Surfing

NATIONAL PHYSICS

Unit 2

Linear Motion and Waves

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Contents

Introduction

Each book in the *Surfing* series contains a summary, with occasional more detailed sections, of all the mandatory parts of the syllabus, along with questions and answers.

All types of questions – multiple choice, short response, structured response and free response – are provided. Questions are written in exam style so that you will become familiar with the concepts of the topic and answering questions in the required way.

Answers to all questions are included.

A topic test at the end of the book contains an extensive set of summary questions. These cover every aspect of the topic, and are useful for revision and exam practice.

Words To Watch

account, account for State reasons for, report on, give an account of, narrate a series of events or transactions.

analyse Interpret data to reach conclusions.

annotate Add brief notes to a diagram or graph.

apply Put to use in a particular situation.

assess Make a judgement about the value of something.

calculate Find a numerical answer.

clarify Make clear or plain.

classify Arrange into classes, groups or categories.

comment Give a judgement based on a given statement or result of a calculation.

compare Estimate, measure or note how things are similar or different.

construct Represent or develop in graphical form.

contrast Show how things are different or opposite.

create Originate or bring into existence.

deduce Reach a conclusion from given information.

define Give the precise meaning of a word, phrase or physical quantity.

demonstrate Show by example.

derive Manipulate a mathematical relationship(s) to give a new equation or relationship.

describe Give a detailed account.

design Produce a plan, simulation or model.

determine Find the only possible answer.

discuss Talk or write about a topic, taking into account different issues or ideas.

distinguish Give differences between two or more different items.

draw Represent by means of pencil lines.

estimate Find an approximate value for an unknown quantity.

evaluate Assess the implications and limitations.

examine Inquire into.

explain Make something clear or easy to understand.

extract Choose relevant and/or appropriate details.

extrapolate Infer from what is known.

hypothesise Suggest an explanation for a group of facts or phenomena.

identify Recognise and name.

interpret Draw meaning from.

investigate Plan, inquire into and draw conclusions about.

justify Support an argument or conclusion.

label Add labels to a diagram.

list Give a sequence of names or other brief answers.

measure Find a value for a quantity.

outline Give a brief account or summary.

plan Use strategies to develop a series of steps or processes.

predict Give an expected result.

propose Put forward a plan or suggestion for consideration or action.

recall Present remembered ideas, facts or experiences.

relate Tell or report about happenings, events or circumstances.

represent Use words, images or symbols to convey meaning.

select Choose in preference to another or others.

sequence Arrange in order.

show Give the steps in a calculation or derivation.

sketch Make a quick, rough drawing of something.

solve Work out the answer to a problem.

state Give a specific name, value or other brief answer.

suggest Put forward an idea for consideration.

summarise Give a brief statement of the main points.

synthesise Combine various elements to make a whole.

Surfing

Linear Motion and Force

1 Distance and Displacement

Distance is a measure of how far an object has moved. Distance is measured in units like centimetres (cm), metres (m), and kilometres (km).

Displacement is a measure of how far, and in what direction, an object is from its starting point. Displacement is also measured in centimetres, metres and kilometres. A direction must be given.

For example, Billy Box rolls from the shade of his favourite tree to a creek bed. The creek is 300 metres from the tree in a westerly direction. When he gets to the creek Billy will have rolled 300 metres west. We say:

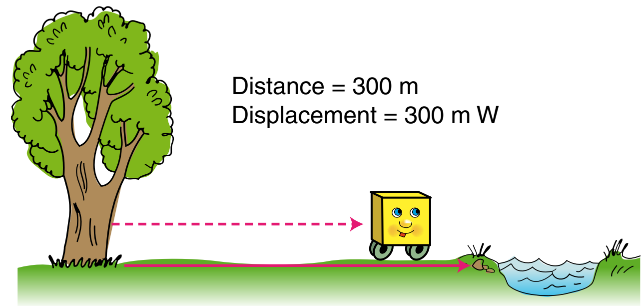
- Distance Billy rolled is 300 m.
- Displacement is 300 m west.

Note that the only difference between the distance travelled and the displacement is that the *direction* of the displacement is (and *must be*) stated. However, when Billy Box is halfway back to the tree notice that:

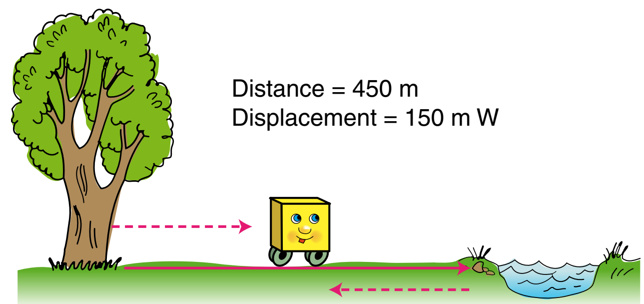
- Distance Billy rolled is 450 m.
- Displacement is 150 m west.

