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Module 3: Waves and thermodynamics

Module 4: Electricity and magnetism

How to use this book

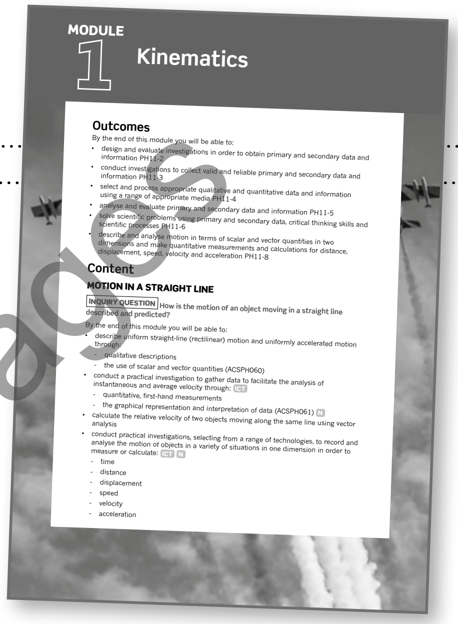
The *Pearson Physics 11 New South Wales Skills and Assessment Book* takes an intuitive, self-paced approach to science education that ensures every student has opportunities to practise, apply and extend their learning through a range of supportive and challenging activities. While offering opportunities for reinforcement of key concepts, knowledge and skills, these activities enable flexibility in the approach to teaching and learning.

Explicit scaffolding makes learning objectives clear, and there are regular opportunities for student reflection and self-evaluation at the end of individual activities throughout the book. Students are also guided in self-reflection at the end of each module. There are rich opportunities to take the content further with the explicit coverage of Working scientifically skills and key knowledge in the depth studies.

This resource has been written to the new New South Wales Physics Stage 6 Syllabus and addresses the first four modules of the syllabus. Each module consists of five main sections:

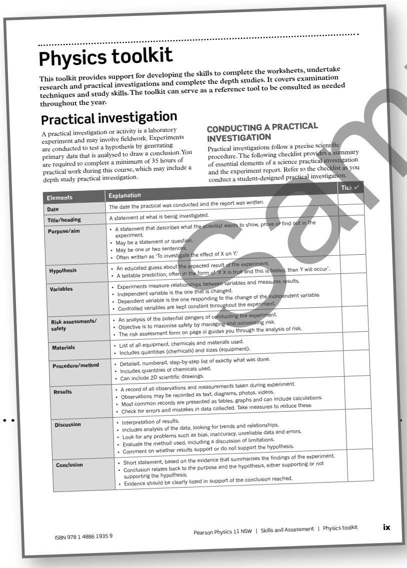
- key knowledge
- worksheets
- practical activities
- depth study
- module review questions.

Explore how to use this book below.



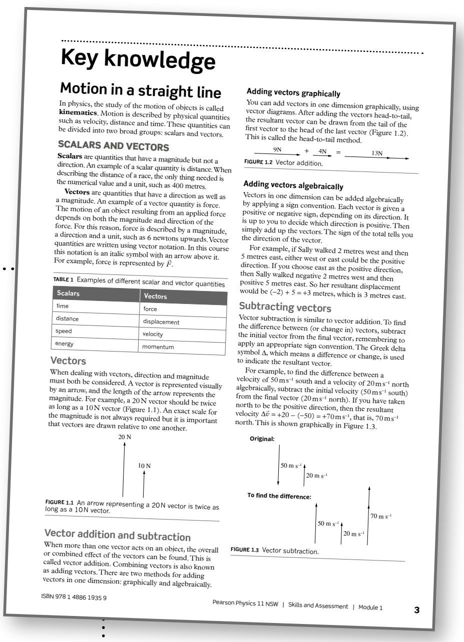
Physics toolkit

The Physics toolkit supports development of the skills and techniques needed to undertake practical investigations secondary-sourced investigations and depth studies, and covers examination techniques and study skills. It also includes checklists, models, exemplars and scaffolded steps. The toolkit can serve as a reference tool, to be consulted as needed.



Module opener

Each book is divided to follow the four modules of the syllabus, with the module opener linking the module content to the syllabus.



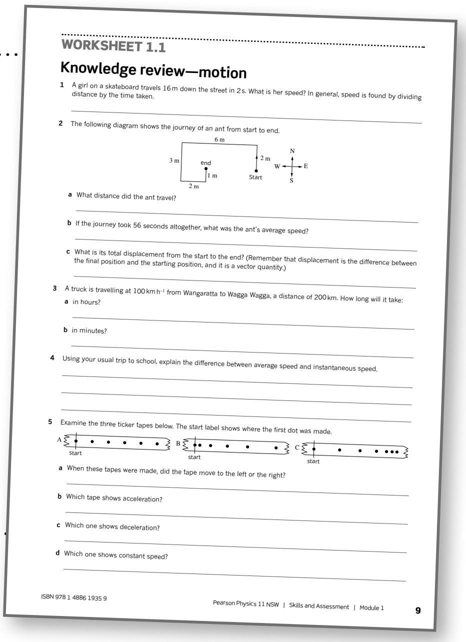
Key knowledge

Each module begins with a key knowledge section. The key knowledge consists of a set of succinct summary notes that cover the key knowledge set out in each module of the syllabus. This section is highly illustrative and written in a straightforward style to assist students of all reading abilities. Key terms are bolded for ease of navigation. It also serves as a ready reference for completing the worksheets and practical activities.

Worksheets

A diverse offering of instructive and self-contained worksheets is included in each module. Common to all modules are the initial 'Knowledge review' worksheet to activate prior knowledge, a 'Literacy review' worksheet to explicitly build understanding and application of scientific terminology, and finally a 'Thinking about my learning' worksheet, which students can use for reflection and self-assessment. Other worksheet types provide opportunities to revise, consolidate and further student understanding.

All worksheets function as formative assessment and are clearly aligned to the syllabus. A range of questions building from foundation to challenging are included within worksheets.


WORKSHEET 1.1

Knowledge review—motion

1 A girl on a skateboard travels 16 m down the street in 2 s. What is her speed? In general, speed is found by dividing distance by the time taken.

2 The following diagram shows the journey of an ant from start to end.

a What distance did the ant travel?

b If the journey took 56 seconds altogether, what was the ant's average speed?

c What is its total displacement from the start to the end? (Remember that displacement is the difference between the final position and the starting position, and it is a vector quantity.)

3 A truck is travelling at 100 km h⁻¹ from Wangaratta to Wagga Wagga, a distance of 200 km. How long will it take:

a in hours?

b in minutes?

4 Using your usual trip to school, explain the difference between average speed and instantaneous speed.

5 Examine the three ticker tapes below. The start label shows where the first dot was made.

a When these tapes were made, did the tape move to the left or the right?

b Which tape shows acceleration?

c Which one shows deceleration?

d Which one shows constant speed?

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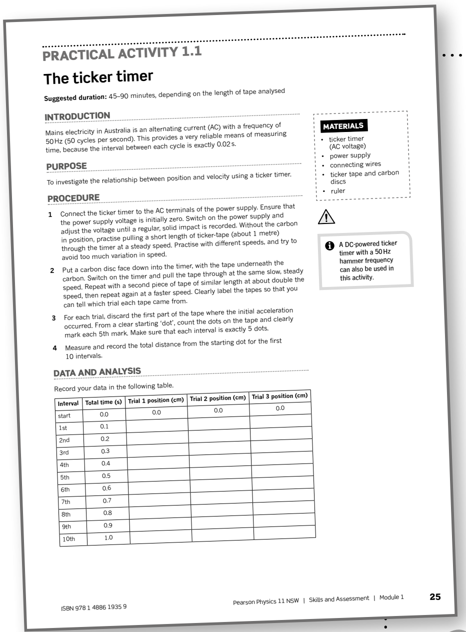
PRACTICAL ACTIVITY 1.1

The ticker timer

Suggested duration: 45–90 minutes, depending on the length of tape analysed

INTRODUCTION

Mains electricity in Australia is an alternating current (AC) with a frequency of 50 Hz (50 cycles per second). This provides a very reliable means of measuring time, because the interval between each cycle is exactly 0.02 s.

