PEARSON

PHYSICS

NEW SOUTH WALES

STUDENT BOOK

11

NSW STAGE 6

Contents

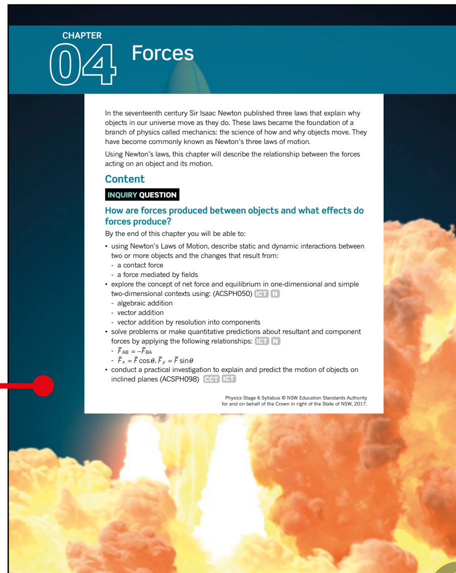
How to use this book

Pearson Physics 11 New South Wales

Pearson Physics 11 New South Wales has been written to the new New South Wales Physics Stage 6 Syllabus. The book covers Modules 1 to 4 in an easy-to-use resource. Explore how to use this book below.

Chapter opener

The chapter opening page link the Syllabus to the chapter content. Key content addressed in the chapter is clearly listed.



CHAPTER 04 Forces

In the seventeenth century Sir Isaac Newton published three laws that explain why objects in our universe move as they do. These laws became the foundation of a branch of physics called mechanics: the science of how and why objects move. They have become commonly known as Newton's three laws of motion.

Using Newton's laws, this chapter will describe the relationship between the forces acting on an object and its motion.

Content

INQUIRY QUESTION

How are forces produced between objects and what effects do forces produce?

By the end of this chapter you will be able to:

- using Newton's Laws of Motion, describe static and dynamic interactions between two or more objects and the changes that result from:
  - a contact force
  - a force mediated by fields
- explore the concept of net force and equilibrium in one-dimensional and simple two-dimensional contexts using: (ACSPH050) ICT N
  - algebraic addition
  - vector addition
  - vector addition by resolution into components
- solve problems or make quantitative predictions about resultant and component forces by applying the following relationships: ICT N
  - $\vec{F}_{AB} = -\vec{F}_{BA}$
  - $\vec{F}_x = \vec{F}\cos\theta, \vec{F}_y = \vec{F}\sin\theta$
- conduct a practical investigation to explain and predict the motion of objects on inclined planes (ACSPH098) CCT ICT

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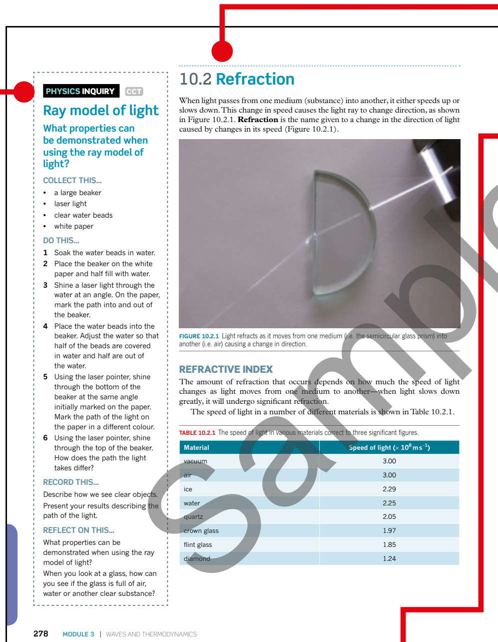
Section

Each chapter is clearly divided into manageable sections of work. Best-practice literacy and instructional design are combined with high quality, relevant photos and illustrations to help students better understand the idea or concept being developed.



PHYSICS INQUIRY CCT

Ray model of light

What properties can be demonstrated when using the ray model of light?

COLLECT THIS...

- a large beaker
- laser light
- clear water beads
- white paper

DO THIS...

1 Soak the water beads in water.
2 Place the beaker on the white paper and half fill with water.
3 Shine a laser light through the water at an angle. On the paper, mark the path into and out of the beaker.
4 Place the water beads into the beaker. Adjust the water so that half of the beads are covered in water and half are out of the water.
5 Using the laser pointer, shine through the bottom of the beaker at the same angle initially marked on the paper. Mark the path of the light on the paper in a different colour.
6 Using the laser pointer, shine through the top of the beaker. How does the path the light takes differ?

RECORD THIS...

Describe how we see clear objects.

Present your results describing the path of the light.

REFLECT ON THIS...

What properties can be demonstrated when using the ray model of light?

When you look at a glass, how can you see if the glass is full of air, water or another clear substance?

10.2 Refraction

When light passes from one medium (substance) into another, it either speeds up or slows down. This change in speed causes the light ray to change direction, as shown in Figure 10.2.1. **Refraction** is the name given to a change in the direction of light caused by changes in its speed (Figure 10.2.1).

FIGURE 10.2.1 Light refracts as it moves from one medium (i.e. the semicircular glass prism) into another (i.e. air) causing a change in direction.

REFRACTIVE INDEX

The amount of refraction that occurs depends on how much the speed of light changes as light moves from one medium to another—when light slows down greatly, it will undergo significant refraction.

The speed of light in a number of different materials is shown in Table 10.2.1.

TABLE 10.2.1 The speed of light in various materials correct to three significant figures.

Material	Speed of light ($\times 10^8$ m s^{-1})
vacuum	3.00
air	3.00
ice	2.29
water	2.25
quartz	2.05
crown glass	1.97
flint glass	1.85
diamond	1.24

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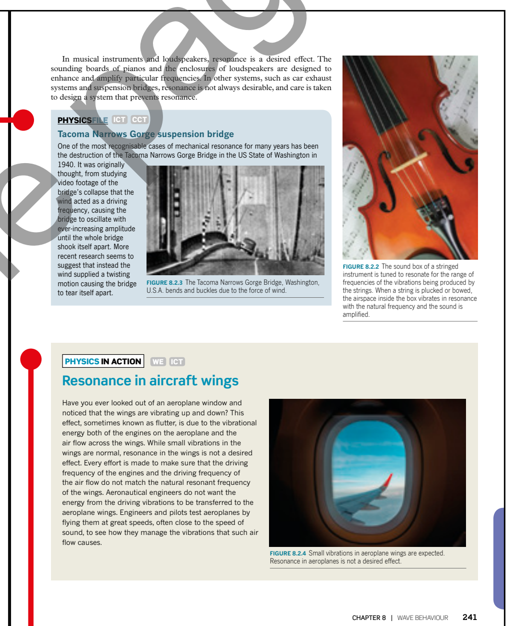


In musical instruments and loudspeakers, resonance is a desired effect. The sounding boards of pianos and the enclosures of loudspeakers are designed to enhance and amplify particular frequencies. In other systems, such as car exhaust systems and suspension bridges, resonance is not always desirable, and care is taken to design a system that prevents resonance.

PHYSICSFILE ICT CCT

Tacoma Narrows Gorge suspension bridge

One of the most recognisable cases of mechanical resonance for many years has been the destruction of the Tacoma Narrows Gorge Bridge in the US State of Washington in 1940. It was originally thought, from studying video footage of the bridge's collapse that the wind acted as a driving frequency, causing the bridge to oscillate with ever-increasing amplitude until the whole bridge shook itself apart. More recent research seems to suggest that instead the wind supplied a twisting motion causing the bridge to tear itself apart.

FIGURE 8.2.3 The Tacoma Narrows Gorge Bridge, Washington, U.S.A. bends and buckles due to the force of wind.

FIGURE 8.2.2 The sound box of a stringed instrument is tuned to resonate for the range of frequencies of the vibrations being produced by the strings. When a string is plucked or bowed, the airspace inside the box vibrates in resonance with the natural frequency and the sound is amplified.

PHYSICS IN ACTION WE ICT

Resonance in aircraft wings

Have you ever looked out of an aeroplane window and noticed that the wings are vibrating up and down? This effect, sometimes known as flutter, is due to the vibrational energy both of the engines on the aeroplane and the air flow across the wings. While small vibrations in the wings are normal, resonance in the wings is not a desired effect. Every effort is made to make sure that the driving frequency of the engines and the driving frequency of the air flow do not match the natural resonant frequency of the wings. Aeronautical engineers do not want the energy from the driving vibrations to be transferred to the aeroplane wings. Engineers and pilots test aeroplanes by flying them at great speeds, often close to the speed of sound, to see how they manage the vibrations that such air flow causes.

FIGURE 8.2.4 Small vibrations in aeroplane wings are expected. Resonance in aeroplanes is not a desired effect.

CHAPTER 8 | WAVE BEHAVIOUR 241

Physics Inquiry

Physics Inquiry features are inquiry-based activities that pre-empt the theory and allow students to engage with the concepts through a simple activity that sets students up to 'discover' the science before they learn about it. They encourage students to think about what happens in the world and how science can provide explanations.

Physics in Action

Physics in Action boxes place physics in an applied situation or a relevant context. These refer to the nature and practice of physics, applications of physics and the associated issues and the historical development of concepts and ideas.

PhysicsFile

PhysicsFiles include a range of interesting and real-world examples to engage students.

Highlight box

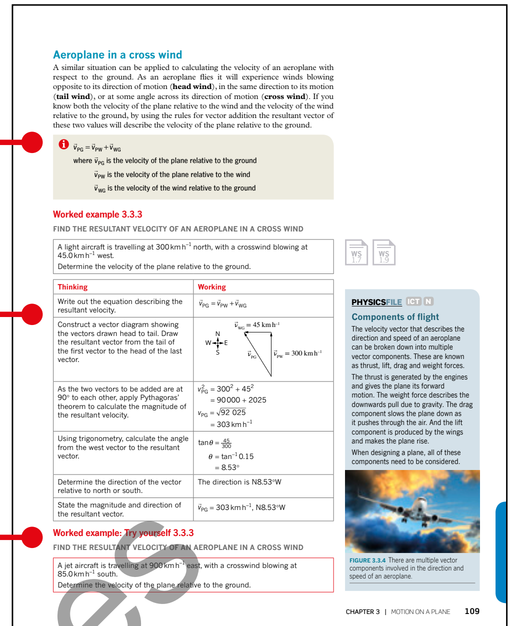
Highlight boxes focus students' attention on important information such as key definitions, formulae and summary points.

Worked examples

Worked examples are set out in steps that show thinking and working. This format greatly enhances student understanding by clearly linking underlying logic to the relevant calculations.

Each Worked example is followed by a Try Yourself activity. This mirror problem allows students to immediately test their understanding.

Fully worked solutions to all Worked example: Try yourself are available on *Pearson Physics 11 New South Wales* Reader+.