Notice the distance travelled and the displacement are quite different this time. When Billy Box is back at the tree:

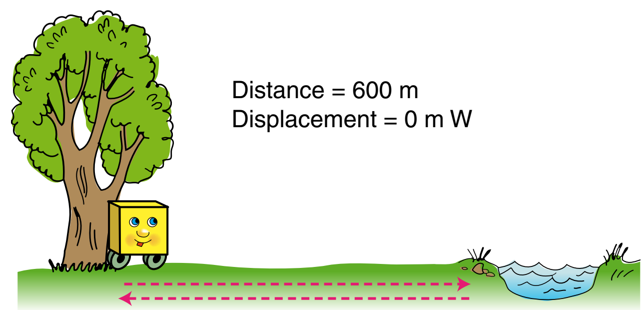
- Distance Billy rolled is 600 m.
- Displacement is zero.



Billy Box at the creek



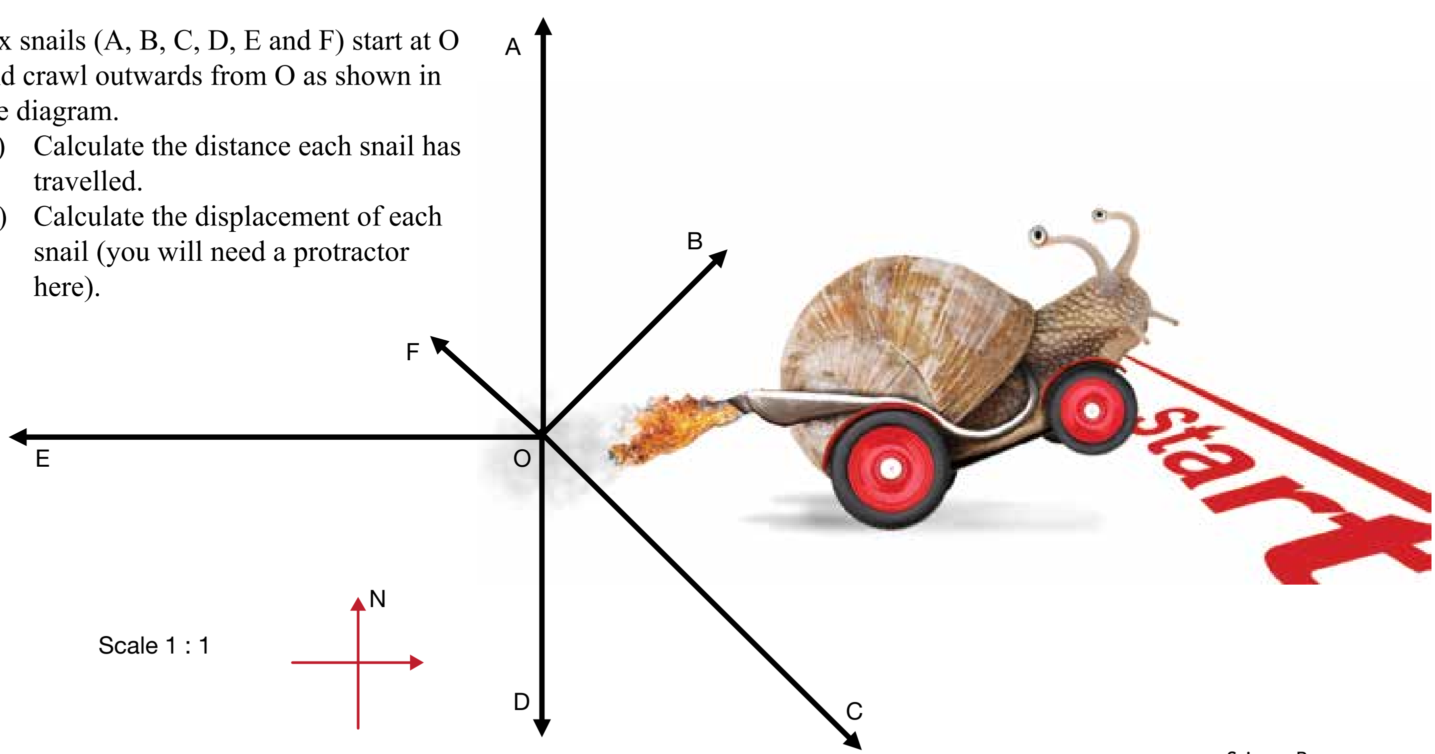
Billy Box halfway back



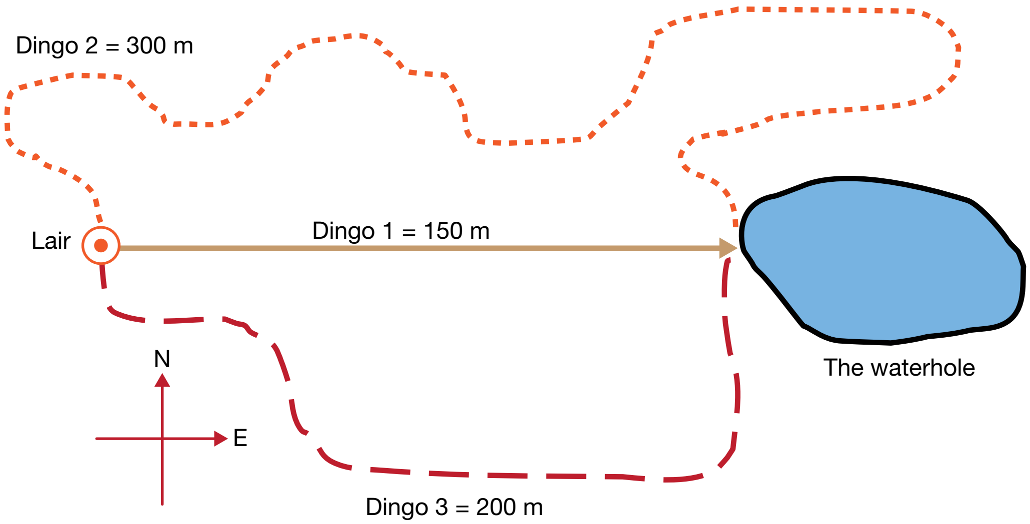
Billy Box back at the tree

QUESTIONS

1. Six snails (A, B, C, D, E and F) start at O and crawl outwards from O as shown in the diagram.
   (a) Calculate the distance each snail has travelled.
   (b) Calculate the displacement of each snail (you will need a protractor here).



2. Three dingoes leave their lair in the morning. One heads straight for the waterhole which is 150 metres to the east. He stops here and rests. The other two dingoes travel by the pathways shown in the diagram. They also end up at the waterhole with the first dingo.



(a) Where did each dingo start?
(b) Where did each dingo end up?
(c) Where is the waterhole relative to the lair? (That is, how far and in what direction?)
(d) How far did dingo 1 travel?
(e) How far did dingo 2 travel?
(f) How far did dingo 3 travel?
(g) At the waterhole, how far is dingo 1 from the lair?
(h) At the waterhole, how far is dingo 2 from the lair?
(i) At the waterhole, how far is dingo 3 from the lair?
(j) What is the displacement of dingo 1 at the waterhole?
(k) What is the displacement of dingo 2 at the waterhole?
(l) What is the displacement of dingo 3 at the waterhole?

Now suppose the dingoes all walk *straight back* to the lair.

(m) What total distance has each now travelled?
(n) What is the displacement of each dingo now?