PURPOSE

To investigate the relationship between position and velocity using a ticker timer.

MATERIALS

- ticker timer (AC voltage)
- power supply
- connecting wires
- ticker tape and carbon discs
- ruler

PROCEDURE

1 Connect the ticker timer to the AC terminals of the power supply. Ensure that the power supply voltage is initially zero. Switch on the power supply and adjust the voltage until a regular, solid impact is recorded. Without the carbon in position, practise pulling a short length of ticker-tape (about 1 metre) through the timer at a steady speed. Practise with different speeds, and try to avoid too much variation in speed.

2 Put a carbon disc face down into the timer, with the tape underneath the carbon. Switch on the timer and pull the tape through at the same slow, steady speed. Repeat with a second piece of tape of similar length at about double the speed, then repeat again at a faster speed. Clearly label the tapes so that you can tell which trial each tape came from.

3 For each trial, discard the first part of the tape where the initial acceleration occurred. From a clear starting 'dot', count the dots on the tape and clearly mark each 5th mark. Make sure that each interval is exactly 5 dots.

4 Measure and record the total distance from the starting dot for the first 10 intervals.

A DC-powered ticker timer with a 50 Hz hammer frequency can also be used in this activity.

DATA AND ANALYSIS

Record your data in the following table.

Interval	Total time (s)	Trial 1 position (cm)	Trial 2 position (cm)	Trial 3 position (cm)
start	0.0	0.0	0.0	0.0
1st	0.1			
2nd	0.2			
3rd	0.3			
4th	0.4			
5th	0.5			
6th	0.6			
7th	0.7			
8th	0.8			
9th	0.9			
10th	1.0			

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Practical activities

Practical activities give students the opportunity to complete practical work related to the various themes covered in the syllabus. All practical activities referenced in outcomes within the syllabus have been covered. Across the suite of practical activities, students have opportunities to design, conduct, evaluate, gather and analyse data, appropriately record results and prepare evidence-based conclusions. Students have opportunities to evaluate safety and risk, and identify any potential hazards.

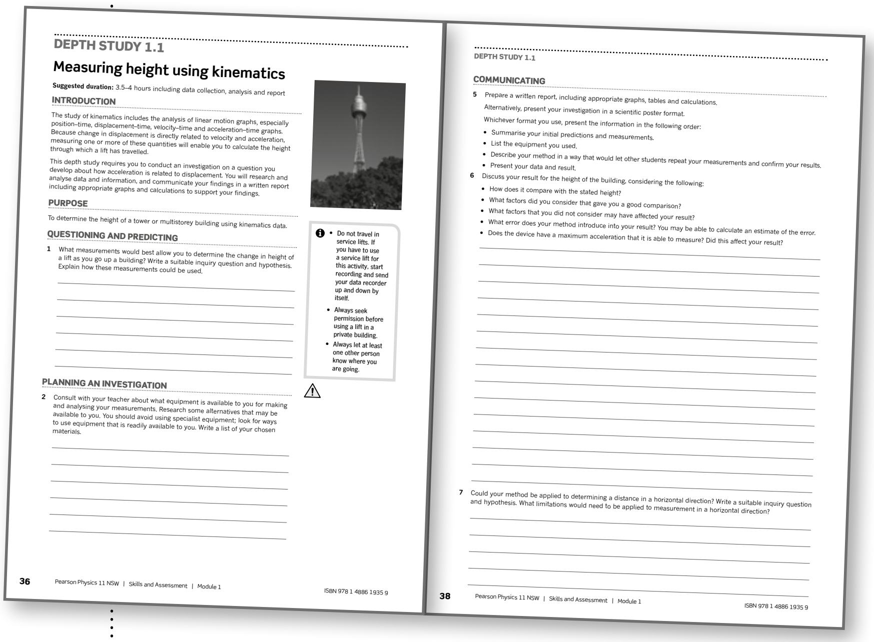
Each practical activity includes a suggested duration. Along with the depth studies, the practical activities meet the 35 hours of practical work mandated at Year 11 in the syllabus. Where there is key knowledge that will support the completion of a practical activity, students are referred back to it.

Like the worksheets, the practical activities include a range of questions, building from foundation to challenging.

Depth study

Each module contains at least one suggested depth study. The depth studies allow further development of one or more concepts found within or inspired by the syllabus. They allow students to acquire a depth of understanding and take responsibility for their own learning, and promote differentiation and engagement.

Each depth study allows for the demonstration of a range of Working scientifically skills, with all depth studies addressing the Working scientifically outcomes of Questioning and predicting and Communicating. A minimum of two additional Working scientifically skills and at least one Knowledge and Understanding outcome are also assessed.


DEPTH STUDY 1.1

Measuring height using kinematics

Suggested duration: 3.5–4 hours including data collection, analysis and report

INTRODUCTION

PURPOSE

To determine the height of a tower or multistorey building using kinematics data.

QUESTIONING AND PREDICTING

1 What measurements would best allow you to determine the change in height of a lift as you go up a building? Write a suitable inquiry question and hypothesis. Explain how these measurements could be used.

PLANNING AN INVESTIGATION

2 Consult with your teacher about what equipment is available to you for making and analysing your measurements. Research some alternatives that may be available to you. You should avoid using specialist equipment; look for ways to use equipment that is readily available to you. Write a list of your chosen materials.

- Do not travel in service lifts. If you have to use a service lift for this activity, start recording and send your data recorder up and down by itself.
- Always seek permission before using a lift in a private building.
- Always let at least one other person know where you are going.

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DEPTH STUDY 1.1

COMMUNICATING

5 Prepare a written report, including appropriate graphs, tables and calculations. Alternatively, present your investigation in a scientific poster format. Whichever format you use, present the information in the following order:
- Summarise your initial predictions and measurements.
- List the equipment you used.
- Describe your method in a way that would let other students repeat your measurements and confirm your results.
- Present your data and result.

6 Discuss your result for the height of the building, considering the following:
- How does it compare with the stated height?
- What factors did you consider that gave you a good comparison?
- What factors that you did not consider may have affected your result?
- What error does your method introduce into your result? You may be able to calculate an estimate of the error.
- Does the device have a maximum acceleration that it is able to measure? Did this affect your result?

7 Could your method be applied to determining a distance in a horizontal direction? Write a suitable inquiry question and hypothesis. What limitations would need to be applied to measurement in a horizontal direction?

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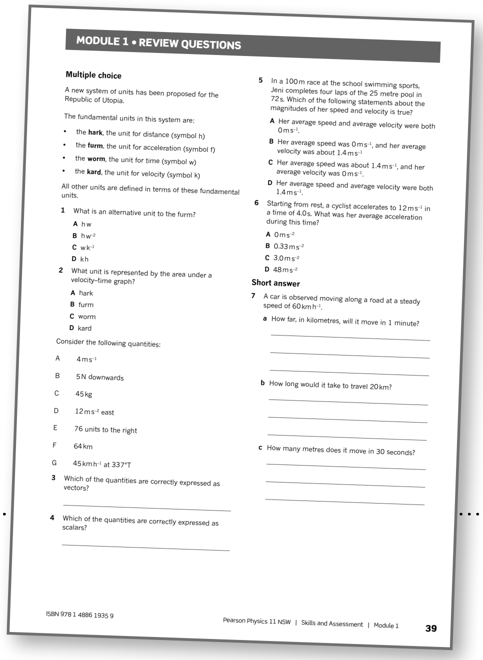
Module review questions

Each module finishes with a comprehensive set of questions, consisting of multiple choice, short answer and extended response, which helps students to draw together their knowledge and understanding and apply it to these styles of question.



