Course Companion

for Pearson Level 3 AAQ BTEC National in Applied Science (Extended Certificate)

Unit 3 Principles and Applications of Physics

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Contents

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Teacher's Introduction

This course companion has been written specifically for the BTEC Level 3 National Extended Certificate in Applied Science AAQ (first teaching from September 2025). The theory notes and recap questions cover the essential knowledge and understanding prescribed in the Unit 3 specification.

About Unit 3: Principles and Applications of Physics

Unit 3 $^{(60\ \text{GLH})}$ is assessed through one examination of 50 marks lasting 1 hour.

There are two opportunities for assessment each year – in January and in May/June.
The first assessment availability is May/June 2026.

Remember!

Always check the exam board website for new information, including changes to the specification and sample assessment material.

The essential content is set out under three content areas (A–C), each of which is given its own section in this resource. These are as follows:

A. Understanding waves and optical fibres
B. Forces in transportation and Newton's laws of motion
C. Electrical circuits and the transfer of energy

Within each section there are student notes covering the specification content and structure.
These notes include descriptions of theory, supported with examples and diagrams.
Key terms are defined throughout.

Questions are interspersed throughout the guide to test and develop understanding.
Suggested answers are included at the back of this resource.

October 2025

A: Understanding waves and op

A1 Working with waves

Key points covered

- Features common to waves
- Similarities and differences between transverse and longitudinal waves
- Key concepts and e
- Applications of sta

A1.1 Wave types and features

A1.1.1 Features common to waves

Waves are characterised by a continuous **oscillation** in a physical medium or **field** that results in energy transfer without the transfer of matter. The direction of the wave is given by the direction of energy transfer. A wave that travels from one place to another is called a **progressive wave**.

Waves can be described as **longitudinal** and **transverse**. Back when you were first introduced to waves, the chances are an undulating rope was used to represent a transverse wave with its peaks and troughs and a slinky spring used to demonstrate a longitudinal wave.

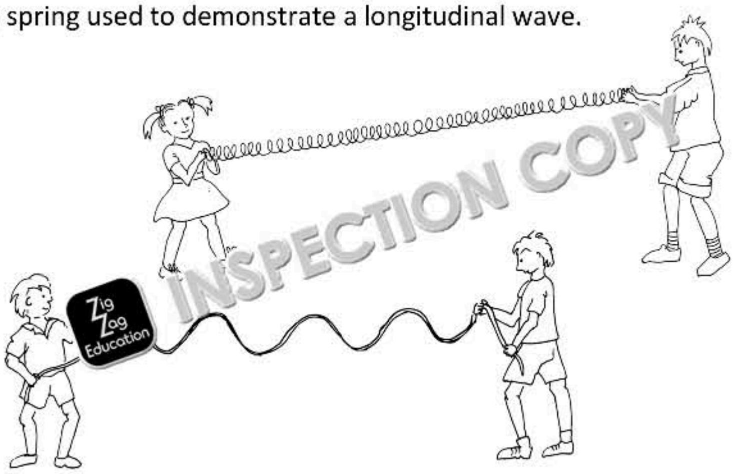


Figure 1.1 Longitudinal and transverse waves

Several key terms are used when describing waves:

- **Amplitude (A)** is the maximum displacement from the rest position. It tells us how much energy the wave is carrying.
- **Wavelength (λ)** is the distance between identical points on consecutive wave such as peak to peak, or compression to compression.
- **Frequency (f)** is how many complete waves pass a point in one second.
- **Period (T)** is the time taken for one complete wave cycle. It is the inverse of fre

$$\text{Period} = 1 \div \text{frequency}$$

$$T = \frac{1}{f}$$

- **Wave speed (v)** is how fast the wave moves through the medium. The speed of a wave depends on both its frequency and wavelength. The relationship is

$$\text{Wave speed} = \text{frequency} \times \text{wavelength}$$

$$v = f\lambda$$

This equation shows that increasing either the frequency or the wavelength (while keeping the other constant) will increase the wave's speed – unless th

A1.1.2 Graphical representations of waves

Transverse waves

When you think of a wave, you probably imagine a water wave or a wave on a ro
transverse waves. This is where the oscillations are perpendicular to the directio

An example is given in **Figure 1.1**.

The waves of the electromagnetic spectrum are transverse waves that can propag
interact with the electromagnetic field.

We can describe any transverse wave using a displacement–time graph as shown

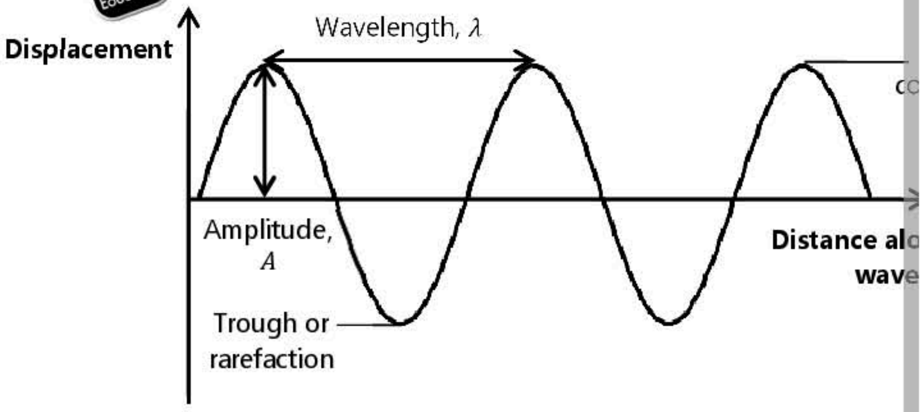


Figure 1.2 A graph of displacement against distance along the w

Longitudinal waves

These waves are more difficult to visualise but we can model them using a long s
stretch a long spring you can model a **longitudinal wave**, as shown in **Figure 1.3**.

In the spring you can see regions of **compression** and **rarefaction** where the coils are close together and further apart respectively.

Compression – region in a longitudinal wave where particles are bunched together at their closest

Rarefaction – region in a longitudinal wave where particles are furthest apart

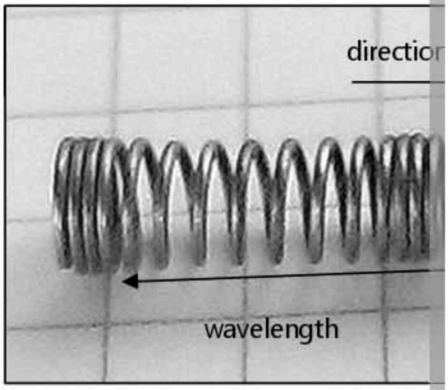


Figure 1.3 A longitudinal w

This is how a sound wave moves through air or any other medium. Some source
loudspeaker cone or a person's vocal cords makes air particles vibrate. This expla
pass through a vacuum, because a sound wave needs particles in order to propag

Note that **Figure 1.2** can apply equally to a transverse wave or a longitudinal wave. The peaks and troughs are representing the areas of compression and rarefaction on the longitudinal wave. By standardising our representation of all waves, we can better demonstrate the features they have in common.

Look ca
represe
only be
is on the
only whe

A1.2
Similarities and differences between transverse and

Both transverse and longitudinal waves transfer energy through a medium withou
In both types of wave, particles or fields oscillate about a central position, and the
source. The wave speed depends on the properties of the medium, and both type
and diffract under the right conditions.

The differences between transverse waves and longitudinal waves are summarise

Feature	Transverse waves	Lo
Oscillation direction	Perpendicular to energy transfer	Parall
Can travel in vacuum?	Yes	
Pressure changes	No	Yes – due to c

***Table 1.1** The differences between transverse waves and longitudi*

Test your knowledge – Wave basics

1. a) Define each of the following terms and, where appropriate, give its unit
   - (i) Wavelength
   - (ii) Frequency
   - (iii) Period
   - (iv) Amplitude
   - (v) Displacement

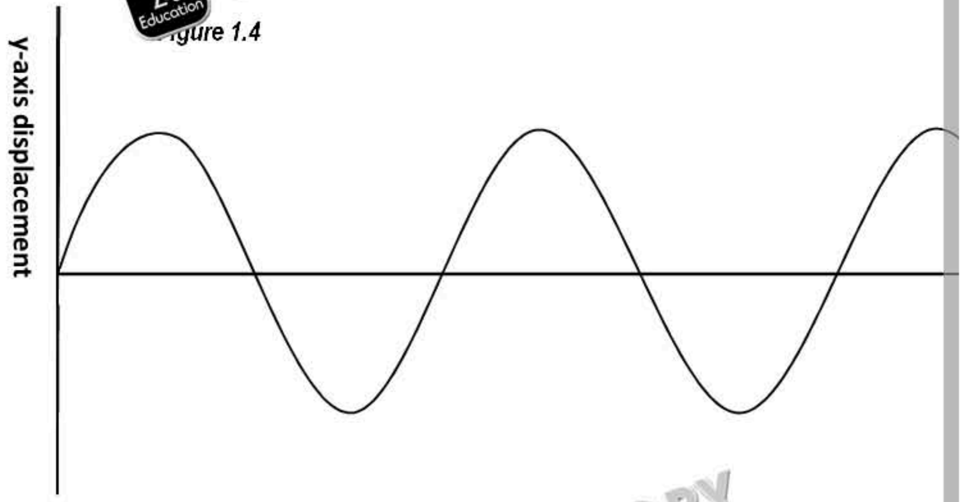
   b) Explain why amplitude represents one value of displacement and occurs
   and why displacement is a vector quantity (has both size **(magnitude)** a
   amplitude is a scalar quantity (has only size (magnitude)).

A1.3 Concepts of: displacement, coherence, path dif difference and superposition of waves as applied to

Displacement

If we look again at the graphical representation of a wave, the sinuous line descri the **displacement** (on the y-axis) of the medium or field from the central point or x-axis (**Figure 1.4**, below). Displacement is a **vector** quantity and has both **magnit** and direction, so the line undulates back and forth through the line of no displacement. Notice that the x-axis is labelled time or distance. This is for illustration in this case; any true plot or representation will be either displacement/time or displacement/distance.

Figure 1.4



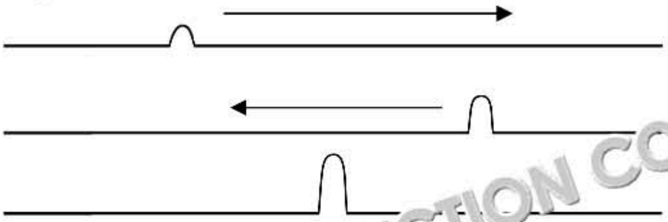
Remember that it is the energy that travels through the medium or field. A point of n in **Figure 1.4** (above).

Interference

In the diagram in **Figure 1.5**, two displacements combine; this is termed **interference**. The combination of the combined displacement is a resultant of the individual displacements. This is termed **superposition**.

Although the diagram shows a single pulse, superposition also applies to continuous waves.

Figure 1.5



Interference – occurs same point of a mediu

Superposition – the more displacements

Coherence – waves constant phase relatio

Constructive interfer waves are in phase a

Destructive interfere waves are exactly ou correspond with the tr

Phase – a way of des terms of a fraction of i be 'in phase' if their p

When pulses or waves pass through the same point of the medium, they are supe **coherent**, they interact **constructively** or **destructively**. If the waves are not c interfere, but the resultant is a complex wave.

Coherence between waves describes there being a fixed relationship between the same frequency. Such interaction, or interference, results in stable interference p

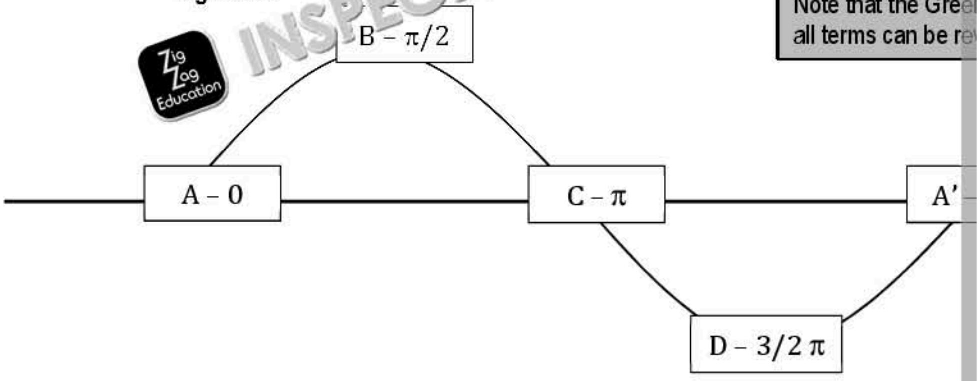
Phases

The phase of an oscillation describes where it is in its repeating cycle or period; s fraction of a period and is given in radians. For a regular oscillation, there is a rel and displacement.

Points A, B, C and D on the sine wave (**Figure 1.6**) correspond to the fractions of a 2pi radians. So, any displacement can be described as a fraction of a complete ro

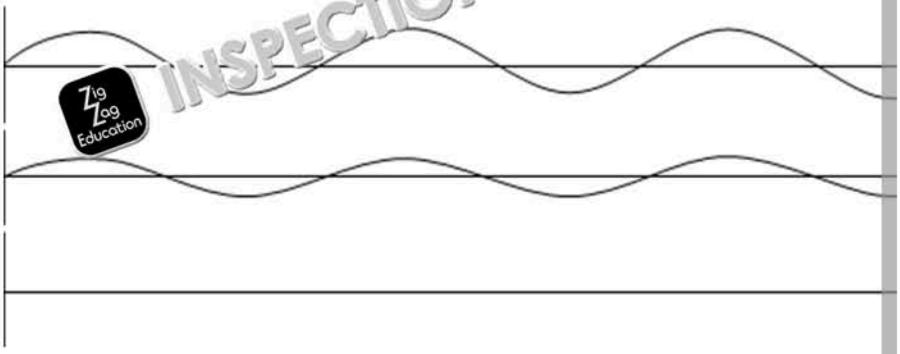
Note that the Gree
all terms can be re

Figure 1.6



Test your knowledge – Interference and phases

1. The two waves depicted below are in phase and travelling in the same direct same medium. Copy the lower (empty) axis and draw the resultant wave for superposition of the two waves.



2. Imagine that the two waves depicted above were in phase but travelling in
   a) Would your answer look any different?
   b) Explain your response.

Diffraction gratings

Waves approaching a narrow slit will be diffracted and will spread out into a fan shape beyond the slit.

Two or more slits will diffract waves so that their paths cross. This results in superposition and the waves will interfere. The interfering waves will be **coherent** so they will interfere constructively and destructively to form a regular waveform.

Diffraction – the c
pass round an obje
direction is differen

Monochromatic li

Diffraction gratin
parallel slits or gro
together. Light pas

If **monochromatic light** is [illegible] through two slits, a pattern of light and dark ba
Figure 1.7. The light areas (peaks) are areas of constructive interference, and the
of destructive interference.