3. A parrot in a tree walks up and down a branch. The branch points straight out from the tree trunk towards the south. The parrot walks 50 cm towards the trunk, stops at A, turns around and then walks 80 cm back to B. It stops at B and listens for its mate's call. Hearing nothing, it walks 30 cm further along the branch to point C where it stops and listens again. It turns around and heads back towards the tree trunk, walking another 70 cm before stopping again at D. It now hears its mate's call and flies away.

(a) Look briefly at questions (b), (c) and (d) and then draw up a table to fit your answers.
(b) What total distance has the parrot travelled from its starting point on the branch when it is at each point A, B, C and D?
(c) Using compass directions, what is the displacement of the parrot from its starting position at each point?
(d) What are these displacements using the +/– method of indication directions? (Remember to define which direction is + and –)

2 Working Out Directions Another Way

Not all movement is conveniently in a main compass direction, or at one of the 45° angles from these (north-east or south-west and the like). We need to learn how to express directions that are not like these.

Let's look a bit more closely at how we work out directions.

An elephant walks from his favourite tree to a waterhole, a distance of 300 metres as shown in Figure 2.1.

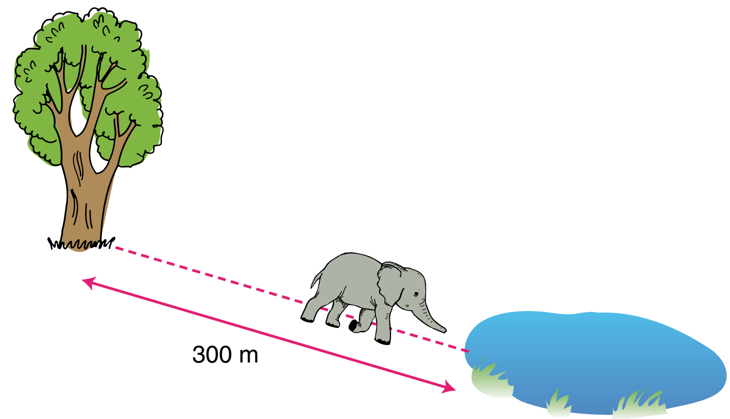


Figure 2.1

We need to draw a set of axes representing north, south, east and west, centred on the elephant's starting position (Figure 2.2).

We can now measure the angle *A* with a protractor. We can then say that the displacement of the elephant is 300 metres **east 25° south** (also Figure 2.2).

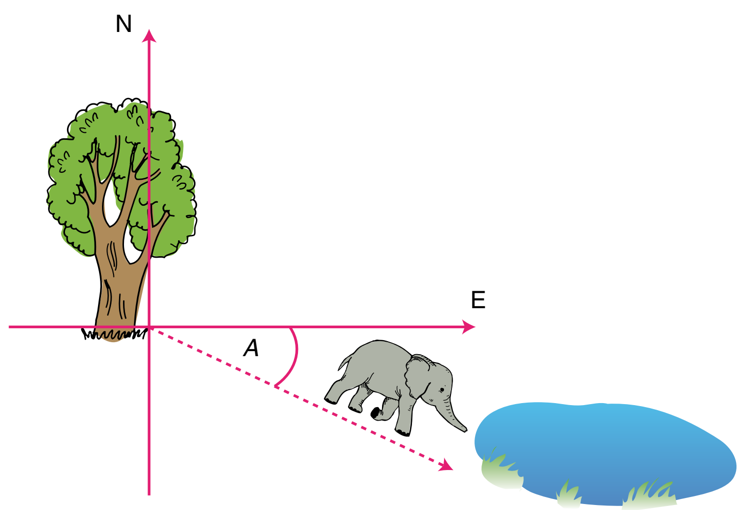


Figure 2.2

Or, we draw a set of axes representing north, south, east and west, centred on the elephant's starting position as before (Figure 2.3).