MODULE 1 • REVIEW QUESTIONS

Multiple choice

A new system of units has been proposed for the Republic of Utopia.

The fundamental units in this system are:

- the **hark**, the unit for distance (symbol h)
- the **furm**, the unit for acceleration (symbol f)
- the **worm**, the unit for time (symbol w)
- the **kard**, the unit for velocity (symbol k)

All other units are defined in terms of these fundamental units.

1 What is an alternative unit to the furm?

A $h\,w$
B $h\,w^{-2}$
C $w\,k^{-1}$
D $k\,h$

2 What unit is represented by the area under a velocity–time graph?

A hark
B furm
C worm
D kard

Consider the following quantities:

A $4\,m\,s^{-1}$
B 5 N downwards
C 45 kg
D $12\,m\,s^{-2}$ east
E 76 units to the right
F 64 km
G $45\,km\,h^{-1}$ at 337°T

3 Which of the quantities are correctly expressed as vectors?

______

4 Which of the quantities are correctly expressed as scalars?

______

5 In a 100 m race at the school swimming sports, Jeni completes four laps of the 25 metre pool in 72 s. Which of the following statements about the magnitudes of her speed and velocity is true?

A Her average speed and average velocity were both $0\,m\,s^{-1}$.
B Her average speed was $0\,m\,s^{-1}$, and her average velocity was about $1.4\,m\,s^{-1}$
C Her average speed was about $1.4\,m\,s^{-1}$, and her average velocity was $0\,m\,s^{-1}$.
D Her average speed and average velocity were both $1.4\,m\,s^{-1}$.

6 Starting from rest, a cyclist accelerates to $12\,m\,s^{-1}$ in a time of 4.0 s. What was her average acceleration during this time?

A $0\,m\,s^{-2}$
B $0.33\,m\,s^{-2}$
C $3.0\,m\,s^{-2}$
D $48\,m\,s^{-2}$

Short answer

7 A car is observed moving along a road at a steady speed of $60\,km\,h^{-1}$.

a How far, in kilometres, will it move in 1 minute?

______

b How long would it take to travel 20 km?

______

c How many metres does it move in 30 seconds?

______

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Rating my learning

This feature is an innovative tool that appears at the bottom of the final page of most worksheets and all practical activities. It provides students with the opportunity for self-reflection and self-assessment. It encourages them to look ahead to how they can continue to improve, and it helps them to identify focus areas for further skill and knowledge development.

The teacher may choose to use student responses to the 'Rating my learning' feature as a formative assessment tool. At a glance, teachers can assess which topics and which students need intervention for improvement.

RATING MY LEARNING	My understanding improved	Not confident ◯ ◯ ◯ ◯ ◯ Very confident	I answered questions without help	Not confident ◯ ◯ ◯ ◯ ◯ Very confident	I corrected my errors without help	Not confident ◯ ◯ ◯ ◯ ◯ Very confident

Icons and features

The 2018 New South Wales Physics Stage 6 Syllabus Learning Across the Curriculum content is addressed and identified.

AHC A CC CCT DD EU ICT
IU L N PSC S WE

The **safety icon** highlights significant hazards, indicating caution is needed.

The **safety glasses icon** highlights that protective eyewear is to be worn during the practical activity.

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

> Consult the manuals for your electronic equipment or see your teacher for the options to set these values with your equipment and software.

Teacher Support

Comprehensive answers and fully worked solutions for all worksheets, practical activities, depth studies and module review questions are provided via the *Pearson Physics 11 New South Wales* Teacher Support. An editable suggested assessment rubric for depth studies is also provided.

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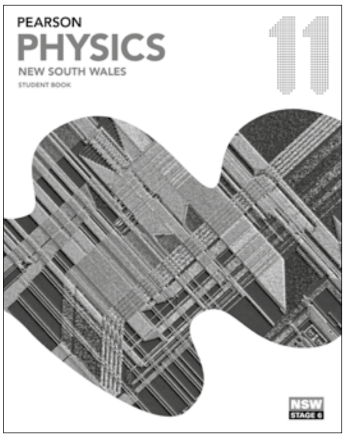
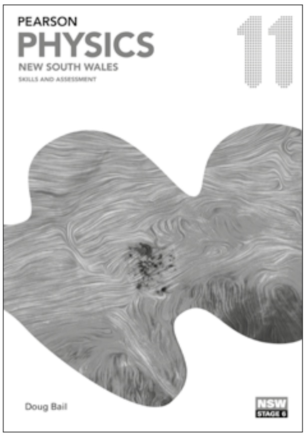


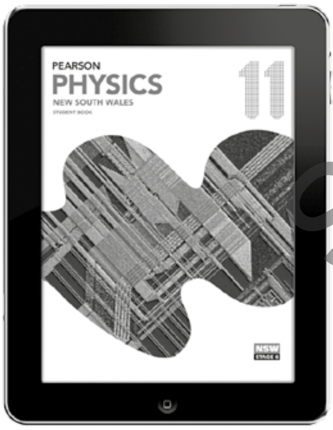
Student Book

Pearson Physics 11 New South Wales has been written to fully align with the new New South Wales Physics Stage 6 Syllabus. 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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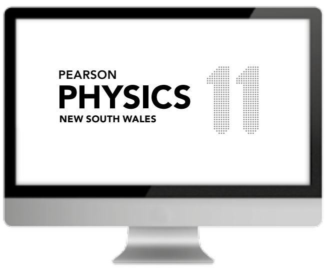

Teacher Support

The Teacher Support available includes syllabus grids and a scope and sequence plan to support teachers with programming. It also provides the 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's checklist and recipes are available for all practical activities. Depth studies are supported with suggested assessment rubrics and exemplar answers.

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Module 1 • Kinematics

- 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

MOTION ON A PLANE

INQUIRY QUESTION **How is the motion of an object that changes its direction of movement on a plane described?**

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

- analyse vectors in one and two dimensions to:
  - resolve a vector into two perpendicular components
  - add two perpendicular vector components to obtain a single vector (ACSPH061) N
- represent the distance and displacement of objects moving on a horizontal plane using:
  - vector addition
  - resolution of components of vectors (ACSPH060) ICT N
- describe and analyse algebraically, graphically and with vector diagrams, the ways in which the motion of objects changes, including: ICT
  - velocity
  - displacement (ACSPH060, ACSPH061) N
- describe and analyse, using vector analysis, the relative positions and motions of one object relative to another object on a plane (ACSPH061)
- analyse the relative motion of objects in two dimensions in a variety of situations, for example:
  - a boat on a flowing river relative to the bank
  - two moving cars
  - an aeroplane in a crosswind relative to the ground (ACSPH060, ACSPH132) ICT N

Key knowledge

Motion in a straight line

In physics, the study of the motion of objects is called **kinematics**. Motion is described by physical quantities such as velocity, distance and time. These quantities can be divided into two broad groups: scalars and vectors.

SCALARS AND VECTORS

Scalars are quantities that have a magnitude but not a direction. An example of a scalar quantity is distance. When describing the distance of a race, the only thing needed is the numerical value and a unit, such as 400 metres.

