Mastering Physics

MODULE 1

NSW

Kinematics

Brian Shadwick

Science Press

First published 2020

Science Press
Unit 7, 23-31 Bowden Street
Alexandria NSW 2015 Australia
Tel: +61 2 9020 1840 Fax: +61 2 9020 1842
sales@sciencepress.com.au
www.sciencepress.com.au

Contents

Motion In a Straight Line

Motion On a Plane

ISBN 978-0-85583-8201

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.

ISBN 978-0-85583-8201

Motion In a Straight Line

ISBN 978-0-85583-8201

1.1 Describing Motion

Describe uniform straight line (rectilinear) motion and uniformly accelerated motion through qualitative descriptions.

Distance and displacement

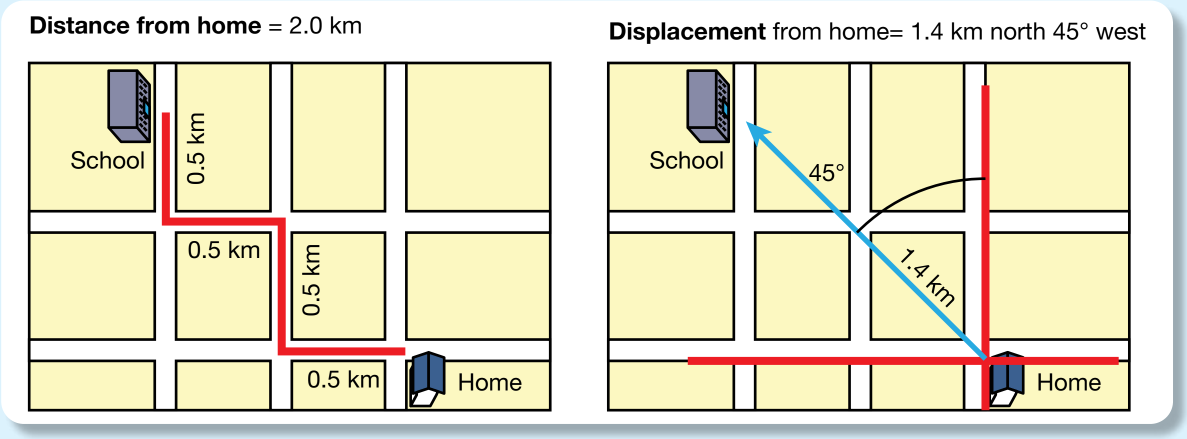
Distance

- Distance is a measure of how far an object has moved.
- Distance is measured in units like centimetres (cm), metres (m), and kilometres (km).
- Distance is a **scalar quantity** which means **no direction** is required.
- In equations, distance is given the symbols ***d***, or ***r*** (radius) or ***h*** (height) or similar.

Displacement

- **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.
- Displacement is a **vector quantity** which means a **direction must be given** whenever we state a displacement.
- In equations, displacement is given the symbol ***s***.