Measure angle *B* – notice that this represents the elephant's position relative to north – and state the displacement as 300 metres **bearing 115°** (Figure 2.3).

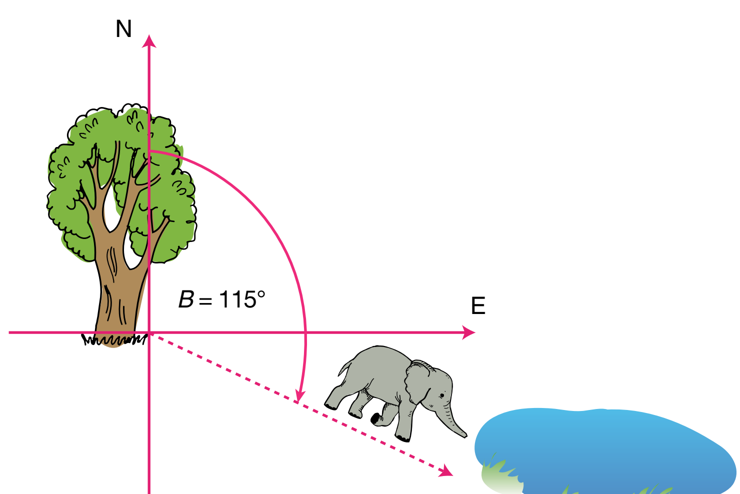


Figure 2.3

QUESTIONS

1. Expressing the directions as *bearings*, calculate the displacement of each of the snails in Figure 2.4. Each snail started at the origin (Don't forget the scale!).

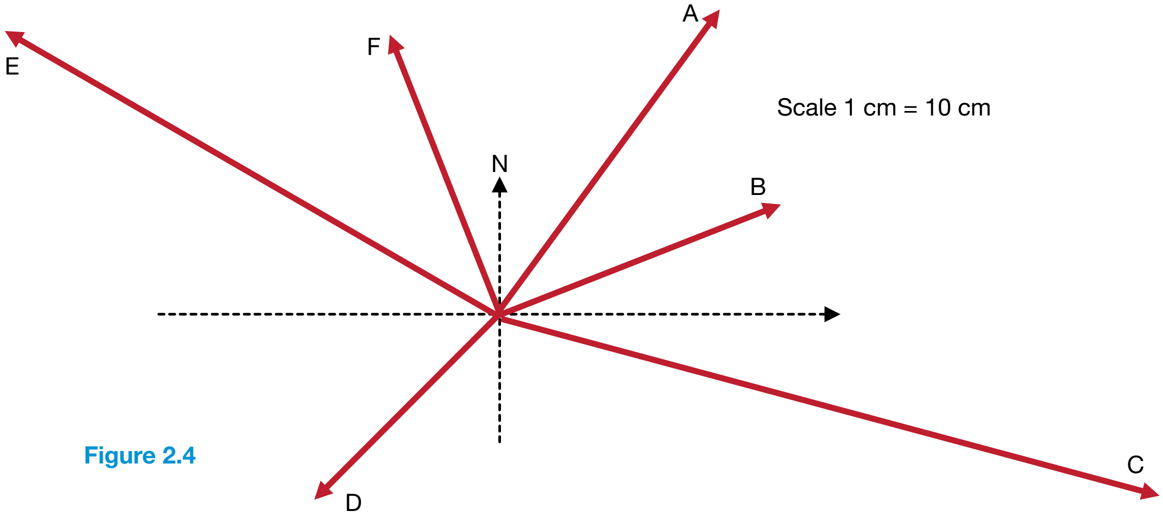


Figure 2.4

2. A car travels from S to T, 70 km apart, by the road shown in Figure 2.5. Draw up a table to show how far the car has travelled when it is at A, B, C, D and T, and what its displacement is at each position. Record the displacement direction in the two different ways shown above.

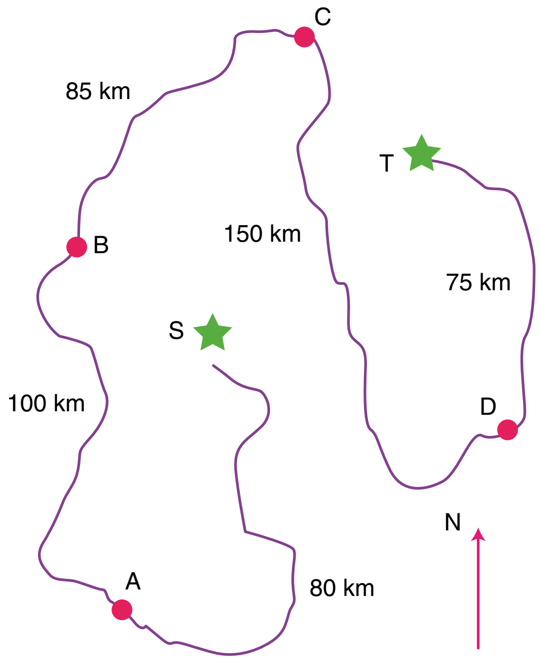


Figure 2.5

3. The map in Figure 2.6 has been drawn to scale where 1 cm = 10 km. Imagine that 10 different people start from J. Nine of them travel to each of the other marked places, and the tenth travels to the top of Little Ugly. What is the displacement of each person when each is at his/her destination?