Vectors are quantities that have a direction as well as a magnitude. An example of a vector quantity is force. The motion of an object resulting from an applied force depends on both the magnitude and direction of the force. For this reason, force is described by a magnitude, a direction and a unit, such as 6 newtons upwards. Vector quantities are written using vector notation. In this course this notation is an italic symbol with an arrow above it. For example, force is represented by $\vec{F}$.

TABLE 1.1 Examples of different scalar and vector quantities

Scalars	Vectors
time	force
distance	displacement
speed	velocity
energy	momentum

Vectors

When dealing with vectors, direction and magnitude must both be considered. A vector is represented visually by an arrow, and the length of the arrow represents the magnitude. For example, a 20 N vector should be twice as long as a 10 N vector (Figure 1.1). An exact scale for the magnitude is not always required but it is important that vectors are drawn relative to one another.

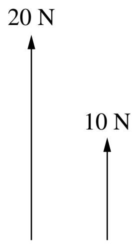

FIGURE 1.1 An arrow representing a 20 N vector is twice as long as a 10 N vector.

Vector addition and subtraction

When more than one vector acts on an object, the overall or combined effect of the vectors can be found. This is called vector addition. Combining vectors is also known as adding vectors. There are two methods for adding vectors in one dimension: graphically and algebraically.

Adding vectors graphically

You can add vectors in one dimension graphically, using vector diagrams. After adding the vectors head-to-tail, the resultant vector can be drawn from the tail of the first vector to the head of the last vector (Figure 1.2). This is called the head-to-tail method.

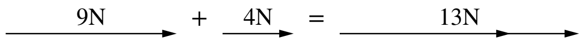

FIGURE 1.2 Vector addition.

Adding vectors algebraically

Vectors in one dimension can be added algebraically by applying a sign convention. Each vector is given a positive or negative sign, depending on its direction. It is up to you to decide which direction is positive. Then simply add up the vectors. The sign of the total tells you the direction of the vector.

For example, if Sally walked 2 metres west and then 5 metres east, either west or east could be the positive direction. If you choose east as the positive direction, then Sally walked negative 2 metres west and then positive 5 metres east. So her resultant displacement would be (–2) + 5 = +3 metres, which is 3 metres east.

Subtracting vectors

Vector subtraction is similar to vector addition. To find the difference between (or change in) vectors, subtract the initial vector from the final vector, remembering to apply an appropriate sign convention. The Greek delta symbol Δ, which means a difference or change, is used to indicate the resultant vector.

For example, to find the difference between a velocity of 50 m s^{-1} south and a velocity of 20 m s^{-1} north algebraically, subtract the initial velocity (50 m s^{-1} south) from the final vector (20 m s^{-1} north). If you have taken north to be the positive direction, then the resultant velocity $\Delta\vec{v}$ = +20 – (–50) = +70 m s^{-1}, that is, 70 m s^{-1} north. This is shown graphically in Figure 1.3.

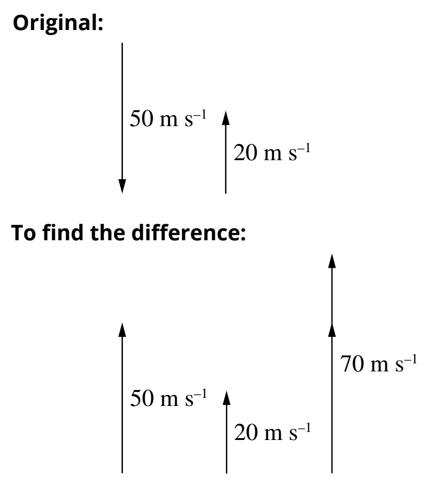

FIGURE 1.3 Vector subtraction

DISPLACEMENT, SPEED AND VELOCITY

In kinematics, the words used to describe motion have very precise meanings that must be understood clearly. Position, distance, displacement, speed and velocity are the focus in this section, because they are all used to describe **rectilinear motion**.

> The motion of an object travelling in a straight line is known as rectilinear motion.

Position

Position defines the location of an object with respect to a defined origin. For example, you might see a bird take off from its nest in front of you and land on a post 100 m to your right. If the nest is considered to be the origin, its final position is 100 m to the right of the origin. It is important to note that the origin can be any reference point; it all depends on the information given, and what you are trying to determine.

Distance and displacement

Distance travelled, d, tells us how far an object has travelled in total, but not the direction. Distance travelled is therefore a scalar.

Displacement, $\vec{s}$, tells us the change in the position of an object, and the direction of the change. Displacement is therefore a vector: $\vec{s}$ = final position − initial position. If the final position is the same as the initial position, it is important to note a distance has been covered but the displacement is zero.

In Figure 1.4, a person practising for a race runs 100 m north to the finish line, then turns around and jogs south for 50 m. The distance they have travelled is therefore 150 m, and their displacement from the start is 50 m north.

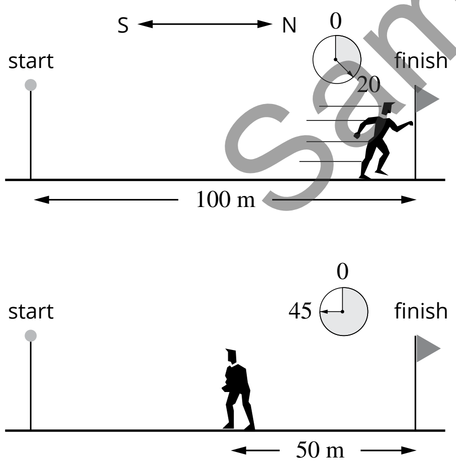

FIGURE 1.4 Distance and displacement

Speed and velocity

In everyday language 'speed' and 'velocity' are often used interchangeably, but in kinematics they are not the same. **Speed** is the rate of change of distance and is a scalar quantity represented by v. **Velocity** is the rate of change of displacement and is a vector quantity represented by $\vec{v}$. Instantaneous speed and velocity are measured at one point in time. Average speed and velocity are measured over a period of time.

> The instantaneous speed of an object is a measure of how fast it is moving at a particular point in time. Its instantaneous velocity has the same magnitude as the instantaneous speed, but also has direction.

The formulae for average speed and average velocity are as follows:

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

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

The SI unit for speed and velocity is metres per second ($m\,s^{-1}$), but kilometres per hour ($km\,hr^{-1}$) is often used when describing the motion of vehicles or aircraft. You can convert from one unit to the other by converting metres to kilometres and seconds to hours (or vice versa), but that can be difficult. Figure 1.5 shows a short cut for converting between these two units.

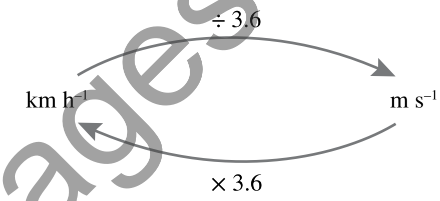

FIGURE 1.5 Unit conversion

> 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.

ACCELERATION

Motion that involves speeding up, slowing down, or changing direction involves acceleration. **Acceleration** is a measure of how quickly velocity changes. It can be calculated if you know the initial velocity and final velocity, and the time taken for the change in velocity.

The formulae for change in speed and change in velocity are as follows:

The change in speed is a scalar calculation:

$$\Delta v = \text{final speed} - \text{initial speed} = v - u$$

The change in velocity is a vector calculation:

$$\Delta\vec{v} = \text{final velocity} - \text{initial velocity} = \vec{v} - \vec{u}$$

If the final velocity is smaller than the initial velocity, the change in velocity is negative, which indicates that the object is slowing down in the direction of travel. This is known as deceleration.