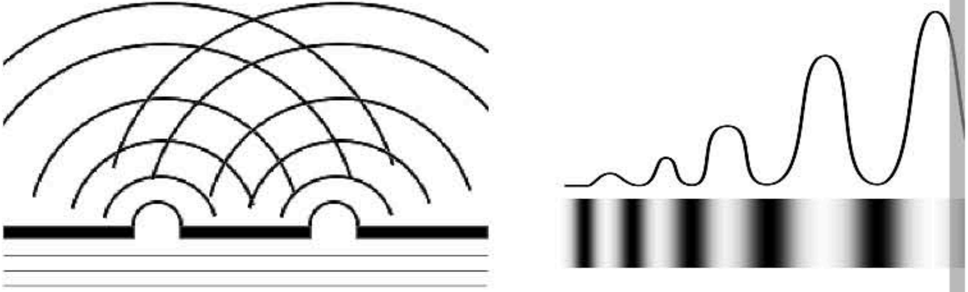


Figure 1.7 Interference pattern on a screen from a double slit ex

When light passes through multiple slits (a diffraction grating), the waves from each slit spread out and overlap. This is **superposition**. If the waves are **coherent** – meaning they have the same frequency and a constant phase relationship – they interfere in a regular pattern.

At certain angles, light from each slit travels different distances to the same point on a screen. If the **path difference** is a whole number of wavelengths, the waves arrive in **phase** and interfere **constructively**, forming a bright fringe. This means the **phase difference** is an integer multiple of 2π.

If the path difference is a half wavelength (or 1½λ, 2½λ, etc.), the waves arrive **out of phase** and interfere **destructively**, forming a dark fringe (phase difference π, 3π, etc.).

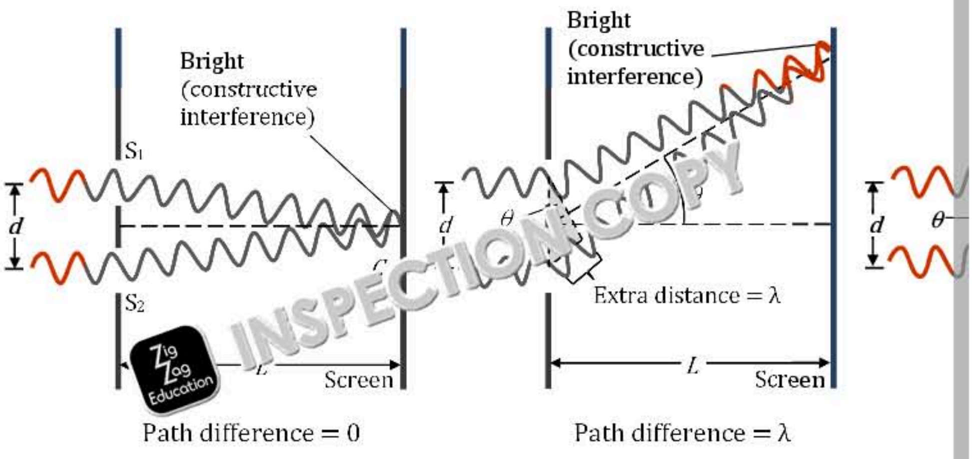


Figure 1.8

A1.3.1 Energy levels and light frequencies

Atoms have a small, dense nucleus surrounded by electrons. These electrons occupy specific energy levels. In their most stable arrangement, electrons are in the ground state.

If an atom absorbs energy (e.g. from heat or radiation), an electron can move to a higher energy level – this is called an excited state.

Excited electrons do not stay at high energy levels for long; they soon return to the ground state; when they do, they release energy in the form of a **photon**. The energy of the photon depends on the difference between the energy levels.

This energy determines the frequency and wavelength of the emitted light. Different energy gaps release photons of different colours – red for smaller energy changes, violet for larger ones.

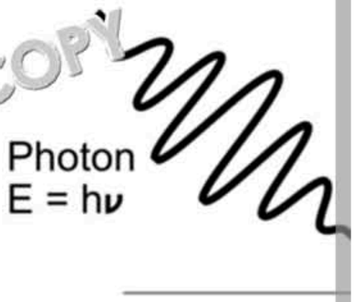


Figure 1.9 *Electron excita*
The photon allows movement

Photon – a massles
light and constitutes

A1.3.2 Line emission spectra

The photons emitted by excited electrons produce a **line emission spectrum** – a series of sharp, coloured lines on a dark background. Each line corresponds to a specific wavelength of light released by an electron transition.

To view these lines clearly, the light is passed through a **diffraction grating**. This device splits the light into its individual wavelengths using the diffraction and interference. The result is a clear pattern of coloured lines at specific angles.

Line emission spe
lines on a dark back
of photons

Diffraction spectro
through the grid inte
resulting in distinct
demonstrated on a s

Extend your knowledge

Using an emission spectrometer, patterns of banded, different-coloured light can
screen and the sample chemicals deduced. This forms the basis of **diffraction sp**
One instance where such a diagnostic tool is useful is in determining what chemi
from the light they emit under certain circumstances. This can allow scientists to
are present in distant stars, identify contaminants in food, or pesticides in the env
science inquiries.

A1.3.3 Identifying elements from emission spectra

Each element has a unique set of energy levels, so it produces a unique **emission** fingerprint. By comparing the pattern of spectral lines from a sample with known **elements present**, even in hot gases or distant stars.

This method is called **emission spectroscopy** and is widely used in astronomy, che forensic science.

Worked example

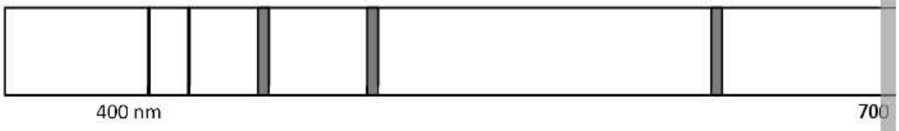
A scientist observes a bright yellow spectral line at a wavelength of 589 nm in th star. By comparing this line to known emission spectra, the scientist identifies it

What does this tell the scientist about the star?

Since the emission spectrum shows a strong line matching sodium's known spec sodium atoms in its atmosphere. This helps the scientist understand the star's c

Test your knowledge – Diffraction spectroscopy

1. Below are two emission spectra for hydrogen and helium.



The laboratory that produced these spectra also has an unknown spectrum w be from a protostar in a nearby galaxy. A protostar is a young star which co pulled together by gravity. Fusion takes place in the hot interior.

a) Use your knowledge and the spectra of hydrogen and helium to suppo this suggestion.

b) The gas atoms in the star are likely to be in an <u>excited state</u> due to the i Explain this term and its relevance to emission spectra.

A1.4 Using the wave equation

The speed of a wave depends on how frequently it oscillates (its **frequency**, f) and (its **wavelength**, λ). The **wave speed** (v) tells us how fast the energy is moving thr measured in metres per second (m s^{-1}).

$$\text{Wave speed} = \text{frequency} \times \text{wavelength}$$

$$v = f\lambda$$

This equation applies to **all types of wave**, including sound, water, and electroma Since wavelength is a distance and frequency is the number of waves per second, special form

$$speed = \frac{distance}{time} \text{ or } s = \frac{d}{t}$$

This is because wavelength is a distance, measured in metres, and frequency is eq substituted for λ and $\frac{1}{T}$ for f, the familiar equation $v = \frac{s}{t}$ results.

Worked example

An electromagnetic wave has a frequency of 250 Hz and travels at a speed of 3.

Calculate the wavelength of this wave.

$$\text{wavelength} = \text{wave speed} / \text{frequency}$$

$$\text{wavelength} = 3.0 \times 10^{8} / 250$$

$$= 1.2 \times 10^{6} \text{ m}$$

Test your knowledge – The wave equation

1. P waves are longitudinal seismic waves. A typical wave speed of a P wave pa of water might be 1450 m s^{-1} and through granite (a type of igneous rock) 5 If the frequency of the wave is 2.05 Hz, calculate the wavelength in a) water Give your answer to the nearest metre.
2. Red light from the Sun travels at 3×10^{8} m s^{-1}. If the wavelength of red light calculate its frequency. Give your answer to two significant figures and in sta

A1.5 Concepts and applications of stationary waves resonance in strings and pipes

A1.5.1 Musical instruments

Stationary waves, or standing waves, represent a special type of interference.

A **stationary wave** (or standing wave) forms when two waves of the same frequency and wavelength travel in opposite directions in the same medium and interfere. If the waves are **in phase**, their interference produces points of no displacement (**nodes**) and points of maximum displacement (**antinodes**).

- The distance between adjacent nodes (or antinodes) is ½λ.
- Unlike progressive waves, energy is not transferred along a stationary wave –

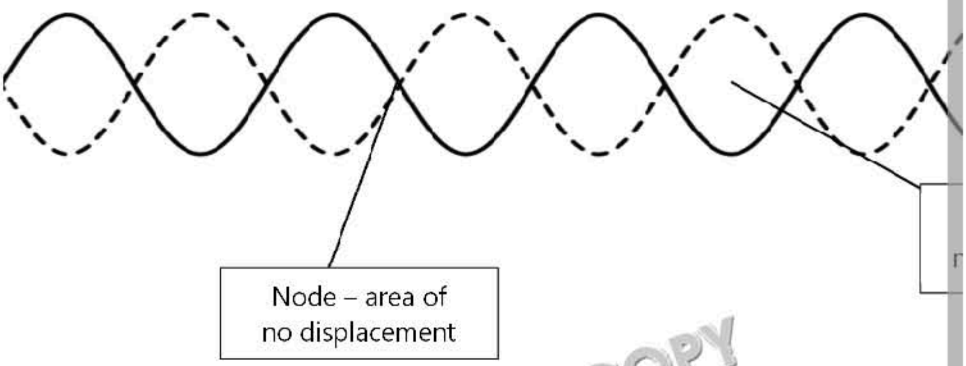


Figure 1.10

Sometimes the vibration of an object can cause another object to vibrate at its natural frequency – this is called **resonance**. In musical instruments, this often results in stationary waves forming in the resonating object. The initial vibration is called the **driving force**. When the frequency of the driving force is close to or equal to the **natural frequency** of the resonating object, it too vibrates. Some objects will oscillate with a series of frequencies that have a mathematical relationship and produce rich harmonic tones, but other objects vibrate with many frequencies that have no relationship to each other; we call this noise. The natural harmonic resonances of pipes and strings are the basis of many musical instruments.

Strings

A violin has four strings that vary in diameter and what they are made of; they ca
specific pitches. The force that drives their resonance comes from the friction ca
rosined[1] hairs of the bow as it is slid across the string. Stationary waves are gener
vibrates the air around the string and produces a note.

---

[1] Rosin is a slightly sticky resin that is worked onto the hairs of a bow.

In instruments such as violins and guitars, strings are fixed at both ends, so nodes
When a string vibrates:

- The **first harmonic** has one antinode in the middle and a wavelength of **2 × string length (L)**.
- Higher harmonics are shown using the symbol n and follow the pattern:

$$\lambda_n = \frac{2L}{n}$$

First harmonic

Second harmonic

Third harmonic

Tuning is achieved by changing the string's length, tension, or mass per unit length, which affects the pitch (frequency) of the note produced.

Pipes (wind instruments)

In wind instruments, stationary waves form in a column of air inside a pipe.

- Open ends form **antinodes** (air moves freely).
- Closed ends form **nodes** (no air movement).

Types of pipe

- Open at both ends (e.g. flute): all harmonics are possible.
- Closed at one end (e.g. clarinet): only odd harmonics form.

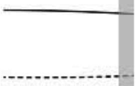
The term **fixed boundary** refers to the end of a string or a closed end of a tube and a **free boundary** is the term given to an open end.

Fixed b
object, c
will form

Free bo
moveme

Test your knowledge – Stationary waves

1. A resonance plate [illegible] metal that is used to demonstrate resonance the pl[illegible] is bowed (with a violin bow) until the plate vibrates a rearr[illegible]to patterns. Where the plate is fixed to its support, it is not free t
   a) What do you think will happen to the sand at this point where it is not f
   b) Can you say whether this fixed point is a node or an antinode?
   c) Explain why the sand rearranges so that it accumulates in some points sparse in others.
2. The table below illustrates the harmonics sequences for a flute (two free bou (one free and one fixed boundary). Copy and complete the table by drawing

 Flute		
Two free boundaries		One free only the o
	First harmonic	
	Second harmonic	
	Third harmonic	
	Fourth harmonic	
	Fifth harmonic	

A1.5.2 Applications of wave speed of transverse waves

The speed of transmission of energy, the wave speed, depends on the medium o medium, the slower the transmission. For waves transmitted along strings, the st the string affect the speed of transmission. These qualities are the string's **tensio**

Wave speed on a string is given by:

$$v = \sqrt{\frac{T}{\mu}}$$

From this equation we can see that:

- Increasing tension increases wave speed and raises the pitch.
- Increasing mass per unit length lowers wave speed and pitch.

This explains how adjusting a string's tension or thickness affects the note it prod

Worked example

A string on a guitar has a length of 0.65 m, a tension of 120 N, and a linear dens

Calculate the frequency of the second harmonic (n = 2)

$$v = \sqrt{\frac{T}{\mu}} = \sqrt{\frac{120}{0.01}} = \sqrt{12\,000} = 109.5\,m/s$$

Calculate the wavelength of the second harmonic using:

$$\lambda = \frac{2L}{2} = L = 0.65\,m$$

Use $v = f\lambda$ to calculate the frequency:

$$f = \frac{v}{\lambda} = \frac{109.5}{0.65} = 168.5\,Hz$$

Test your knowledge – Wave speed and strings

1. A violin has four strings (E, A, D and G) each 65 cm long. The first harmonic frequency of 659.25 Hz and its linear density is 3.47×10^{-4} kg/m. Calculate t Give your answer to one decimal place and give units.

A2 Principles of optical fibres

Key points covered

- Concept of refraction and total internal reflection and the critical angle
- Calculating refractive index and critical angle
- Practical uses of fi
- Differences betwe

A2.1 Concept of refraction and total internal reflecti

Refraction and total internal reflection occur because light travels at different speeds in different mediums. This is because different mediums have different optical density and optical properties. Where light passes from a medium with a lower refractive index to a higher one, the speed of transmission will decrease. The frequency of light is unaltered but the wavelength changes to preserve the $v = f\,\lambda$ relationship. The slowing down or speeding up causes different parts of th waveform to travel at different speeds and this changes the direction of the wave.

A2.1.1 Equations for the refractive index

Refraction

The amount by which light slows down in a material is measured by its **refractive index (n)**. This is determined by calculating the ratio between the speed of light in vacuum (3.00×10^8 m s^{-1}) and the speed of light in the medium it travels through.