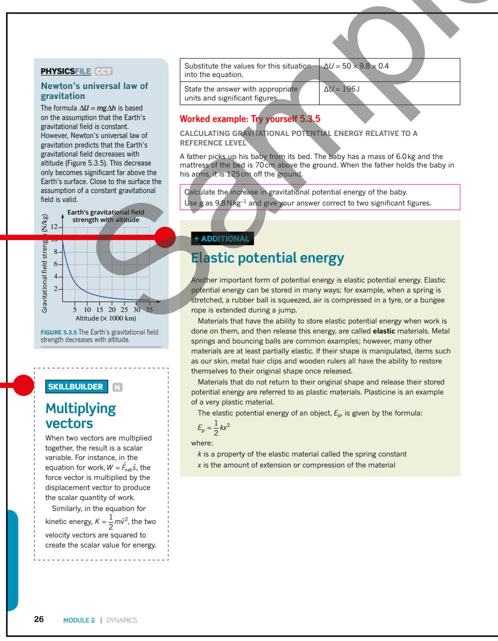


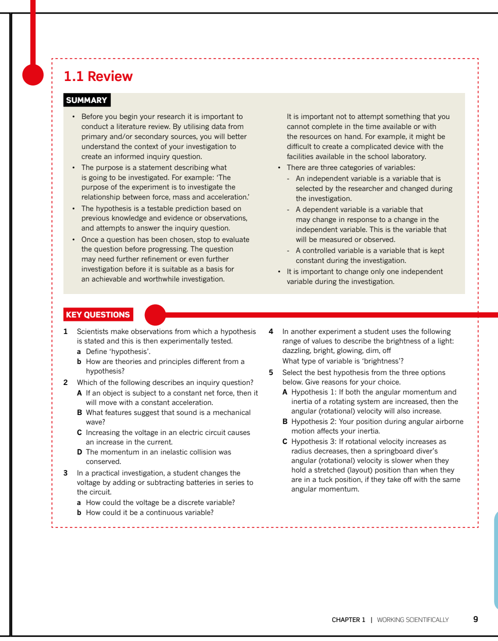
Additional content

Additional content features include material that goes beyond the core content of the Syllabus. They are intended for students who wish to expand their depth of understanding in a particular area.

Section summary

Each section has a section summary to help students consolidate the key points and concepts of each section.





SkillBuilder

A skillBuilder outlines a method or technique. They are instructive and self-contained. They step students through the skill to support science application.

Section review questions

Each section finishes with key questions to test students' understanding and ability to recall the key concepts of the section.

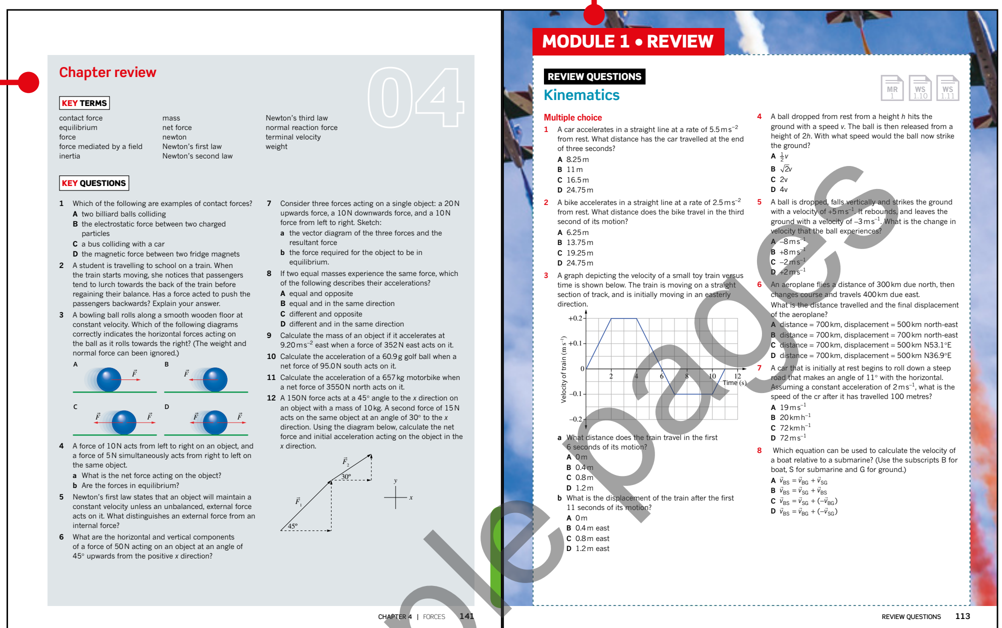
How to use this book

Chapter review

Each chapter finishes with a list of key terms covered in the chapter and a set of questions to test students' ability to apply the knowledge gained from the chapter.

Module review

Each module finishes with a set of questions, including multiple choice, short answer and extended response. These questions assist students in drawing together their knowledge and understanding, and applying it to these types of questions.



Icons

The New South Wales Stage 6 Syllabus 'Learning across the curriculum' and 'General capabilities' content are addressed throughout the series and are identified using the following icons.

AHC A CC CCT DD EU ICT

IU L N PSC S WE

'Go to' icons are used to make important links to relevant content within the same Student Book.

GO TO ➤

This icon indicates when it is the best time to engage with a worksheet (WS), a practical activity (PA), a depth study (DS) or module review (MR) questions in *Pearson Physics 11 New South Wales Skills and Assessment Book.*

WS 3.1

This icon will indicate when the best time is to engage with a practical activity on *Pearson Physics 11 New South Wales* Reader+.

PA 3.1

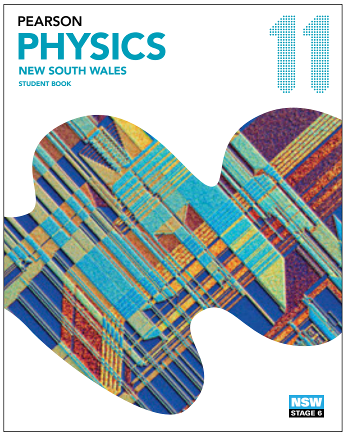
Glossary

Key terms are shown in **bold** in sections and listed at the end of each chapter. A comprehensive glossary at the end of the book includes and defines all the key terms.

Answers

Numerical answers and key short response answers are included at the back of the book. Comprehensive answers and fully worked solutions for all section review questions, Worked example: Try yourself features, chapter review questions and module review questions are provided on *Pearson Physics 11 New South Wales* Reader+.

Pearson Physics 11
New South Wales

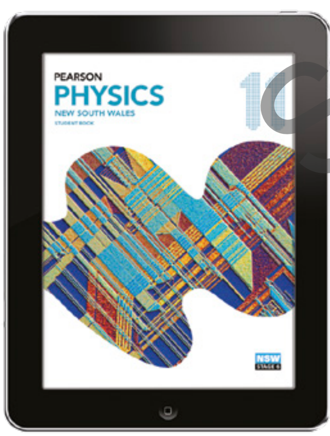


Student Book

Pearson Physics 11 New South Wales has been written to fully align with the new Physics Stage 6 Syllabus for New South Wales. The Student Book includes the very latest developments and applications of physics and incorporates best-practice literacy and instructional design to ensure the content and concepts are fully accessible to all students.

Skills and Assessment Book

The *Skills and Assessment Book* gives students the edge in preparing for all forms of assessment. Key features include a toolkit, key knowledge summaries, worksheets, practical activities, suggested depth studies and module review questions. It provides guidance, assessment practice and opportunities to develop key skills.



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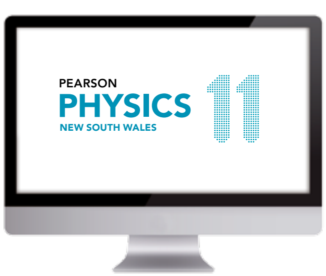

Teacher Support

The Teacher Support available includes syllabus grids and a scope and sequence plan to support teachers with programming. It also includes fully worked solutions and answers to all Student Book and *Skills and Assessment Book* questions, including all worksheets, practical activities, depth studies and module review questions. Teacher notes, safety notes, risk assessments and a laboratory technician checklist and recipes are available for all practical activities. Depth studies are supported with suggested marking schemes and exemplar answers.

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CHAPTER 02

Motion in a straight line

Motion, from simple to complex, is a fundamental part of everyday life. In this chapter you will learn how to use the mathematical quantities of scalars and vectors to understand the concepts of forces and motion. From a train pulling in to a station to a swimmer completing a lap of a pool, physics can model the motion of just about anything.

Content

INQUIRY QUESTION

How is the motion of an object moving in a straight line described and predicted?

By the end of this chapter you will be able to:

- describe uniform straight-line (rectilinear) motion and uniformly accelerated motion through:
  - qualitative descriptions
  - the use of scalar and vector quantities (ACSPH060)
- conduct a practical investigation to gather data to facilitate the analysis of instantaneous and average velocity through: ICT
  - quantitative, first-hand measurements
  - the graphical representation and interpretation of data (ACSPH061) N
- calculate the relative velocity of two objects moving along the same line using vector analysis
- conduct practical investigations, selecting from a range of technologies, to record and analyse the motion of objects in a variety of situations in one dimension in order to measure or calculate: ICT N
  - time
  - distance
  - displacement
  - speed
  - velocity
  - acceleration
- use mathematical modelling and graphs, selected from a range of technologies, to analyse and derive relationships between time, distance, displacement, speed, velocity and acceleration in rectilinear motion, including:
  - $\vec{s} = \vec{u}t + \frac{1}{2}\vec{a}t^2$
  - $\vec{v} = \vec{u} + \vec{a}t$
  - $\vec{v}^2 = \vec{u}^2 + 2\vec{a}\vec{s}$ (ACSPH061) ICT N

2.1 Scalars and vectors

You will come into contact with many physical quantities in the natural world every day. For example, time, mass and distance are all physical quantities. Each of these physical quantities has units with which to measure them; for example, seconds, kilograms and metres.

Some measurements only make sense if there is also a direction included. For example, a GPS navigation system tells you when to turn and in which direction. Without both of these two instructions, the information is incomplete.

All physical quantities can be divided into two broad groups based on what information you need for the quantity to make sense. These groups are called scalars and vectors. Often vectors are represented by arrows. Both of these types of measures will be investigated throughout this section.

SCALARS

Many physical quantities can be described simply by a **magnitude** (size) and a **unit**. For example, you might say that the **speed** of a car is 60 kilometres per hour. The magnitude is 60 and the unit is kilometres per hour. Quantities like this that have only a magnitude and a unit are called **scalars**.

The magnitude depends on the unit chosen. For example, 60 kilometres per hour can also be described as 1 kilometre per minute. Here the magnitude is 1 and the unit is kilometres per minute. Some examples of scalars are:

- time
- distance
- volume
- speed.