Acceleration is a vector. The average acceleration of an object, $\vec{a}_{av}$, is defined as the rate of change of velocity:

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

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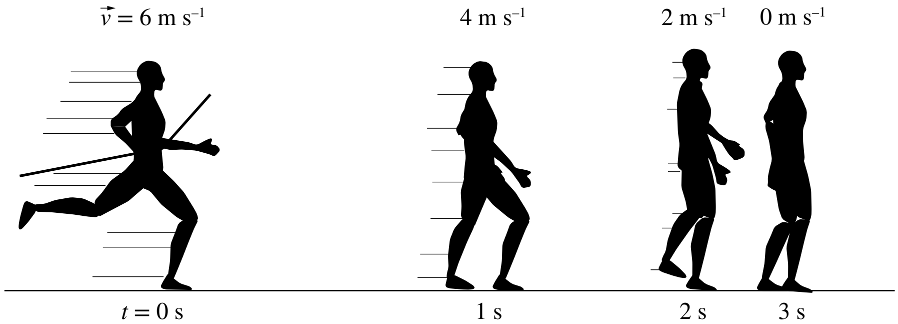

FIGURE 1.6 Negative acceleration, also known as deceleration

The standard unit for acceleration is metres per second squared ($m\,s^{-2}$).

In Figure 1.6, the runner decreased their velocity by $4 - 6 = -2\,m\,s^{-1}$ in the first second of motion after crossing the finish line. In the next second the runner again slowed down by $-2\,m\,s^{-1}$, and again in the third second. This means that during each second their velocity decreased by $2\,m\,s^{-1}$, so their acceleration was $-2\,m\,s^{-1}$ per second, or $-2\,m\,s^{-2}$.

GRAPHING POSITION, VELOCITY AND ACCELERATION OVER TIME

Graphs and tables are often used to represent the motion of an object. Position, velocity or acceleration are plotted on the *y*-axis, against time on the *x*-axis.

A position–time graph shows the position of an object at any given time. Other information about the object's motion can also be derived from a position–time graph:

- the displacement, which is the difference in *y* values between two points on the graph
- the average velocity, which is the gradient of the graph between two points
- the instantaneous velocity, which is the gradient at one point in time (or the tangent to the curve if the graph is not straight).

A velocity–time graph shows the velocity of an object at any given time. Other information can be also be derived from a velocity–time graph:

- the displacement, which is the total area between the graph and the *x*-axis, measured between two points on the graph
- the average acceleration, which is the gradient between two points on the graph
- the instantaneous acceleration, which is the gradient of the graph at one point in time (or the tangent to the curve if the graph is not straight).

The area under an acceleration–time graph is the change in velocity of the object. This is calculated using the same method as determining the displacement from a velocity–time graph.

Consider the position–time graph shown in Figure 1.7, for an object moving in a straight line. The origin of the graph represents the object's initial position.

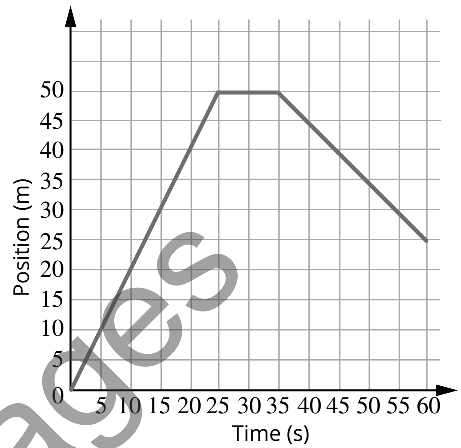

FIGURE 1.7 An example of a position–time graph

The displacement can be determined by reading points off the graph.

$$\vec{s} = \text{final position} - \text{initial position}$$
$$= +25 - 0$$
$$= +25\,m$$

The average velocity can be determined from the gradient, which is the change in displacement over time. For example, in the first 25 seconds the object travelled 50 m in the positive direction, so its average velocity during this time was $\frac{+50\,m}{25\,s} = +2\,m\,s^{-1}$.

Now consider Figure 1.8, which shows a velocity–time graph for an object moving in a straight line.

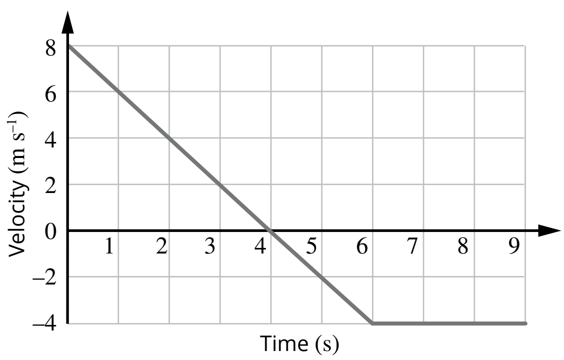

FIGURE 1.8 An example of a velocity–time graph

The average acceleration of the object can be determined from the gradient of the slope, which is the change in velocity over time. For example, in Figure 1.8 during the first 6 seconds of motion the velocity changed from +8 m s^{-1} to −4 m s^{-1}, so:

$$\begin{aligned}\vec{a}_{av} &= \frac{\vec{v}-\vec{u}}{\Delta t}\\ &= \frac{-4-8}{6}\\ &= -2\,\mathrm{m\,s^{-2}}\end{aligned}$$

To calculate the displacement during the whole 9 seconds, the area can be split into two sections: the area above the x-axis (positive) and the area below the x-axis (negative). The area above the x-axis is a triangle, and the area below the x-axis is a trapezium consisting of a triangle (T) and a rectangle (R).

$$\begin{aligned}\text{area}_{\text{above}} &= \frac{1}{2}(b \times h)\\ &= \frac{1}{2}(4 \times +8)\\ &= +16\,\mathrm{m}\end{aligned}$$

$$\begin{aligned}\text{area}_{\text{below}} &= \frac{1}{2}(b_{\mathrm{T}} \times h_{\mathrm{T}}) + (b_{\mathrm{R}} \times h_{\mathrm{R}})\\ &= \frac{1}{2}(2 \times -4) + (3 \times -4)\\ &= -4 + (-12)\\ &= -16\,\mathrm{m}\end{aligned}$$

The total displacement is +16 − 16 = 0 m. (But note that the distance travelled is 16 + 16 = 32 m.)

EQUATIONS OF MOTION

In situations involving straight-line (rectilinear) motion, the equations of motion can be used to find an unknown variable using known variables. These equations can only be used in situations where there is constant acceleration.

> The equations of motion:
> - $\vec{v} = \vec{u} + \vec{a}t$
> - $\vec{s} = \vec{u}t + \frac{1}{2}\vec{a}t^2$
> - $\vec{s} = \vec{v}t - \frac{1}{2}\vec{a}t^2$
> - $\vec{v}^2 = \vec{u}^2 + 2\vec{a}\vec{s}$
> - $\vec{s} = \frac{1}{2}(\vec{u} + \vec{v})t$
>
> where:
>
> $\vec{s}$ is the displacement (in m)
>
> $\vec{u}$ is the initial velocity (in m s^{-1})
>
> $\vec{v}$ is the final velocity (in m s^{-1})
>
> $\vec{a}$ is the acceleration (in m s^{-2})
>
> t is the time (in s).

In solving for the unknown variable, it is important to identify all the known variables in order to select the appropriate equation. For example if the unknown variable is acceleration and the initial velocity, final velocity and displacement are known, the equation $\vec{v}^2 = \vec{u}^2 + 2\vec{a}\vec{s}$ can be used to find the acceleration.

A sign and direction convention for the motion needs to be used with these equations. For example, if the motion is along a north–south line, north is usually taken to be the positive direction.

VERTICAL MOTION

If you throw an object upwards, it will eventually fall back to the ground because of the Earth's gravity. If air resistance is ignored, all objects falling freely near the Earth will move with the same constant acceleration. The acceleration due to gravity is represented by g and is equal to 9.8 m s^{-2} downwards (i.e. towards the centre of the Earth). The motion of an object thrown or fired into the air is often called projectile motion.