Refractive index = speed of light in a vacuum ÷ speed of light

$$n = \frac{c}{v}$$

c = is the speed of light in a vacuum (3×10^8 *m* s^{-1})

v = is the speed of light in the medium

The denser the medium, the slower the speed of transmission, and the larger the refractive index. Any medium is directly proportional to its optical density and i speed of light within the medium.

A larger refractive index means the light travels more slowly in that medium.

Snell's law

The direction of light travelling into a material is described using the angle of inci between the incoming ray of light and a line perpendicular to the surface it strike

Similarly, once the light has entered the material, the change in direction is meas refraction (r). In this case, it is the angle between the normal line and the refract

For light entering from air ($n \approx 1$), the relationship between how much light bend the two materials is given by Snell's law.

$$n = \frac{\sin i}{\sin r}$$

This can be used to determine the angle of refraction as follows

$$\sin r = \frac{\sin i}{n}$$

By using the inverse sin function ($\sin^{-1}$) we can work out the size of the angle r

$$r = \sin^{-1}\left(\frac{\sin i}{n}\right)$$

The refractive index of medium 1 is given the term n_i where the subscript i refers medium, and the refractive index of medium 2 is given by the term n_r where the s the *refracting* medium.

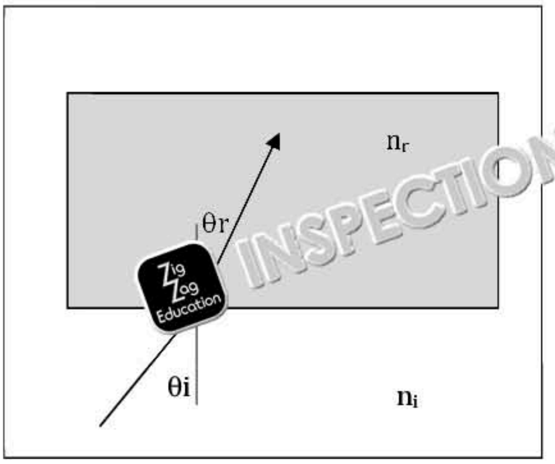
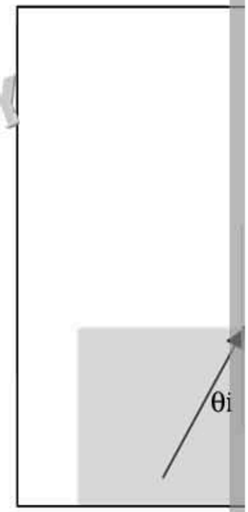


Figure 1.12



If $n_i < n_r$ then the ray of light turns towards the normal and the angle of incidence (θi) is greater than the angle of refraction (θr) (**Figure 1.12**, above).

Whereas if $n_i >$ n away from the n incidence (θi) is l refraction (θr) (Fi

A2.1.2 Critical angle

When $n_i > n_r$, as θ_i increases the refracted ray approaches the boundary. The angle of incidence in the medium with a higher refractive index is termed the critical angle (c) at the point that the refracted ray is refracted exactly along the boundary – see **Figure 1.14**.

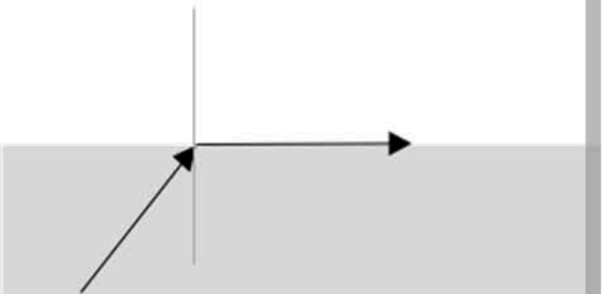


Figure 1.14

A2.1.3 Total internal reflection at the glass–air interface

Total internal reflection (TIR) occurs where the angle of incidence in a more optically dense medium (one with a higher refractive index) is greater than the critical angle. The light remains within the optically denser medium and is reflected off the boundary. The light obeys the laws of reflection.

As the angle of incidence is equal to the angle of reflection, if the material has parallel sides, light will be both trapped within the material and transmitted along it. This is the basis of optical fibres; information is contained and propagated.

Inciden

When the second material is air (n ≈ 1), the critical angle is calculated by taking th
the less dense medium (l) and the denser medium (n).

$$\sin c = \frac{l}{n}$$

Worked example

A ray of light travels from air into a glass block. The glass has a refractive index c
angle of incident light.

$$\sin c = \frac{1}{n}$$

Insert the value for the refractive index.

$$\sin c = \frac{1}{1.6}$$

Use the inverse sin function to calculate the critical angle, c.

$$c = \sin^{-1}(\frac{1}{1.6}) = 39°$$

Test your knowledge – Concept of refraction and total internal reflec

1. A light ray is directed at the vertical face of a glass cube. The refractive index
   Calculate the critical angle.
2. The critical angle of a medium is 65°. Calculate its refractive index.
3. At an air/glass boundary the angle of incidence in the air (θi) is 45° and the a
   a) Calculate the refractive index of the glass. Give your answer to 3 s.f. Do
   b) Calculate the speed of transmission of the light travelling through the g
      Give your answer to 3 s.f. and give units.
4. A light ray passes from a medium with a refractive index (n_i) of 1.60 into air w
   of 1.00. Calculate the critical angle of this boundary. Give you answer in radi

A2.1.4 Cladding of optical fibres and the critical angle in the

Optical fibres are extremely useful for medical and other image applications and communications. Optical fibres make use of the phenomenon of **total internal reflection** (TIR) which traps light within the fibre and facilitates transmission of energy with minimal losses.

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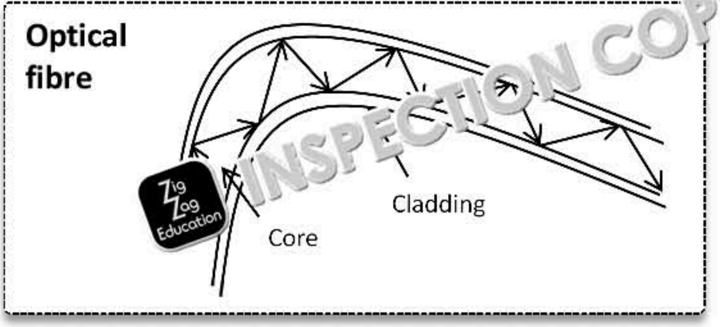


Figure 1.16

Extend your knowledge

In many cases, optical fibres have replaced copper wires. The very fine strands of encased in cladding made of a different type of glass and an outer protective lay energy losses and heating that are found using electrically conductive materials.

For many applications, the absence of these electrical side effects is important.

Cladding is used to direct more light through the core of an optical fibre and minimise losses. Around the cladding there is sometimes an outer sheath. The refractive index of the core must be greater than that of the cladding, and the refractive index of the cladding must be greater than that of the outer sheath.

C
m
c
p

$$n_{(\text{core})} > n_{(\text{cladding})} > n_{(\text{outer she}}$$

Using $\sin c = \frac{1}{n}$, if n_r is greater than one, then $\sin c$ becomes smaller and hence smaller. This may seem counterintuitive as fewer incident rays will have an angle hence experience TIR, but those that do will be closer to parallel to the fibre axis, and be transmitted more quickly. Also, light that passes into the cladding can un

The additional boundaries, where the refractive index of the incident material is g material, not only create additional opportunities for TIR but each successively tu normal and increasingly parallel to the fibre, decreasing both losses and the path,

A2.2
Applications of optical fibres in engineering, communi

Communications: Internet cables and components, telephone and cable television

Sensors: in the automotive industries and anywhere a remote sensor that doesn't need a p

Medical imaging: for diagnosis and keyhole surgeries; also used in dentistry

Military and space applications: secure transmission of information over long distances

Decorations and lighting: for light-hearted use within the household (some Christmas

Test your knowledge – Uses of fibre optics

1. Endoscopes allow doctors to produce images of the inside of a patient's bo statements about how endoscopes work. Put the letters in the correct order
   - A *Combining this information with other forms of medical imaging, a diagn*
   - B *This light reflects off the organ being examined and is picked up by the re*
   - C *The endoscope consists of a bundle of optic fibres.*
   - D *An image of the organ is created.*
   - E *Light is returned to the imaging computer along the remaining fibres.*
   - F *Some of the fibres deliver light to the examination site.*

2. Fibre optic cables are now used in communications where copper cable mig Fibre optic cables have a number of advantages over copper. Copy and com information provided below.

Factor	Fibre	
Speed	Up to 60 Tbps (terabits per second)	
Reach		Only transmits
Reliability	About 3 % signal loss/100 m	
Durability	Can withstand up to 900 N	
Security	Impossible to tap	

Optical fibre has significant advantages over copper in communication network speeds in fibre can be up to 60 Tbps with a reach of up to 25 miles compared to transmits 100 metres. Copper cable can experience 90 % losses over those 100 m from fibre. And fibre is less fragile, withstanding almost nine times the pressure also affected by electromagnetic signals and is easier to 'tap' than fibre and is co

A2.3 Differences between analogue and digital sign

Fibre optic cables transmit information using **light pulses**. These signals can be ei **analogue** or **digital**, depending on how the information is encoded.

An **analogue signal** varies continuously over time, using changes in amplitude, frequ or phase of the light wave to represent information. However, analogue signals are susceptible to degradation over long distances and can be affected by noise.

In contrast, a **digital signal** represents information in binary form – as discrete on/ corresponding to 1s and 0s). Digital signals are more resistant to noise and can be distances with minimal loss of quality, especially when combined with repeaters t

Test your knowledge – Analogue and digital signals

1. Information can be transmitted as either a digital signal or an analogue sign of transmitting information as a digital signal.

A3 Uses of electromagnetic waves in co

! Key points covered

- All electromagnetic waves travel at the speed of light in a vacuum
- Use the inverse square law in relation to the intensity of a wave: $I = \frac{k}{r^2}$
- Regions of electro have different freq
- Practical uses of el

A3.1 and A3.2 Electromagnetic waves

Electromagnetic waves are transverse waves that are propagated in the **electromagnetic field**. Electromagnetic waves involve two types of oscillation – an oscillating electric field and an oscillating magnetic field, hence the name electromagnetic.

Figure 1.17 shows the direction of these oscillations with respect to the direction of energy transfer.

In a vacuum, all waves of this type travel at the speed of light, which is given to be 3×10^8 m s^{-1} and takes the symbol 'c'.

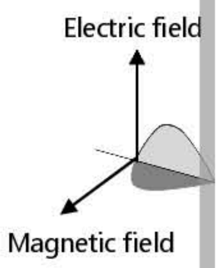


Figure 1.17 The oscillati perpendicular to

Electromagnetic waves – oscillations in the electromagnetic field

Electromagnetic field – describes the perpendicular interaction between invisible electric and magnetic forces

Electromagnetic spectrum – a range of wavelengths and frequencies divided into broad classifications that describe oscillations in the electromagnetic field

There is a broad range of wavelengths and frequen **electromagnetic spectrum (EMS)**: radio waves, mic ultraviolet, X-rays and gamma rays. The product of frequency and wavelength of all parts of the spectrum passing thr equivalent and equal to the speed in that medium. decrease from radio waves through to gamma rays,

The names that scientists give to the broad areas o microwaves, etc.) are for convenience and it is imp sharp cut-off between, say, radio waves and microv waves and long wavelength microwaves being func However, the terminology is very useful in describi different bands of the spectrum, and much easier t wavelengths or frequencies.

Figure 1.18 gives the range of wavelengths and frequencies found in the electromagn light of the above explanation that there will be some overlap and these are not strict

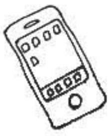
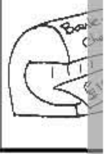
Electromagnetic spectrum	Radio waves	Microwaves	Infrared	Visible light	Ultra
Frequency Hz	<3×10^{11}	3 × [illegible] – 1[illegible]	10^{13} – 4×10^{14}	4×10^{14} – 7.5×10^{14}	10^{14} –
Wavelength	[illegible]	1 mm – 25 μm	25 μm – 750 nm	750 nm – 400 nm	400 nm
Example use					

Figure 1.18

A3.2 Use the inverse square law in relation to the in

When you refer to the loudness of a sound or the brightness of a light, you are referring to a quantity that we call **intensity**. Intensity is the power per unit area arriving at a surface from a wave. Its symbol is *I* and its unit is W m^{-2}.

An oscillation in the electromagnetic field produced by a source, perhaps a light source or a radio transmitter, will travel out from the source. As it does so, it spreads out. Consider the beam of light from a torch; if you hold it close to a screen a small diameter, bright image is seen. As the distance between the torch image gets wider and less bright. The brightness, as seen on the screen, is terme power/area incident on the screen and has the unit W m^{-2}.

Irradiance obeys an inverse square law with respect to distance from the source t example above, the distance from the torch to the screen. An inverse square law inversely proportional to the square of another. In the torch experiment, the irra proportional to the square of the distance between the torch and the screen.

The intensities of all oscillations in the electromagnetic spectrum obey an inverse square relationship with the distance from the source.

The formula to calculate the intensity of a wave is given by

$$I = \frac{k}{\mathbf{r}^2}$$

Where I – is the irradiance, power/unit area at the screen/surface (W m^{-2})

r – is the distance between the emitter and the screen/surface (m)

k – is a constant given by Ir^2

As k is a constant it follows that for any given distance from a radiating source $Ir^2_{(\text{distance 1})} = Ir^2_{(\text{distance 2})}$

Practical

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the signal, i
the phone t
nearest rela

A gamma e
very intense
cells at close
potentially
distance. Th
be used in
widespread

Worked example

A light source emits electromagnetic radiation uniformly in all directions. At a di source, the irradiance (intensity) is measured to be 40 W m^{-2}.

Calculate the irradiance at a distance of 4.0 metres from the same source.

$$\text{Since } k = I_1{r_1}^2 = I_2{r_2}^2$$

$$I_2 = \frac{I_1{r_1}^2}{{r_2}^2} = \frac{40 \times 2^2}{4^2} = \frac{160}{16} = 10\ Wm^{-2}$$

Test your knowledge – Intensity

1. Jayden has found an old-fashioned slide projector, but the light bulb in it has bulb with a 40 W [illegible], but although the light comes on, they can't on their screen. Suggest what Jayden could do to get a higher intensity imag behind your ideas.
2. A mobile phone user is 2.3 km from a phone mast.
   a) Calculate the irradiance (signal) in W m^{-2} in their position using $I = \frac{k}{r^2}$
   Give your answer to two significant figures and in standard form. Give
   b) For a signal to be received, the intensity must be greater than 9 × 10^{-10}.
   Can the mobile phone user make a call from their position?