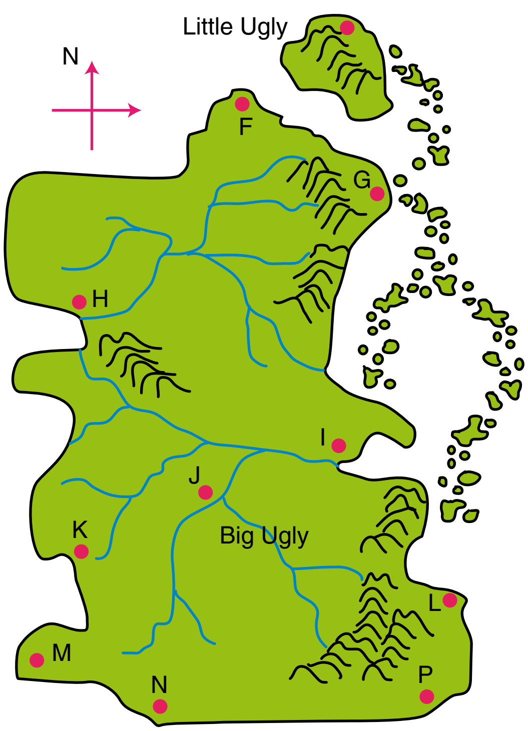


Figure 2.6

3 Speed

The following definitions describe speed.

Speed is a measure of how fast an object is moving.

Speed is a measure of the rate at which an object moves.

Speed is a measure of the rate of change of position of an object.

Speed is measured in units, e.g. metres per second (m s^{-1}), or kilometres per hour (km h^{-1}), or centimetres per 100 years.

Imagine a car travels a distance of 80 km in 2 hours. Assuming the car travelled at the same speed (i.e. no traffic lights, hills, corners, or any other things which might cause it to slow down or speed up, or in other terms, **no acceleration**) in 1 hour the car would have travelled 40 km. Its **average speed** would be 40 km h^{-1}. It moves at an **average rate** of 40 km h^{-1}. Its **average rate of change of position** is 40 km h^{-1}. We can use the following equation to calculate the average speed of an object.

$$\text{Average speed} = \frac{\text{total distance travelled}}{\text{time taken}} = \frac{d}{t} = \frac{\text{initial speed} + \text{final speed}}{2}$$

Example: A car travels 200 metres in 15 seconds. Calculate its average speed.

Solution:

Data:

Distance = 200 m

Time = 15

Average speed = ? m s^{-1}

Calculation:

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

$$= \frac{200 \text{ metres}}{15 \text{ seconds}}$$

$$= 13.33 \text{ m s}^{-1}$$

The average speed of the car is 13.33 m s^{-1}.

Of course, in real life, a car would not travel at the same speed all the time. Its speed would vary according to road, traffic, weather and other conditions. To talk sensibly about things moving we need different kinds of speeds to cover different situations. These are as follows.

Constant speed is the speed of an object which is travelling the same distance in every period of time.

Average speed is the constant speed at which an object would need to travel so as to travel the same distance in the same time.

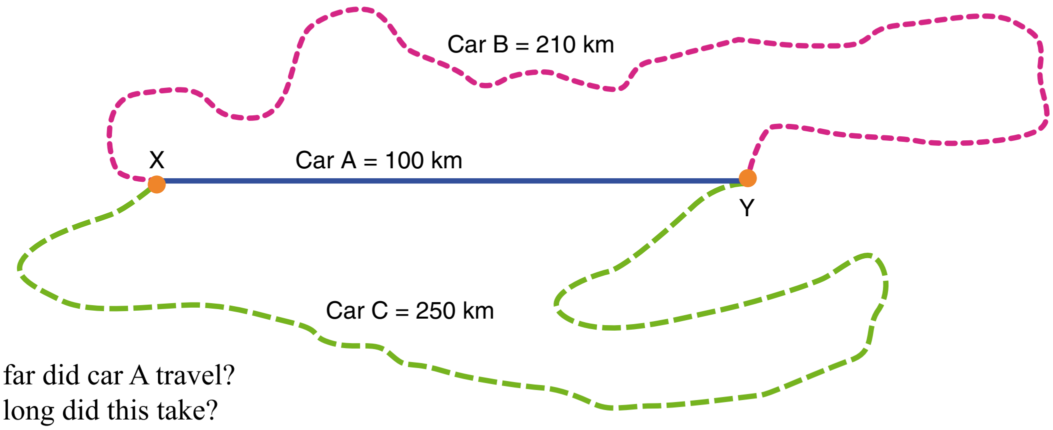
Instantaneous speed is the speed of an object in the instant of time we consider it. This will vary from instant to instant depending on, e.g. road and traffic conditions.

