endorsed for edexcel

# Edexcel AS/A level PHYSICS 1

Miles Hudson

ALWAYS LEARNING

PEARSON

Published by Pearson Education Limited, 80 Strand, London WC2R 0RL.

www.pearsonschoolsandfecolleges.co.uk

Copies of official specifications for all Edexcel qualifications may be found on the website:
www.edexcel.com

Text © Pearson Education Limited 2015
Edited by Susan Gardner and Matt Deacon
Designed by Elizabeth Arnoux for Pearson Education Limited
Typeset by Techset Ltd, Gateshead
Original illustrations © Pearson Education Limited 2015
Illustrated by Techset Ltd and Peter Bull
Cover design by Elizabeth Arnoux for Pearson Education Limited
Picture research by Ruth Smith
Cover photo/illustration © Bridgeman Art Library/Biblioteca Ambrosiana, Milan, Italy/
De Agostini Picture Library/G. Cigolini/© Veneranda Biblioteca Ambrosiana – Milano

The right of Miles Hudson to be identified as author of this work has been asserted by him in accordance with the Copyright, Designs and Patents Act 1988.

First edition published 2008
Second edition published 2015

19 18 17 16 15
10 9 8 7 6 5 4 3 2 1

**British Library Cataloguing in Publication Data**
A catalogue record for this book is available from the British Library

ISBN 978 1 447 99118 2



Printed in Slovakia by Neografia

**Acknowledgements**
Every effort has been made to contact copyright holders of material reproduced in this book. Any omissions will be rectified in subsequent printings if notice is given to the publishers.

**A note from the publisher**
In order to ensure that this resource offers high-quality support for the associated Edexcel qualification, it has been through a review process by the awarding body to confirm that it fully covers the teaching and learning content of the specification or part of a specification at which it is aimed, and demonstrates an appropriate balance between the development of subject skills, knowledge and understanding, in addition to preparation for assessment.

While the publishers have made every attempt to ensure that advice on the qualification and its assessment is accurate, the official specification and associated assessment guidance materials are the only authoritative source of information and should always be referred to for definitive guidance.

Edexcel examiners have not contributed to any sections in this resource relevant to examination papers for which they have responsibility.

No material from an endorsed book will be used verbatim in any assessment set by Edexcel.

Endorsement of a book does not mean that the book is required to achieve this Edexcel qualification, nor does it mean that it is the only suitable material available to support the qualification, and any resource lists produced by the awarding body shall include this and other appropriate resources.

**Picture credits**
The publisher would like to thank the following for their kind permission to reproduce their photographs:

(Key: b-bottom; c-centre; l-left; r-right; t-top)