VECTORS

Sometimes a physical quantity also has a direction. For example, you might say that a car is travelling at 60 kilometres per hour north. Quantities like this that have a magnitude, a unit and a direction are called **vectors**. Some examples of vectors are:

- position
- displacement
- velocity
- acceleration
- force.

Scalars are represented by a simple italic symbol, such as t for time and d for distance.

Vectors are represented using **vector notation**. The most common type of vector notation uses an arrow above the symbol. For example, force is written as $\vec{F}$ and velocity is written as $\vec{v}$. Without an arrow, F means only the magnitude of force and v means only the magnitude of velocity.

You might see a different type of vector notation in books and journals. This uses bold or bold italics to represent a vector, instead of an arrow. For example, force is written as **F** or ***F*** and velocity is written as **v** or ***v***.

VECTORS AS ARROWS

A vector has both a magnitude and a direction. Any vector can be represented visually by an arrow. The length of the arrow represents the magnitude of the vector, and the direction of the arrow (from tail to head) represents the direction of the vector.

A diagram in which one or more vectors are represented by arrows is called a **vector diagram**. Figure 2.1.1 is a vector diagram that shows two vectors.

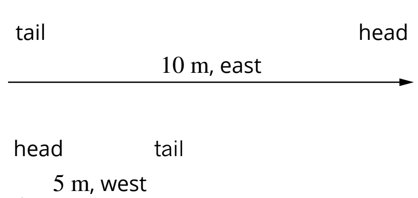


FIGURE 2.1.1 A simple vector diagram. The top vector is twice as long as the bottom vector, so it has twice the magnitude of the bottom vector. The arrowheads indicate that the vectors are in opposite directions.

A force is a push or a pull, and the unit of measure for force is the **newton** (N). If you push a book to the right, it will respond differently compared to pushing it to the left. So a force is described properly only when a direction is included, which means that force is a vector. Forces are described in more detail in Chapter 4.

In most vector diagrams, the length of the arrow is drawn to scale so that it accurately represents the magnitude of the vector.

In the scaled vector diagram in Figure 2.1.2, a force $\vec{F} = 4\,\text{N}$ left acting on the toy car is drawn as an arrow with a length of 2 cm. In this example a scale of 1 cm = 2 N force is used.

An exact scale for the magnitude is not always needed, but it is important that vectors are drawn accurately relative to one another. For example, a vector of 50 m north should be half as long as a vector of 100 m south, and should point in the opposite direction.

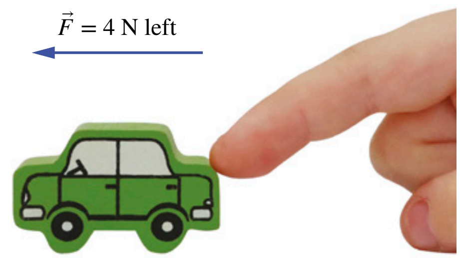


FIGURE 2.1.2 A force of 4 N left acts on a toy car.

Point of application of arrows

Vector diagrams may be presented slightly differently, depending on what they are depicting. If the vector represents a force, the tail end of the arrow is placed at the point where the force is applied to the object. If it is a displacement vector, the tail is placed where the object started to move.

Figure 2.1.3 shows a force applied by a foot to a ball (95 N east) and an opposing friction force (20 N west).

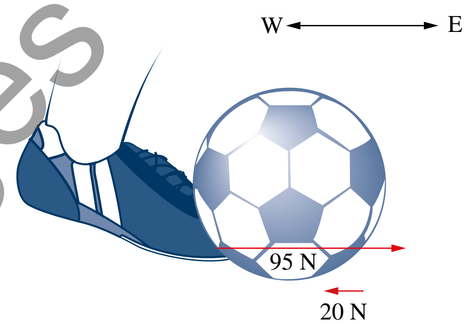


FIGURE 2.1.3 The force applied by the foot acts at the point of contact between the ball and the foot. The friction force acts at the point of contact between the ball and the ground. The kicking force, as indicated by the length of the arrow, is much larger than the friction force.

DIRECTION CONVENTIONS

Vectors need a direction in order to make sense. However, there needs to be a way of describing the direction that everyone understands and agrees upon.

Vectors in one dimension

For vector problems in one **dimension**, there are a number of direction conventions that can be used. For example:

- forwards or backwards
- up or down
- left or right
- north or south
- east or west.

For vectors in one dimension there are only two possible directions. The two directions must be in the same dimension or along the same line. The **direction convention** that is used should be shown graphically in all vector diagrams. Some examples are shown in Figure 2.1.4. Arrows like these are placed near the vector diagram so that it is clear which convention is being used.

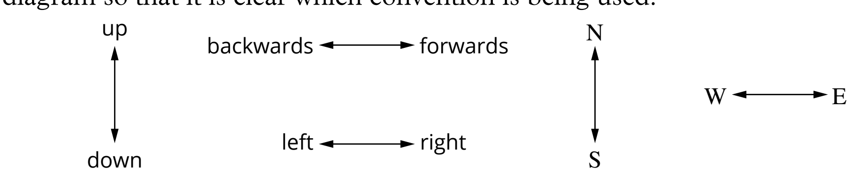


FIGURE 2.1.4 Some common one-dimensional direction conventions.

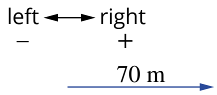
Sign convention

In calculations involving one-dimensional vectors, a sign convention can also be used to convert physical directions to the mathematical signs of positive and negative. For example, forwards can be positive and backwards can be negative, or right can be positive and left can be negative. A vector of 100 m up can be described as −100 m, as long as the relationship between sign and direction conventions are clearly indicated in a legend or key. Some examples are shown in Figure 2.1.4.

The advantage of using a sign convention is that the signs of positive and negative can be entered into a calculator, while words such as 'up' and 'right' cannot. This is useful when adding or subtracting vectors.

Worked example 2.1.1

DESCRIBING VECTORS IN ONE DIMENSION



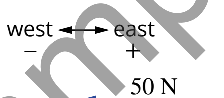
Describe the vector above using:

a the direction convention shown	
Thinking	**Working**
Identify the magnitude and unit of the vector.	The magnitude is 70 and the unit is m (metres).
Identify the vector direction according to the direction convention.	The vector is pointing to the right according to the direction convention.
Combine the magnitude, unit and direction.	The vector is 70 m right.

b the sign convention shown.	
Thinking	**Working**
Convert the physical direction to the corresponding mathematical sign.	The physical direction of right is positive and left is negative. In this example, the arrow is pointing right, so the mathematical sign is +.
Combine the mathematical sign with the magnitude and unit.	The vector is +70 m.

Worked example: Try yourself 2.1.1

DESCRIBING VECTORS IN ONE DIMENSION



Describe the vector above using:

a the direction convention shown

b the sign convention shown.

ADDING VECTORS IN ONE DIMENSION

Most real-life situations involve more than one vector acting on an object. If this is the case, it is usually desirable to combine the vector diagrams to find the overall effect of the vectors. When two or more vectors are in the same dimension, they are said to be **collinear** (in line with each other).

This means that the vectors must either point in the same direction or point in opposite directions. For example, the vectors 10 m west, 15 m east and 25 m west are all in one dimension, because east is the opposite direction to west. When vectors are combined, it is called adding vectors.

Graphical method of adding vectors

Vector diagrams, like those shown in Figure 2.1.5, are convenient for adding vectors. To combine vectors in one dimension, draw the first vector, then start the second vector with its tail at the head of the first vector. Continue adding arrows 'head to tail' until the last vector is drawn. The sum of the vectors, or the **resultant** vector, is drawn from the tail of the first vector to the head of the last vector.

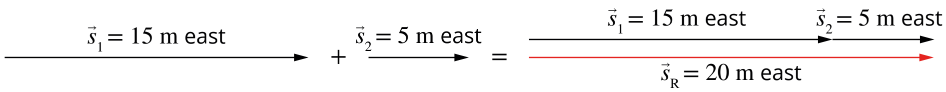


FIGURE 2.1.5 Adding vectors head to tail. This particular diagram represents the addition of 15 m east and 5 m east. The resultant vector, shown in red, is 20 m east.

In Figure 2.1.5 the two vectors $\vec{s}_1$ (15 m east) and $\vec{s}_2$ (5 m east) are drawn separately. The vectors are then redrawn with the head of $\vec{s}_1$ connected to the tail of $\vec{s}_2$. The resultant vector $\vec{s}_R$ is drawn from the tail of $\vec{s}_1$ to the head of $\vec{s}_2$. The magnitude (size) of the resultant vector is the sum of the magnitudes of the separate vectors: 15 m + 5 m = 20 m.

Alternatively, vectors can be drawn to scale; for example, 1 cm = 1 m. The resultant vector is then measured directly from the scale diagram. The direction of the resultant vector is the direction from the tail of the first vector to the head of the last vector.

Algebraic method of adding vectors

To add vectors in one dimension using algebra, a sign convention is used to represent the direction of the vectors, as in Figure 2.1.4 on page 49. When applying a sign convention, it is important to provide a key explaining the convention used.

The sign convention allows you to enter the signs and magnitudes of vectors into a calculator. The sign of the final magnitude gives the direction of the resultant vector.

Vectors are added head to tail. The resultant vector is drawn from the tail of the first vector to the head of the last vector.

Worked example 2.1.2

ADDING VECTORS IN ONE DIMENSION USING ALGEBRA

A student walks 25 m west, 16 m east, 44 m west and then 12 m east.
Use the sign convention in Figure 2.1.4 on page 49 to determine the resultant displacement for the student.

Thinking	Working
Apply the sign convention to change each of the directions to signs.	25 m west = –25 m 16 m east = +16 m 44 m west = –44 m 12 m east = +12 m
Add the magnitudes and their signs together.	Resultant vector = (–25) + (+16) + (–44) + (+12) = –41 m
Refer to the sign and direction conventions to determine the direction of the resultant vector.	Negative is west.
State the resultant vector.	The resultant vector is 41 m west.

Worked example: Try yourself 2.1.2

ADDING VECTORS IN ONE DIMENSION USING ALGEBRA

A box has the following forces acting on it: 16 N up, 22 N down, 4 N up and 17 N down. Use the sign and direction conventions in Figure 2.1.4 on page 49 to determine the resultant force on the box.

PHYSICSFILE N

Double negatives

It is important to differentiate between the terms subtract, minus, take away or difference between and the term negative. The terms subtract, minus, take away or difference between are processes, like add, multiply and divide. You will find them grouped together on your calculator. The term negative is a property of a number that means that it is opposite to positive. There is a separate button on your calculator for this property.

When a negative number is subtracted from a positive number, the two numbers are added together. For example, $5 - (-2) = 7$.

FIGURE 2.1.6 Velocity is a vector, so its direction is important. The velocity of a tennis ball immediately before it hits a racquet is different to its velocity immediately after it leaves the racquet, because it is travelling in a different direction.