Initial speed is the speed of an object when we first consider it, i.e. the object's speed at the start of its journey.

Final speed is the speed of an object at the end of its journey or when we finish our consideration of its motion.

QUESTIONS

1. Consider three cars which started at town X and travelled to town Y by three different roads as shown in the diagram. Car A travelled from X to Y in 2 hours. Car B made its trip in 3 hours, while car C took 5 hours to go from X to Y.



(a) How far did car A travel?
(b) How long did this take?
(c) On average, how far did car A travel each hour?
(d) Calculate the average speed of car A.
(e) Calculate the average speed of car B.
(f) Calculate the average speed of car C.
(g) Explain why we are only talking about *average* speeds here.

2. A swimmer, travelling at a steady rate, swims the 50 metre pool in 30 seconds. Calculate her average speed.

3. A rocket travels 10 000 m in 6.5 seconds. Calculate its average speed.

4. Convert to m s^{-1}:
(a) 40 km h^{-1}
(b) 250 cm s^{-1}
(c) 60 km h^{-1}
(d) 100 km h^{-1}

5. Convert to km h^{-1}:
(a) 20 m s^{-1}
(b) 60 m s^{-1}
(c) 1000 cm s^{-1}

6. A racing car is attempting to break the 'standing kilometre' time record. When the starting light turns green, it accelerates at maximum rate and crosses the finish line at 180 km h^{-1} 40 s later (on a racing track of course).
(a) Identify the initial speed of the car.
(b) Identify its final speed.
(c) Calculate its average speed.
(d) Estimate its instantaneous speed 20 s after starting. Justify your answer.
(e) Predict the constant speed to cover the same distance in the same time.

7. Fill in the missing quantities in the table.

	Distance travelled	Time taken	Average speed
(a)	1500 m	30 s	
(b)	270 m	9 s	
(c)	243 m	27 s	
(d)	12.3 m	3.2 s	
(e)	640 m	16 s	
(f)	800 m		25 m s^{-1}
(g)	300 m		12 m s^{-1}
(h)	250 km		12.5 km h^{-1}
(i)	3.6 km		12 m s^{-1}
(j)	160 km		8 km h^{-1}
(k)		3.5 hr	16 km h^{-1}
(l)		150 s	5 m s^{-1}
(m)		2 min	10 m s^{-1}
(n)		25 s	0.5 m s^{-1}
(o)		0.3 s	90 m s^{-1}

4 Velocity

These definitions describe velocity.

Velocity is a measure of how fast, and in what direction, an object is going or has gone.

Velocity is the speed of an object with its direction of travel also given.

Velocity is a measure of the rate of change of displacement of an object.

Velocity is measured in the same units as speed. The direction of travel must also be given.

$$\text{Average velocity} = v_{av} = \frac{\text{total displacement}}{\text{total time taken}} = \frac{s}{t} = \frac{\text{initial velocity} + \text{final velocity}}{2}$$

Where s = displacement of the object in metres

t = time taken for displacement

v_{av} = average velocity in m s^{-1} (Again, this assumes acceleration is zero.)

Example: A car, travelling at constant velocity, travels 250 metres south in 20 seconds. Calculate its average velocity.

Solution: Data:

Displacement = 250 m S

Time = 20 s

Average velocity = ? m s^{-1}

Calculation:

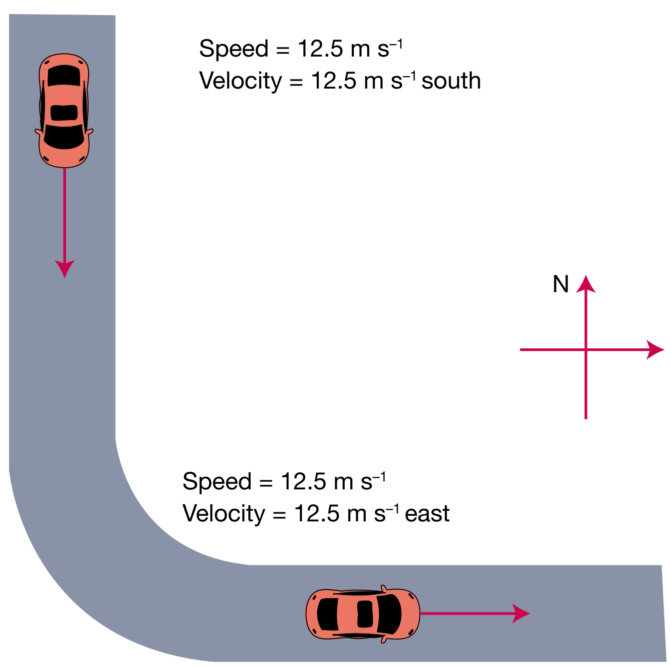
$$\text{Average velocity} = \frac{\text{displacement}}{\text{time taken}}$$