The equations of motion can be used to solve vertical motion problems. Upwards is usually considered to be the positive direction. For example, consider an object being thrown vertically upwards with an initial velocity of 30 m s^{-1}. In this problem the only variable given is the initial velocity, but there is also a downwards acceleration of 9.8 m s^{-2} due to gravity. Near the Earth's surface, objects decelerate at 9.8 m s^{-2} going up and accelerate at this same rate going down. There are three other pieces of information that can be useful in solving problems about projectile motion:

- time taken to go up = time taken to come down
- final velocity = − initial velocity
- at the highest point, $\vec{v}$ = 0 m s^{-1}.

Motion on a plane

Analysing motion in one dimension requires only simple mathematics. However, vectors in two dimensions may involve a change in direction, such as walking up a hill or running around a block. In theses cases, more complex methods are needed to describe and analyse motion.

VECTORS IN TWO DIMENSIONS

Graphical analysis

The head-to-tail method used for adding and subtracting vectors in one dimension can also be used to add and subtract vectors in two dimensions. The difference is that the direction of the vectors must be indicated by a bearing or angle instead of a plus or minus sign. Compass bearings (such as south-west or S45°W), true bearings (such as 225°T) or simple angles are used in problems to indicate directions.

In the example in Figure 1.9, the vectors are drawn to a scale of 1 cm for every 5 N. A protractor is needed to draw the 45° angle and measure the angle of the resultant. This method can be used to add or subtract any number of vectors.

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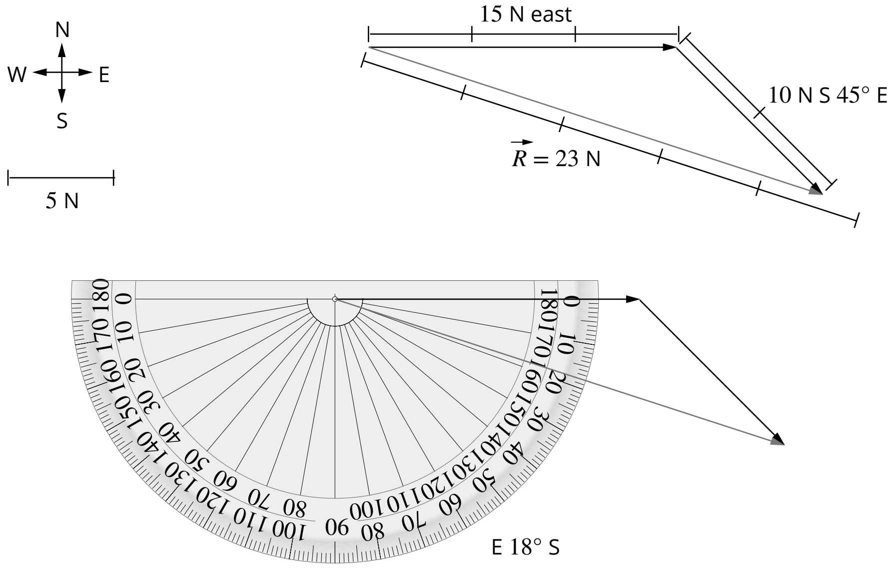

FIGURE 1.9 Graphical method for adding vectors in two dimensions

When only two vectors are involved, an alternative graphical method is to construct a parallelogram from the vectors. In this method the vectors are drawn tail-to-tail. The resultant is then a line drawn from the tails of the vectors to the opposite vertex of the parallelogram. An example of this method is shown in Figure 1.10, with the resultant vector represented by $\vec{R}$.

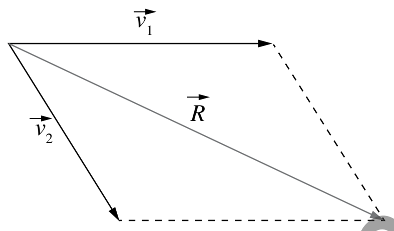

FIGURE 1.10 The parallelogram method for finding a resultant vector

Algebraic analysis

Vectors at right angles to each other can be added and subtracted using Pythagoras' theorem and the trigonometric ratios of a right-angled triangle, as shown in Figure 1.11.

To calculate the magnitude of the resultant vector, Pythagoras' theorem is used:

$$a^2 + b^2 = c^2$$

where c is the length of the hypotenuse, and a and b are the lengths of the other two sides.

To find the direction of the resultant vector, the appropriate trigonometric ratio is used:

$$\sin\theta = \frac{\text{opposite}}{\text{hypotenuse}}$$

$$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}}$$

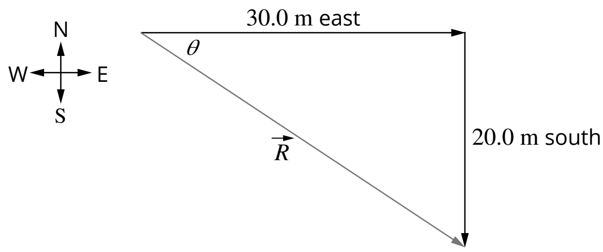

FIGURE 1.11 Geometric method for adding vectors at right angles to each other

VECTOR COMPONENTS

Consider someone pulling a cart, as shown in Figure 1.12. The force exerted on the cart can be resolved (broken up) into two perpendicular components: a vertical component and a horizontal component.

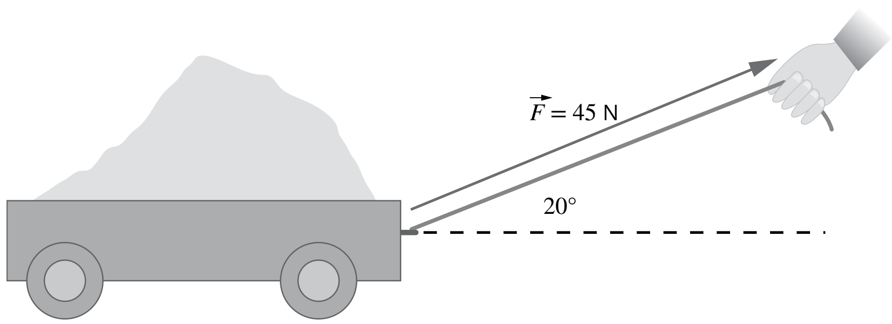

FIGURE 1.12 Vector components: pulling a cart

The perpendicular components are at right angles to each other and therefore make a right-angled triangle, with the original force vector forming the hypotenuse. This means that some properties of right-angled triangles can be used to find the magnitudes of the components:

- Any component vector must be smaller in magnitude than the original vector, because the hypotenuse is the longest side of the triangle.
- Graphically, a right-angled triangle vector diagram can be drawn with the original vector as the hypotenuse and the perpendicular components drawn from the tail to the head of the original vector.
- Algebraically, the magnitudes of the perpendicular components can be found using the trigonometric ratios.

Resolving vectors into components is an important tool for analysing the effects of two or more forces acting on an object. For example, if an additional friction force is applied to the wheels in Figure 1.12, it affects only the horizontal component. The new horizontal component can be easily calculated and then recombined with the unchanged vertical component to find the new resultant force vector.

RELATIVE MOTION

If a car heading north passes a pedestrian waiting to cross the road, the pedestrian would believe that they are stationary and the car is moving north. But the driver of the car could say that the car is stationary and the pedestrian is moving south. In physics, both of these views are correct.

How motion is described depends on the **frame of reference** that is used. An object's frame of reference is the coordinate system that is used to describe the motion of an object. It can be stationary (like the pedestrian's frame of reference) or it can be moving (like the driver's frame of reference).

