Describing motion

WOW!

One rule for Earth, another for the heavens?

The ancient Greek philosopher Aristotle, whose ideas had enormous influence for thousands of years, believed that all motion on Earth occurred in straight lines. There was one problem with this: at the time he also believed that the Sun, Moon and other heavenly bodies all circled the Earth. To overcome this contradiction, Aristotle proposed that the heavens were the home of the gods, so they would not be governed by earthly laws!

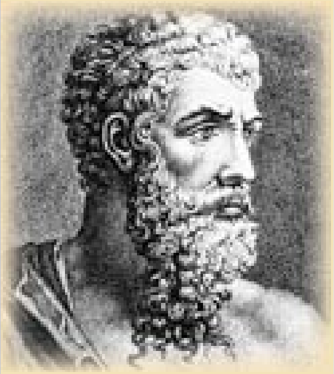


Figure 7.1 Aristotle (384–322 BC)

In order to understand the motion of any object, you need to be able to describe it accurately. This means you must clearly state the position, speed and direction of the moving object and how these are changing with time.

The pirate's treasure

Suppose you are given a pirate's map for a buried treasure (Figure 7.2).

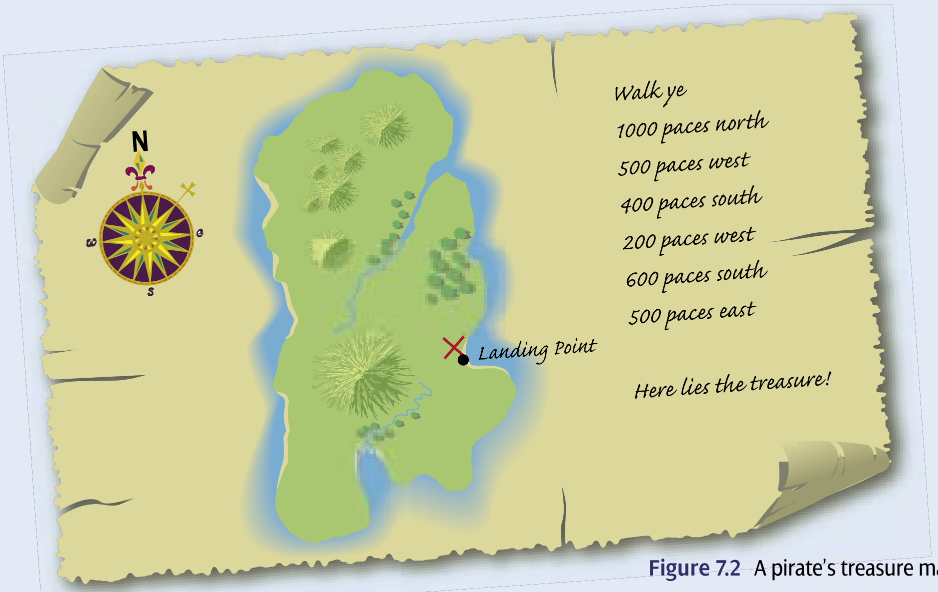


Figure 7.2 A pirate's treasure map

Now if you follow the clues on the map and draw a diagram of the path the pirates would have taken (Figure 7.3), you can see that they will have ended up at point T, where the treasure was supposed to be buried. But then it is obvious that they could have reached the treasure with far less effort by simply walking 200 paces due west from where they landed! (The red arrow shows this.)

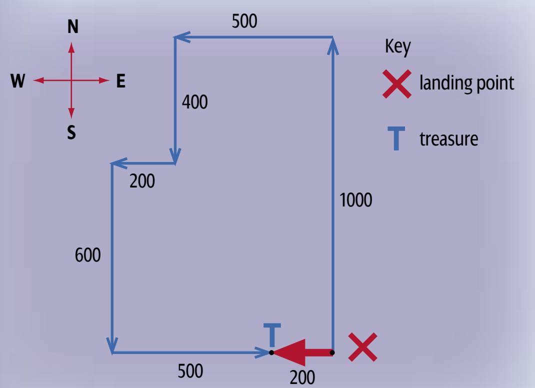


Figure 7.3 The paths to the treasure

Position

The **position** of the treasure or any other object is a statement of its distance and direction from a clearly defined fixed point. This point is termed the **reference point**. In the case of the treasure, the reference point is X, the landing point. The position of the treasure, T, is stated as 200 paces W of X.