A3.3.1 Practical uses of electromagnetic waves in communic

It is generally the longer wavelength, lower frequency parts of the electromagneti
communications. Radio waves and microwaves are used extensively. Infrared, vi
have particular uses.

Extend your knowledge

Radio waves have the longest wavelengths and lowest frequencies in the EMS. W
from 1 mm to 10 000 m, this represents a wide range of wavelengths and hence a
uses: radio and television broadcasting, smart meters, radar and industrial uses (f
communications in areas where security is important).

Short wavelength radio waves (frequencies around 3 MHz) are suitable for commu
that are in 'line of sight'. In practice, because of the curvature of Earth, this mean
here does not necessarily mean one antenna can be seen by the other using opti
wavelength radio waves are not impeded by things like buildings and trees that w
Long wavelength radio waves have the additional advantage of diffracting along
they curve and communicate with more distant antennae that do not have a line
radio waves (frequencies below 3 MHz) are practically 'invisible' to Earth's surface
impeded, making them very useful for surface communication. However, their ve
amount of information that can be transmitted over any given time.

Microwaves have many of the advantages of short wavelength radio waves and ar
over shorter distances, 40–60 km. They are employed in mobile phone communica
communication (although radio waves are also used) and for communications wit
Microwaves can be absorbed by moisture in the air and this attenuation can prese
transmission causing a significant loss of signal intensity over distance. However, f
satellites, microwaves are not considered to be greatly diminished by passing thro
relatively higher frequencies allow for faster transmission speeds.

Electrical signals can be converted into electromagnetic waves, and vice versa; the
electrical current is converted into wave oscillation. The frequency of oscillation c
of information transfer with higher frequency waves transmitting more informati
emitters and receivers are digital, electrical devices, but energy and information a
wave form.

Mobile phones

When someone makes a mobile phone call, the analogue signal of their voice is co
signal, which in turn creates a microwave signal that is transmitted to a mobile ph
the signal to a geostationary satellite, which relays it to another mast and to the r
microwave signal is reconverted into a digital electrical signal and then into an an

Satellite communication and GPS positioning

Geostationary satellites are positioned by matching the orbit speed and direction
These satellites remain in the same position relative to Earth, allowing for uninter
between them and an area on Earth's surface. There are numerous satellites in g
allowing for fast global communications but also facilitating GPS.

GPS stands for Global Positioning System and is a US-owned network of 24 netwo
maintained in exact position. Consumers can own receiver units, often on their ph
that communicate with the satellite network in order to determine the user's thre
The computerised linking of this spatial mapping to the road network, or weather
important tools for travellers or farmers. The technology also has significant milit
microwaves are used for GPS communications.

Remote controls

Infrared (IR) radiation loses intensity over short distances in air; think about how c
feel its heat. It doesn't pass through walls or other obstacles. However, this can b
items such as TV remotes. It is relatively cheap technology, it is harmless to huma
discrete beam. Not interacting with all the devices in your home or in other home
stopped by the walls of your room, is a significant advantage here. Wavelengths a
are utilised.

Wi-Fi

The use of light in fibre optics for communication has been well discussed. There
kilometres of submarine fibre-optic cable serving the World Wide Web linking cor
recognise that IR is also used in fibre communications. Due to the lower frequenc
is experienced due to impurities in the glass; however, lower frequencies transmit
signals are often transmitted to your home or business by fibre-optic cables as thi
wires. Some Internet users use entirely wired access, but many now use Wi-Fi, wh
Sometimes users have a choice of two frequencies with different data speeds and
network is received and interpreted by the modem and sent onto other user devi

Bluetooth

Bluetooth© communication can work without Internet cover. It is a device-to-dev
ultra-high frequency radio waves, frequencies in the overlap area between radio w
The devices have built-in emitters and receivers. Bluetooth© operates over comp
about 10 metres.

Experiments are ensuing regarding the use of ultraviolet (UV) radiation in commu
atmosphere and needs a strong emitter to transmit a maximum of a few kilometr
the data/second speed is attractive. Sometimes, rather than absorb, the atmosph
the UV, allowing it to spread over a wide area. This can result in information bein
locations where there is no direct line of communication.

Discussion question

Mobile phones use waves with a range of frequencies in the microwave region of
Compare the advantages and disadvantages of using microwaves for mobile pho

Test your knowledge – Communication using EMS

1. Redraw the table below and enter information from the section 'Practical us
waves in communication'.

Radiation	Use	Advantages	Disadvantages
Radio waves			
Microwaves			
IR			
Visible light			
UV			

B: Forces in transportati
Newton's laws of mot

B1 Measurement and representation of r

Key points covered

- Standard SI units relating to motion
- Calculations for speed and average speed
- Describing motion using scalar and vector quantities
- Describing motic
- Applications of a

B1.1 Standard SI units

When studying motion, we use standard symbols and SI units for different quanti

Table 2.1 shows each of the quantities, its standard letter and its unit.

***Table 2.1** Suvat quantities and their standard letters and un*

Name of quantity	Standard letter	Unit
displacement	s	m
initial velocity	u	m s^{-1}
final velocity	v	m s^{-1}
acceleration	a	m s^{-2}
time taken	t	s

These symbols are used in equations of motion to describe how objects move.

Speed is how fast something moves, and it can be measured in different units. To fact that **1 km = 1000 m** and **1 hour = 3600 seconds**.

Table 2.2 shows the two most common non-SI units for speed, their symbol, and l

***Table 2.2** Non-SI units for speed, symbol and conversion fa*

Name of quantity	Unit	Conversion
kilometres per second	$km\ s^{-1}$	1 km s^{-1} = 1000
kilometres per hour	$km\ h^{-1}$	1 km h^{-1} = 0.278

These quantities can be used for very fast objects such as asteroids and spacecraf occurrences, e.g. measuring car speeds **(km h^{-1})**.

B1.2 Calculating speed and average speed

B1.2.1 speed = distance ÷ time

We can calculate the **speed** of an object if we know how far it has moved **over a certain time**.

$$\text{speed (m s}^{-1}) = \frac{\text{distance (m)}}{\text{time (s)}}$$

B1.2.2 average speed = total distance ÷ total time

Sometimes, **speed** changes over time, so we use average speed to find the overall motion of the object.

The **total distance** is how far the object has moved over the whole journey. The total time is the time taken to complete the journey.

We express average speed in calculations as the total distance divided by the total ti

$$\text{average speed (m s}^{-1}) = \frac{\text{total distance (m)}}{\text{total time (s)}}$$

This helps in calculating motion over long journeys or when the conditions are chang journey will travel at different speeds throughout its journey so it is useful to be able

B1.3 Using vector and scalar quantities to describe

Scalars and vectors

Velocity and speed are different types of quantity that we call **vector** and **scalar** quantities respectively.

Both types of quantity have a **magnitude**. An object travelling at -10 m s^{-1} has a magnitude of 10.

Vectors also have direction. We represent vector quantities with arrows. The length of the arrow shows the magnitude, and the arrow also shows the direction of the vector.

To be more precise about the distance moved, we need to introduce another qua

Displacement is distance moved in a certain direction. For example, if you walk a distance of 100 metres in a straight line, then your displacement is 100 metres.

However, if you walk back again to your starting point, your displacement since st have walked a total distance of 200 metres.

scalar quantity	vector quantity
speed	velocity
distance	displacement

You can travel round a curve at constant speed, but your velocity will be changing constantly changing.

You can walk out and back and you may cover a lot of distance, but your displacer to your starting point.

Velocity is the change in *displacement* with time. Speed is the change in distance

We refer to average velocity in many calculations.

$$\text{average velocity (m s}^{-1}) = \frac{\text{displacement (m)}}{\text{time taken (s)}}$$

Worked example

A person walks 1200 metres due east in 10 minutes, then turns around and walks 80

Calculate their average velocity for the whole journey.

$$\text{Total displacement} = 1200\text{ m (east)} - 800\text{ m (west)} = 4$$

$$\text{Total time} = 10\text{ min} + 8\text{ min} = 18\text{ min} = 1080\text{ seco}$$

Using the formula for average velocity:

$$\text{average velocity (m s}^{-1}) = \frac{\text{displacement (m)}}{\text{time taken (s)}} = \frac{400}{1080} = 0.37$$

Describing motion using graphs

Movements are often described using displacement–time graphs and velocity–tim

Displacement–time graphs

A **displacement–time graph** has displacement on the y-axis and time on the x-axis

Think about an object moving with constant velocity, starting with displacement zero. Every second, its displacement changes by the same number of metres. Hence, a displacement–time graph of this will be a straight line with positive gradient passing through the origin, as shown in **Figure 2.1**.

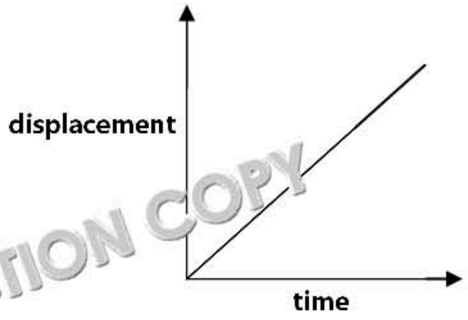


*Figure 2.1 A displacement–time graph for an object moving **at a constant sp***

Now think of another object, also starting with displacement zero, this time movi constant velocity.

This object will travel a greater number of metres every second than our first obje so its displacement–time graph will be steeper. We say that its **gradient** is greate **Figure 2.2** shows this.

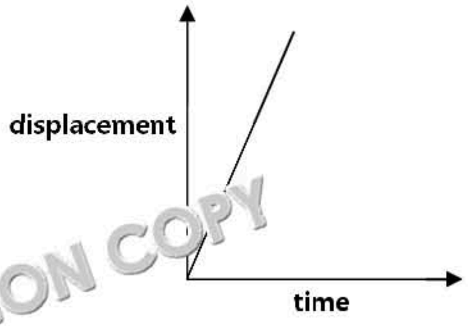


*Figure 2.2 A displacement–time graph for an object moving in **a similar way to tha***

As we calculate gradient from the change in *y*-direction (displacement) divided by we can infer that:

The gradient of a displacement–time graph gives the velocity

If the line slopes down (negative gradient) then the velocity is negative. That mea opposite to when the velocity was positive.

Look at the displacement–time graph in **Figure 2.3**.

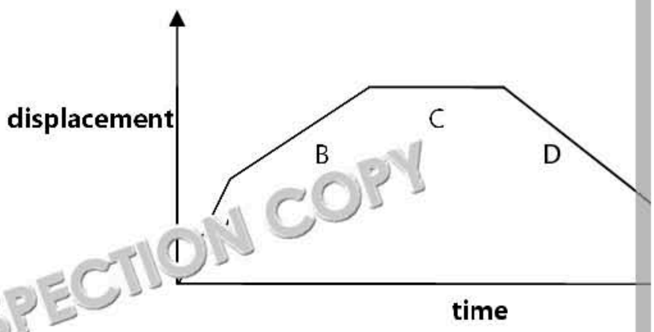


***Figure 2.3** The displacement–time **graph of a car**.*

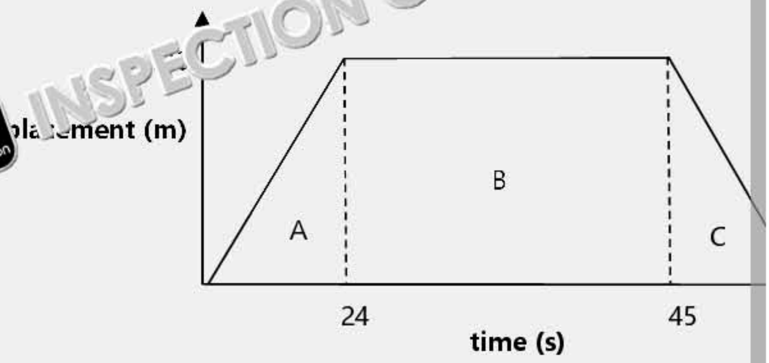
This example shows the motion of a car.

- Part A shows the car travelling quickly.
- Part B shows the car continuing in the same direction as in part A, but more
- Part C shows the car is stopped but for a longer time than in part E.
- Part D shows the car moving back towards its original position – velocity is n
- Part E shows the car is stopped but for a shorter time than in part C.
- Part F shows the car moving back to its original position – velocity is negative

Worked example

Emily walks along a straight path from her house to the park. She stops at the back home.

Her journey is represented on a displacement–time graph.



Use the graph to calculate:

a) The total distance travelled

b) The average speed over the whole journey

c) Emily's speed when travelling to the park

d) How long Emily spends at the park

a) This is the sum of the displacements for the three sections of the journey.

$$\text{Total distance} = A + B + C = 120\text{ m} + 0\text{ m} + 120\text{ m} =$$

b) This is the sum of the distances divided by the total time taken for the

$$\text{Average speed} = \frac{\text{total distance}}{\text{total time}} = \frac{240\text{ m}}{60\text{ s}} = 4.0\text{ m s}^{-1}$$

c) This is the gradient of the line in the first part of the journey.

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{120\text{ m}}{24\text{ s}} = 5\text{ m s}^{-1}.$$

d) This is the horizontal section of the graph where displacement does not ch

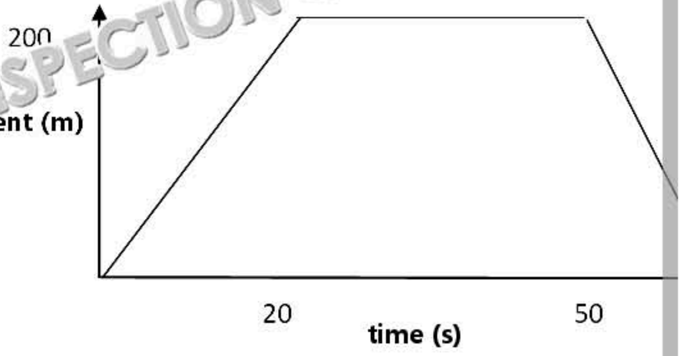
$$\text{Total time at park} = 45\text{ s} - 24\text{ s} = 21\text{ s}$$

Test your knowledge 1

Liam goes for a run in the park. He starts by jogging at a steady pace, then stops for a while.

After resting, he sprints back to his starting point.

His motion is represented by the displacement–time graph.



Using the graph:

a) Calculate the total distance Liam travels
b) Calculate his speed while jogging
c) Compare Liam's speed while jogging with his speed while sprinting

Velocity–time graphs

A **velocity–time graph** has velocity on the *y*-axis and time on the x-axis. Now, the gradient shows acceleration, so the steeper the line, the greater the acceleration. If the line slopes down (negative gradient) then the object has negative acceleration.