**123RF.com:** David Holm 54 (Motorbike), khunaspix 51tr; **Alamy Images:** blickwinkel 115, Buzz Pictures 51br, Cal Sport Media 56b, Chris Hellier 122bc, Cultura RM 112, David A. Eastley 169, dpa picture alliance 116tl, dpa picture alliance archive 54 (Hammer), fStop 52–53, Horizon Images/Motion 126–127, Hugh Threlfall 109r, Justin Kase z11z 17b, Paul John Fearn 66t, Phil Crow 17t, Pictorial Press Ltd 94, Richard Cooke 160tl, Simon Balson 16, Stephen Barnes/Sport 45, Terry Oakley 39, Washington Imaging 110–111; **Construction Photography:** BuildPix 103; **Corbis:** Aurelien Meunier/Icon SMI 71, Bettmann 188–189, Markus Moellenberg 60 (a), Monalyn Gracia 136; **Digital Stock:** 86; **Fotolia.com:** antbphotos 8b, Artem Furman 88–89, Boggy 46, ChrisVanLennepPhoto 140–141, Dario Lo Presti 56tl, Dayzi 152–153, Georgios Kollidas 26, Joggie Botma 119tl, suziwheatley 36, Zoe Schumacher 40–41; **Getty Images:** AFP 10, Alexander Gerst/ESA 8t, Bill Frakes/Sports Illustrated 48t, Gary Gladstone 9b, Hanneke Luijting 42t, Hisham Ibrahim 57, Jonathan Wood 117, Matthew Lewis 21, Paul Gilham 48b, Peter Cade 9t, Ralph Morse/The LIFE Picture Collection 12r, Rob Monk/Procycling Magazine 60 (b), zeljkosantrac 125tl; **GNU Free Documentation License: Wikipedia:** Fizped/Zátonyi Sándor (ifj.) 173, 175; **IBM Research:** 197cr; **Jeff La Favre:** 166; **Lascells Ltd:** 182; **Library of Congress:** Philosophiae naturalis principia mathematica/ Isaac Newton 55; **Martyn F. Chillmaid:** 20, 44, 143t, 180; **Masterfile:** 122r; **NASA:** JPL-Caltech/MSSS 106; **National Geophysical Data Center:** 148; **National Institute of Standards and Technology:** 11; **OBO Goalkeeping, New Zealand:** 60 (c); **Pearson Education Ltd:** 12l, 105t, 138, 139, Coleman Yuen 161b, Martyn F. Chillmaid 66c, Trevor Clifford 58, 58c, 98, 102, 114, 116tr, 135, Tsz-shan Kwok 75, 172; **PhotoDisc:** Doug Menuez 54 (Skateboard); **Physio Control:** 84; **Prof. (emeritus) Dr. Michael M. Raith:** from Fig. 4–18 of the second edition: Michael M. Raith, Peter Raase and Jürgen Reinhardt, 2012. Guide to Thin Section Microscopy, (2nd edition, ISBN 978-3-00-037671-9) 184l; **Reprinted courtesy of the Central Research Laboratory, Hitachi, Ltd., Japan:** Demonstration of single-electron buildup of an interference pattern: Tonomura, A.; Endo, J.; Matsuda, T.; Kawasaki, T.; Ezawa, H. American Journal of Physics, Volume 57, Issue 2, pp. 117–120 (1989) 197cl; **Rex Features:** LumiGram 187; **Robert Harding World Imagery:** Amanda Hall 116bc, James Emmerson 116bl; **Science & Society Picture Library:** Science Museum 191; **Science Photo Library Ltd:** 119tr, Andrew Lambert Photography 157, 160tr, 197tl, Cordelia Molloy 109b, Edward Kinsman 54 (Bullet), 155, 161tl, 161tr, 161cr, 200, Erich Schrempp 164, GIPhotostock 174, 190, 196, Jim Amos 143b, Peter Aprahamian/Sharples Stress Engineers Ltd 183tr, Sheila Terry 125tr; **Shutterstock.com:** Anton Balazh 64–65, Brian Kinney 42b, drohn 184r, gualtiero boffi 23, LIGHTWORK 50cr, naipung 162, Ryan Jorgensen – Jorgo 181, Salvador Tali 69, Sebastian Kaulitzk 197tr, spe 122r, Vaclav Volrab 170–171, vectorlib.com 50bl, waniuszka 14–15; **Toone Images:** 72; **TSG@MIT Physics:** 183tl; **Veer/Corbis:** Jason Maehl 43br, Paul Fleet 43l

The equipment on pages 20, 44, 143t and 180 was kindly provided by www.philipharris.co.uk
All other images © Pearson Education Limited

We are grateful to the following for permission to reproduce copyright material:

**Figures**
Figure on page 20 adapted from Acceleration–time graph of a skydiver, 'Exploring Mathematics with Sage' by Paul Lucas, http://www.arachnoid.com/sage/terminal_velocity.html, copyright © 2009, P. Lutus; Figure on page 23 adapted from 'balanced seesaw', www.animatedscience.co.uk, copyright © 2014 Animated Science. Reproduced by kind permission; Figures on page 60 adapted from http://www.obo.co.nz/the-o-lab, OBO. Reproduced by permission; Figure on page 80 adapted from 'What is an electrical resistance?', http://www.artinaid.com/2013/04/what-is-an-electrical-resistance/. Reproduced by permission of Artinaid; Figure on page 81 'Diodes' adapted from http://www.learnabout-electronics.org/diodes_01.php, copyright © 2007–2013 Eric Coates MA BSc. (Hons) All rights reserved; Figure on page 84 adapted from 'Current waveform image and data table for Lifepak 1000', p.52, A-2, http://www.physio-control.com/uploadedFiles/Physio85/Contents/Emergency_Medical_Care/Products/Operating_Instructions/LP1000_OI_3205213-008.pdf, copyright © 2012 Physio-Control, Inc; Figure on page 134 adapted from 'stress strain graph for an IMPRESS Alloy', http://www.spaceflight.esa.int/impress/text/education/Mechanical%20Properties/Question_Mechanical_Properties_23.html, copyright © ESA; Figures on page 136 from 'static elongation test' and 'fall test', copyright © Pit Schubert, Neville McMillan and Georg Sojer, 2009; and 'new equations', Dynamic Mountaineering Ropes, UIAA-101, EN-892, www.theuiaa.org, copyright © UIAA. Reproduced with permission; Figures on page 136 adapted from Mountaineering: The Freedom of the Hills, 6th Edition, published by Mountaineers Books, Seattle and Quiller Publishing, Shrewsbury 148, copyright © 1997. Illustration and table reprinted with permission of the publisher; Figure on page 146 adapted from 'Appendix: Pressure waves vs. Displacement waves. Physics 2010, Sound Waves Experiment 6' http://www.colorado.edu/physics/phys2010/phys2010LabMan2000/2010labhtml/Lab6/EXP6LAB99.html, copyright © Regents of the University of Colorado; Figures on page 148 adapted from 'Seismic Waves,' and ' Seismogram recorded in the UK' http://www.bgs.ac.uk/discoveringGeology/hazards/earthquakes/, copyright © NERC 2015; Figure on page 155 adapted from 'Physics 3B, Principle of superposition' http://www.greenwood.wa.edu.au/resources/Physics%203B%20WestOne/content/001_mechanical_waves/page_15.htm, SCIENCE1194, copyright © WestOne Services. Image courtesy of Dept Training & Workforce Development WA; Figure on page 155 adapted from 'Did the Draupner wave occur in a crossing sea?', Proceedings A, DOI: 10.1098/rspa.2011.0049, Figure 1 (T. A. A. Adcock, P. H. Taylor, S. Yan, Q. W. Ma, P. A. E. M. Janssen), June 2011, The Royal Society, copyright © 2015, The Royal Society; Figures on pages 157 and 158 adapted from 'Creating musical sounds'. Figure 6: Formation of a standing wave from two travelling waves travelling in opposite directions, http://projects.kmi.open.ac.uk/role/moodle/mod/page/view.php?id=1139; and 'Creating musical sounds'. 5.4 Vibrating string: normal modes of vibration. Figure 10: The first four normal modes of vibration of a string fixed at each end, http://projects.kmi.open.ac.uk/role/, ROLE. Reproduced by permission of The Open University; Figure on page 160 adapted from Friday, November 12, 2010, Wave Theory and Principles Interpretted. Part II, Source: http://fish-kc79.blogspot.co.uk/2010/11/wave-theory-and-principles-interpretted_12.html; Figure on page 164 adapted from 'Waves Tutorial 7 – Interference, Q4', http://www.antonine-education.co.uk/Pages/Physics_2/Waves/WAV_07/Waves_Page_7.htm Reproduced with permission; Figures on page 166 from 'Tuning the Marimba Bar and Resonator', 'third torsional mode', http://lafavre.us/tuning-marimba, copyright © 2007 Jeffrey La Favre; Figure on page 175 adapted from 'The Digital Camera: Snell's Window (the view from a fish's eye)', 4 August 2011, http://uptrout.com/2011/08/04/the-digital-camera-snells-window-the-view-from-a-fishs-eye/, copyright © 2011 Timothy Schulz; Figure on page 180 adapted from 'Optical Magnification' by David W. Knight, http://www.camerasunderwater.co.uk/articles/optics/opt-mag, copyright © Cameras Underwater Ltd. 2012; Figure on page 183 adapted from 'Reflection can polarise waves' in Glare and Polarized Light in Machine Vision Applications by Chris Walker, 08/17/2012, http://chriswalkertechblog.blogspot.co.uk/2012/08/glare-and-polarized-light-in-machine.htm. Reproduced with kind permission; Figure on page 184 adapted from Guide to Thin Section Microscopy, Second Edition by Michael M. Raith, Peter Raase and Jürgen Reinhardt, Fig. 4-18, 2012, http://www.minsocam.org/msa/openaccess_publications/Thin_Sctn_Mcrscpy_2_rdcd_eng.pdf, copyright © 2012 by M.M. Raith (University of Bonn) P. Raase (University of Kiel), J. Reinhardt (University of KwaZulu-Natal); Figure on page 190 from 'Huygens' postulate from Huygens' Construction', http://www.a-levelphysicstutor.com/wav-Huygens.php, copyright © 2011 A-level Physics Tutor. All rights reserved; Figure on page 195 adapted from 'KE vs frequency', from 'Resource Lesson Famous Discoveries: The Photoelectric Effect', http://dev.physicslab.org/Document.aspx?doctype=3&filename=AtomicNuclear_PhotoelectricEffect.xml, copyright © 1997–2014, Catharine H. Colwell. All rights reserved; Figure on page 202 from 'Amazing Map: Total Solar Panels To Power The United States', December 23, 2013, by Ken Jorgustin, http://modernsurvivalblog.com/alternative-energy/amazing-total-area-of-solar-panels-to-power-the-united-states/, map data copyright © Google.

**Logos**
Logo on page 84 from LIFEPAK® 1000 DEFIBRILLATOR brochure, http://www.physio-control.com/uploadedFiles/Physio85/Contents/Emergency_Medical_Care/Products/Brochures/LP1000_Brochure%20w%20Rechargable%20Battery_3303851_C.pdf, copyright © 2012 Physio-Control, Inc.