Distance versus displacement

Suppose the pirates simply followed the directions for finding the treasure. The total **distance**, symbol ***d***, they walked from their starting point is obtained by adding up the length of each section of the walk. Each section of a journey is termed a **leg**. The legs add up to 3200 paces, though usually distance is measured in metres (m) or kilometres (km).

Physicists also have a second way of measuring the distance of the pirates from their starting point. This is their **displacement**, symbol Δx, which is a statement of their direct distance and direction from the starting point to the finishing point.

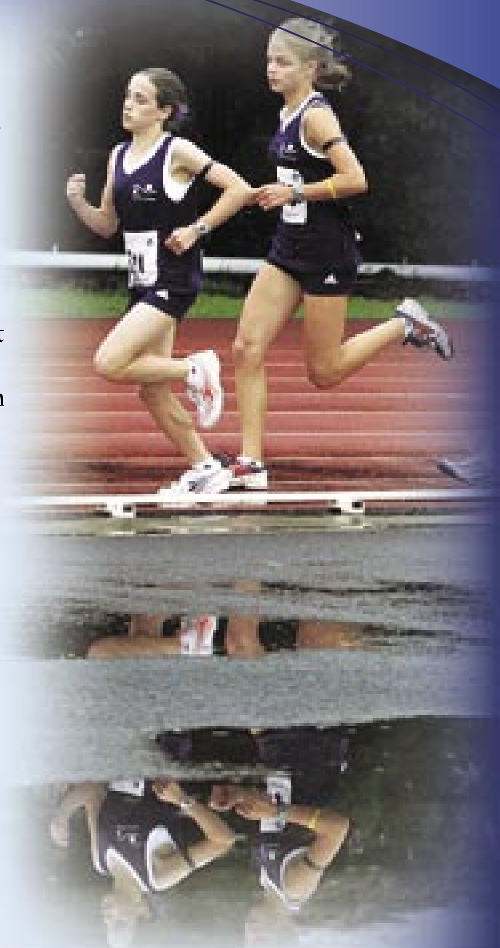
In Figure 7.3, the red arrow shows the displacement of the pirates when they reach the treasure at T. So we say that when they have arrived at T from X:

$$d = 3200 \text{ paces}$$
$$\Delta x = 200 \text{ paces W}$$

BLM 7.1 Some interesting theories!

Position–time graphs

Motion can be very complex, so we will now restrict ourselves to motion along a straight line. In the next sections we will only consider objects that move at a steady (unchanging) speed on each leg of the journey. This is termed a **constant speed**.



A 100 m sprint

Figure 7.3 shows how we could map out the journey to the pirate's treasure. But suppose we consider a school athlete, Tom, who is training for a 100 m sprint event. The running track at school is straight and the finishing line is due north of the starting block, which we will use as the reference point.

The coach asks Tom to run as fast as he can from the instant he leaves the starting block, then turn around the instant he reaches the finishing line and jog back to the start again. The coach starts his stopwatch when Tom leaves the starting block. At 12 seconds Tom reaches the finishing line and at 30 seconds he is back at the starting block.

There are two ways to represent this trip. The first is a diagram of the back and forth movement along the running track. The second is a **position–time graph**, a graph that shows the position of a moving object against the time that has elapsed. These are shown in Figure 7.4.

Each type of representation gives us valuable information. The diagram enables us to 'picture' the athlete's run and to see at a glance the total distance travelled. The arrows show the direction of travel in each leg of the run. The graph, on the other hand, allows us to determine the position of the athlete at any time during the run, and hence his displacement. It also can be used to calculate his speed on each leg, which will be considered later.