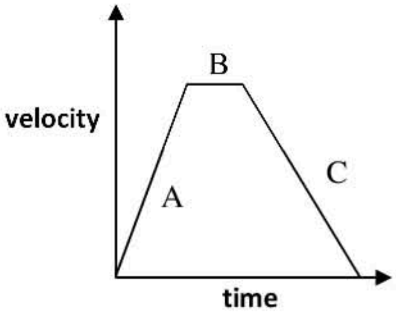


***Figure 2.4** A velocity–time graph for an object accelerating rapidly, travellin*
then accelerating negatively more gradually than it accelera

The velocity–time graph in **Figure 2.4** could represent the motion of a cyclist:

- Part A shows the cyclist accelerating from rest (positive gradient).
- Part B shows the cyclist moving at a constant velocity (zero gradient – a horizontal line).
- Part C shows where the cyclist then negatively accelerates to a stop (negative gradient) but with a deceleration of lower magnitude to the original acceleration.

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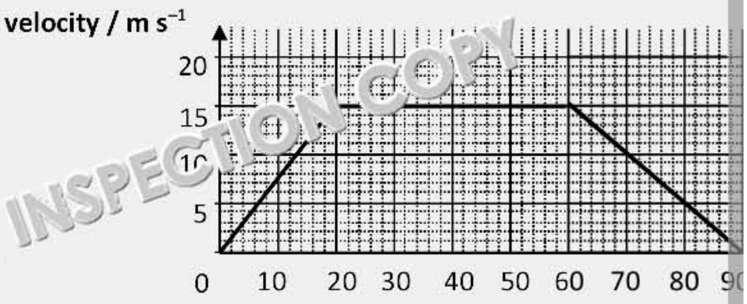
We can determine the distance travelled from a velocity–time graph from the are

Worked example

A tram starts from rest at Station A and accelerates uniformly until it reaches a
It maintains this speed for a while before decelerating uniformly to rest at Static
for the tram's journey is shown below.



Use the graph to calculate:

a) The acceleration of the tram when leaving the first station
b) The deceleration of the tram when arriving at the next station
c) The distance between the two stations

a) This is the gradient of the upward slope

$$\text{acceleration} = \frac{15 - 0}{200 - 0}$$

$$\text{acceleration} = 0.075 \text{ m s}^{-2}$$

b) This is the gradient of the downward slope

$$\text{deceleration} = \frac{0 - 15}{90 - 60}$$

$$\text{deceleration} = 0.5 \text{ m s}^{-2}$$

(Note that we omit the minus sign because deceleration means slowing do
acceleration, we would include the minus sign.)

c) This is the area under the graph

$$\text{area under the acceleration part} = ½ \times 20 \times 15$$
$$= 150 \text{ m}$$

$$\text{area under constant velocity part} = 15 \times 40$$
$$= 600$$

$$\text{area under deceleration part} = ½ \times 30 \times 15$$
$$= 450$$

$$\text{total} = 1.2 \times 10^3 \text{ m or } 1.2 \text{ km}$$

Test your knowledge 2

The acceleration of free fall on the Moon is [illegible] on Earth.

1. Sketch a velocity–time graph of an object being dropped on both the Moon labelled M and E on the same set of axes. Neglect air resistance on Earth; the Moon [illegible] resistance.
2. Use [illegible] values of s to calculate the time difference for a ball to fall wh both locations. (Acceleration of free fall on Earth is approximately 10 m s^{-2}.)

Acceleration

When an object is changing velocity, we say that it has **acceleration**.

It is given by the equation

$$\text{acceleration (m s}^{-2}\text{)} = \frac{\text{final velocity (m s}^{-1}\text{)} - \text{initial velocity (m s}^{-1}\text{)}}{\text{time taken (s)}}$$

$$a = \frac{(v-u)}{t}$$

Acceleration is change in velocity with time, so has a unit that is effectively metres per second every second. We write this as m s^{-2}, spoken as 'metres per second squared'.

Worked example

The world's fastest experimental car has a claimed acceleration of 0–60 miles pe

60 miles per hour is 26.8 m s^{-1}.

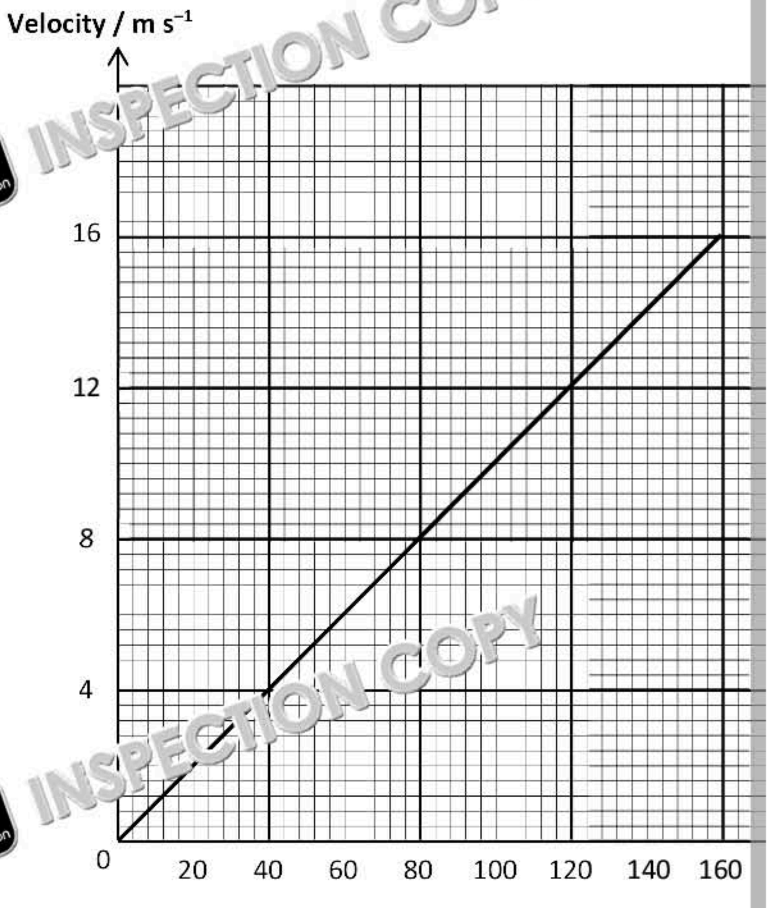
Calculate the acceleration of this car in m s^{-2}.

$$\text{acceleration} = \frac{26.8 - 0}{1.4}$$

$$\text{acceleration} = 19.1 \text{ m s}^{-2}$$

Recap questions

1 The graph shows how the velocity of an accelerating object varies with tim



a) Calculate the acceleration of the object.

b) Calculate the total distance travelled by the object.

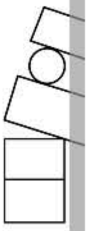
B1.3.7 Find the acceleration of a trolley moving down a gradi

The acceleration of an object changes depending on the conditions in which it tra
happening using a simple experiment; this involves a trolley moving down an adju

To determine the acceleration of a trolley moving down a slope, we need to meas
trolley to travel down the length of the ramp. For this, the following equipment is

Equipment

- Ramp (adjustable to different angles)
- Trolley
- Stopwatch OR light gate and data logger
- Metre [illegible]
- Protrac[illegible] measure the angle slope)



Method

Setting up the experiment

1. Place the ramp on a table and adjust it to a small incline, measured using a protractor.
2. Position the light gate at a set distance from the start OR measure the length over which acceleration is to be determined.
3. Mark the starting position where the trolley will be released.

Collecting data

Using a metre ruler and stopwatch / stop clock / timer:

1. Start the trolley from rest.
2. Time and record how long it takes the trolley to travel the measured length.
3. Repeat the experiment and calculate the average of the times.

Using light gates and a processor:

1. Start the trolley from rest.
2. Non-e[illegible]ncy light gates use time and distance to calculate the acceleratio
3. Repeat [illegible]periment and average the values for acceleration.

Use of calculations

To calculate the average velocity of the trolley using the equation for average velocity.

$$\text{average velocity} = \frac{\text{total displacement}}{\text{total journey time}}$$

To calculate the acceleration, one way could be by using the final velocity.

$$\text{acceleration} = \frac{\text{final velocity (m s}^{-1}\text{) – initial velocity (m s}^{-1}\text{)}}{\text{time taken (s)}} = \frac{\text{final velocity} - 0}{\text{total journey time}} = \frac{\text{final vel}}{\text{total journ}}$$

However, as we can't measure the final velocity, the acceleration could be found by using the following formula:

$$s = ut + \frac{1}{2}at^2$$

However, u[illegible]erefore:

$$s = \frac{1}{2}at^2$$

$a = \frac{2s}{t^2}$, where s is the displacement and is the total journey time.

1.3.8 The suvat equations

When an object is accelerating in a straight line, you can do useful calculations. U
these standard abbreviations that you used at the start of the resource.

Table 2.3 provides a reminder of each of the suvat quantities, its standard letter a

Table 2.3 Suvat quantities and their standard letters and un

Name of quantity	Standard letter	Unit
displacement	s	m
initial velocity	u	m s^{-1}
final velocity	v	m s^{-1}
acceleration	a	m s^{-2}
time taken	t	s

As the standard letters, written in this order, spell the word 'suvat' we call the equations that use them the **suvat equations**.

Suv
four
acce

The suvat equations are

$$v = u + at$$

$$s = \frac{(u+v)t}{2}$$

$$s = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

A good method for revising
each one in turn so that eac
the subject. Do not try to me
just gain confidence in hanc

Tip!

When given information in a calculation question, write the letters 'suvat' down the page. Read the information in the question, and fill in the three values that you are given. Remember, you may not see numbers for all of them For example, 'from rest' means that u is zero and 'comes to a stop' means v is zero, etc.

Then write ? beside the one you are asked to work out.

Cross out the letter that is not part of the question.

Then choose the equation that has your four remaining terms.

Rearrange the equation if you need to.

Worked example

A motorcycle accelerates unifor
10 m s^{-1} to a final velocity of 30 m s

Calculate the time taken for th

t = ?, u = 10 m s^{-1}, v

So we use t

$$s = \frac{(u}{}$$

$$t =$$

$$t = \frac{2 \times 180}{10 + 30}$$

Test your knowledge 3

1. A cyclist starts from rest and accelerates uniformly at 0.8 m s^{-2}. After coverin
   cyclist reaches a speed of v. Calculate the cyclist's final velocity, and the time
2. A cyclist moving at 12 m s^{-1} begins to brake and slows down uniformly at 3
   Calculate the time taken to stop and the distance travelled during braking.

? Recap questions: suvat equations

1 A car accelerates from rest down a hill that is 120 m long. When it reache
travelling at 25 m s^{-1}.

   a) Calculate the car's acceleration.
   b) Once the car reaches the bottom of the hill, the road levels out and th
   coming to a stop in 30 s.

   Calculate the deceleration of the car from the bottom of the hill to wh

B1.4 Understand the applications of accelerometers 'fitbits', mobile phones and blood pressure monitor

Applications of accelerometers

Accelerometers are sensors that measure acceleration. They detect changes in m
them essential in many modern devices. It is necessary to understand what devic
work and how they are useful.

1. Fitbits

- Fitbits use accelerometers to track movement and measure physical activity.
- They can count steps by detecting small changes in acceleration when a person walks or runs.
- The accelerometer helps estimate calories burned by analysing the amount of movement over a period.

2. Mobile phones

- Mobile phones rely on accelerometers for scre
- If you turn your phone sideways, the acceleron
  the display.
- Accelerometers improve location tracking in yc
  movement even when the signal is weak.

3. Blood pressure monitors

- Some digital blood pressure monitors use accelerometers to detect subtle movements, ensuring accurate readings.
- This helps identify body position, which is crucial since blood pressure can vary depending on whether a person is standing, sitting or lying down.
- Wearable blood pressure monitors detect arm movement and adjust measurements to improve accuracy.

Summary

Type	What do they do?	
Fitbit	Estimates calories burned over a period.	Tracks phy
Mobile phone	Estimates location during movement.	Tr
Blood pressure monitor	Adjusts measurements depending on position.	Ide

Your turn

Investigate the use of accelerometers in one of the following situations, and creat
explaining the physics behind its use:

- Airbag deployment
- Vehic[illegible] th[illegible] system
- Fall detection for the elderly

B2 Laws of motion

Key points covered

- Newton's three laws of motion
- Inertia, mass and weight
- Coefficient of friction (μ)
- Calculating mome
- Balanced and unb

B2 Laws of motion

Newton's first law of motion

Newton's first law of motion states that

An object will remain at rest or in uniform motion in a straight line unless acted

At rest means stationary and **uniform motion** means at a constant velocity, so not accelerating, decelerating or changing direction.

Think of how some different objects obey this law:

- A book on a table is acted upon by two **balanced forces** – its **weight** pulling it down and the **normal contact force** from the table pushing it back up. The forces add to zero; therefore, the book stays at rest.
- The book is pushed gently from one side but does not move – the pushing force is opposed by a force of **friction** that acts between the surfaces in contact.
- Pioneer 10 is a space probe that left the Solar System in 1983; it is currently travelling in uniform motion at 45 000 km h^{-1} away from the Sun because it is not acted upon by any forces (there is no air resistance in space, and gravity from the Sun will be nearly zero).
- A parachutist in the final stage of their descent falls with uniform motion because the force of their weight acting down is opposed by the force of air resistance acting up: there is no **net force**.

Tip!
Do not make the mistake of thinking an object at rest must have no forces acting on it.

Mass and weight

Mass and weight are related but not the same.

Mass is the amount of matter that makes up an object. It is measured in kilogram no matter where the object is.

The greater an object's mass, the greater its resistance to a change in velocity (its

Mass is a scalar quantity (it has size but no direction).

For example, a 10 kg dumb-bell has the same mass whether it is on Earth, the Moon, or in space.

On the other hand, **weight** is the force exerted on an object due to **gravity**.

It is measured in newtons (N) and relates to the mass and **gravitational field strength** an object experiences.

Weight is a **vector quantity** (it has both size and direction).

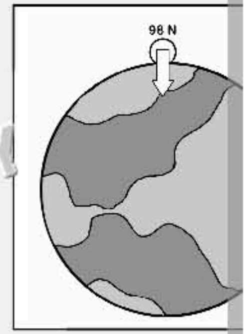
It is calculated using

$$\text{Weight} = \text{mass} \times \text{gravitational field strength.}$$
$$W = mg$$

Worked example: Weight of a dumb-bell on Earth and the

On Earth, a 10 kg object has a weight of

$$W = m \times g\ (\text{Earth}) = 10\ \text{kg} \times 9.81\ \text{m s}^{-2} = 98.1\ \text{N}$$



However, the object weighs less on the Moon, where gravity is weaker.

$$W = m \times g\ (\text{Moon}) = 10\ \text{kg} \times 1.6\ \text{m s}^{-2} = 16\ \text{N}$$

This shows that objects with the same mass can have a different weight depending on the gravitational field strength.