$$= \frac{\text{250 m south}}{\text{20 seconds}}$$

= 12.5 m s^{-1} south

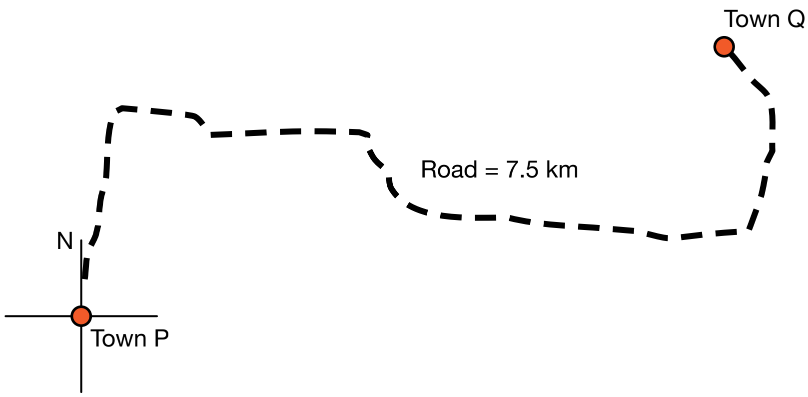
Of course, as with speed, a car would not travel at the same velocity all the time. Its speed (and therefore its velocity) would vary according to road, traffic, weather and other conditions. However, the **direction of travel** would change often also – most journeys involve turning corners. Because velocity includes direction, even if the speed stays the same, a direction change would indicate a velocity change.

Suppose the car in the example above turned a corner and started travelling towards the east. Its speed would still be the same, 12.5 m s^{-1}, but its velocity would change to 12.5 m s^{-1} east. These differences are shown in the diagram.



QUESTIONS

1. A car travelled 200 km north in 4 hours. Calculate its average speed and velocity.
2. A ball rolled 6.0 m from X to Y. This took 3 s. Calculate its average speed and velocity.
3. A cyclist left P and rode to Q, 7.5 km away as shown in the diagram. Because of bends, the road was 3.0 km longer than the actual distance between P and Q. The journey took 30 minutes.



(a) Calculate the cyclist's average speed for the trip.
(b) Calculate his average velocity.

4. PQRS is a rectangular field where PQ is 3.0 km and QR is 4.0 km. R is south of S and west of Q. A rider travels around the field, starting at P and travels PQRSPQR. This takes 7 hours.
(a) Calculate the total distance the rider travels.
(b) Calculate the average speed of the rider.
(c) Calculate the displacement of the rider when she is at each corner of the field.
(d) Calculate the rider's displacement at the end of the ride.
(e) Calculate the average velocity of the rider for the whole trip.
(f) Calculate the average velocity of the rider as she moves along PQ.

5. Complete the table.

	Displacement	Time taken	Average speed	Average velocity
(a)	2000 m south	40 s		
(b)	250 m east	12.5 s		
(c)	120 m west	4 s		
(d)	5.6 m NW	1.4 s		
(e)	525 m bearing 063°	2.5 s		
(f)	800 m bearing 142°		40 m s^{-1}	
(g)	300 m bearing 237°		15 m s^{-1}	
(h)	80 km bearing 010°		5 km h^{-1}	
(i)	2.6 km NW		20 m s^{-1}	
(j)	150 km N		25 km h^{-1}	
(k)		1.5 hr		20 km h^{-1} W
(l)		15 s		2.5 m s^{-1} SE
(m)		12 min		6 m s^{-1} NE
(n)		35 s		0.6 m s^{-1} S
(o)		0.5 s		40 m s^{-1} bearing 042°

Answers

1 Distance and Displacement

1. A = 5.5 cm, 5.5 cm north
   B = 3.5 cm, 3.5 cm north-east
   C = 6.0 cm, 6.0 cm south-east
   D = 4.0 cm, 4.0 cm south
   E = 7.0 cm, 7.0 cm west
   F = 2.0 cm, 2.0 cm north-west
2. (a) At the lair.
   (b) At the waterhole.
   (c) 150 m east
   (d) 150 m
   (e) 300 m
   (f) 200 m
   (g) 150 m
   (h) 150 m
   (i) 150 m
   (j) 150 m east
   (k) 150 m east
   (l) 150 m east
   (m) 1 = 300 m, 2 = 450 m, 3 = 350 m
   (n) Zero
3.

Parrot at	Total distance travelled	Displacement using north/south convention	Displacement using +/– convention (+ = north)
A	50 cm	50 cm N	+50 cm
B	130 cm	30 cm S	–30 cm
C	160 cm	60 cm S	–60 cm
D	210 cm	10 cm N	+10 cm

2 Working out Directions Another Way

1. A = 50 cm bearing 035°
   B = 40 cm bearing 069°
   C = 90 cm bearing 106°
   D = 35 cm bearing 225°
   E = 75 cm bearing 300°
   F = 40 cm bearing 340°
2. Distances:
   Scale: 1 cm = 20 km using ST distance.
   At A = 80 km
   At B = 180 km
   At C = 265 km
   At D = 415 km
   At E = 490 km
   Displacements:
   At A = 70 km bearing 195°
   At B = 40 km bearing 300°
   At C = 76 km bearing 016°
   At D = 70 km bearing 108°
   At T = 70 km bearing 050°
3. F = 61 km bearing 006°
   G = 53.5 km bearing 030°
   H = 34 km bearing 325°
   I = 21 km bearing 070°
   K = 21 km bearing 244°
   L = 40 km bearing 112°
   M = 37 km bearing 225°
   N = 33.5 km bearing 193°
   P = 46.5 km bearing 132°
   Hint: Little Ugly = 75 km bearing 016°