Example



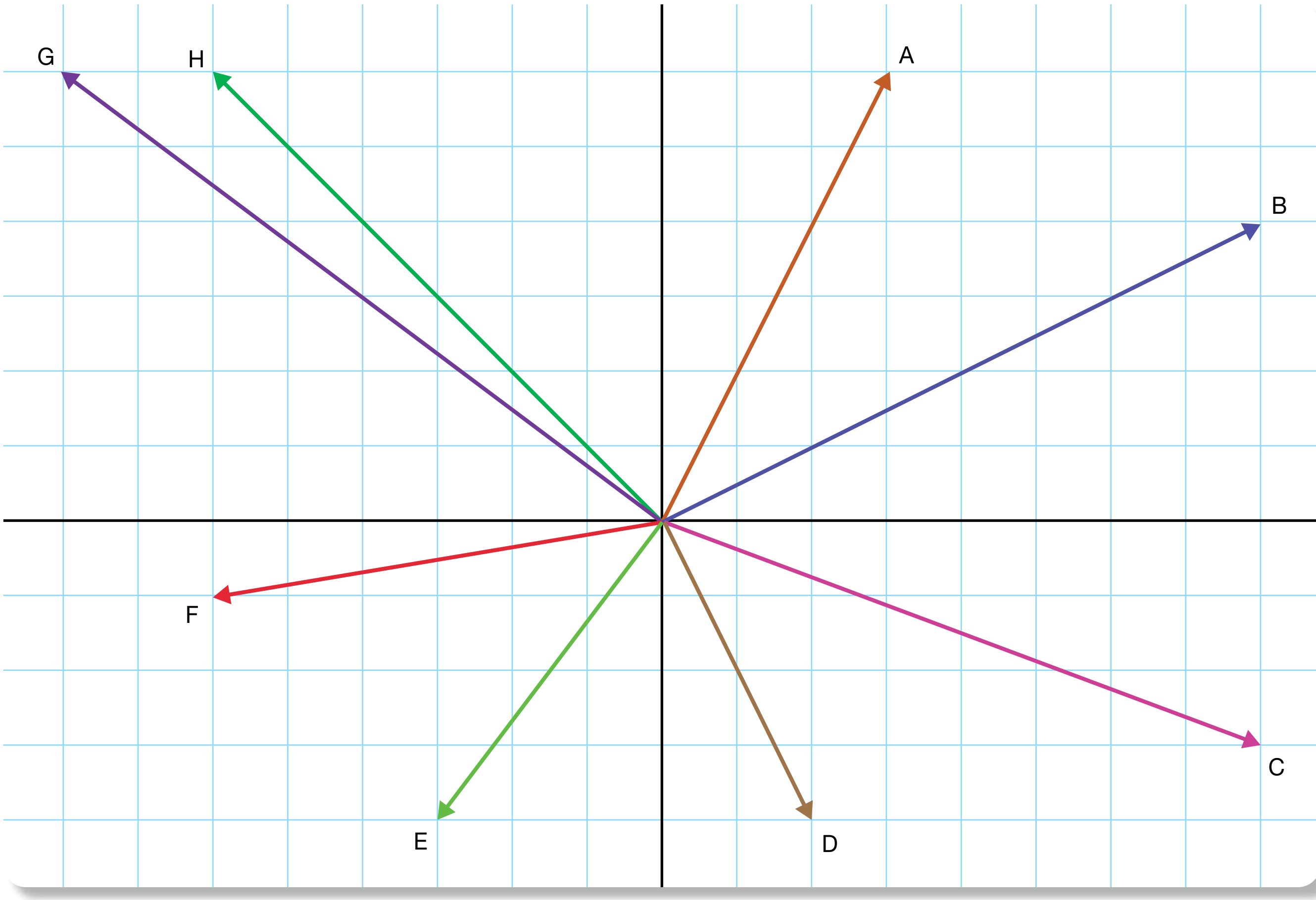
Stating the direction of displacement

- Displacement direction can be given as a **compass direction** or as a **bearing from north**.
- A **bearing is the angle of the displacement measured clockwise from north**.
- It is always expressed as a three number bearing.
- Due north will be bearing 000°.
- East will be bearing 045°.
- South will be expressed as bearing 180°.
- In the example above, the school from home is 90 + 90 + 90 + 45 = bearing 325°.
- Bearings are used in navigation and are preferred to compass directions because they are easier to compute and to communicate.

ISBN 978-0-85583-8201

Sample *Questions*

1. The diagram shows the displacements of several points from a central point. Each square in the grid represents a 1.0 m × 1.0 m area. Find the displacements represented by the coloured arrows from O. Give your directions as bearings to the nearest degree.



2. Consider the diagram, and giving all directions where needed as bearings to the nearest degree:

(a) Find the distance between B and C.

(b) Find the distance between A and C.

(c) Find the distance between A and B.

(d) Find the displacement of B from A.

(e) Find the displacement of A from B.