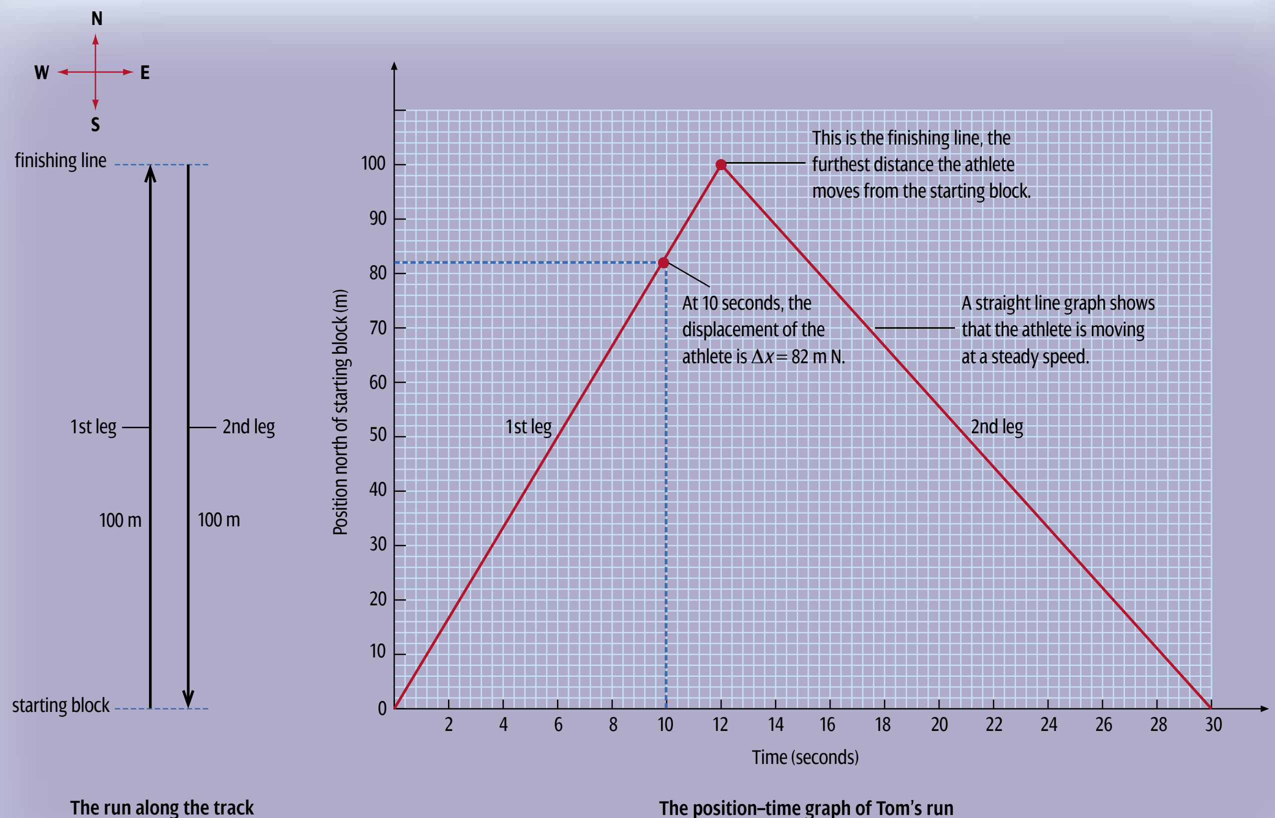
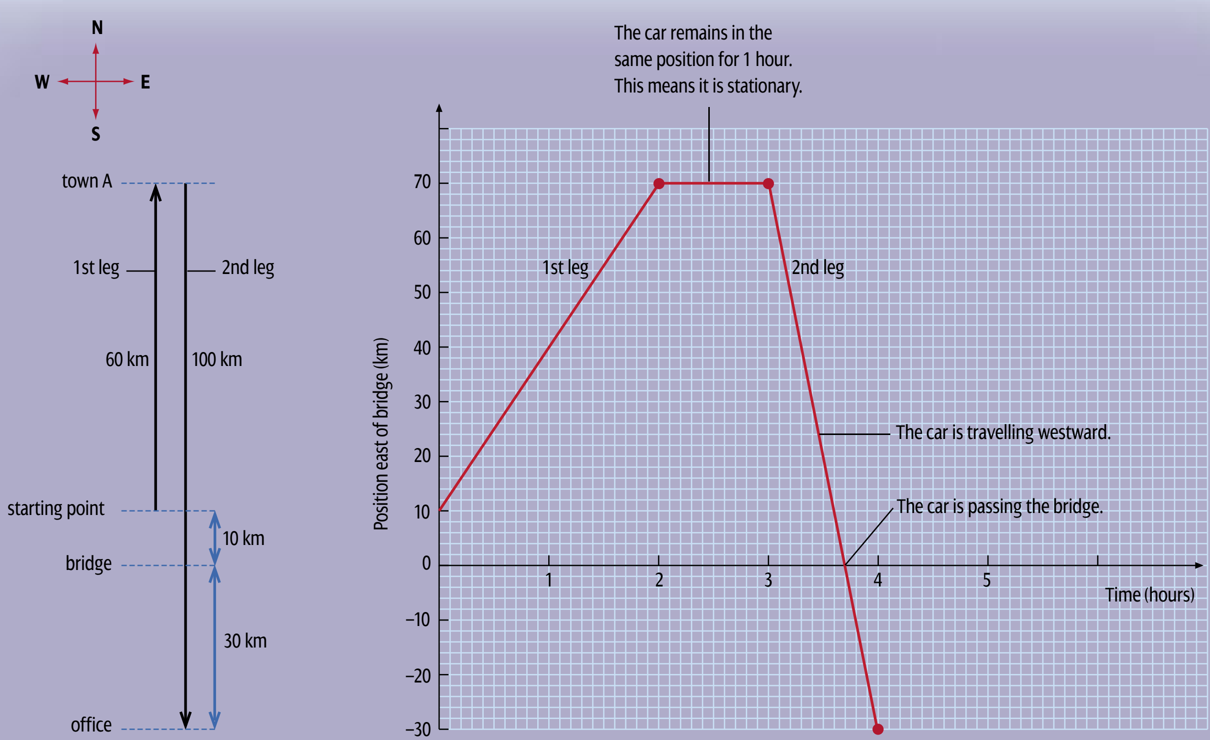