When describing the velocity of one object (A) relative to another object (B), the vector notation used is $\vec{v}_{AB}$. The first subscript refers to the object that is considered to be stationary, and the second subscript refers to the object considered to be in motion. It is useful to note that $\vec{v}_{AB} = -\vec{v}_{BA}$.

To calculate the relative velocity of two objects, a frame of reference is needed. In most problems this is defined by a surface (such as the ground or a road) or a point (such as a stationary object or observer).

The velocity of A relative to B is then given by:

$$\vec{v}_{AB} = \vec{v}_{AC} + \vec{v}_{CB}$$

In words this is:

The velocity of A relative to B is the sum of the velocity of A relative to C and the velocity of C relative to B.

Notice that the subscripts on the right-hand side are ordered so that if you crossed out each C you would be left with AB.

Consider two cars travelling in the same direction on a freeway. Car A is travelling at 90 km h^{-1} relative to the road, and car B is travelling at 100 km h^{-1} relative to the road, what is the velocity of car A relative to car B?

The first step is to identify what information has been given. Let R = road, A = car A and B = car B.

$\vec{v}_{AR} = 90\,\text{km h}^{-1}$, $\vec{v}_{BR} = 100\,\text{km h}^{-1}$, $\vec{v}_{AB} = ?$

$$\vec{v}_{AB} = \vec{v}_{AR} + \vec{v}_{RB}$$

Because $\vec{v}_{BR}$ is given instead of $\vec{v}_{RB}$, use $\vec{v}_{RB} = -\vec{v}_{BR}$.

So:

$$\begin{aligned}\vec{v}_{AB} &= \vec{v}_{AR} + (-\vec{v}_{BR}) \\ &= 90 - 100 \\ &= -10\,\text{km h}^{-1}\end{aligned}$$

Therefore car A is travelling at −10 km h^{-1} relative to car B.

In this example the vectors are in one dimension. When considering relative velocity in two dimensions, the same process is followed but Pythagoras' theorem and trigonometric ratios may be needed.

Consider a boat (B) moving forward at 4 m s^{-1} across a river (R) where the current is 6 m s^{-1}, as shown in Figure 1.13. What is the velocity of the boat relative to the ground at the river's edge (G)?

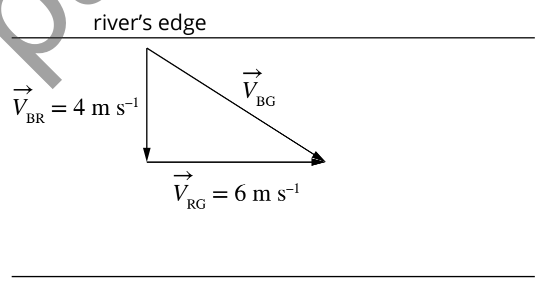

FIGURE 1.13 Analysing relative motion in two dimensions

$\vec{v}_{BR} = 4\,\text{m s}^{-1}$, $\vec{v}_{RG} = 6\,\text{m h}^{-1}$, $\vec{v}_{BG} = ?$

$$\vec{v}_{BG} = \vec{v}_{BR} + \vec{v}_{RG}$$

Using Pythagoras' theorem and trigonometry:

$$\begin{aligned}\vec{v}_{BG} &= \sqrt{6^2 + 4^2} \\ &= 7.2\,\text{m s}^{-1} \\ \theta &= \tan^{-1}\frac{4}{6} \\ &= 33.7°\end{aligned}$$

∴ $\vec{v}_{BG}$ = 7.2 m s^{-1} at an angle of 33.7° to the ground at the river's edge.

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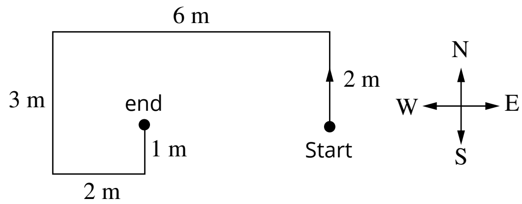
WORKSHEET 1.1

Knowledge review—motion

1 A girl on a skateboard travels 16 m down the street in 2 s. What is her speed? In general, speed is found by dividing distance by the time taken.

2 The following diagram shows the journey of an ant from start to end.



a What distance did the ant travel?

b If the journey took 56 seconds altogether, what was the ant's average speed?

c What is its total displacement from the start to the end? (Remember that displacement is the difference between the final position and the starting position, and it is a vector quantity.)

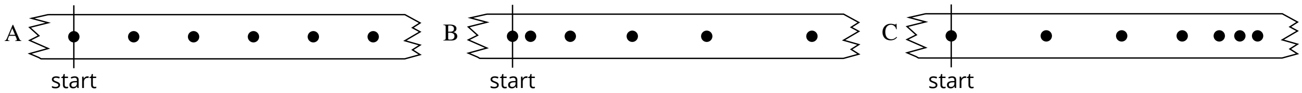
3 A truck is travelling at 100 km h^{-1} from Wangaratta to Wagga Wagga, a distance of 200 km. How long will it take:

a in hours?

b in minutes?

4 Using your usual trip to school, explain the difference between average speed and instantaneous speed.

5 Examine the three ticker tapes below. The start label shows where the first dot was made.



a When these tapes were made, did the tape move to the left or the right?

b Which tape shows acceleration?

c Which one shows deceleration?

d Which one shows constant speed?

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PRACTICAL ACTIVITY 1.1

The ticker timer

Suggested duration: 45–90 minutes, depending on the length of tape analysed

INTRODUCTION

Mains electricity in Australia is an alternating current (AC) with a frequency of 50 Hz (50 cycles per second). This provides a very reliable means of measuring time, because the interval between each cycle is exactly 0.02 s.

MATERIALS

- ticker timer (AC voltage)
- power supply
- connecting wires
- ticker tape and carbon discs
- ruler

PURPOSE

To investigate the relationship between position and velocity using a ticker timer.

PROCEDURE

1 Connect the ticker timer to the AC terminals of the power supply. Ensure that the power supply voltage is initially zero. Switch on the power supply and adjust the voltage until a regular, solid impact is recorded. Without the carbon in position, practise pulling a short length of ticker-tape (about 1 metre) through the timer at a steady speed. Practise with different speeds, and try to avoid too much variation in speed.

2 Put a carbon disc face down into the timer, with the tape underneath the carbon. Switch on the timer and pull the tape through at the same slow, steady speed. Repeat with a second piece of tape of similar length at about double the speed, then repeat again at a faster speed. Clearly label the tapes so that you can tell which trial each tape came from.

3 For each trial, discard the first part of the tape where the initial acceleration occurred. From a clear starting 'dot', count the dots on the tape and clearly mark each 5th mark. Make sure that each interval is exactly 5 dots.