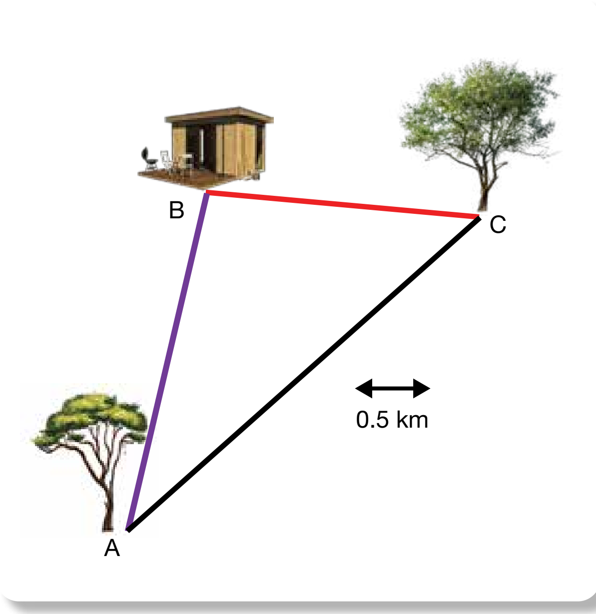
(f) Find the displacement of C from A.

(g) Find the displacement of A from C.

(h) Find the displacement of B from C.

(i) Find the displacement of C from B.

(j) Consider your answer pairs to (d) and (e), then (f) and (g), then (h) and (i). What do these answers tell you about the directions on the displacements in each pair of answers?



ISBN 978-0-85583-8201

Speed

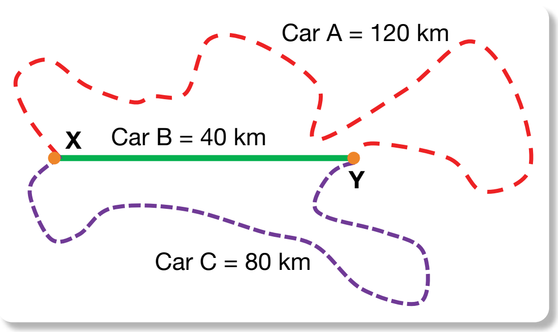
- **Speed** is a measure of how fast an object is moving.
- **Speed** is a measure of the rate at which an object moves.
- **Speed** is a measure of the rate of change of position of an object.
- **Speed** is measured in units like metres per second (m s^{-1}), or kilometres per hour (km h^{-1}), or centimetres per 100 years.
- **Speed** is a scalar quantity so no direction is required when stating it.
- **Speed** can be found using the equation:

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

- **Constant speed:** The speed an object which is travelling the same distance in every period of time.
- **Average speed:** The constant speed at which an object would need to travel so as to travel the same distance in the same time.
- **Instantaneous speed:** 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:** The speed of an object when we first consider it, e.g. the object's speed at the start of its journey.
- **Final speed:** The speed of an object at the end of its journey or when we finish our consideration of its motion.

Sample Questions

1. Consider three cars which started at town X and travelled to town Y by three different roads as shown. Car A travelled from X to Y in 3 hours. Car B made its trip in 1 hour, while car C took 1.5 hours to go from X to Y.



(a) Calculate the average speed of car A.
(b) Calculate the average speed of car B.
(c) Calculate the average speed of car C.
(d) Explain why we are only talking about *average* speeds here.

2. A sprinter runs the 800 metre race in exactly 2.0 minutes. Calculate her average speed in m s^{-1}.

3. A satellite travels 12 000 m in 1.53 seconds. Calculate its orbital speed.

4. A racing car attempts to break the 'standing kilometre' time record. When the starting light turns green, it accelerates at maximum rate and crosses the finish line 18 s later.
(a) Identify the initial speed of the car.
(b) Calculate its average speed.
(c) For an object with uniform acceleration, the final speed is twice the average speed. Use this idea to find the final speed of the car.