FIGURE 2.1.8 Subtracting vectors using the graphical method.

SUBTRACTING VECTORS IN ONE DIMENSION

To find the difference between two vectors, you must subtract the initial vector from the final vector. To do this, work out which is the initial vector, then reverse its direction to obtain the opposite of the initial vector. Then add the final vector to the opposite of the initial vector.

This technique can be applied both graphically and algebraically.

Graphical method of subtracting vectors

Velocity indicates how fast an object is moving, and in what direction. It is a vector because it involves both magnitude and direction. For example, in Figure 2.1.6 the velocity of the tennis ball as it hits the racquet is different from the velocity of the ball when it leaves the racquet, because the ball has changed direction. The concept of velocity is covered in more detail in Section 2.2, but it is useful to use the example of velocity now when discussing the subtraction of vectors. The processes applied to the subtraction of velocity vectors works for all other vectors.

To subtract velocity vectors in one dimension using a graphical method, determine which vector is the initial velocity and which is the final velocity. The final velocity is drawn first. The initial velocity is then drawn, but in the opposite direction to its original form. The sum of these vectors, or the resultant vector, is drawn from the tail of the final velocity to the head of the reversed initial velocity. This resultant vector is the difference between the two velocities, $\Delta\vec{v}$.

The mathematical symbol Δ (delta) is used to represent the change in a variable. For example, $\Delta\vec{v}$ means the change in velocity.

To find the difference between two vectors in the same dimension, subtract the initial vector from the final vector. Vectors are subtracted by adding the negative of one vector to the positive of the other vector.

In Figure 2.1.7, two velocity vectors $\vec{v}_1$ (9 m s^{-1} east) and $\vec{v}_2$ (3 m s^{-1}, east) are drawn separately. The initial velocity $\vec{v}_1$ is then redrawn in the opposite direction to form $-\vec{v}_1$ or 9 m s^{-1} west.

FIGURE 2.1.7 Subtracting vectors using the graphical method

Figure 2.1.8 illustrates how the difference between the vectors is found. First the final velocity, $\vec{v}_2$, is drawn. Then the opposite of the initial velocity, $-\vec{v}_1$, is drawn head to tail. The resultant vector, $\Delta\vec{v}$, is drawn from the tail of $\vec{v}_2$ to the head of $-\vec{v}_1$.

The magnitude of the resultant vector, $\Delta\vec{v}$, can be calculated from the magnitudes of the two vectors. Alternatively, you could draw the vectors to scale and then measure the resultant vector against that scale, for example 1 m s^{-1} = 1 cm.

The direction of the resultant vector, $\Delta\vec{v}$, is the same as the direction from the tail of the final velocity, $\vec{v}_2$, to the head of the opposite of the initial velocity, $-\vec{v}_1$.

Algebraic method of subtracting vectors

To subtract velocity vectors in one dimension algebraically, a sign convention is used to represent the direction of the velocities. Some examples of one-dimensional directions include east and west, north and south and up and down. These options are replaced by positive (+) or negative (–) signs when calculations are performed. To change the direction of the initial velocity, simply change the sign from positive to negative or from negative to positive.

The equation for finding the change in velocity is:

change in velocity = final velocity − initial velocity

$$\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$$

which is the same as:

change in velocity = final velocity + the opposite of the initial velocity

$$\Delta\vec{v} = \vec{v}_2 + (-\vec{v}_1)$$

The final velocity is added to the opposite of the initial velocity. Because the change in velocity is a vector, it will consist of a sign, a magnitude and a unit. The sign of the answer can be compared with the sign and direction convention (Figure 2.1.9) to determine the direction of the change in velocity.

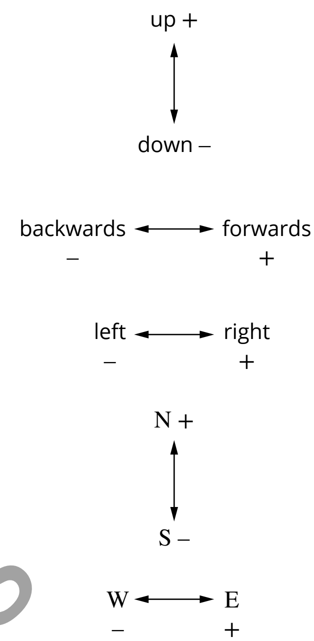


FIGURE 2.1.9 One-dimensional direction conventions can also be expressed as sign conventions.

Worked example 2.1.3

SUBTRACTING VECTORS IN ONE DIMENSION USING ALGEBRA

An aeroplane changes course from 255 m s^{-1} west to 160 m s^{-1} east. Use the sign and direction conventions in Figure 2.1.9 to determine the change in the velocity of the aeroplane.

Thinking	Working
Apply the sign and direction convention to change the directions to signs.	$\vec{v}_1$ = 255 m s^{-1} west = −255 m s^{-1} $\vec{v}_2$ = 160 m s^{-1} east = +160 m s^{-1}
Reverse the direction of the initial velocity $\vec{v}_1$ by reversing the sign.	$-\vec{v}_1$ = 255 m s^{-1} east = +255 m s^{-1}
Use the formula for change in velocity to calculate the magnitude and the sign of $\Delta\vec{v}$.	$\Delta\vec{v} = \vec{v}_2 + (-\vec{v}_1)$ = (+160) + (+255) = +415 m s^{-1}
Refer to the sign and direction convention to determine the direction of the change in velocity.	Positive is east.
State the resultant vector.	The resultant vector is 415 m s^{-1} east.

Worked example: Try yourself 2.1.3

SUBTRACTING VECTORS IN ONE DIMENSION USING ALGEBRA

A rocket accelerates from 212 m s^{-1} to 2200 m s^{-1} upwards. Use the sign and direction conventions in Figure 2.1.9 to determine the change in velocity of the rocket.

2.1 Review

SUMMARY

- Scalar quantities have only a magnitude and a unit.
- Vector quantities have a magnitude, a unit and a direction. They are represented using vector notation. An arrow above the variable indicates that it is a vector.
- Combining vectors is known as adding vectors.
- Adding vectors in one dimension can be done graphically using vector diagrams. After adding vectors head to tail, the resultant vector can be drawn from the tail of the first vector to the head of the last vector.
- Adding vectors in one dimension can be done algebraically by applying a sign convention. Vectors with direction become vectors with either positive or negative signs.
- To find the difference between two vectors, subtract the initial vector from the final vector.
- Vectors are subtracted by adding the negative, or opposite, of a vector.
- Subtracting vectors in one dimension can be done graphically using a scale.
- Subtracting vectors in one dimension can also be done algebraically.

KEY QUESTIONS

1 Find the resultant vector when the following vectors are combined: 2 m west, 5 m east and 7 m west.

2 Add the following vectors to find the resultant vector: 3 m up, 2 m down and 3 m down.

3 Determine the resultant vector of a model train that moves in these directions: 23 m forwards, 16 m backwards, 7 m forwards and 3 m backwards.

4 When adding vector B to vector A using the head to tail method, from what point, and to what point, is the resultant vector drawn?

A from the head of A, to the tail of B
B from the tail of B, to the head of A
C from the head of B, to the tail of A
D from the tail of A, to the head of B

5 A car that was initially travelling at a velocity of 3 m s^{-1} west is later travelling at 5 m s^{-1} east. What is the difference between the two vectors?

6 Determine the change in velocity of a runner who changes from running at 4 m s^{-1} to the right on grass to running 2 m s^{-1} to the right in sand.

7 A student throws a ball up into the air at 4 m s^{-1}. A short time later the ball is travelling back downwards to hit the ground at 3 m s^{-1}. Determine the change in velocity of the ball during this time.

8 Jamelia applies the brakes on her car and changes her velocity from 22.2 m s^{-1} forwards to 8.2 m s^{-1} forwards. Calculate the change in velocity of Jamelia's car.

2.2 Displacement, speed and velocity

In order to describe and analyse motion, it is important to understand the terms used to describe it, even in its simplest form. In this section you will learn about some of the terms used to describe **rectilinear** or straight-line motion, such as position, distance, displacement, speed and velocity.

CENTRE OF MASS

Motion is often more complicated than it seems at first. For example, when a freestyle swimmer travels at a constant speed of $2\,m\,s^{-1}$, their head and torso move forwards at this speed, but the motion of their arms is more complex. At times their arms move forwards through the air faster than $2\,m\,s^{-1}$, and at other times they move backwards through the water.

It is beyond the scope of this course to analyse such a complex motion. However, the motion of the swimmer can be simplified by treating the swimmer as a simple object located at a single point called the **centre of mass**. The centre of mass is the balance point of an object. For a person, the centre of mass is just above the waist. The centres of mass of some objects are shown in Figure 2.2.1.

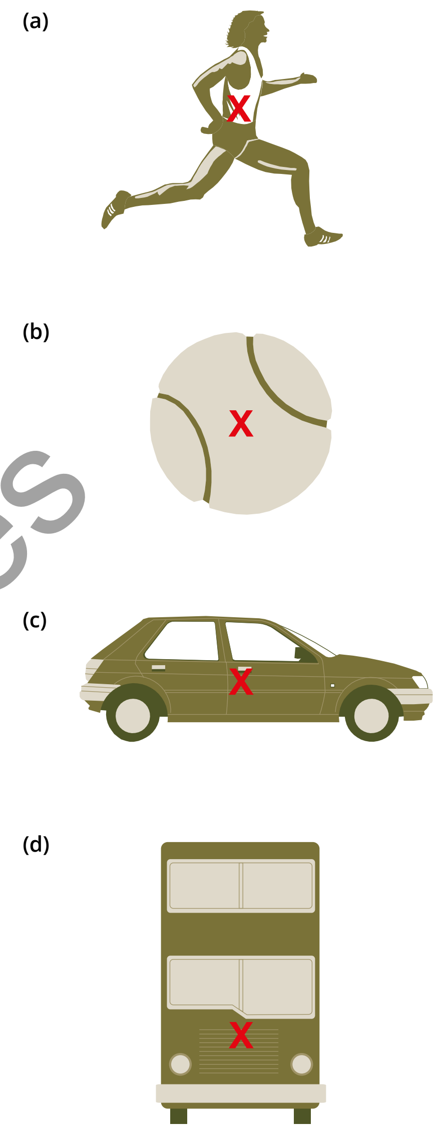


FIGURE 2.2.1 The centre of mass of each object is indicated by a cross.

POSITION, DISTANCE AND DISPLACEMENT

Position

One important term to understand when analysing straight-line motion is **position**.

- Position describes the location of an object at a certain point in time with respect to the origin.
- Position is a vector quantity and therefore requires a direction.

Consider Sophie doing laps in a 50 m pool, as shown in Figure 2.2.2. To simplify her motion, Sophie is treated as a point object with her centre of mass just above her waist. The pool can be treated as a one-dimensional number line, with the starting block defined as the origin. The direction to the right of the starting block is taken to be positive.