Free body diagrams

When describing forces, we often use diagrams. Objects such as cars, books, people on seats, etc. are replaced by simple shapes such as rectangles. Forces are shown by arrows whose direction shows the direction of the force and whose length is the magnitude of the force. We call these **free body diagrams** because they provide a simple way to visualise the forces on one object.

A free body diagram for the example of the book being pushed on the table but n
Figure 2.5.

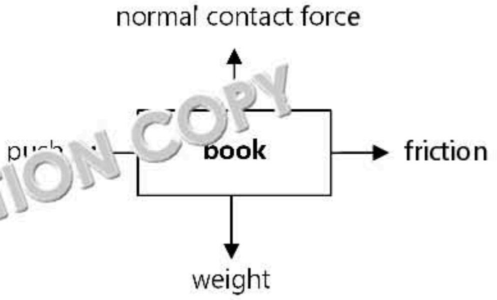


Figure 2.5 *A free body diagram of a book on a table being pushed bu*

Notice in the free body diagram in **Figure 2.5** that:

- We cannot tell from the diagram alone that the book is not moving. It could because the push force is balanced by friction. All we can tell is that it is not first law applies.
- The lengths of the arrows for the push and friction forces are equal and opp these forces add to zero.
- The lengths of the arrows for the weight and normal contact forces are equal conclude that these forces add to zero (they are greater in magnitude to the the arrows are longer).

B2.3 Calculation of the coefficient of friction (μ) usi force $F = \mu$N where N is the normal reaction force, t on a horizontal surface

Friction is the force that resists motion between two surfaces in contact.
It depends on how smooth or rough a surface is and the **normal reaction force** of the object (N).

The equation for calculating friction is:

$$\text{Friction} = \text{coefficient of friction} \times \text{normal contact f}$$

$$F = \mu N$$

The normal force is calculated by multiplying the mass of the object by the gravita

$$\text{Normal contact force} = \text{mass} \times \text{gravitational field str}$$

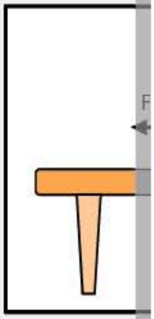
$$\text{N} = \text{m} \times \text{g}$$

On a horizontal surface, the normal force is equal to the object's weight because t

Worked example

A box of mass 5.00 kg is pushed along a horizontal table with a frictional force of 10 N.

Calculate the coefficient of friction (μ).



Step 1: Calculate normal force (F_N)

$$\text{N} = \text{mg} = 5.00 \times 9.81 = 49.05\ N$$

Step 2: Use the equation $\mu = \frac{F}{N}$

$\mu =$ [illegible] $= 0.204$

B2.3.1 Measuring coefficient of static friction, where F is the the object is about to move

We can use this result to determine how much force is required to just start movi

This is called the coefficient of static friction (μ_s).

Method

1. Measure the mass (m) of the object using a digital balance.
2. Calculate the normal force (N):

$$N = 9.81 \times m$$

3. Attach a force meter to the block and pull it horizontally with a slow, increasi
4. Record the force (F_s) at the exact moment the object starts moving (this is th
5. Calculate μ_s:

$$\mu_s = \frac{F_s}{N}$$

B2.3.2 Measuring coefficient of dynamic (kinetic) friction, wh applied to keep the object moving at a constant velocity

The **coefficient of dynamic (kinetic) friction (μ_k)** is the frictional force acting whe constant velocity.

It is usually lower than the coefficient of static friction because less force is neede to start it moving.

We can calculate this using the previous equation for friction.

Coefficient of kinetic friction = kinetic friction force ÷ normal

$$\mu_k = \frac{F_K}{N}$$

Method

1. Measure the mass (m) of the object using a digital balance.
2. Calculate the normal force (N):

$$N = 9.81 \times m$$

3. Attach a force meter to the block and pull it horizontally at a constant speed.
4. Record the force (F_K) required to keep the object moving steadily.
5. Calculate μ_k:

$$\mu_k = \frac{F_k}{N}$$

Always draw a
clearly. The di
motion of the

Worked example

A piece of furniture with a mass of 23 kg is at rest on a horizontal floor. A horiz the furniture. Calculate the coefficient of friction between the furniture and the

$$F = 80 \text{ N}$$

The normal force is the same magnitude as the weight acting on an object.

$$W = N = 23 \times 9.81 = 225.63 \text{ (to 2 d.p.)}$$

The coefficient of friction is already the subject, so

$$\mu = \frac{80}{225.63} = 0.35 \text{ (to 2 d.p.)}$$

Test your knowledge 5

1. A 10 kg box is pushed along a horizontal surface with a force of 50 N. A hori is applied to the box.
   a) Calculate the coefficient of friction between the box and the surface.
   b) Now, a horizontal force of [illegible] N is applied. Determine whether the box

B2.4 Calculating the momentum (ρ) of objects usin

Momentum calculation

Linear momentum (ρ) is related to how fast an object is moving in a straight line. metres per second (kg m s^{-1}).

Momentum is a **vector quantity** (has size and direction).

We can calculate the momentum of an object by multiplying its **mass** and **velocit**

$$\rho = m \times v$$

A heavier car moving at the same velocity as a lighter object will always have m is more difficult to change its motion.

Worked example: Heavy vehicle motion

An empty HGV with mass 10 000 kg is moving at 20 m/s. Calculate its momentu

$$\rho = 10\ 000 \times 20 = 200\ 000 \text{ kg m s}^{-1}$$

With this information we can say how hard it would be to make an object stop.

In this case, the car has lots of momentum and therefore it will be difficult to ma complete stop.

Test your knowledge 6

1. A bicycle of mass 10 kg is moving at 20 m s^{-1}
   a) Calculate the momentum of the bicycle.
   b) An empty HGV with mass 10,000 kg is moving at the same velocity. Which would cause more damage during an impact?

Newton's second law of motion

Newton's second law of motion states that

> *A net force acting on an object will produce acceleration that is directly pro and inversely proportional to its mass.*

We can write an equation to summarise Newton's second law like this:

$$\text{Net force (N)} = \text{mass (kg)} \times \text{acceleration (m s}^{-2}\text{)}$$

Worked example

The total mass of a Formula One car at the start of a race is 900 kg.
Calculate the net force required to produce an acceleration of 12 m s^{-2}.

$$\text{Net force} = \text{mass} \times \text{acceleration}$$
$$\text{Net force} = 900 \times 12$$
$$\text{Net force} = 10\ 800 \text{ N or } 10.8 \text{ kN}$$

B2.5.1 Calculations using Newton's second law

Newton's second law of motion also tells us that the force acting on an object is e
momentum over time. This is written as

$$F = \frac{(mv - mu)}{\Delta t}$$

Where F = force (N), mv = final momentum (kg m s^{-1}), mu = initial r
and Δt = time taken for the change (s)

This means that a larger force causes the momentum to change more quickly.

If the mass is constant then this simplifies down to

$$F = ma$$

This is how we can return to the form of Newton's second law as stated above. T
over time, like when a parachute deploys or when a car crashes (where crumple z
which momentum changes, reducing force and impact).

B2.5.2 Implications for transportation when travelling at hig and low speed with high mass

The speed and mass of a vehicle affect its movement, stability and safety. Lighter
struggle with braking and stability at high speeds, while heavier vehicles take long
at low speeds.

The following summarises how the mass affects each aspect of a high- and low-m

High speed with low mass (e.g. sports cars, motorcycles, aeroplanes)

- **Braking and safety:** Small, lightweight vehicles can accelerate easily as they h stop at high speeds as they have less traction and stability, which can reduce control during sudden stops. This increases the risk of accidents.
- **Fuel efficiency:** Uses less fuel to maintain speed because of less weight, but h more e
- **Stability:** Lightweight vehicles can be unstable at high speeds, especially in st small cars are easily pushed off course.
- **Collisions:** More damage occurs in crashes because light vehicles don't absor to seriously injure a pedestrian.

Low speed with high mass (e.g. trucks, buses, trains)

- **Braking and safety:** Heavy vehicles take longer to stop, even at low speeds, c
- **Fuel efficiency:** Large vehicles need more fuel to move, especially in stop-sta
- **Stability:** Heavy vehicles are stable at low speeds and less affected by wind b speeds as there is increased friction between the road and the tyres.
- **Collisions:** Heavier vehicles cause and sustain more damage in crashes becau

Summary

Factor	High speed, low mass (e.g. sports cars, motorcycles)	Lo (e
Braking and safety	Hard to stop at high speeds, increased accident risk.	Takes longer to
Fuel efficiency	More efficient at maintaining speed, but high speeds use more energy.	Uses more fuel in traffic.
Stability	Less stable at high speeds, affected by wind.	More stable at at high speeds.
Collisions	More damage in crashes due to low mass.	Causes more da

B2.5.3 Use of impact force controls

Modern vehicles use safety features to reduce injuries in crashes. These features passengers by reducing the negative acceleration. This is by spreading the impact hence reducing the force the passenger experiences. Below summarises how the force control.

1. **Airbags**
    - **How they work:** Airbags are inflatable cushions that pop out during a cr
    - **Impact force control:** They help soften the blow and slow down the pers hit hard things such as the steering wheel or dashboard.
2. **Seat belts**
    - **How they work:** Seat belts keep you secure in your seat.
    - **Impact force control:** They stop you from flying forwards during a crash over safer parts of your body (such as your chest and hips).
3. **Helmets (for motorcycle riders)**
    - **How they work:** Helmets protect your head in crashes. They're made of padding inside.
    - **Impact force control:** The helmet absorbs the shock from hitting someth skull from damage.
4. **Passenger 'cells' (safety cells)**
    - **How they work:** The passenger part of a car is built extra strong.
    - **Impact force control:** This strong structure keeps the area around you fr protecting you inside.
5. **Crumple zones**
    - **How they work:** Crumple zones are parts of a car that are meant to crun (usually the front and back).
    - **Impact force control:** They help slow down the car gradually instead of s reduces the force on you.

Research questions

Racing car drivers experience extreme forces during high-speed crashes. To pro use **HANS (Head and Neck Support) devices, roll cages, and energy-absorbing** b belts and helmets.

1. Describe how HANS devices and helmets reduce impact forces on a driver's
2. Explain how crumple zones and roll cages work together to protect the driv

Test your knowledge 7

1. Crumple zones are designed to collapse at speeds over **12 m s^{-1}**, with a dece while passenger cells stay rigid to protect occupants.

   Explain how these safety features help reduce injury in a crash.

Newton's third law of motion

Newton's third law of motion relates the force acting on one body to the force ac
action and reaction are equal and opposite.

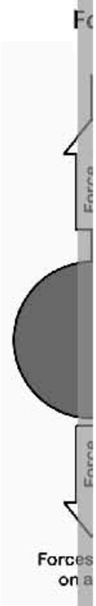
Think of these examples:

- For a force of attraction to exist on a magnet, there must be either an opposi piece of magnetic material close by.
- For a push force when you walk, your foot must push back on the ground.
- For a charge to experience a repelling force, there must be another like charg
- When a ball falls due to gravity, there must be a large mass causing that grav

B2.7 Know that if *F* is the resultant force on an object, the o if the forces are balanced *F* is zero and the object is moving velocity or stationary

If there is a **resultant force** the object will accelerate. This means it will speed up, slow down, or change direction.

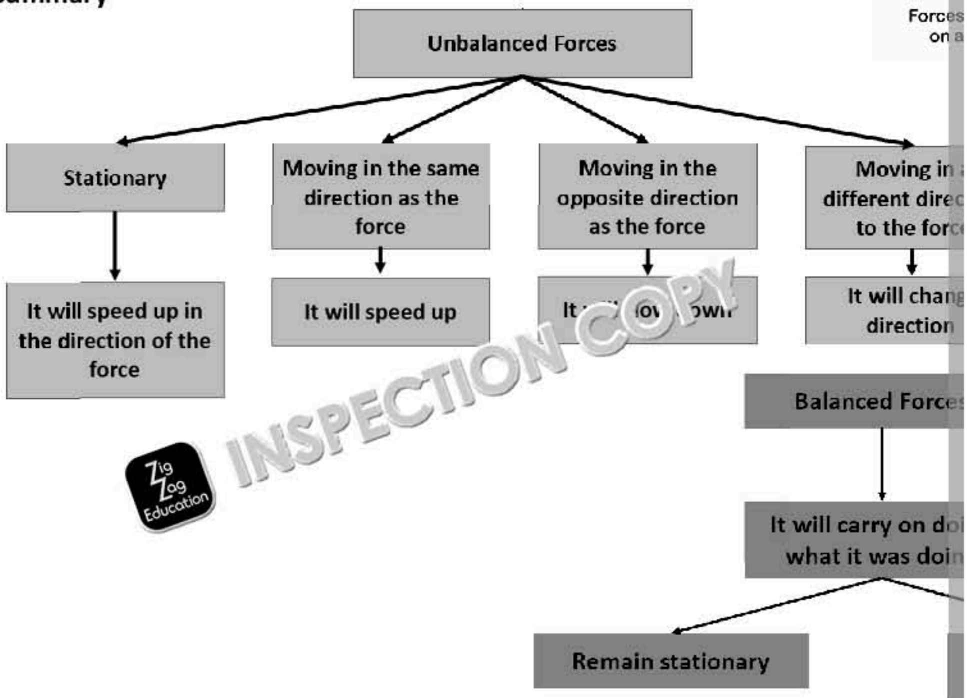
When the forces are balanced the object could be stationary or moving at a constant velocity. As there is no resultant force, it will just keep doing what it was doing before.



However, when the forces are unbalanced, giving a resultant force, the object can speed up, slow down, or change direction. This can be summarised using the diagram below, which shows what the motion of the object will be according to the resultant force.

Top Tip!
Always use a diagram to show all the forces acting on an object. This will make it easier to determine the resultant force.

Summary



B2.7.1 Effect of air resistance, drag and terminal velocity

When objects move through air or liquids, they experience resistance forces such as drag, which slow them down. This section summarises how **air resistance**, **drag** and **terminal velocity** affect vehicles on roads, falling parachutes, and objects in liquids, helping to explain real-world motion and energy efficiency.

Vehicles on roads

- **Air resistance and drag**: When a car [illegible], the air pushes against it, creating resistance (drag). This slows down the car a little.
- **Effect on cars**: The faster the car goes, the more drag it faces. To go faster, [illegible] more power, which uses more fuel. Streamlined cars ([illegible] shapes) are designed to reduce drag and save fuel.
- **Terminal velocity**: Cars don't usually reach terminal velocity on the road bec
speeding them up, but if the engine stops (e.g. going downhill), drag slows d

Falling parachutes

- **Air resistance and drag**: When a parachute opens, it creates a lot of drag becau
- **Effect on parachutes**: The parachute slows the fall by creating drag. Eventua
gravity, and the parachutist reaches a constant speed (called terminal velocit
without the parachute.
- **Terminal velocity**: The parachute decreases the terminal velocity of the para
reach the ground at a low enough velocity that the impact does not cause inj

Objects falling in liquids

- **Air resistance and drag**: When an object falls in water (or any liquid), it faces
because liquids are denser than air.
- **Effect on objects in liquids**: The object will slow down quickly because the lic
opposes the motion of the object.
- **Terminal velocity**: It will reach a terminal velocity faster than in air, and this s
depending on the object's shape and density.