4 Measure and record the total distance from the starting dot for the first 10 intervals.

⚠

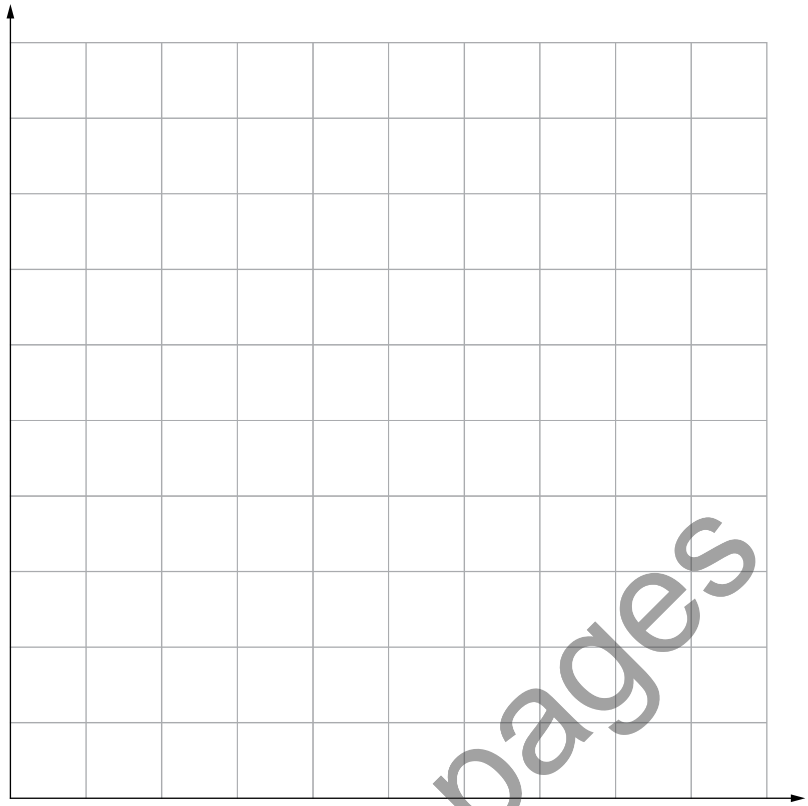
ℹ A DC-powered ticker timer with a 50 Hz hammer frequency can also be used in this activity.

DATA AND ANALYSIS

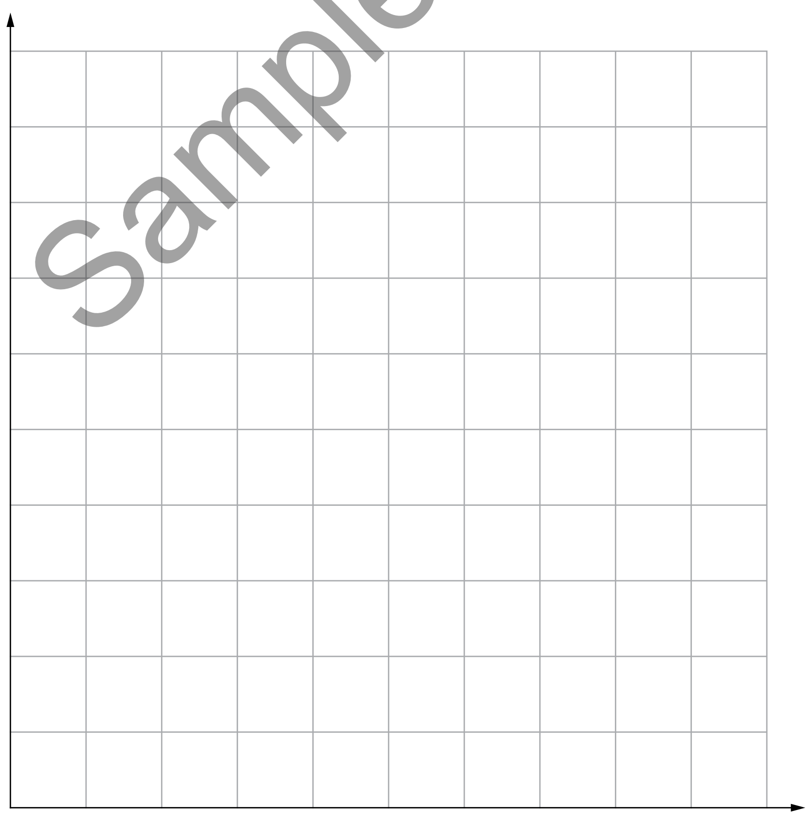
Record your data in the following table.

Interval	Total time (s)	Trial 1 position (cm)	Trial 2 position (cm)	Trial 3 position (cm)
start	0.0	0.0	0.0	0.0
1st	0.1			
2nd	0.2			
3rd	0.3			
4th	0.4			
5th	0.5			
6th	0.6			
7th	0.7			
8th	0.8			
9th	0.9			
10th	1.0			

1 Use your measurements to construct a position–time graph for each trial. Because you are using an AC ticker timer and the supply has a frequency of 50 Hz, each tick represents 0.02 s. This means each interval of 5 dots represents 0.1 s.



2 Using the data table or position–time graph, construct a velocity–time graph for one of the trials. Calculate the average velocity over the total distance for this trial.



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CONCLUSION

1 Describe how you calculated velocity from the position–time graph.

2 Does the velocity–time graph show instantaneous velocity versus time or average velocity versus time? Explain.

3 Comment on the reliability and practicality of the ticker timer as a means of measuring position, time and, hence, velocity.

4 Why is it important that the hammer of the ticker timer strikes at a constant rate?

5 You were told to discard the first part of each ticker-tape because it recorded unavoidable acceleration. Why is this acceleration unavoidable?

6 What is the major source of error in this activity? What are some other possible sources of error?

RATING MY LEARNING	My understanding improved	Not confident ◄—► Very confident ○ ○ ○ ○ ○	I answered questions without help	Not confident ◄—► Very confident ○ ○ ○ ○ ○	I corrected my errors without help	Not confident ◄—► Very confident ○ ○ ○ ○ ○

DEPTH STUDY 1.1

Measuring height using kinematics

Suggested duration: 3.5–4 hours including data collection, analysis and report

INTRODUCTION

The study of kinematics includes the analysis of linear motion graphs, especially position–time, displacement–time, velocity–time and acceleration–time graphs. Because change in displacement is directly related to velocity and acceleration, measuring one or more of these quantities will enable you to calculate the height through which a lift has travelled.

This depth study requires you to conduct an investigation on a question you develop about how acceleration is related to displacement. You will research and analyse data and information, and communicate your findings in a written report including appropriate graphs and calculations to support your findings.

PURPOSE

To determine the height of a tower or multistorey building using kinematics data.

- Do not travel in service lifts. If you have to use a service lift for this activity, start recording and send your data recorder up and down by itself.
- Always seek permission before using a lift in a private building.
- Always let at least one other person know where you are going.

QUESTIONING AND PREDICTING

1 What measurements would best allow you to determine the change in height of a lift as you go up a building? Write a suitable inquiry question and hypothesis. Explain how these measurements could be used.

PLANNING AN INVESTIGATION

2 Consult with your teacher about what equipment is available to you for making and analysing your measurements. Research some alternatives that may be available to you. You should avoid using specialist equipment; look for ways to use equipment that is readily available to you. Write a list of your chosen materials.

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3 Describe your final method, using graphs to illustrate your intended calculations.

ANALYSING DATA AND INFORMATION

4 From your data, calculate the height of the building. Detail your analysis below. You may prefer to record some data in tables and print out any graphs you have used, with annotations to explain your analysis. Include any other relevant information, such as observations or measurements of the lift stops relative to the full height of the building. What other factors could influence your results?

Height of building: ______________________

Details of analysis: ______________________

COMMUNICATING

5 Prepare a written report, including appropriate graphs, tables and calculations.

Alternatively, present your investigation in a scientific poster format.

Whichever format you use, present the information in the following order:

- Summarise your initial predictions and measurements.
- List the equipment you used.
- Describe your method in a way that would let other students repeat your measurements and confirm your results.
- Present your data and result.

6 Discuss your result for the height of the building, considering the following:

- How does it compare with the stated height?
- What factors did you consider that gave you a good comparison?
- What factors that you did not consider may have affected your result?
- What error does your method introduce into your result? You may be able to calculate an estimate of the error.
- Does the device have a maximum acceleration that it is able to measure? Did this affect your result?

7 Could your method be applied to determining a distance in a horizontal direction? Write a suitable inquiry question and hypothesis. What limitations would need to be applied to measurement in a horizontal direction?

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