Sophie's position as she is warming up behind the starting block is −10 m, as shown in Figure 2.2.2(a). The negative sign indicates the direction from the origin, i.e. to the left. Her position could also be described as 10 m to the left of the starting block.

At the starting block, Sophie's position is 0 m, as shown in Figure 2.2.2(b). Then after swimming a little over half a length of the pool she is +25 m or 25 m to the right of the origin, as shown in Figure 2.2.2(c).

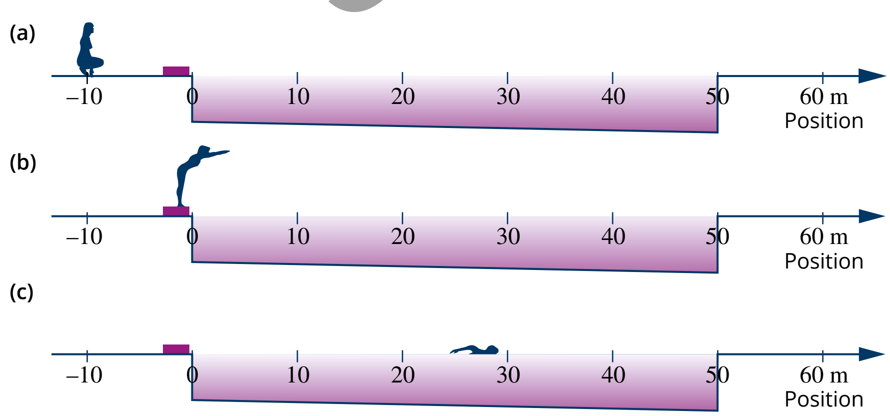


FIGURE 2.2.2 The position of the swimmer is given with reference to the starting block. (a) While warming up, Sophie is at −10 m. (b) When she is on the starting block, her position is zero. (c) After swimming for a short time, she is at a position of +25 m.

Distance travelled

Position describes where an object is at a certain point in time. But **distance travelled** is how far a body travels during a journey. For example, the tripmeter or odometer of a car or bike measures distance travelled. Distance travelled is represented by the symbol *d*.

- Distance travelled (*d*) describes the length of the path covered during an object's entire journey.
- Distance travelled is a scalar quantity and is measured in metres (m).

For example, if Sophie completes three lengths of the pool, the distance travelled during her swim will be 50 + 50 + 50 = 150 m.

The distance travelled is not affected by the direction of the motion. That is, the distance travelled by an object always increases as it moves, regardless of its direction.

Displacement

Displacement is the change in position of an object, and is represented by the symbol $\vec{s}$. Displacement considers only where the motion starts and finishes. The route taken between the start and finish has no effect on displacement. If the motion is in one dimension, a word such as east or west, or a positive or negative sign, can be used to indicate the direction of the displacement.

- Displacement is the change in position of an object in a given direction.
- Displacement $\vec{s}$ = final position − initial position.
- Displacement is a vector quantity and is measured in metres (m).

Consider the example of Sophie completing one length of the pool. During her swim, the distance travelled is 50 m. Her final position is +50 m and her initial position is 0 m. Her displacement is:

$$\begin{aligned}\vec{s} &= \text{final position} - \text{initial position}\\ &= 50 - 0\\ &= +50\text{ m or } 50\text{ m in a positive direction}\end{aligned}$$

Notice that magnitude, units and direction are required for a vector quantity. The distance will be equal to the magnitude of displacement only if the body is moving in a straight line and does not change direction. If Sophie swims two lengths, her distance travelled will be 100 m (50 m out and 50 m back) but her displacement during this swim will be:

$$\begin{aligned}\vec{s} &= \text{final position} - \text{initial position}\\ &= 0 - 0\\ &= 0\text{ m}\end{aligned}$$

Even though Sophie has swum 100 m, her displacement is zero because the initial and final positions are the same.

The above formula for displacement is useful if you already know the initial and final positions of the object. An alternative method to determine total displacement, if you know the displacement of each section of the motion, is to add up the individual displacements for each section of motion.

The total displacement is the sum of individual displacements.

GO TO ➤ Section 2.1, page 50

It is important to remember that displacement is a vector and so, when adding displacements, you must obey the rules of vector addition (discussed in Section 2.1).

In the example above, in which Sophie completed two laps, overall displacement could have been calculated by adding the displacement of each lap:

$$\begin{aligned}\vec{s} &= \text{sum of displacements for each lap}\\ &= 50\text{ m in the positive direction} + 50\text{ m in the negative direction}\\ &= 50 + (-50)\\ &= 0\text{ m}\end{aligned}$$

SPEED AND VELOCITY

For thousands of years, humans have tried to travel at ever greater speeds. This desire has contributed to the development of all sorts of competitive activities, as well as major advances in engineering and design. World records for some of these pursuits are given in Table 2.2.1.

TABLE 2.2.1 World record speeds for a variety of sports or modes of transport

Activity or object	World record speed ($m\,s^{-1}$)	World record speed ($km\,h^{-1}$)
luge	43	140
train	167.5	603
tennis serve	73.1	263
waterskiing (barefoot)	60.7	218
cricket delivery	44.7	161
racehorse	19.7	71

Speed and **velocity** are both quantities that give an indication of how quickly the position of an object is changing. Both terms are in common use and are often assumed to have the same meaning. In physics, however, these two terms have different definitions.

- Speed is the rate at which distance is travelled. Like distance, speed is a scalar. A direction is not required when stating the speed of an object.
- Velocity is the rate at which displacement changes. It has direction, so it is a vector quantity. A direction must always be given when stating the velocity of an object.
- The standard SI unit for speed and velocity is metres per second ($m\,s^{-1}$).

Instantaneous speed and velocity

Instantaneous speed and instantaneous velocity tell you how fast something is moving at a particular point in time. The speedometer on a car or bike indicates instantaneous speed.

If a speeding car is travelling north and is detected on a police radar gun at $150\,km\,h^{-1}$, it indicates that this car's instantaneous speed is $150\,km\,h^{-1}$, while its instantaneous velocity is $150\,km\,h^{-1}$ north. The instantaneous speed is always equal to the magnitude of the instantaneous velocity.

Average speed and velocity

Average speed and average velocity both give an indication of how fast an object is moving over a particular time interval.

average speed $v_{av} = \frac{\text{distance travelled}}{\text{time taken}} = \frac{d}{\Delta t}$

average velocity $\vec{v}_{av} = \frac{\text{displacement}}{\text{time taken}} = \frac{\vec{s}}{\Delta t}$

FIGURE 2.2.3 Australian Anna Meares won the UCI Mexico Track World Cup 2013. She rode 500 m in a world record time of 32.836 s. Her average speed around the track was 55.6 km h^{-1}, but her average velocity was zero.

PHYSICSFILE N

Reaction time

Drivers are often distracted by loud music or phone calls. These distractions result in many accidents and deaths on the road. If cars are travelling at high speeds, they will travel a large distance in the time that the driver takes just to apply the brakes. A short reaction time is very important for all road users. This is easy to understand given the relationship between speed, distance and time.

distance travelled = $v \times t$

Average speed is equal to instantaneous speed only when a body's motion is uniform; that is, if it is moving at a constant speed.

The average speed of a car that takes 30 minutes to travel 20 km from Macquarie Park to Manly Beach is 40 km h^{-1}. But this does not mean that the car travelled the whole distance at this speed. In fact it is more likely that the car was sometimes moving at 60 km h^{-1}, and at other times was not moving at all.

A direction (such as north, south, up, down, left, right, positive, negative) must be given when describing a velocity. The direction of velocity is always the same as the direction of displacement. And like the relationship between distance and displacement, average speed will be equal to the magnitude of average velocity only if the body is moving in a straight line and does not change direction.

For example, in a cycling race of one lap around a track (Figure 2.2.3), the magnitude of the average velocity will be zero, because the displacement is zero. This is true no matter what the average speed for the lap is.

SKILLBUILDER N

Converting units

The usual unit used in physics for velocity is m s^{-1}, but km h^{-1} is often used in everyday life. So it is important to understand how to convert between these two units.

Converting km h^{-1} to m s^{-1}

You should be familiar with 100 km h^{-1} because it is the speed limit for most freeways and country roads in Australia. Cars that maintain this speed would travel 100 km in 1 hour. Since there are 1000 metres in 1 kilometre and 3600 seconds in 1 hour (60 s × 60 min), this is the same as travelling 100 000 m in 3600 s.

$$\begin{aligned} 100\,\text{km h}^{-1} &= 100 \times 1000\,\text{m h}^{-1} \\ &= 100\,000\,\text{m h}^{-1} \\ &= \tfrac{100\,000}{3600}\,\text{m s}^{-1} \\ &= 27.8\,\text{m s}^{-1} \end{aligned}$$

So km h^{-1} can be converted to m s^{-1} by multiplying by $\frac{1000}{3600}$ (or dividing by 3.6).

Converting m s^{-1} to km h^{-1}

A champion Olympic sprinter can run at an average speed of close to 10 m s^{-1}. Each second, the athlete will travel approximately 10 metres. If they could maintain this rate, in 1 hour the athlete would travel 10 × 3600 = 36 000 m = 36 km.

$$\begin{aligned} 10\,\text{m s}^{-1} &= 10 \times 3600\,\text{m h}^{-1} \\ &= 36\,000\,\text{m h}^{-1} \\ &= \tfrac{36\,000}{1000}\,\text{km h}^{-1} \\ &= 36\,\text{km h}^{-1} \end{aligned}$$

So m s^{-1} can be converted to km h^{-1} by multiplying by $\frac{3600}{1000}$ or 3.6.

When converting a speed from one unit to another, it is important to think about the speeds to ensure that your answers make sense. The diagram in Figure 2.2.4 summarises the conversion between the two common units for speed.

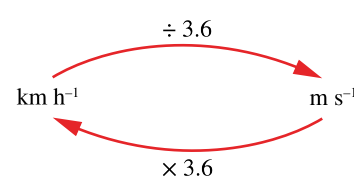
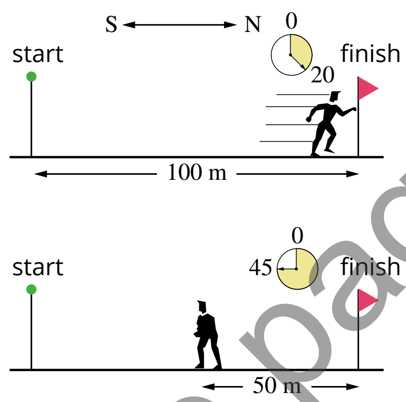


FIGURE 2.2.4 Rules for converting between m s^{-1} and km h^{-1}.