5. What is your average speed, in km h^{-1} and m s^{-1} if you travel 20 km in 1 hour and 15 minutes?

6. Sally runs at 5.6 km h^{-1}. If she ran for a period of 2.5 hours, how far has she travelled?

7. If you were travelling at 30 km h^{-1}, how long would it take to travel a distance of 70 km?

ISBN 978-0-85583-8201

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.
- **Velocity** is a **vector quantity**, so direction **must** be given when stating it.

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

- **Constant velocity:** The velocity an object which is travelling the same distance in the same direction in every period of time.
- **Average speed:** The constant velocity at which an object would need to travel so as to travel the same displacement in the same time (symbol $\bar{v}$ or v_{av}).
- **Instantaneous speed:** The velocity of an object in the instant of time we consider it. This will vary from instant to instant depending, e.g. on road and traffic conditions.
- **Initial speed:** The velocity of an object when we first consider it. The object's velocity at the start of its journey (symbol u).
- **Final speed:** The velocity of an object at the end of its journey or when we finish our consideration of its motion (symbol v).

Sample Questions

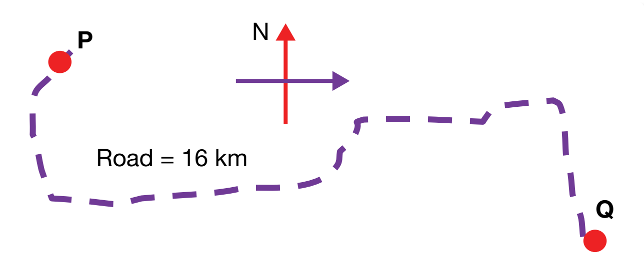
1. A car travelled 150 km south in 3 hours. Calculate its average speed and velocity.

2. A ball rolled 5.0 m from X to Y. This took 1.25 s. Calculate its average speed and velocity.

3. A cyclist rides from P to Q, 12 km away from P as shown in the diagram. Because of bends, the road was 4.0 km longer than the distance between P and Q. The ride 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 6.0 km and QR is 8.0 km. R is south of S and east of Q. A rider travels around the field, starting at P and travels PQRSPQR. This takes 6.5 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 he 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 he moves along PQ.

(g) Calculate the average velocity of the rider as he moves along QR.

(h) Calculate the average velocity of the rider as he moves along RS.

(i) Calculate the average velocity of the rider as he moves along ST.

ISBN 978-0-85583-8201

Acceleration

- When an object speeds up we say that it **accelerates** or has an acceleration **in the direction of the motion**, or that it has a **positive acceleration**.
- When an object slows down, it also accelerates, but more correctly we say that it has a **negative acceleration** or that it has an acceleration **against the motion**, or that it decelerates.
- A moving object also accelerates when it **changes direction** whether its speed changes or stays the same because a change in direction is a change in velocity.
- **Acceleration** is a measure of the rate at which velocity changes.
- **Acceleration** may be positive (speeds up) or negative (slows down).
- **Acceleration** tells us how much the velocity changes each second.
- **Acceleration** is usually measured in metres per second per second (m s^{-2}).
- **Acceleration** also occurs when the direction of travel changes.
- **Acceleration** is a **vector quantity** and direction **must** be stated.

$$\textbf{Acceleration} = \frac{\textbf{change in velocity}}{\textbf{time taken}} = \frac{s}{t} = \frac{\textbf{final velocity} - \textbf{initial velocity}}{t}$$

Which becomes $a = \frac{\Delta v}{t} = \frac{v - u}{t}$ or $v = u + at$

Where a = acceleration in m s^{-2}
u = initial velocity in m s^{-1}
v = final velocity in m s^{-1}
t = time taken for change in s