Figure 7.4 The athlete's run

A car journey

Suppose we now consider a car travelling back and forth along a straight highway that lies in the east–west direction. Our reference point is a certain bridge along the highway. When timing starts, the driver is 10 km east of the bridge. First she travels east in peak hour traffic. When she reaches her destination, a small town 70 km east of the bridge, she stops for an hour to meet a client. Then she turns around and heads west along the highway. Timing stops when she arrives back at her office, which is 30 km west of the bridge.



The journey along the straight highway

The position–time graph of the journey

Figure 7.5 The car trip

The two representations of her trip are shown in Figure 7.5. Notice how a stop is shown on the position–time graph. Notice too that a sign convention has been used to show east or west of the bridge. As a positive sign means a position east of the bridge, to represent a position west of the bridge we must use a negative sign. This means that her final displacement can be written:

Δx = –30 km, or 30 km W

It also means that the graph goes below the horizontal axis as soon as she is west of the bridge.

Speed

There are two ways we can think about how fast an object is travelling. These are shown in Figures 7.6 and 7.7.

Both ways of describing speed are valid and useful, but in Physics we use the approach taken in Figure 7.7. So we define the **average speed** of an object, symbol s_{av}, as the total distance travelled by the object per given time period. The units generally used are kilometres per hour (km/h or kph) or metres per second (m/s).

The formula for this is:

$$\text{average speed} = \frac{\text{total distance travelled}}{\text{total time taken}}$$

In symbols: $s_{av} = \frac{d}{t}$

It is important to realise that the average speed of travel does not tell you the actual speed at any particular moment on the journey. The actual speed is called the **instantaneous speed** and is what the speedometer in a car shows.

Average speed can be determined by using a position–time graph or by substituting into the above formula. First you will learn the graphical method.

Figure 7.6 A faster speed means that you take less time to travel the same distance.

Figure 7.7 A faster speed means you cover more distance in the same time.

Determining average speed from a position–time graph

SKILLS

For an object moving at a constant speed, the magnitude of the gradient of the graph for a particular leg of the journey gives us the average speed during that leg. This is shown in Figure 7.8.