Worked example

A car is accelerating along a horizontal track.

a) Draw and label the diagram to show the three forces acting on the vehicle.

b) Describe and explain how air resistance will change as the car speeds up.

As the velocity of the car increases, the air resistance will increase.
This is because the air particles collide with the car, opposing its motion.

Test your knowledge 8

A parachutist jumps out of an aeroplane and initially accelerates due to gravity. After a few seconds, they open their parachute.

1. What happens to their speed immediately after opening the parachute?
2. Why does the parachutist eventually reach a constant speed before landing?

? Recap questions: Effect of air resistance

I A small metal ball is dropped into a tank of water.
   a) Describe how the forces acting on the ball change as it falls.
   b) Explain why the ball reaches terminal velocity more quickly in water th

C: Electrical circuits and the trans

C1 Use of electrical components

! ***Key points covered***

- Identifying circuit symbols
- Defining terminology – current, potential difference, energy and power
- Connecting circuits with cells, resistors, variable resistors, sw
- Using electrical components i

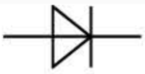
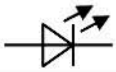
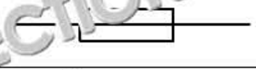
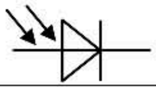
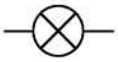
C1.1 Use of electrical components

Circuit symbols and diagrams

In science, we draw diagrams rather than draw pictures. Diagrams are simplified illustrations focusing on the essential elements and their functions.

Circuit symbols are international standard symbols which represent various electr functions in a circuit diagram. These symbols allow people to easily understand th needing to see the actual layout of the components. **Table 3.1** shows the circuit s

Table 3.1 Standard circuit symbols.

Component name	Component symbol	Component name
Current direction / energy or signal flow		Primary or secondary c
Conductors crossing with no connection		Battery of cells
Junction of conductors		Thermistor
Make contact, normally open, general switch		Light-dependent resist
Open terminals		Variable resistor
Capacitor		Fixed resistor
Diode		Potentiometer
Light-emitting diode		Ammeter
Photovoltaic cell		Voltmeter
Fuse		Wattmeter
Photodiode		Electric bell
Motor		Buzzer
Indicator / light source		

C1.2 Defining terminology

Current

Electric **current** is the rate of flow of **charge** through a medium.

In wires, which are usually made from metal, the charge is carried by **electrons**. In liquids, or solutions, the charge can be carried by **ions**. A solution in which charge flows is called an **electrolyte**. Wires and electrolytes are both conductors of electricity.

Current is measured in **amperes** (A), which is the rate of flow of charge. One ampere is equal to one **coulomb** (C) of charge passing a specific point in a circuit per second. The greater the number of charged particles flowing through a conductor per unit time, the higher the current.

1 C in a metal wire is made up of 6.25×10^{18} electrons. That's more than 50 million times the number of humans that have ever lived! Many currents that you will encounter are measured in mA (milliamperes). The prefix m means divided by 1000 or multiplied by 10^{-3}.

Potential difference

We use voltmeters to measure a quantity that has the unit of volts. This quantity is **potential difference**. Potential difference is the energy transferred as charge passes through a component in a circuit. A larger potential difference will result in a larger current through the component.

Potential difference is measured *across* components; current is measured *in* com

Power

Electrical power is measured in watts (W) and is a measure of how much electrical work is done by an appliance or device per **unit time**. One watt is equivalent to one joule per second.

Energy

Circuits allow energy to do useful jobs for us: lighting, making sounds, making things move, and heating. When someone pays an electricity bill, they are paying for the **energy** that has been transferred in their appliances.

By transferring electrical energy, for example by lighting, the electricity does **work**.

Work and energy are equivalent quantities, so both have the unit joules (J). That means when 100 J of energy is transferred, 100 J of work can be done.

Resistance in ohms

Every component in a circuit has a property called **resistance**. Electrical resistance reduces the flow of electric current and is measured in ohms (Ω). The symbol is the upper-case Greek letter omega, which has the same shape as a horseshoe.

Components made of good conductors like copper, silver and gold have very low
Whereas components made of insulators like wood and plastic have very high res
has a low resistance, then only a small potential difference is needed to drive cur

C1.3 Connecting circuits

Series connections

Series connections are the simplest type of circuit: each component is connected to the next one in one continuous loop. In a circuit with series connections, the current in each component is the same.

Figure 3.1 shows a circuit with a cell (C), a filament lamp (L) and a resistor (R) connected in series.

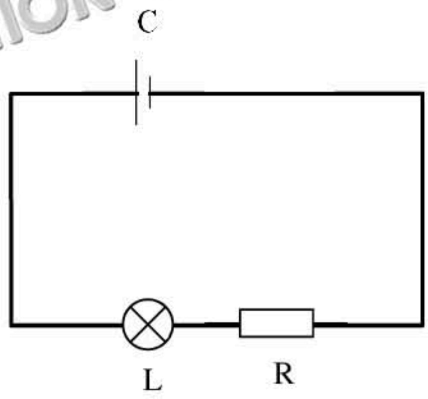


Figure 3.1 *A circuit with a cell (C), a filament lamp (L) and a resistor (R) co*

As the current is the same, charge does not get lost.

As the potential difference may be different across different components, the electrical power in each component may vary.

Parallel connections

Parallel connections are different because there are multiple loops.

Figure 3.2 shows a circuit with a lamp and a resistor connected in parallel with a c

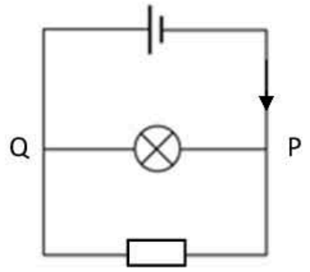


Figure 3.2 *A circuit with a lamp and a resistor connected in paralle*

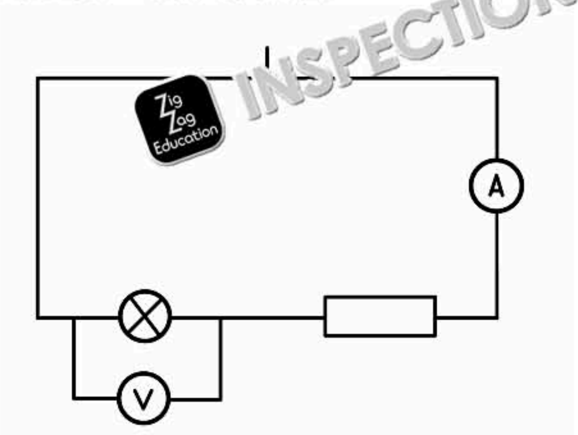
There are two loops in this circuit. The resistances may be different, so the curren
The current in the cell is equal to the current in the lamp plus the current in the re

Measuring current and potential difference

To measure current, you use an **ammeter**. It is important that the ammeter is connected in **series** with the component you are measuring.

To measure potential difference, you use a **voltmeter**. It is important that it is connected in **parallel** across the component you are measuring.

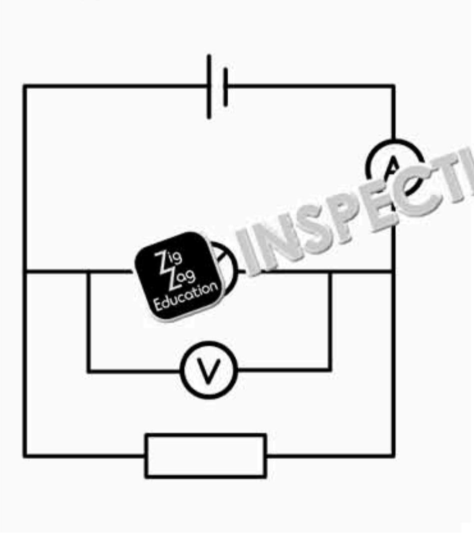
The following circuit diagram shows how to connect an ammeter and a voltmeter in a series circuit.



In a series circuit:

- The current is the
- You can place the circuit and it will
- The total potentia is shared betweer
- The sum of the vo equals the total vo

In a parallel circuit, the voltage and current changes depending on the resistance The diagram below shows how to connect an ammeter and a voltmeter in a parall



In a parallel circuit:

- The current splits betweer
- The current in each branc the branch.
- The potential difference a as the voltage of the powe
- Each branch gets the full v

Circuit rules

Quantity	Instrument	Connection style	Series circuit
Current (A)	Ammeter	In series	Same everywhere
Potential difference (V)	Voltmeter	In parallel	Shared between components

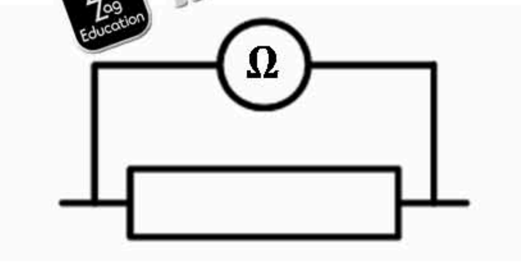
C1.3.2 Using an ohmmeter to measure the resistance of a co

Resistance is a measure of how much a component opposes the flow of **current** measured in ohms (Ω).

To measure the resistance, you use an **ohmmeter**. The ohmmeter must be connected **in parallel** with the component you are measuring.

You must also remove the component from the circuit first, or the **circuit must be switched off**, otherwise the other components will interfere with the measurement.

The following shows how to connect an **ohmmeter** across a resistor.



Tip!
Resistance depends on t
Some components get h
their resistance increase

It is important to understand the resistance across a component to determine its components break when a large enough voltage is applied across it.

C1.4 Using electrical components in circuits

Expand your knowledge: Ohm's law and ohmic conductors

Ohm's law states that for a constant resistance, the current through a conductor i difference across it. It is named after Georg Simon Ohm who discovered it. Diffe components which we can use in circuits can be described as either ohmic or non

This means a graph of current, I (on the y-axis) against potential difference, V (on through the origin, as shown in **Figure 3.3**.

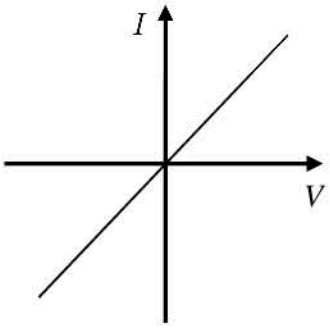


Figure 3.3 The variation of current with potential difference is a st through the origin for an ohmic conductor.

The gradient of the line in this graph is $\frac{1}{R}$ so the steeper the line, the smaller the re

We refer to components that obey Ohm's law as **ohmic conductors** and those tha approximately, as **non-ohmic conductors**.

Examples of ohmic conductors include thick metal wire and **resistors**. Resistors a the specific function of providing resistance to current.

Notice that the letter I is used as an abbreviation for current. This is because And on current, called it *intensité du courant* in French, hence the letter I.

The graph is sometimes referred to as the I-V characteristic of an ohmic conducto

Filament lamps

One example of a non-ohmic conductor is a filament lamp. As the potential difference across a filament lamp increases, the current through it also increases. Current warms the filament (which makes it glow) and increases the resistance.

The graph has this shape because each increase in potential difference results in a smaller increase in current through the filament. A greater resistance has a smaller gradient. Hence, the I-V characteristic of a filament lamp is a curve, as shown in **Figure 3.4**.

Figure 3.4 *The I*

Diodes and light-emitting diodes (LEDs) and photodiodes

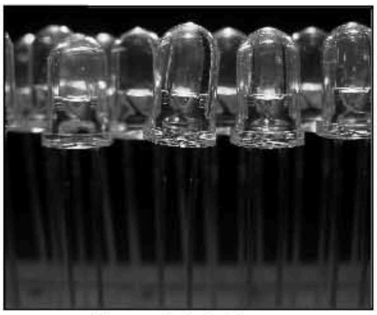


Figure 3.5 *An image of blue LEDs.*

A **diode** is like an electrical valve, allowing curr in one direction but blocking current in the opposite direction. Some diodes are designed emit light when there is current in the diode. These are called **light-emitting diodes (LEDs)**.

Other special types of diodes respond to light instead of producing it. These are called photodiodes. A photodiode generates a small electric current when light falls on it and is usu operated in reverse bias. The amount of curre produces depends on the intensity of the light.

Diodes and LEDs both have a similar I-V characteristic which looks like the graph i

To the left of the I axis, the potential difference is trying to pass current through the diode in the wrong direction. The resistance is very large so no current flows. The line on the graph follows the horizontal axis because the value of I is zero at all values of V. To the right of the I axis, the potential difference tries to pass current in the correct direction. The resistance decreases with increasing potential difference, resulting in a curve.

Figure 3.6 *The I-*

Thermistors

The thermistor is a component designed so the resistance falls with an increase in temperature. For this reason, they are sometimes called **negative temperature coefficient (NTC) thermistors.**

NTC thermistor – a component whose resistance decreases with increasing temperature

The I-V characteristic of a thermistor is shown by the graph in **Figure 3.7**. The graph shows the thermistor at two different constant temperatures.

At higher temperatures, the resistance of the NTC thermistor is less, so the gradient of the line on the graph is steeper.

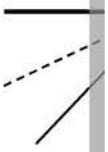


Figure 3.7 *The I-V c*

Light-dependent resistor

Another example of a non-ohmic conductor is a **light-dependent resistor** (LDR). This is a component whose resistance decreases with increasing light intensity.

Light-dependent resistor (LDR) – a component whose resistance decreases with increasing light intensity

The *I*-*V* characteristic of an LDR looks like the graph in **Figure 3.8**.

The LDR obeys Ohm's law at constant light intensity. However, increasing the light intensity decreases the resistance, so the gradient of the line on the *I*-*V* graph at higher light intensity has a steeper gradient.

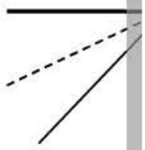
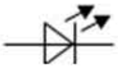


Figure 3.8 The I-

Recall questions 1

1. Write a definition of current.
2. Name a particle that carries the negative elementary charge.
3. What does this symbol mean in a circuit diagram?