Sample *Questions*

1. A car, at rest, accelerates at 5 m s^{-2} N for 9 s. Calculate its velocity after 3, 5 and 11 s.

2. A rock falls from rest. Its speed hitting the ground 4 s later is 39.2 m s^{-1}. Find its acceleration.

3. A car moving at 24 m s^{-1} E hits a wall and stops in 0.16 s. Find the acceleration stopping the car.

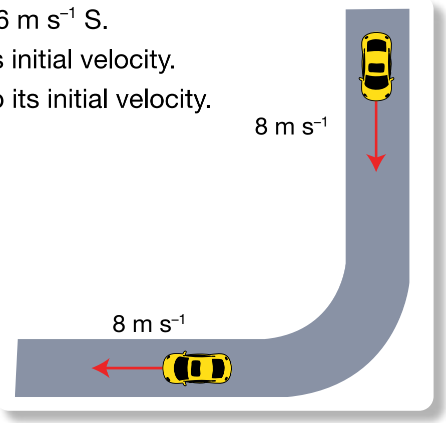
4. (a) After 6 s of accelerating at 0.8 m s^{-2}, a car moves at 9.8 m s^{-1}. Find its initial velocity if the acceleration was positive (in direction of motion).
   (b) Find the initial velocity if the acceleration was negative (opposing motion).

5. A rocket accelerates at 38 m s^{-2} until its speed is 1900 m s^{-1}. How long does this take?

6. A car accelerates at 3.5 m s^{-2} S for 9 s. After this time it is moving at 36 m s^{-1} S.
   (a) Find its initial velocity if acceleration is in the same direction as its initial velocity.
   (b) Find its initial velocity if acceleration is in the opposite direction to its initial velocity.

7. A car accelerates at 3.0 m s^{-2} E for 15 s. After this time the car is moving at 10 m s^{-1} W. Calculate its initial velocity.

8. The diagram shows a car moving south, turning a corner, then moving west.
   (a) What is its initial and final speeds?
   (b) What is its initial and final velocities?
   (c) Does the car accelerate? Justify your answer.



ISBN 978-0-85583-8201

SI units and powers of 10

Standard System of units

- SI units are units of measurement which form the Standard System of units.
- These are agreed on internationally and used so that communications of quantities between nations is easier.
- All units are lower case unless they are named in honour of a person (e.g. amperes = A). The only exception is L for litre to avoid confusion with some typeface number 1's or i' s.
- If a combination of units is used, e.g. metres per second, then there are three acceptable formats:
  - m/s (use a slider between the m and the s^{-1})
  - $m.s^{-1}$ (a full stop between the m and the s^{-1})
  - m s^{-1} (a space between the m and the s^{-1}) – this is the preferred format to use.

Other units

- For large measurements, it is more sensible to use units which better suit that measurement.
- For example, we would not measure the distance to the next galaxy in metres.
- Light years, or parsecs are much more sensible units.
- While they are not SI, there is international agreement on their use.

Powers of ten – indices

- Are commonly used for expressing small or large numbers in science.
- For our purposes, use the format (e.g.) **5.6×10^3** – i.e. only one decimal point (rounded off) – this format is commonly referred to as **scientific notation**.
- Note that we also use prefixes on units to indicate the indices – e.g. mg = 10^{-3} g, ML = 10^6 L.

Sample Questions

1. Complete the table for common quantities in physics and their SI units.

2. Complete the table below to show some of the prefixes and symbols used for numbers expressed in scientific notation.

Unit prefix	Symbol	Meaning	Unit prefix	Symbol	Meaning
deca					10^{-1}
hecta					10^{-2}
kilo					10^{-3}
mega					10^{-6}
giga					10^{-9}
tera					10^{-12}

Quantity	SI unit (name and symbol)	Quantity	SI unit (name and symbol)
Mass		Electric potential difference	
Length		Electrical resistance	
Time		Electric current	
Displacement		Speed	
Force		Velocity	
Energy		Acceleration	
Power		Volume	

ISBN 978-0-85583-8201

1.2/3 Motion-Time Graphs

Use mathematical modelling and graphs to analyse and derive relationships between time, distance, displacement, speed, velocity and acceleration in rectilinear motion.
Describe ways in which the motion of objects changes and describe and analyse these graphically for velocity and displacement.

Displacement-time graphs 1

Displacement-time graphs

- Read directly from the graph to find the distance travelled or the displacement of an object at particular times, or vice versa.
- Calculate the **speed** or **velocity** of the object from the **gradient** of the graph.
- Notice that because distance is a scalar quantity, direction is not required on the *y*-axis of a distance travelled-time graph.
- Notice that because displacement is a vector quantity, direction is required on the *y*-axis of a displacement-time graph.