3 Speed

1. (a) 100 km
   (b) 2 hours
   (c) 50 km
   (d) Average speed = distance/time = 100/2 = 50 km h^{-1}
   (e) Average speed = 210/3 = 70 km h^{-1}
   (f) Average speed = 250/5 = 50 km h^{-1}
   (g) Data does not take into account hills, stoplights, corners – cars rarely travel at constant speeds.
2. Average speed = 50/30 = 1.67 m s^{-1}
3. Average speed = 10000/6.5 = 1538.5 m s^{-1}
4. (a) 40 km h^{-1} = 40 × 1000 metres/1 × 60 × 60 sec = 40000/3600 = 11.1 m s^{-1}
   (b) 250 cm s^{-1} = 250/100 = 2.5 m s^{-1}
   (c) 60 km h^{-1} = 60 × 1000/3600 = 16.67 m s^{-1}
   (d) 100 km h^{-1} = 100 × 1000/3600 = 27.8 m s^{-1}
5. (a) 20 m s^{-1} = 3600 × 20/1000 = 72 km h^{-1}
   (b) 60 m s^{-1} = 3600 × 60/1000 = 216 km h^{-1}
   (c) 1000 cm s^{-1} = 3600 × 1000/100000 = 36 km h^{-1}
6. (a) Zero
   (b) 180 km h^{-1} (50 m s^{-1})
   (c) Average speed = (0 + 180)/2 = 90 km h^{-1} (25 m s^{-1})
   (d) Instantaneous speed = 90 km h^{-1} (25 m s^{-1}) as 420 s is half the time taken.
   (e) Constant speed = 3600 × 1/40 = 90 km h^{-1} (25 m s^{-1})
7. (a) Average speed = 1500/30 = 50 m s^{-1}
   (b) Average speed = 270/9 = 30 m s^{-1}
   (c) Average speed = 243/27 = 9 m s^{-1}
   (d) Average speed = 12.3/3.2 = 3.8 m s^{-1}
   (e) Average speed = 640/16 = 40 m s^{-1}
   (f) Time = distance/average speed = 800/25 = 32 s
   (g) Time = 300/12 = 25 s
   (h) Time = 250/12.5 = 20 hours
   (i) Time = (3.6 × 1000)/12 = 300 s
   (j) Time = 160/8 = 20 hours
   (k) Distance = average speed × time = 16 × 3.5 = 56 km
   (l) Distance = 5 × 150 = 750 km
   (m) Distance = 10 × (2 × 60) = 1200 m
   (n) Distance = 0.5 × 25 = 12.5 m
   (o) Distance = 90 × 0.3 = 27 m

4 Velocity

1. Average speed = 200/4 = 50 km h^{-1}, v_{av} = 50 km h^{-1} north
2. Average speed = 6.0/3 = 2 m s^{-1}, v_{av} = 2 m s^{-1} from X to Y
3. Average speed = 7.5/0.5 = 15 km h^{-1}, v_{av} = 4.5/0.5 = 9 km h^{-1} bearing 067°
4. (a) d = 3 + 4 + 3 + 4 + 3 + 4 = 21 km
   (b) Average speed = 21/7 = 3 km h^{-1}
   (c) P = 0, Q = 3 km S, R = 5 km bearing 127° S = 4 km E
   (d) s = 5 km bearing 127°
   (e) v_{av} = 5/7 = 0.71 km h^{-1} bearing 127°
   (f) v_{av} = 3 km h^{-1} bearing 180°
5. (a) Average speed = 2000/40 = 50 m s^{-1}, v_{av} = 50 m s^{-1} S
   (b) Average speed = 250/12.5 = 20 m s^{-1}, v_{av} = 20 m s^{-1} E
   (c) Average speed = 120/4 = 30 m s^{-1}, v_{av} = 30 m s^{-1} W
   (d) Average speed = 5.6/1.4 = 4 m s^{-1}, v_{av} = 4 m s^{-1} NW
   (e) Average speed = 525/2.5 = 210 m s^{-1}, v_{av} = 210 m s^{-1} bearing 063°
   (f) Time = 800/40 = 20 s, v_{av} = 40 m s^{-1} bearing 142°
   (g) Time = 300/15 = 20 s, v_{av} = 15 m s^{-1} bearing 237°
   (h) Time = 80/5 = 16 hours, v_{av} = 5 km h^{-1} bearing 010°
   (i) Time = 2.6 × 1000/20 = 130 s, v_{av} = 20 m s^{-1} NW
   (j) Time = 150/25 = 6 hours, v_{av} = 25 km h^{-1} N
   (k) s = 20 × 1.5 = 30 km W, average speed = 20 km h^{-1}
   (l) s = 2.5 × 15 = 37.5 m SE, average speed = 2.5 m s^{-1}
   (m) s = 6 × (12 × 60) = 4320 m NE, average speed = 6 m s^{-1}
   (n) s = 0.6 × 35 = 21 m S, average speed = 0.6 m s^{-1}
   (o) s = 40 × 0.5 = 20 m bearing 042°, average speed = 40 m s^{-1}