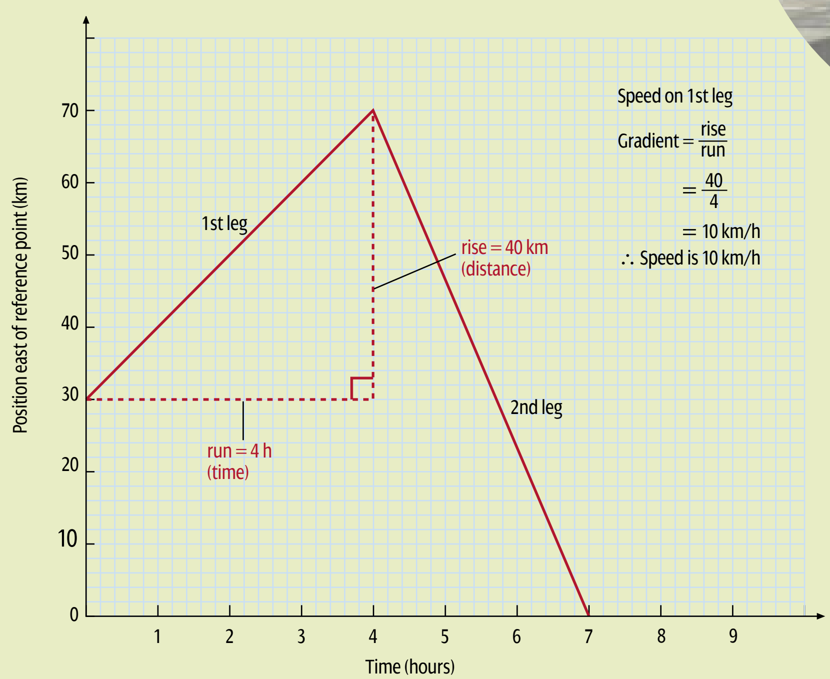


Figure 7.8 How to determine speed from a position–time graph

BLM 7.2 More position–time graphs

Work the Web

Visit **www.scienceedge.com.au** and link to **world solar challenge**. View the images of some of the cars that have entered this famous race. What distance do the cars travel? Where do they start and stop? How many days do most of the entrants take to complete the journey? What record speeds do they reach? Use a search engine to find out more about some of the cars in the race. What are some of their vital features that enable them to complete this journey so swiftly?

Questions 7.1

1 Explain the difference between distance and displacement. Use an example to assist your explanation.

2 Use the position–time graph in Figure 7.5 (page 154) to determine the speed of the driver:
  a as she travelled east
  b as she travelled west

3 Danni went for a run along a straight stretch of beach as part of her training for a triathlon event. The position–time graph for her run is shown in Figure 7.9. The reference point is a pier.

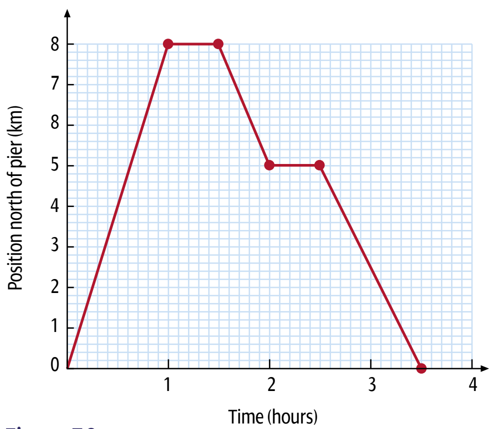


Figure 7.9

  a How many legs were there in Danni's run?
  b Did Danni stop for a breather at any time? Explain how you could tell this from the graph.
  c Draw a diagram to show Danni's run.
  d Calculate the total distance Danni ran.
  e State Danni's displacement at the end of her run.

4 Sam rode his bike 18 km due east of a railway station to a friend's farm. This trip took him 1 hour. He stayed at the farm for 2 hours. The return trip to the station took 90 minutes. To answer the following questions, assume that the railway station is the reference point and timing begins when he leaves the station and ends the moment he arrives back at the station.
  a Draw a diagram to represent Sam's trip.
  b Draw a position–time graph for Sam's trip.
  c Use the graph to determine Sam's displacement:
    i 30 minutes after starting his trip
    ii at the end of his trip.
  d Use the position–time graph to calculate Sam's average speed on each leg of the trip. Show all calculations.

Puzzles

5 Design a treasure map for an island, which satisfies the following conditions. Write the clues for finding the treasure the long way.
  - The treasure should be located a displacement of 100 m E from your landing point.
  - The path you describe should consist of at least three straight tracks, so the person looking for the treasure will travel a total distance of 500 m to the treasure from the landing point.

6 A particle in the surface of a drum was set into a vibration when the drum was hit. Sketch what you think its position–time graph might look like. Assume that it only vibrates along a vertical line, back and forth around a fixed point X (its position before the drum was hit).

Investigate

7 Find out about some interesting speeds. For example, at what speed does the Earth travel around the Sun? What speed does the space shuttle need to reach to exit the Earth's atmosphere?

What is your opinion?

8 Should we be changing the design of our cars so they run on solar power instead of fossil fuels? Clearly outline your opinion and your arguments.