Example

The graph tells us (amongst other things) that:

(a) The object travelled 16 m in 4 s.

(b) The displacement of the object travelled after 2 s is 8 m east.

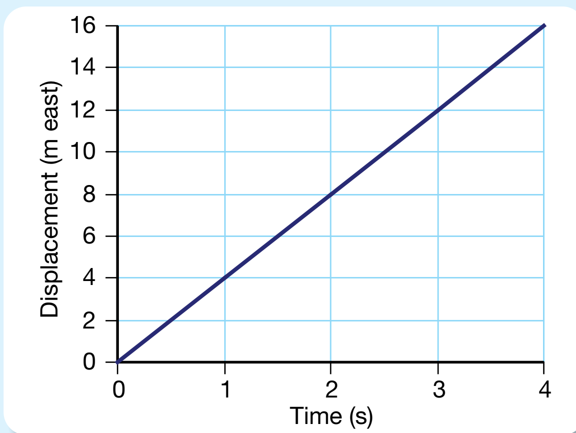
(c) At 2.5 s the object had travelled 10 m east.

(d) From the gradient of the graph we get:

$$\text{Gradient} = \frac{\text{rise}}{\text{run}} = \frac{16}{4}$$

= average velocity = 4 m s^{-1} east

(e) As the gradient is constant, velocity is constant.



Sample Questions

1. With reference to the graph:

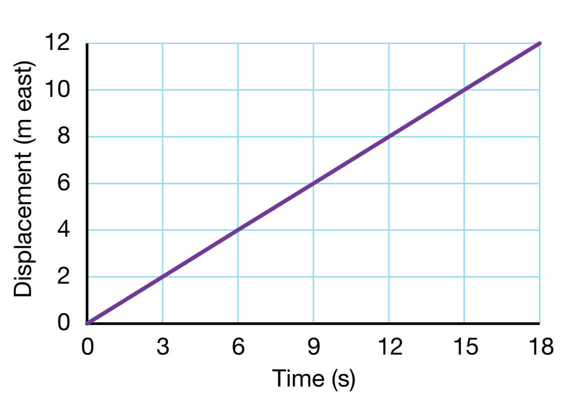
(a) How far did the object travel in 7.5 s?

(b) When was the object 10 m from its starting position?

(c) What was its velocity at time 2.0 s?

(d) What was the velocity of the object at time 3.5 s?

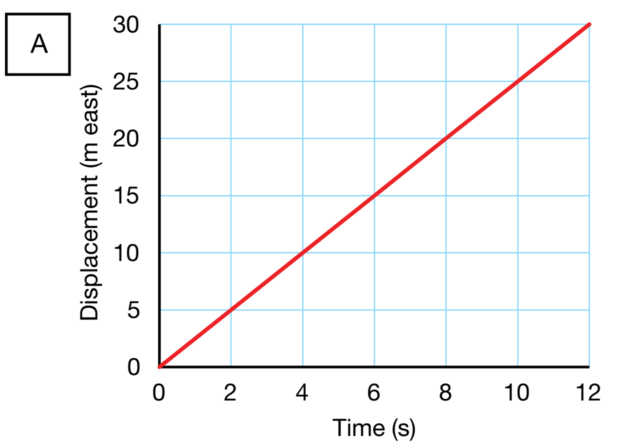
(e) Account for the similarity in your answers to (c) and (d).