**Tables**
Table on page 114 from 'Guidance on Rates and allowances: Excise Duty – Alcohol Duty', http://www.hmrc.gov.uk/rates/alcohol-duty.htm. Contains public sector information licensed under the Open Government Licence (OGL) v2.0. http://www.nationalarchives.gov.uk/doc/open-government-licence; Table on page 136 from Mountaineering: The Freedom of the Hills, 6th Edition, published by Mountaineers Books, Seattle and Quiller Publishing, Shrewsbury 148, copyright © 1997. Illustration and table reprinted with permission of the publisher; Table on page 136 adapted from 'The 2013/14 catalogue of DMM International', www.dmmwales.com. Reproduced with permission from DMM International Ltd; Table on page 202 from 'Electrical Power Annual' report, December 2013, The United States Energy Information Association Source: U.S. Energy Information Administration (Dec 2013).

**Text**
Extract on page 60 from manufacture hockey goalkeeping equipment, 8 July 2014, http://www.obo.co.nz/the-o-lab, OBO. Reproduced by permission; Extract on page 84 from LIFEPAK® 1000 DEFIBRILLATOR brochure, pp. 56–57, http://www.physio-control.com/uploadedFiles/Physio85/Contents/Emergency_Medical_Care/Products/Brochures/LP1000_Brochure%20w%20Rechargable%20Battery_3303851_C.pdf, copyright © 2012 Physio-Control, Inc.; Extract on page 106 from 'Rover Team Working to Diagnose Electrical Issue', 2 November 2013, http://www.jpl.nasa.gov/news/news.php?feature=3958, Source: NASA; Extract on page 122 from 'What is a Plimsoll line?', http://oceanservice.noaa.gov/facts/plimsoll-line.html. Source: NOAA's National Ocean Service; Extract on page 148 from USGC FAQs, http://www.usgs.gov/faq. Source: U.S. Geological Survey Department of the Interior/USGS; Extract on page 166 adapted from 'Tuning the Marimba Bar and Resonator' http://lafavre.us/tuning-marimba, copyright © 2007 Jeffrey La Favre; Extract 5.3.5 from 'Forensic Glass Comparison: Background Information Used in Data Interpretation', publication number 09-04 of the Laboratory Division of the Federal Bureau of Investigation, Vol.11, No 2 (Maureen Bottrell), April 2009, Source: Federal Bureau of Investigation, Quantico, Virginia, USA.

Every effort has been made to contact copyright holders of material reproduced in this book. Any omissions will be rectified in subsequent printings if notice is given to the publishers.

# Contents

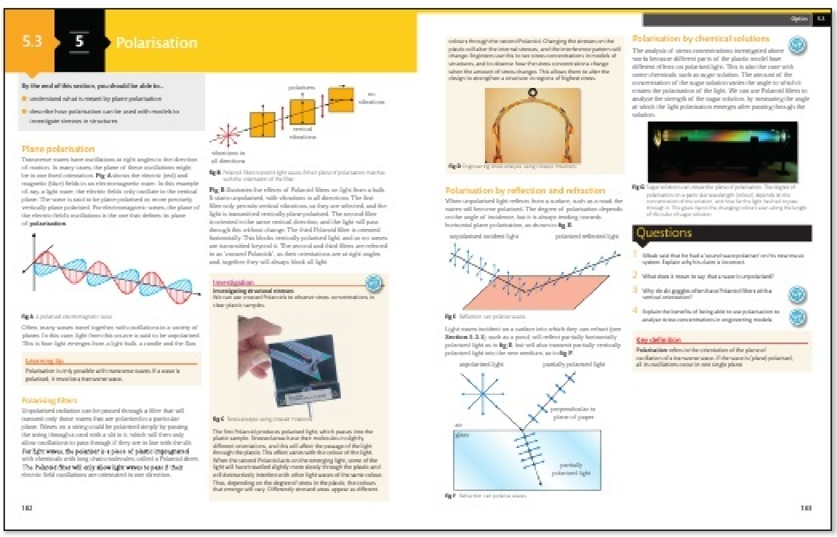
# How to use this book

Welcome to your Edexcel AS/A level Physics course. In this book you will find a number of features designed to support your learning.


## Chapter openers

Each chapter starts by setting the context for that chapter's learning:

- Links to other areas of Physics are shown, including previous knowledge that is built on in the chapter, and future learning that you will cover later in your course.
- The **All the maths you need** checklist helps you to know what maths skills will be required.




## Main content

The main part of each chapter covers all the points from the specification that you need to learn. The text is supported by diagrams and photos that will help you understand the concepts.