4. When measuring the resistance of a thermistor at different temperatures usi what happens to the current if the temperature increases, assuming a consta

Recap questions

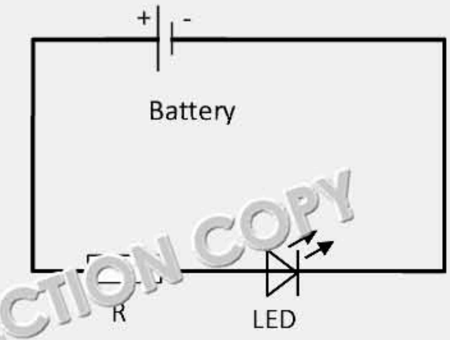
1 Which of these carries moving charge in a copper wire when there is curre Select **one** option.

A Protons **B** Electrons **C** Ions **D** Atoms

2 Describe what makes the resistance of an NTC thermistor increase.

Worked example

Draw a simple circuit diagram showing how a light-emitting diode (LED) can be c resistor to protect the LED. Label the LED and resistor in your diagram, and indi current flow through the LED.



The resistor should be connected in series with the LED to the battery, and the L correct direction so that it is forward-biased. Then, the current will be limited b from the positive terminal of the battery, through the resistor and LED, to the n

C2 Equations

! ***Key points covered***

- power = potential difference × current
- voltage = current × resistance
- power = work don
- energy = potential

C2.1 Using equations for electrical calculations

Voltage, current and resistance

The relationship between current, potential difference and resistance is given by t

$$\text{potential difference (V)} = \text{current (A)} \times \text{resistance}$$

We can use this relationship to conclude that a potential difference of 1 V will dri
resistance of 1 Ω.

We can rearrange the equation above to define resistance:

$$\text{resistance } (\Omega) = \frac{\text{potential difference (V)}}{\text{current (A)}}$$

The resistance of a component is the ratio of the potential difference across it to t

Worked example 1

A current of 0.5 A is required in a conductor of resistance 20 Ω.
Calculate the potential difference needed to provide this current.

$$\text{potential difference} = \text{current} \times \text{resistance}$$

$$\text{potential difference} = 0.5 \times 20$$

$$\text{potential difference} = 10 \text{ V}$$

Worked example 2

A potential difference of 6 V across a conductor drives a current of 1.5 A.
Calculate the resistance of this conductor.

$$\text{resistance } (\Omega) = \frac{\text{potential difference (V)}}{\text{current (A)}}$$

$$\text{resistance } (\Omega) = \frac{6}{1.5}$$

$$\text{resistance } (\Omega) = 4\ \Omega$$

Calculating electrical power

Appliances are rated in watts (W) or kilowatts (kW), which tells you how much th
electricity when you use power to run an appliance. The longer you run it for, or t
you pay. You pay for energy, or work done, calculated by power multiplied by tim

$$\text{energy (joules)} = \text{power (watts)} \times \text{time (seconds)}$$

This can also be rearranged to calculate power:

$$\text{power} = \frac{\text{work done (joules)}}{\text{time (seconds)}}$$

Because potential difference connects power and current, you can also write:

$$\text{power (watts)} = \text{potential difference (volts)} \times \text{current (amperes)}$$

You can therefore calculate energy using electrical quantities, because power in w
is equal to potential difference (volts) × current (amperes).

$$\text{energy (joules)} = \text{potential difference (volts)} \times \text{current (amperes)} \times \text{time (sec}$$

Worked example 1

A 2 kW electric heater is used for 3 hours. Calculate the total energy consumed

Use the formula:

energy (joules) = power (watts) × time (seconds) $E = Pt$

$$E = 2000 \times 3 \times 60 \times 60 = 21\ 600\ 000\ J = 21.6\ MJ$$

Worked example 2

An electric kettle operates with a potential difference of 230 V and draws a curr
5 minutes, calculate the energy transferred by the kettle.

Use the formula:

energy (joules) = potential difference (volts) × current (amperes) × time (

$$E = 230 \times 8 \times 5 \times 60 = 552\ 000\ J = 552\ kJ$$

Worked example 3

A toaster uses 900,000 joules of energy in 5 minutes. Calculate the power ratin

Use the formula:

$$power = \frac{work\ done\ (joules)}{time\ (seconds)} \qquad P = \frac{E}{t}$$

$$P = \frac{900\ 000}{5 \times 60} = \frac{900\ 000}{300} = 3000\ W = 3\ kW$$

Apply your knowledge 1

1. A 9.0 V battery runs a current of 300 mA for 5.0 minutes. Calculate the work
2. A ceiling light runs from mains electricity at 230 V and transfers 96 J of ener
charge which flows through the light every second. Give your answer to two

Recap questions 2

1 There is a potential difference of 1.5 V across a 300.0 Ω resistor.
Calculate the current in this resistor.
Give your answer in mA.

2 An electric heater has a rated input power of 2.2 kW.
   a) State the energy transferred to the heater in 1.0 s.
   b) Calculate the current drawn by the heater when operating at a potenti

C3 Electrical energy usage

! ***Key points covered***

- Energy use of domestic appliances
- Fuse size and current
- Energy transferred

C3.1 Relating to different domestic appliances to calc

Energy usage depends on how long the appliance is used and its power rating.

The relationship between energy transferred, power, and time is given by the equation

energy transferred (kilowatt-hours) = power (kilowatts) × time (hours)

$$E = P \times t$$

Common household appliances such as kettles, washing machines, and hairdryers power in watts (e.g. 2000 W = 2.0 kW).

The unit **kilowatt-hour (kWh)** is used by electricity companies to charge for energ

Worked example

A kettle has a power rating of 2000 W and is used for 0.5 hours.
Calculate the energy transferred by the kettle during this time in kWh.

Power P = 2000 W = 2 kW
Time t = 0.5 hours

We have to use the formula:

$$\text{energy transferred (kilowatt-hours)} = \text{power (kilowatts)}$$

$$E = P \times t$$

$$E = 2 \times 0.5 = 1\,kWh$$

Apply your knowledge 2

1. Find out about the electrical power rating of various domestic appliances (su components (such as light bulbs). You can do this by looking at labels on ap user manuals) or by searching online.

   You should be able to find domestic appliances with power ratings ranging f

2. Find the potential difference of the mains supply in the UK and use this to ca used by each of your listed appliances. Remember that appliances such as w different power requirements at different times in their operating cycles.)

C3.2 Relating fuse size to current

A **fuse** is a safety device that protects appliances from too much current.

It contains a thin wire that melts and breaks the circuit if the current is too high.

To choose a fuse, calculate the **current** by doing power divided by voltage.

$$\text{Current (A)} = \text{Power (W)} \div \text{Voltage (V)}$$

$$I = \frac{P}{V}$$

Fuses are typically rated at **3 A**, **5 A**, or **13 A**.

Always use a **fuse slightly above** the calculated current as this means the applianc
breaking the fuse.

C3.3 Calculating transferred energy using the equat transferred = power in kilowatts × time in hours (kW

The **kWh** (kilowatt-hour) is a unit of **energy**, not power.

1 kWh = the energy used by a 1 kW appliance running fo

This is a **simplified version** of the energy transfer equation for domestic use.

This is often used to **calculate electricity costs**. Joules are too small for househol
bill was in joules, you would be dealing with large numbers that would be hard to

Recap questions 3

1 A microwave has a power rating of 1.8 kW and is used for 5 minutes every

- a) Calculate the energy it uses in one day.
- b) How much energy will it use in one week?
- c) If electricity costs £0.30 per kWh, how much would it cost to run for

C4 Energy transfer

Key points covered

- Joules, kilojoules and mega joules
- Converting between Celsius and Kelvin
- Energy transfers in change of te
- Specific heat capacity

C4.1 Defining units – joules (J), kilojoules (kJ), mega

The joule (J) is the standard **unit of energy** in science.

For larger amounts of energy, we use:

1 kilojoule (kJ) = 1000 joules
1 mega joule (MJ) = 1,000,000 joules

These units are commonly used:

joules – in small systems (like heating water)
kJ or MJ – in food labels, engines, fuel energy, and power stations

C4.2 Converting temperatures between Celsius (°C)

We use the Kelvin scale in science because it starts at absolute zero, which is the coldest possible temperature!

The **Kelvin scale** starts at **absolute zero**, where particles have [illegible] thermal energy.

To convert from degrees Celsius to Kelvin you add 273.

$$K = °C + 273$$

Conversely [illegible] convert from Kelvin to degrees Celsius you subtract 273.

$$°C = K - 273$$

The table below shows some examples of converting between units:

Degrees Celsius (°C)	K
0	
100	
20	

This is used in future calculations for specific heat capacity, and specific latent hea the Kelvin scale.

C4.3 The transfer of energy to give a change of tem change of state

When energy is added [illegible] substance, it can:

- Increase temperature (particles move faster)
- Change [illegible]ate (e.g. solid to liquid), by breaking bonds without changing te

For example, when we heat water from room temperature (22 °C) to its boiling po temperature, but once the water reaches its boiling point there is a change of stat breaks bonds with no change in temperature.

C4.4 Temperature change

Specific heat capacity is measured in **joules per kilogram per kelvin**. This is a measure of how much energy is required to raise the temperature of 1 kg of a material by 1 °C or 1 K.

To measure the **specific heat capacity** of a solid you need to measure the amount of energy transferred to the material and the temperature change that follows. This requires a **joulemeter**, a heater, a **thermometer** and an insulated block.

For liquids, the set-up is slightly different, requiring the use of a **calorimeter**.

Specifi
is requi
a mater

Joulem
amount

Thermo
the tem

Calorim
thermal
substan
phase c

The thermal energy is related to the mass, specific heat capacity, and temperature change by the following equation:

Thermal energy (J) = Mass (kg) × Specific heat capacity (J kg^{-1} K^{-1}) × T

$$Q = m \times C \times \Delta T$$

Knowing the specific heat capacity of a substance is useful, as material with a high **lots of energy** without large temperature changes. This is ideal for central heating

Recap questions 4

1 A metal block of mass **1.5 kg** is heated from **25 °C** to **75 °C**. The **specific heat capacity** of the metal is **500 J kg^{-1} K^{-1}**.

a) Convert the temperature change from degrees Celsius to Kelvin.
b) Calculate the energy transferred to the metal block.

C5 Change of state

! ***Key points covered***

- Specific latent heat fusion and vapourisation
- Thermal energy = r

C5.1 Measuring specific latent heat fusion and vapo

The **specific latent heat** of a substance is the energy required to **change the state** of 1 kg of a substance **without changing its temperature**.

There are two types of specific latent heat, separated by their associated state changes:

Latent heat of fusion – energy to melt or freeze.
Latent heat of vapourisation – energy to boil or condense.

To calculate **thermal energy required for a phase change**, you require the mass and **specific latent heat** of an object. This is related by the following equation:

$$\text{Thermal energy (J)} = \text{Mass (kg)} \times \text{Specific latent heat}$$

$$Q = mL$$

This is important in heating and cooling systems such as fridges, air conditioners, substances that absorb or release large amounts of energy as they change state.

C5.2 Using the equation: Thermal energy = mass × s

In the previous section we described how the specific heat capacity is used when temperature, but this equation is used when changing state, not temperature.

Below shows the standard units used when using the equation.

Quantity	Sta
Mass (m)	Kilo
Specific latent heat (L)	Joules pe
Thermal energy (Q)	E

It might be necessary to change from **grams to kilograms (÷1000)**, or from **kilojoules to joules (×1000)**.

Remember that the **specific latent heat of fusion** and **vapourisation** do not have to be the same values.

Before su
equation,
everythin

Water has a much larger value latent heat of vapourisation (2 260 000 J kg^{-1}) than (334 000 J kg^{-1}). This means it takes much more energy to boil or condense water

? ***Review Questions 5***

1 a) How much energy is needed to **evaporate 0.2 kg** of water?
(Specific latent heat of vapourisation for water = 2 260 000 J kg^{-1})
b) Explain why the temperature of a substance remain constant during a
energy is still being transferred.

Answers

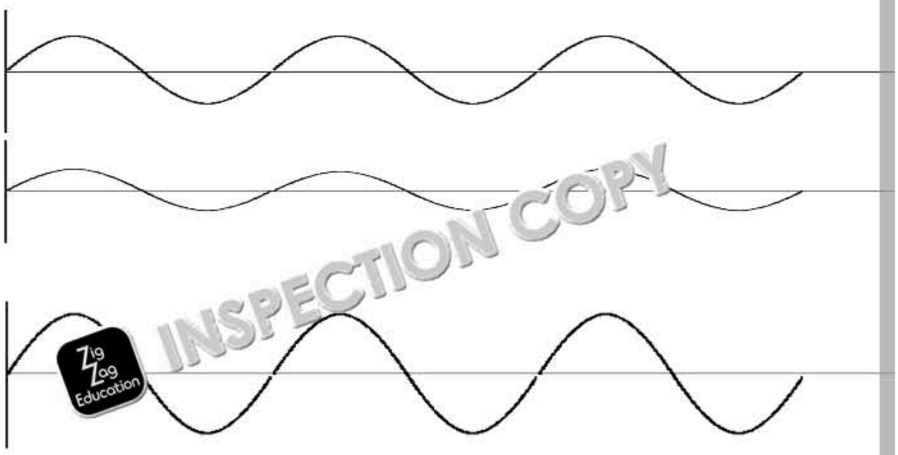
A1 Working with waves

Wave basics

1. a) (i) Wavelength – The distance from any point on a wave to the correspondin crest to crest or from trough to trough). Measured in metres [m].
   (ii) Frequency – the number of complete oscillations in one second. Measure
   (iii) Period – The time taken for one complete oscillation. Measured in secon
   (iv) Amplitude – The maximum displacement distance from the point/line of n oscillation. Measured in metres [m].
   (v) Displacement – Is the actual distance (and direction) from the point/line o during an oscillation. Measured in metres [m].
   b) Every oscillation, each point in the medium moves from its undisturbed point t direction returning to the point of no displacement and then repeats this in the point of no displacement to complete the cycle. At all points in the cycle, exce the displacement of the medium can be quantified in both distance and directi displacement is at its maximum value, but in opposite directions. This maximu irrespective of direction, so amplitude is a scalar quantity and direction a vecto

Interference

1.



2. a) The answer would look the same.
   b) The displacements for each wave add together and this is not affected by the d (because the medium is displaced, but does not move in the direction of the en

Diffraction spectroscopy

1. a) The suggestion that this spectrum is from a protostar in a nearby galaxy is subs both hydrogen and helium being present.

   Further explanation – In the young star, hydrogen will be being fused to helium atoms of both elements are likely to become excited with electrons moving be characteristic photons. The spectrum is not greatly red-shifted because the sta

   b) All electrons associated with atoms and molecules have a natural, base state. T configuration for that atom or molecule and is known as the ground state. In c heated or irradiated, electrons are given extra energy and become promoted t known as being in an excited state. The atom or molecule cannot remain in an its ground state giving out energy in the form of a proton which has a discrete characteristic colour.