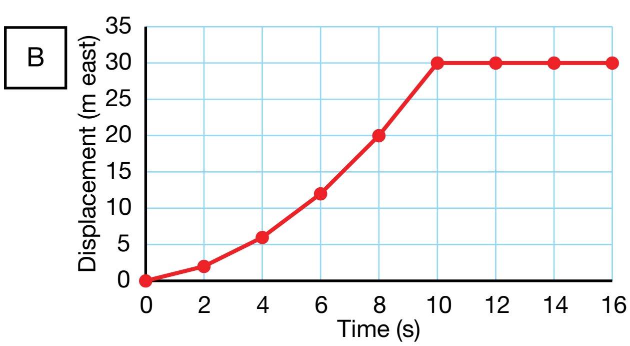


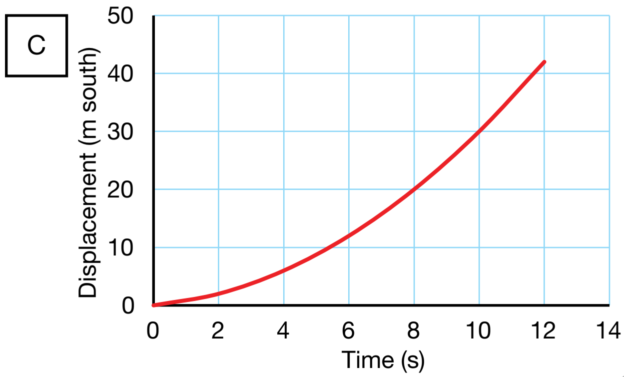
Science Press
MASTERING PHYSICS
ISBN 978-0-85583-8201

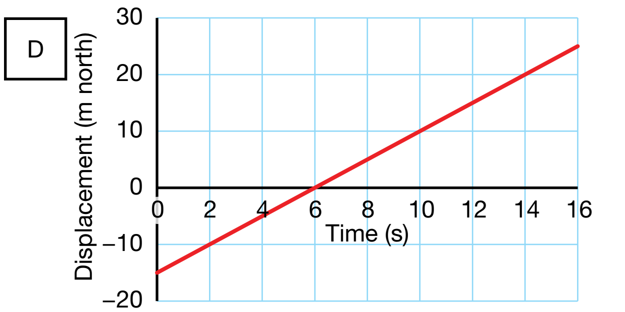
2. For each of the graphs on this page find:

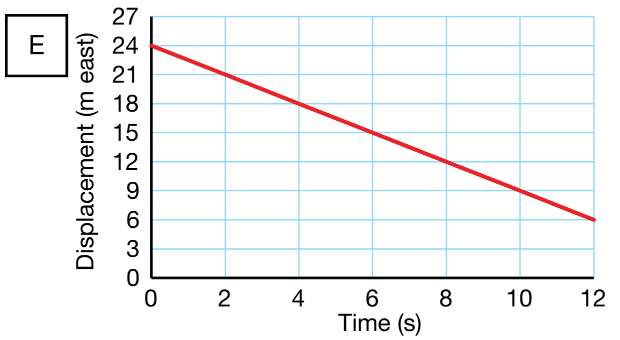
(a) The initial displacement of the object.
(b) The final displacement of the object.
(c) The displacement for the journey.
(d) The total distance each object travelled.
(e) The average velocity for the whole journey.
(f) The average speed for the whole journey.
(g) The instantaneous velocity at time 8 s.
(h) The displacement of the object at time 6 s.
(i) The displacement of the object at time 12 s.
(j) The speed of the object at time 12 s.
(k) The velocity of the object at time 12 s.

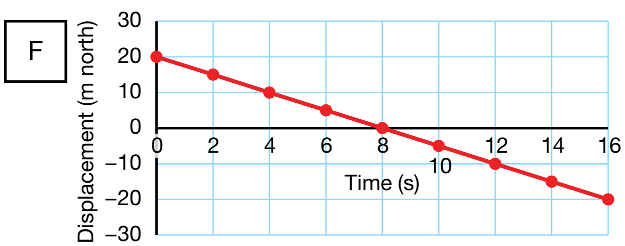












ISBN 978-0-85583-8201

Answers

1.1 Describing Motion

Distance and displacement

(*Note:* If you make these calculations using Pythagoras, you may get slightly different answers to scale measurements. Angles may also vary by 1 or 2 degrees depending on your accuracy and printing/photocopy distortions.)