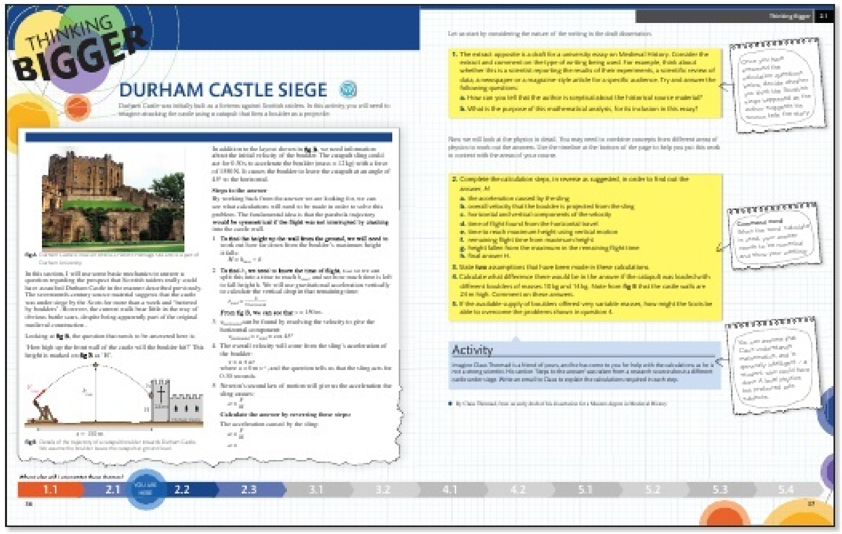
Within each section, you will find the following features:

- **Learning objectives** at the beginning of each section, highlighting what you need to know and understand.
- **Key definitions** shown in bold and collated at the end of each section for easy reference.
- **Worked examples** showing you how to work through questions, and how your calculations should be set out.
- **Investigations** provide a summary of practical experiments that explore key concepts.
- **Learning tips** to help you focus your learning and avoid common errors.
- **Did you know?** boxes featuring interesting facts to help you remember the key concepts.
- **Working as a Physicist** icons highlight key sections that develop your skills as a scientist and relate to the Working as a Physicist section of the specification.
- **Questions** to help you check whether you have understood what you have just read, and whether there is anything that you need to look at again.

## Thinking Bigger

At the end of each chapter there is an opportunity to read and work with real-life research and writing about science. The timeline at the bottom of the spreads highlights which other chapters the material relates to. These spreads will help you to:

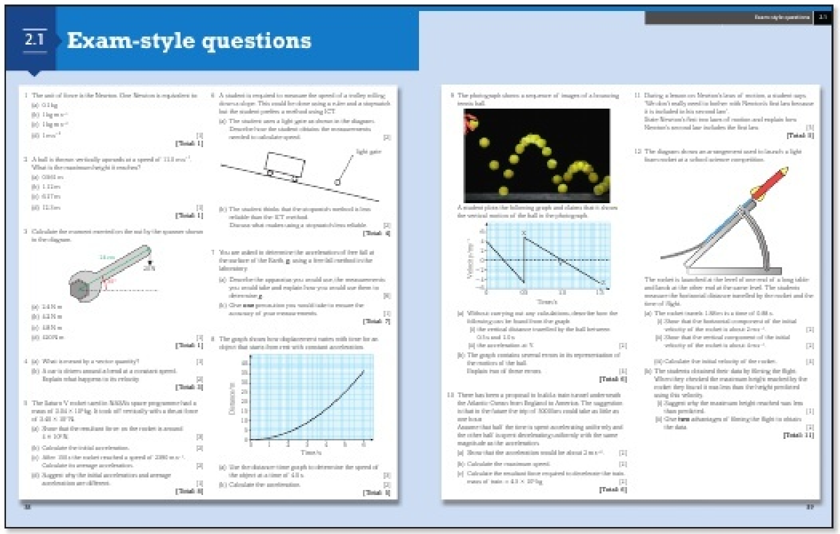
- read real-life material that's relevant to your course
- analyse how scientists write
- think critically and consider the issues
- develop your own writing
- understand how different aspects of your learning piece together.




## Exam-style questions

At the end of each chapter there are also **exam-style questions** to help you to:

- test how fully you have understood the learning
- practise for your exams.




## Getting the most from your online ActiveBook

This book comes with 3 years' access to ActiveBook* – an online, digital version of your textbook. Follow the instructions printed on the inside front cover to start using your ActiveBook.

Your ActiveBook is the perfect way to personalise your learning as you progress through your Edexcel AS/A level Physics course. You can:

- access your content online, anytime, anywhere
- use the inbuilt highlighting and annotation tools to personalise the content and make it really relevant to you
- search the content quickly using the index.