Worked example 2.2.1

AVERAGE VELOCITY AND CONVERTING UNITS

Sam is an athlete performing a training routine by running back and forth along a straight stretch of running track. He jogs 100 m north in a time of 20 s, then turns and walks 50 m south in a further 25 s before stopping.

a What is Sam's average velocity in $m\,s^{-1}$?	
Thinking	**Working**
Calculate the displacement. (Remember that total displacement is the sum of individual displacements.) Sam's total journey consists of two displacements: 100 m north and then 50 m south.	$\vec{s}$ = sum of displacements = 100 m north + 50 m south = 100 + (–50) = +50 m or 50 m north 
Work out the total time taken for the journey.	20 + 25 = 45 s
Substitute the values into the velocity equation.	Displacement is 50 m north. Time taken is 45 s. Average velocity $\vec{v}_{av} = \frac{\vec{s}}{\Delta t}$ $= \frac{50}{45}$ $= 1.1\,m\,s^{-1}$
Velocity is a vector, so a direction must be given.	$1.1\,m\,s^{-1}$ north

b What is the magnitude of Sam's average velocity in $km\,h^{-1}$?	
Thinking	**Working**
Convert from $m\,s^{-1}$ to $km\,h^{-1}$ by multiplying by 3.6.	$\vec{v}_{av} = 1.1\,m\,s^{-1}$ $= 1.1 \times 3.6$ $= 4.0\,km\,h^{-1}$ north
As the magnitude of velocity is needed, direction is not required in this answer.	$v_{av} = 4.0\,km\,h^{-1}$

c What is Sam's average speed in $m\,s^{-1}$?	
Thinking	**Working**
Calculate the distance. (Remember that distance is the length of the path covered over the entire journey. The direction does not matter.) Sam travels 100 m in one direction and then 50 m in the other direction.	$d = 100 + 50$ $= 150$
Work out the total time taken for the journey.	$20 + 25 = 45\,s$
Substitute the values into the speed equation.	Distance is 150 m. Time taken is 45 s. Average speed $v_{av} = \frac{d}{\Delta t}$ $= \frac{150}{45}$ $= 3.3\ m\,s^{-1}$

d What is Sam's average speed in $km\,h^{-1}$?	
Thinking	**Working**
Convert from $m\,s^{-1}$ to $km\,h^{-1}$ by multiplying by 3.6.	Average speed $v_{av} = 3.3\,m\,s^{-1}$ $= 3.3 \times 3.6$ $= 12\,km\,h^{-1}$

Worked example: Try yourself 2.2.1

AVERAGE VELOCITY AND CONVERTING UNITS

Sally is an athlete performing a training routine by running backwards and forwards along a straight stretch of running track. She jogs 100 m west in a time of 20 s, then turns and walks 160 m east in a further 45 s before stopping.

a What is Sally's average velocity in $m\,s^{-1}$?

b What is the magnitude of Sally's average velocity in $km\,h^{-1}$?

c What is Sally's average speed in $m\,s^{-1}$?

d What is Sally's average speed in $km\,h^{-1}$? Give your answer to two significant figures.

PHYSICS IN ACTION N

Alternative units for speed and distance

Metres per second is the standard unit for measuring speed because it is derived from the standard unit for distance (metres) and the standard unit for time (seconds). However, alternative units are often used to better suit a certain application.

The speed of a boat is usually measured in knots, where 1 knot = 0.51 $m\,s^{-1}$. This unit originated in the nineteenth century, when the speed of sailing ships would be measured by allowing a rope, with knots tied at regular intervals, to be dragged by the water through a sailor's hands. By counting the number of knots that passed through the sailor's hands, and measuring the time taken for this to happen, the average speed formula could be applied to estimate the speed of the ship.

The speed of very fast aircraft, such as the one in Figure 2.2.5, is often stated using Mach numbers. A speed of Mach 1 equals the speed of sound, which is 340 $m\,s^{-1}$ at the Earth's surface. Mach 2 is twice the speed of sound, or 680 $m\,s^{-1}$, and so on.

The light-year is an alternative unit for measuring distance. The speed of light in a vacuum is nearly 300 000 $km\,s^{-1}$.

FIGURE 2.2.5 Modern fighter aircraft are able to fly at speeds well above Mach 2.

One light-year is the distance that light travels in one year. Astronomers use this unit because distances between objects in the universe are enormous. It takes about 4.24 years for light to travel from the nearest star (Proxima Centauri) to us. That means the distance from our solar system to the nearest star is about 4.24 light-years. Light takes about 8.5 minutes to travel from the Sun to Earth, so you could say that the Sun is 8.5 light-minutes away.

2.2 Review

SUMMARY

- The motion of an object travelling in a straight line is called rectilinear motion.
- Position defines the location of an object with respect to a defined origin.
- Distance travelled, d, tells us how far an object has actually travelled. Distance travelled is a scalar.
- Displacement, $\vec{s}$, is a vector and is defined as the change in position of an object in a given direction: $\vec{s}$ = final position − initial position.
- The average speed of a body, v_{av}, is defined as the rate of change of distance and is a scalar quantity:

  $$\text{average speed } v_{av} = \frac{\text{distance travelled}}{\text{time taken}} = \frac{d}{\Delta t}$$

- The average velocity of a body, $\vec{v}_{av}$, is defined as the rate of change of displacement and is a vector quantity:

  $$\text{average velocity } \vec{v}_{av} = \frac{\text{displacement}}{\text{time taken}} = \frac{\vec{s}}{\Delta t}$$

- The usual SI unit for both speed and velocity is metres per second ($m\,s^{-1}$); kilometres per hour ($km\,h^{-1}$) is another SI unit that is commonly used.
- To convert from $m\,s^{-1}$ to $km\,h^{-1}$, multiply by 3.6.
- To convert from $km\,h^{-1}$ to $m\,s^{-1}$, divide by 3.6.

2.2 Review *continued*

KEY QUESTIONS

1 A girl swims 10 lengths of a 25 m pool. Which one or more of the following statements correctly describes her distance travelled and displacement?

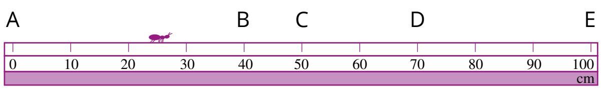
A Her distance travelled is zero.

B Her displacement is zero.

C Her distance travelled is 250 m.

D Her displacement is 250 m.

2 An insect is walking back and forth along a metre ruler, as show in the figure below. Taking the right as positive, determine both the size of the displacement and the distance travelled by the insect as it travels on the following paths.



a A to B

b C to B

c C to D

d C to E and then to D.

3 During a training ride, a cyclist rides 50 km north, then 30 km south.

a What is the distance travelled by the cyclist during the ride?

b What is the displacement of the cyclist for this ride?

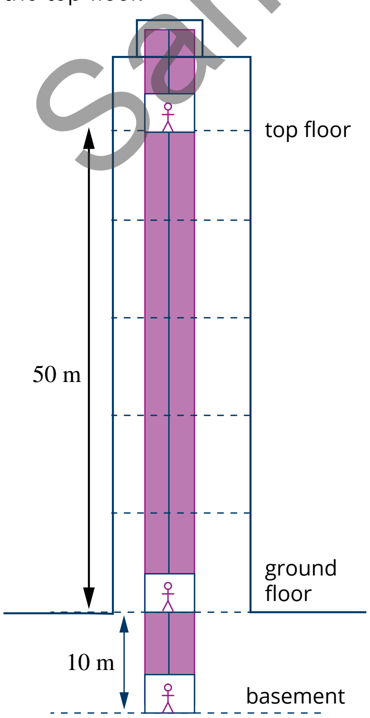
4 A lift in a city building, shown in the figure below, carries a passenger from the ground floor down to the basement, then up to the top floor.

a What is the displacement of the lift as it travels from the ground floor to the basement?

b What is the displacement of the lift as it travels from the basement to the top floor?

c What is the distance travelled by the lift during this entire trip?

d What is the displacement of the lift during this entire trip?



5 A car travelling at a constant speed was timed over 400 m and was found to cover the distance in 12 s.

a What was the car's average speed?

b The driver was distracted and his reaction time was 0.75 s before applying the brakes. How far did the car travel in this time?

6 A cyclist travels 25 km in 90 minutes.

a What is her average speed in $km\,h^{-1}$?

b What is her average speed in $m\,s^{-1}$?

7 Liam pushes his toy truck 5 m east, then stops it and pushes it 4 m west. The entire motion takes 10 seconds.

a What is the truck's average speed?

b What is the truck's average velocity?

8 An athlete in training for a marathon runs 10 km north along a straight road before realising that she has dropped her drink bottle. She turns around and runs back 3 km to find her bottle, then resumes running in the original direction. After running for 1.5 h, the athlete stops when she is 15 km from her starting position.

a What is the distance travelled by the athlete during the run?

b What is the athlete's displacement during the run?

c What is the average speed of the athlete in $km\,h^{-1}$?

d What is the athlete's average velocity in $km\,h^{-1}$?

2.3 Acceleration

PHYSICS INQUIRY CCT N

Modelling acceleration

How is the motion of an object moving in a straight line described and predicted?

COLLECT THIS...

- 5 large metal nuts
- 5 m length of string
- metal baking tray
- ruler or measuring tape

DO THIS...

1 Tie one nut onto the end of the string.
2 Thread the other nuts onto the string one at a time, tying the string to fix them at 10 cm intervals.
3 Place the metal baking tray on the ground, upside down.
4 Standing above the tray, hold the string so that the first nut is just resting on the tray.
5 Drop the string and listen to the beats the nuts make as they hit the tray.
6 Using trial and error, adjust the position of the nuts on the string so they create equally spaced beats when they hit the baking tray.

RECORD THIS...

Present your results in a table.

Describe the spacing between each nut that produced equally spaced beats.

REFLECT ON THIS...

How is the motion of an object moving in a straight line described and predicted?

Explain why the pattern observed in this experiment was created.

Acceleration is a measure of how quickly velocity changes. When you are in a car that speeds up or slows down, you experience acceleration. In an aircraft taking off along a runway, you experience a much greater acceleration. Because velocity has magnitude and direction, acceleration can be caused by a change in speed or a change in direction. In this section you will look at the simple case of acceleration caused by a change in velocity while travelling in a straight line.

FINDING THE CHANGE IN VELOCITY AND SPEED

The velocity and speed of everyday objects are changing all the time. Examples of these are when a car moves away as the traffic lights turn green, when a tennis ball bounces or when you travel on a rollercoaster.

If the initial and final velocity of an object are known, its change in velocity can be calculated. To find the change in any physical quantity, including speed and velocity, the initial value is subtracted from the final value.

Vector subtraction was covered in detail in Section 2.1.

Change in velocity is the final velocity minus the initial velocity:

$$\Delta\vec{v} = \vec{v} - \vec{u}$$

where $\vec{u}$ is the initial velocity in m s^{-1}

$\vec{v}$ is the final velocity in m s^{-1}

$\Delta\vec{v}$ is the change in velocity in m s^{-1}.

