s^{-1}$.

Speed is a scalar quantity.

Check your understanding

6 A sprinter runs 100 metres in 12.5 seconds. Calculate the speed in m/s.

7 A jet can travel at 350 m/s. Calculate how far it will travel at this speed in:

- a 30 seconds
- b 5 minutes
- c half an hour.

8 A snail crawls at a speed of 0.0004 m/s. How long will it take to climb a garden stick 1.6 m high?

9 Convert the following speeds into $m\,s^{-1}$.

(a) A car travelling at $100\,km\,h^{-1}$.
(b) A runner running at $20\,km\,h^{-1}$.

KEY POINT

You can convert a speed in m/s into a speed in km/h.

If the car travels 12.8 metres in one second it will travel

12.8 × 60 metres in 60 seconds (that is, one minute) and

12.8 × 60 × 60 metres in 60 minutes (that is, 1 hour), which is

46 080 metres in an hour or 46.1 km/h (to one decimal place).

We have multiplied by 3600 (60 × 60) to convert from m/s to m/h, then divided by 1000 to convert from m/h to km/h (as there are 1000 m in 1 km).

Rule: to convert m/s to km/h simply multiply by 3.6.

Distance–time graphs

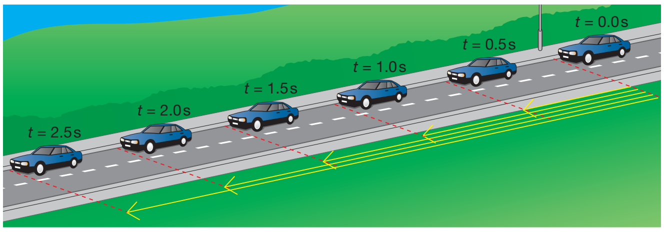


Figure 1.5 A car travelling at constant speed

Figure 1.5 shows a car travelling along a road. It shows the car at 0.5 second intervals. The distances that the car has travelled from the start position after each 0.5 s time interval are marked on the picture. The picture provides a record of how far the car has travelled as time has passed. The table below shows the data for this car. You will be expected to plot a graph of the distance travelled (**vertical** axis) against time (horizontal axis) as shown in Figure 1.6.

Time from start/s	0.0	0.5	1.0	1.5	2.0	2.5
Distance travelled from start/m	0.0	6.0	12.0	18.0	24.0	30.0

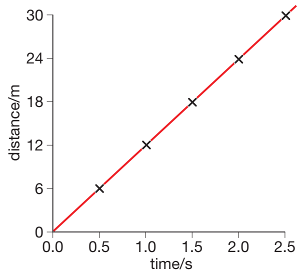


Figure 1.6 Distance–time graph for the travelling car in Figure 1.5

The distance–time graph tells us about how the car is travelling in a much more convenient form than the series of drawings in Figure 1.5. We can see that the car is travelling equal distances in equal time intervals – it is moving at a steady or constant speed. This fact is shown immediately by the fact that the graph is a straight line. The slope or **gradient** of the line tells us the speed of the car – the steeper the line the greater the speed of the car. So in this example:

$$\text{speed} = \text{gradient} = \frac{\text{distance}}{\text{time}} = \frac{30\,\text{m}}{2.5\,\text{s}} = 12\,\text{m/s}$$

KEY POINT

A curved line on distance–time graphs means that the speed or velocity of the object is changing. To find the speed at a particular instant of time we would draw a tangent to the curve at that instant and find the gradient of the tangent.

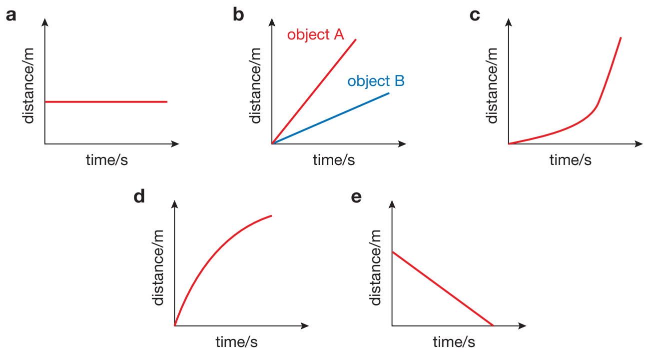
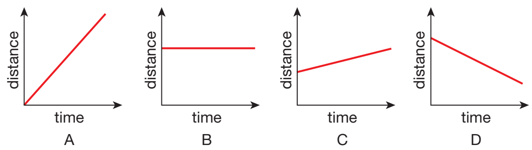


Figure 1.7 Examples of distance–time graphs

In Figure 1.7a the distance is not changing with time – the line is horizontal. This means that the speed is zero. In Figure 1.7b the graph shows how two objects are moving. The red line is steeper than the blue line because object A is moving at a higher speed than object B. In Figure 1.7c the object is speeding up (**accelerating**) shown by the graph line getting steeper (gradient getting bigger). In Figure 1.7d the object is slowing down (decelerating).

Check your understanding

10 Look at the following distance–time graphs of moving objects.



Identify in which graph the object is:

a moving backwards

b moving slowly

c moving quickly

d not moving at all.

Distance–time graphs – continued

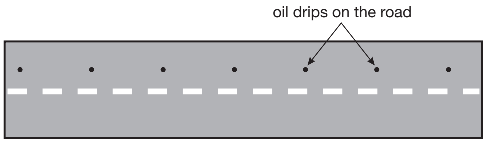
Check your understanding – continued

11 Sketch a distance–time graph to show the motion of a person walking quickly, stopping for a moment, then continuing to walk slowly in the same direction.

12 Plot a distance–time graph using the data in the following table. Draw a line of best fit and use your graph to find the speed of the object concerned.

Distance/m	0.00	1.60	3.25	4.80	6.35	8.00	9.60
Time/s	0.00	0.05	0.10	0.15	0.20	0.25	0.30

13 The diagram below shows a trail of oil drips made by a car as it travels along a road. The oil is dripping from the car at a steady rate of one drip every 2.5 seconds.



a Describe the way the car is moving.

b The distance between the first and the seventh drip is 135 metres. Determine the average speed of the car.