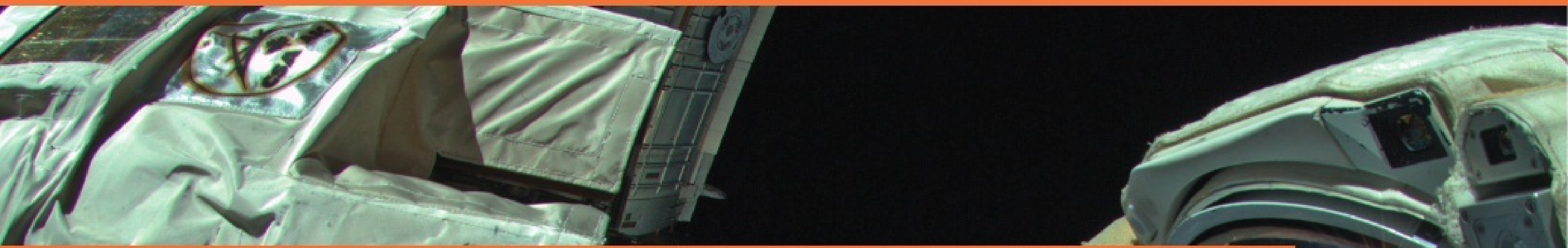
### Highlight tool

Use this to pick out key terms or topics so you are ready and prepared for revision.

### Annotations tool

Use this to add your own notes, for example links to your wider reading, such as websites or other files. Or make a note to remind yourself about work that you need to do.

*For new purchases only. If this access code has already been revealed, it may no longer be valid. If you have bought this textbook secondhand, the code may already be used by the first owner of the book.



# TOPIC 1

## CHAPTER 1.1 Working as a Physicist

## Introduction

Working as a Physicist is a key feature of the Edexcel Physics AS and A level specification. Throughout your study of physics, you will develop knowledge and understanding of what it means to work scientifically, including the ways in which the scientific community functions and how society as a whole uses scientific ideas. Additionally, you will develop confidence in key scientific skills, such as manipulating quantities and units and making estimates.

These skills have been integrated into the approach of this course, so that they will naturally develop as you learn. To help you think about where these skills apply, we have placed a WP alongside any content which specifically covers the Working as a Physicist skills listed in the specification.

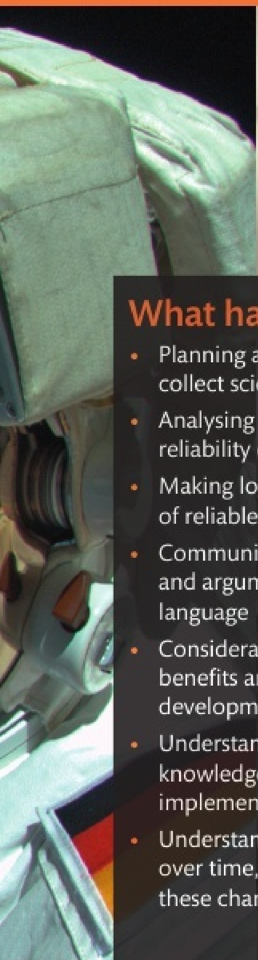
At the end of each chapter in this book, there is a spread entitled Thinking Bigger. These spreads are based broadly on the content of the chapter just completed, but they will also draw on your prior learning from earlier in the course or from GCSE and point towards future learning and less familiar contexts. By working through these spreads, you will:

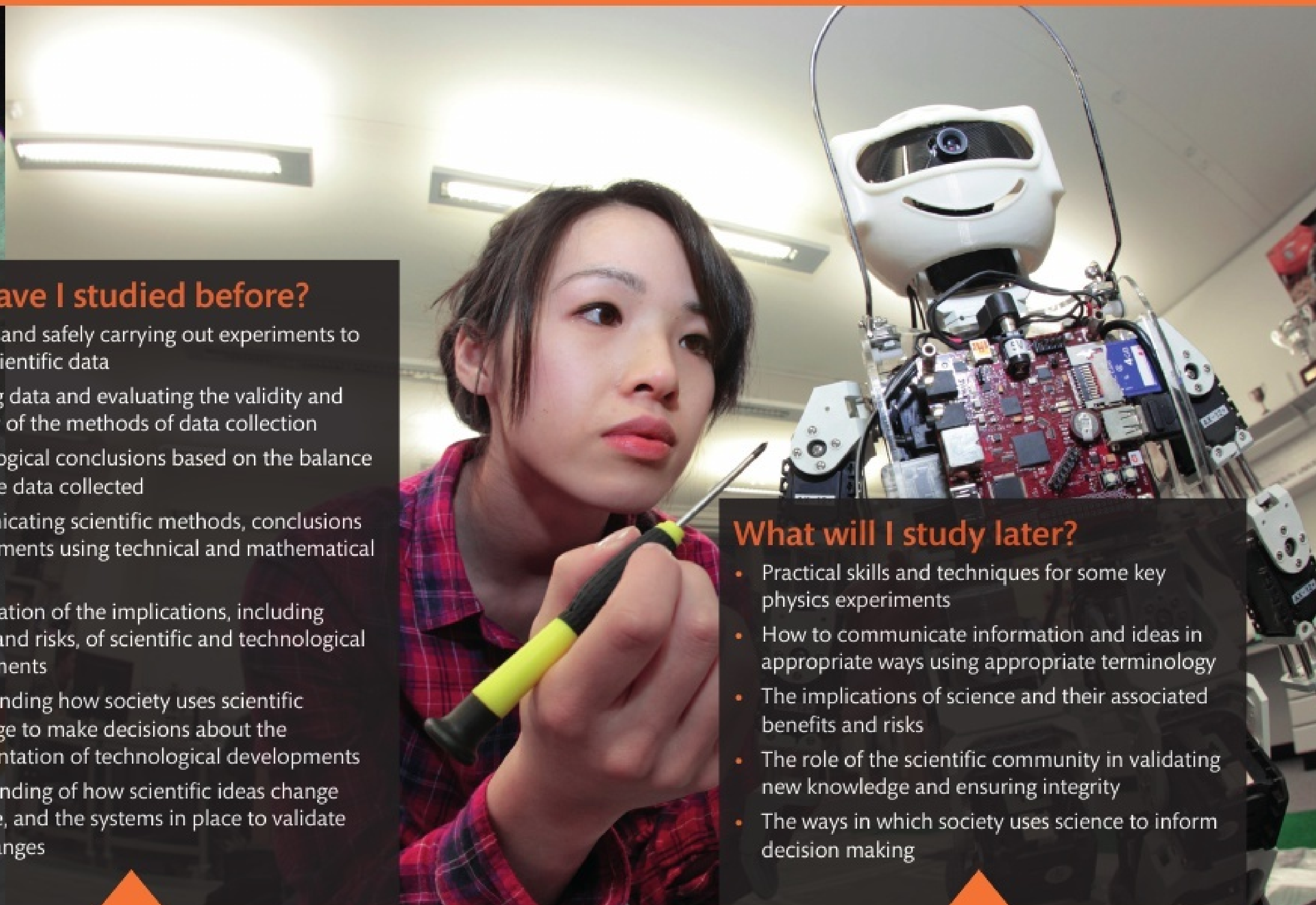
- read real-life scientific writing in a variety of contexts and aimed at different audiences
- develop an understanding of how the professional scientific community functions
- learn to think critically about the nature of what you have read and understand the issues, problems and challenges that may be raised
- gain practice in communicating information and ideas in an appropriate scientific way
- apply your knowledge and understanding to unfamiliar contexts.

You will also gain scientific skills through the hands-on practical work that forms an essential part of your course. As well as understanding the experimental methods of the practicals, it is important that you develop the skills necessary to plan experiments and analyse and evaluate data. Not only are these very important scientific skills, but they will be assessed in your examinations.

### Maths for Physicists

- Recognise and make use of appropriate units in calculations (*e.g. knowing the difference between base and derived units*)
- Estimate results (*e.g. estimating what change there will be to the magnification of a lens system as it is moved closer to the object being viewed*)
- Make order of magnitude calculations (*e.g. estimating approximately what an answer should be before you start calculating, including using standard form*)
- Use algebra to rearrange and solve equations (*e.g. finding the landing point of a projectile*)
- Recognise the importance of the straight line graph as an analysis tool for the verification and development of physical laws by experimentation (*e.g. choosing appropriate variables to plot to generate a straight line graph with experimental data*)
- Determine the slope and intercept of a linear graph (*e.g. finding acceleration from a velocity–time graph*)
- Calculate the area under the line on a graph (*e.g. finding the energy stored in a stretched wire*)
- Use geometry and trigonometry (*e.g. finding components of vectors*)