Because velocity is a vector, this should be done using vector subtraction. Like all vectors, velocity must include a direction.

Change in speed is the final speed minus the initial speed:

$$\Delta v = v - u$$

where u is the initial speed in m s^{-1}

v is the final speed in m s^{-1}

Δv is the change in speed in m s^{-1}.

Since speed is a scalar, direction is not required.

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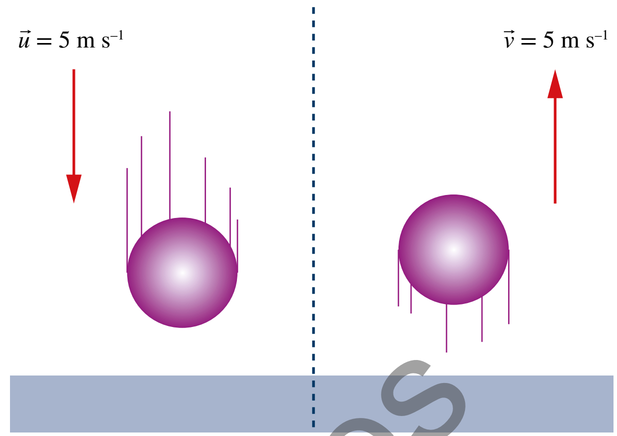
Worked example 2.3.1

CHANGE IN SPEED AND VELOCITY PART 1

A ball is dropped onto a concrete floor and strikes the floor at 5.0 m s^{-1}. It then rebounds at 5.0 m s^{-1}.



a What is the change in speed of the ball?	
Thinking	**Working**
Find the values for the initial speed and the final speed of the ball.	u = 5.0 m s^{-1} v = 5.0 m s^{-1}
Substitute the values into the change in speed equation: $\Delta v = v - u$	$\Delta v = v - u$ $= (5.0) - (5.0)$ $= 0$ m s^{-1}

b What is the change in velocity of the ball?	
Thinking	**Working**
Velocity is a vector. Apply the sign convention to replace the directions.	$\vec{u}$ = 5.0 m s^{-1} down = −5.0 m s^{-1} $\vec{v}$ = 5.0 m s^{-1} up = +5.0 m s^{-1}
As this is a vector subtraction, reverse the direction of u to get $-\vec{u}$.	$\vec{u}$ = −5.0 m s^{-1}, therefore $-\vec{u}$ = +5.0 m s^{-1}
Substitute the values into the change in velocity equation: $\Delta\vec{v} = \vec{v} + (-\vec{u})$	$\Delta\vec{v} = \vec{v} + (-\vec{u})$ $= (+5.0) + (+5.0)$ = +10 m s^{-1}
Apply the sign convention to describe the direction.	$\Delta\vec{v}$ = 10.0 m s^{-1} up

Worked example: Try yourself 2.3.1

CHANGE IN SPEED AND VELOCITY PART 1

A ball is dropped onto a concrete floor and strikes the floor at 9.0 m s^{-1}. It then rebounds at 7.0 m s^{-1}.

a What is the change in speed of the ball?

b What is the change in velocity of the ball?

ACCELERATION

Consider the following information about the velocity of a car that starts from rest, as shown in Figure 2.3.1. The velocity of the car increases by 10 km h^{-1} to the right each second. If right is taken to be the positive direction, the car's velocity changes by +10 km h^{-1} per second, or +10 km h^{-1} s^{-1}.

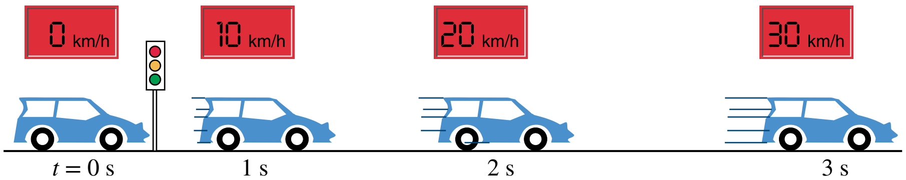


FIGURE 2.3.1 A car's acceleration as its velocity increased from 0 km h^{-1} to +30 km h^{-1}.

The athlete in Figure 2.3.2 takes 3 seconds to come to a stop at the end of a race. The velocity of the athlete changes by −2 m s^{-1} to the right each second. If right is taken to be the positive direction, the athlete's acceleration is −2 metres per second per second, or −2 m s^{-2}.

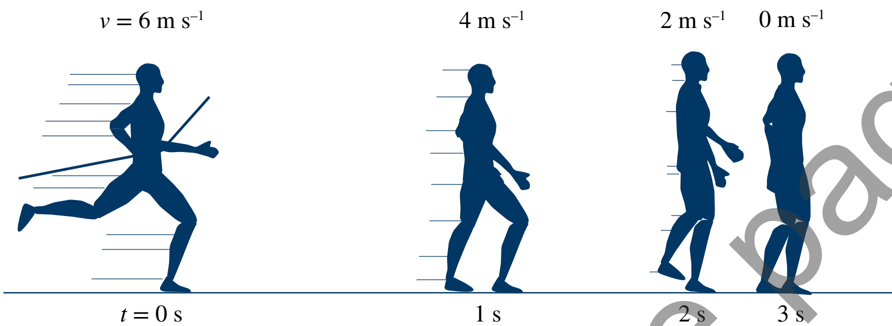


FIGURE 2.3.2 The velocity of the athlete changes by −2 m s^{-1} each second. The acceleration is −2 m s^{-2}.

When the direction of motion is taken to be the positive direction, a negative acceleration means that the object is slowing down in the direction of travel, like the athlete in Figure 2.3.2. A negative acceleration can also mean the object is speeding up but in the opposite direction.

Because acceleration is a vector quantity, a vector diagram can be used to find the resultant acceleration of an object.

Average acceleration

Like speed and velocity, the average acceleration of an object can also be calculated. To do this you need to known how long the change in velocity lasted.

Average acceleration, $\vec{a}_{av}$, is the rate of change of velocity:

$$\vec{a}_{av} = \frac{\text{change in velocity}}{\text{change in time}} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}-\vec{u}}{\Delta t}$$

where $\vec{v}$ is the final velocity in m s^{-1}

$\vec{u}$ is the initial velocity in m s^{-1}

Δt is the time interval in seconds.

PHYSICS IN ACTION ICT

Human acceleration

In the 1950s the United States Air Force used rocket sleds (Figure 2.3.3) to study the effects of extremely large accelerations on humans, with the aim of improving the chances of pilots surviving crashes. At that time it was thought that humans could not survive accelerations above about 175 m s^{-2}, so aircraft seats, harnesses and cockpits were not designed to withstand larger accelerations.

One volunteer, Colonel John Stapp, was strapped into a sled and accelerated to speeds of over 1000 km h^{-1} in a very short time. Water scoops were used to stop the sled in less than 2 seconds, producing a deceleration of more than 450 m s^{-2}. The effects of these massive accelerations are evident on his face (Figure 2.3.4).

The results showed that humans could survive much higher decelerations than previously thought, and that the mechanical failure of seats, harnesses and cockpit structures were major causes of deaths in aircraft accidents.

FIGURE 2.3.3 A rocket-powered sled used to test the effects of acceleration on humans.

FIGURE 2.3.4 Photos showing the distorted face of Colonel John Stapp during a sled run.

Worked example 2.3.2

CHANGE IN SPEED AND VELOCITY PART 2

A ball is dropped onto a concrete floor and strikes the floor at 5.0 m s^{-1}. It then rebounds at 5.0 m s^{-1}. The contact with the floor lasts for 25 milliseconds. What is the average acceleration of the ball during its contact with the floor?

Thinking	Working
Note the values you will need in order to find the average acceleration (initial velocity, final velocity and time). Convert milliseconds into seconds by dividing by 1000. (Note that $\Delta\vec{v}$ was calculated for this situation in the previous Worked example.)	$\vec{u} = -5$ m s^{-1} $-\vec{u} = 5$ m s^{-1} $\vec{v} = 5$ m s^{-1} $\Delta\vec{v} = 10$ m s^{-1} up $\Delta t = 25$ ms $= 0.025$ s
Substitute the values into the average acceleration equation.	$\vec{a}_{av} = \frac{\text{change in velocity}}{\text{time taken}}$ $= \frac{\Delta\vec{v}}{\Delta t}$ $= \frac{10}{0.025}$ $= 400$ m s^{-2}
Acceleration is a vector, so you must include a direction in your answer.	$\vec{a}_{av} = 400$ m s^{-2} up

Worked example: Try yourself 2.3.2

CHANGE IN SPEED AND VELOCITY PART 2

A ball is dropped onto a concrete floor and strikes the floor at $9.0\,m\,s^{-1}$. It then rebounds at $7.0\,m\,s^{-1}$. The contact time with the floor is 35 ms. What is the average acceleration of the ball during its contact with the floor?

2.3 Review

SUMMARY

- Change in speed is a scalar calculation:
  Δv = final speed – initial speed = $v - u$
- Change in velocity is a vector calculation:
  $\Delta\vec{v}$ = final velocity – initial velocity = $\vec{v} - \vec{u}$
- Acceleration is usually measured in metres per second per second ($m\,s^{-2}$).
- Acceleration is a vector. The average acceleration of a body, $\vec{a}_{av}$, is defined as the rate of change of velocity:
  $\vec{a}_{av} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}-\vec{u}}{\Delta t}$

KEY QUESTIONS

1 A radio-controlled car is travelling east at $10\,km\,h^{-1}$. It runs over some sand and slows down to $3\,km\,h^{-1}$ east. What is its change in speed?

2 A lump of Blu Tack falling vertically hits the ground at $5.0\,m\,s^{-1}$ without rebounding. What is its change in velocity during the collision?

3 A ping pong ball hits the floor vertically at $5.0\,m\,s^{-1}$ and rebounds directly upwards at $3.0\,m\,s^{-1}$. What is its change in velocity during the bounce?

4 While playing soccer, Ashley is running north at $7.5\,m\,s^{-1}$. He slides along the ground and stops in 1.5 s. What is his average acceleration as he slides to a stop?

5 Olivia launches a model rocket vertically and it reaches a speed of $150\,km\,h^{-1}$ after 3.5 s. What is the magnitude of its average acceleration in $km\,h^{-1}\,s^{-1}$?

6 A squash ball travelling east at $25\,m\,s^{-1}$ strikes the front wall of the court and rebounds at $15\,m\,s^{-1}$ west. The contact time between the wall and the ball is 0.050 s. Use vector diagrams, where appropriate, to help you with your calculations.

a What is the change in speed of the ball?

b What is the change in velocity of the ball?

c What is the magnitude of the average acceleration of the ball during its contact with the wall?