Answers expressed to nearest 0.1 km and degree.

1. A 6.7 km bearing 027°
B 8.9 km bearing 068°
C 8.5 km bearing 110°
D 4.5 km bearing 154°
E 5.0 km bearing 215°
F 6.1 km bearing 261°
G 10.0 km bearing 305°
H 8.5 km bearing 314°

2. (a) 1.75 km
(b) 3.25 km
(c) 2.8 km
(d) 2.8 km bearing 013°
(e) 2.8 km bearing 193°
(f) 3.25 km bearing 050°
(g) 3.25 km bearing 230°
(h) 1.75 km bearing 274°
(i) 1.75 km bearing 094°
(j) In general, the displacement direction of X from Y and the displacement direction of Y from X are 180° different (get one by adding or subtracting 180 to the other (opposite directions)).

Speed

1. (a) 40 km h^{-1}
(b) 40 km h^{-1}
(c) 53.3 km h^{-1}
(d) Hills, bends in the road, traffic, traffic lights all change the speed of a car as it travels – we have no knowledge of the effect of these so can only talk about the journey as a whole – hence the averages.

2. Average speed = $\frac{800}{2 \times 60}$ = 6.67 m s^{-1}

3. Average speed = $\frac{12\,000}{1.53}$ = 7843 m s^{-1} = 28 235 km h^{-1}

4. (a) Zero – we assume it starts from rest
(b) 55.56 m s^{-1} = 200 km h^{-1}
(c) Final speed = 2 × average speed = 400 km h^{-1} = 111 m s^{-1}

5. Average speed = $\frac{20}{1.25}$ = 16 km h^{-1} = 4.44 m s^{-1}

6. Distance travelled = average speed × time
= 5.6 × 2.5 = 14 km

7. Time = $\frac{\text{distance}}{\text{speed}} = \frac{70}{30}$ = 2.33 hours

Velocity

1. Average speed = $\frac{150}{3}$ = 50 km h^{-1}

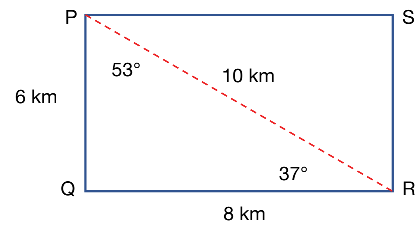
Average velocity = 50 km h^{-1} south (bearing 180°)

2. Average speed = $\frac{5}{1.25}$ = 4.0 m s^{-1}

Average velocity = 4.0 m s^{-1} from X to Y, or, better, bearing 110°

3. (a) Average speed = 32 km h^{-1}
(b) Average velocity = 24 km h^{-1} south (bearing 180°)

4. A diagram of the field is needed to do this question (note that it forms a 3 : 4 : 5 right triangle)
(a) 6 + 8 + 6 + 8 + 6 + 8 = 42 km
(b) Average speed = $\frac{42}{6.5}$ = 6.46 km h^{-1}
(c) At P displacement = 0
At Q displacement = 6 km south (bearing 180°)
At R displacement = 10 km bearing 127°
At S displacement = 8 km east (bearing 090°)
(d) At R displacement = 10 km bearing 127°



(e) For trip, average velocity = $\frac{\text{displacement}}{\text{time}}$
= $\frac{10}{6.5}$ = 1.54 km h^{-1} bearing 127°
(f) 6.46 km h^{-1} south (bearing 180°)
(g) 6.46 km h^{-1} east (bearing 090°)
(h) 6.46 km h^{-1} north (bearing 000°)
(i) 6.46 km h^{-1} west (bearing 270°)

Acceleration

1. From $v = u + at$, velocity after 3 s = 15 m s^{-1} north (bearing 000°)

After 5 s = 25 m s^{-1} north (bearing 000°)

After 11 s = 45 m s^{-1} north (it stops accelerating After 9 s and we assume constant velocity after that).

2. From $v = u + at$, $a = \frac{39.2}{4}$ = 9.8 m s^{-2}

ISBN 978-0-85583-8201