7 A greyhound starts from rest and accelerates uniformly. Its velocity after 1.2 s is $8.0\,m\,s^{-1}$ south.

a What is the change in speed of the greyhound?

b What is the change in velocity of the greyhound?

c What is the acceleration of the greyhound?

Chapter review

02

KEY TERMS

acceleration
air resistance
centre of mass
collinear
dimension
dimensional analysis
direction convention
displacement
distance travelled
free-fall
magnitude
newton
position
rectilinear
resultant
scalar
speed
unit
vector
vector diagram
vector notation
velocity

KEY QUESTIONS

1 Select the scalar quantities in the list below. (There may be more than one answer.)
A force
B time
C acceleration
D mass

2 Select the vector quantities in the list below. (There may be more than one answer.)
A displacement
B distance
C volume
D velocity

3 A basketballer applies a force with his hand to bounce the ball. Describe how a vector can be drawn to represent this situation.

4 Vector arrow A is drawn twice the length of vector arrow B. What does this mean?

5 A car travels 15 m s^{-1} north and another travels 20 m s^{-1} south. Why is a sign convention often used to describe vectors like these?

6 If the vector 20 N forwards is written as –20 N, how would you write a vector representing 80 N backwards?

7 Add the following force vectors using a number line: 3 N left, 2 N right, 6 N right. Then also draw and describe the resultant force vector.

8 Determine the resultant vector of the following motion: 45.0 m forwards, then 70.5 m backwards, then 34.5 m forwards, then 30.0 m backwards.

9 Determine the change in velocity of a bird that changes from flying 3 m s^{-1} to the right to flying 3 m s^{-1} to the left.

10 A car travels at 95 km h^{-1} along a freeway. What is its speed in m s^{-1}?

11 A cyclist travels at 15 m s^{-1} during a sprint finish. What is this speed in km h^{-1}?

The following information relates to questions 12 and 13.
An athlete in training for a marathon runs 15 km north along a straight road before realising that she has dropped her drink bottle. She turns around and runs back 5 km to find her bottle, then resumes running in the original direction. After running for 2.0 hours, the athlete reaches 20 km from her starting position and stops.

12 Calculate the average speed of the athlete in km h^{-1}.

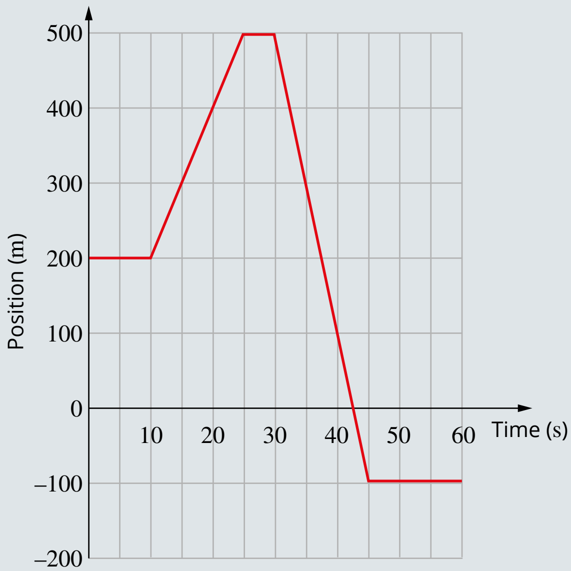
13 Calculate her average velocity in:
a km h^{-1}
b m s^{-1}.

14 A ping pong ball is falling vertically at 6.0 m s^{-1} as it hits the floor. It rebounds at 4.0 m s^{-1} up. What is its change in speed during the bounce?

15 A car is moving in a positive direction. It approaches a red light and slows down. Which of the following statements correctly describes its acceleration and velocity as it slows down?
A The car has positive acceleration and negative velocity.
B The car has negative acceleration and positive velocity.
C Both the velocity and acceleration of the car are positive.
D Both the velocity and acceleration of the car are negative.

16 A skier is travelling along a horizontal ski run at a speed of 15 m s^{-1}. After falling over, the skier takes 2.5 s to come to rest. Calculate the average acceleration of the skier.

17 The following graph shows the position of a motorcycle along a straight stretch of road as a function of time. The motorcycle starts 200 m north of an intersection.



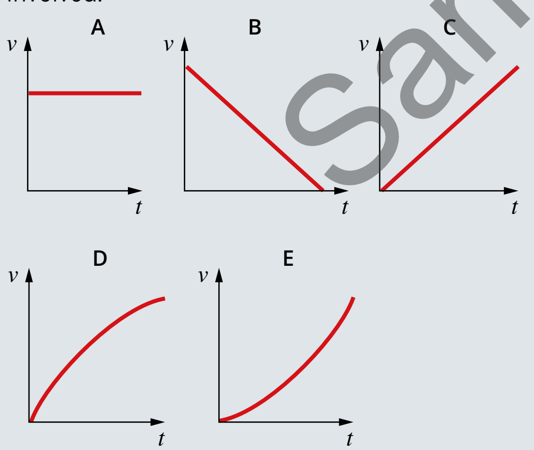
a During what time interval is the motorcycle travelling north?

b During what time interval is the motorcycle travelling south?

c During what time intervals is the motorcycle stationary?

d At what time is the motorcycle passing back through the intersection?

18 For each of the situations listed below, indicate which of the velocity–time graphs best represents the motion involved.

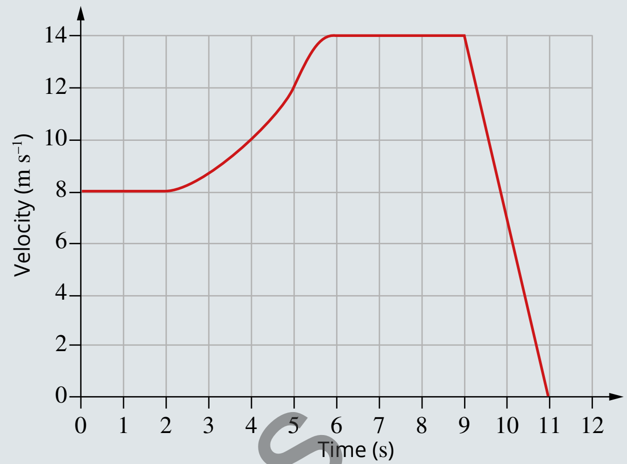


a A car comes to a stop at a red light.

b A swimmer is travelling at a constant speed.

c A motorbike starts from rest with uniform acceleration.

19 The following velocity–time graph is for an Olympic road cyclist as he travels, initially north, along a straight section of track.



a Calculate the displacement of the cyclist during his journey.

b Calculate the magnitude, to three significant figures, of the average velocity of the cyclist during this 11.0 s interval.

c Calculate the acceleration of the cyclist at t = 1 s.

d Calculate the acceleration of the cyclist at t = 10 s.

e Which one or more of the following statements correctly describes the motion of the cyclist?

A He is always travelling north.

B He travels south during the final 2 s.

C He is stationary at t = 8 s.

D He returns to the starting point after 11 s.

20 A car starts from rest and has a constant acceleration of 3.5 m s^{-2} for 4.5 s. What is its final speed?

21 A jet-ski starts from rest and accelerates uniformly. If it travels 2.0 m in its first second of motion, calculate:

a its acceleration

b its speed at the end of the first second

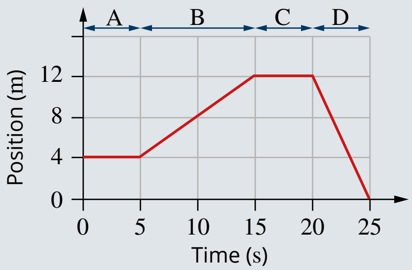
c the distance the jet-ski travels in its second second of motion.

22 A skater is travelling along a horizontal skate rink at a speed of 10 m s^{-1}. After falling over, she takes 10 m to come to rest. Calculate, to two significant figures, the answers to the following questions about the skater's movement.

a What is her average acceleration?

b How long does it take her to come to a stop?

23 The following graph shows the position of Candice as she dances across a stage.



- **a** What is Candice's starting position?
- **b** In which of the sections A–D is Candice at rest?
- **c** In which of the sections A–D is Candice moving in a positive direction, and what is her velocity?
- **d** In which of the sections A–D is Candice moving with a negative velocity and what is the magnitude of this velocity?
- **e** Calculate Candice's average speed during the 25 s motion.

24 Anna is cycling at a constant speed of $12\,\mathrm{m\,s^{-1}}$ when she passes a stationary bus. The bus starts moving just as Anna passes, and it accelerates uniformly at $1.5\,\mathrm{m\,s^{-2}}$.

- **a** When does the bus reach the same speed as Anna?
- **b** How long does the bus take to catch Anna?
- **c** What distance has Anna travelled before the bus catches up?

For the following questions, the acceleration due to gravity is $9.8\,\mathrm{m\,s^{-2}}$ down and air resistance is considered to be negligible.

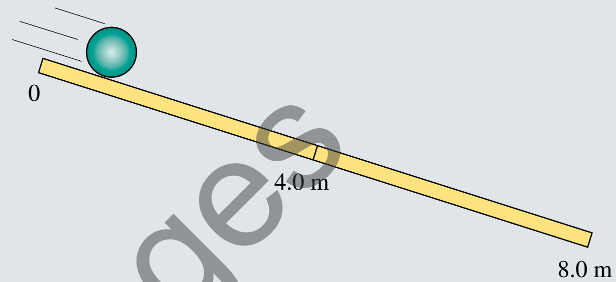
25 Two physics students conduct the following experiment from a very high bridge. Thao drops a 1.5 kg sphere from a height of 60.0 m, while at exactly the same time Benjamin throws a 100 g cube with an initial downwards velocity of $10.0\,\mathrm{m\,s^{-1}}$ from a point 10.0 m above Thao.

- **a** How long does it take the sphere to reach the ground?
- **b** How long does it take the cube to reach the ground?

26 At the start of an AFL football match, the umpire bounces the ball so that it travels vertically upwards and reaches a height of 15.0 m.

- **a** How long does the ball take to reach this maximum height?
- **b** One of the ruckmen is able to leap and reach to a height of 4.0 m with his hand. How long after the bounce should this ruckman try to make contact with the ball?

27 A billiard ball rolls from rest down a smooth ramp that is 8.0 m long. The acceleration of the ball is constant at $2.0\,\mathrm{m\,s^{-2}}$.



- **a** What is the speed of the ball when it is halfway down the ramp?
- **b** What is the final speed of the ball?
- **c** How long does the ball take to roll the first 4.0 m?
- **d** How long does the ball take to travel the final 4.0 m?

28 Four metal bolts are tied to a piece of rope. The rope is dropped and the metal bolts hitting the ground create a steady rhythm, making a sound at 0.25 second intervals. Calculate the distances between each of the metal bolts.

29 After completing the activity on page 63, reflect on the following inquiry question: How is the motion of an object moving in a straight line described and predicted?