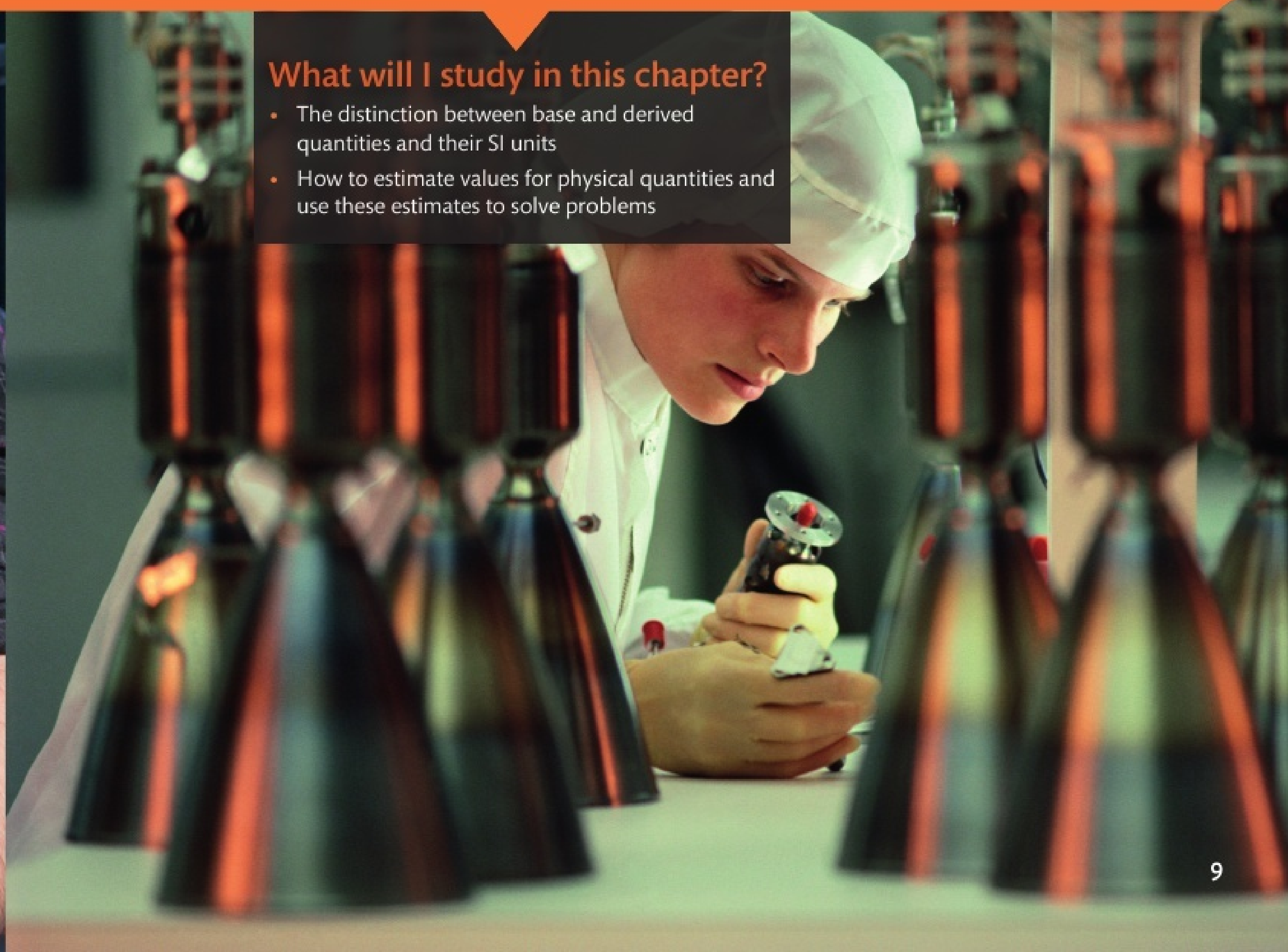


## What have I studied before?

- Planning and safely carrying out experiments to collect scientific data
- Analysing data and evaluating the validity and reliability of the methods of data collection
- Making logical conclusions based on the balance of reliable data collected
- Communicating scientific methods, conclusions and arguments using technical and mathematical language
- Consideration of the implications, including benefits and risks, of scientific and technological developments
- Understanding how society uses scientific knowledge to make decisions about the implementation of technological developments
- Understanding of how scientific ideas change over time, and the systems in place to validate these changes

## What will I study later?

- Practical skills and techniques for some key physics experiments
- How to communicate information and ideas in appropriate ways using appropriate terminology
- The implications of science and their associated benefits and risks
- The role of the scientific community in validating new knowledge and ensuring integrity
- The ways in which society uses science to inform decision making



## What will I study in this chapter?

- The distinction between base and derived quantities and their SI units
- How to estimate values for physical quantities and use these estimates to solve problems

# 1.1 1 Units

By the end of this section, you should be able to...

- understand the distinction between base and derived quantities
- understand the idea of a fixed system of units, and explain the SI system

## Base and derived quantities

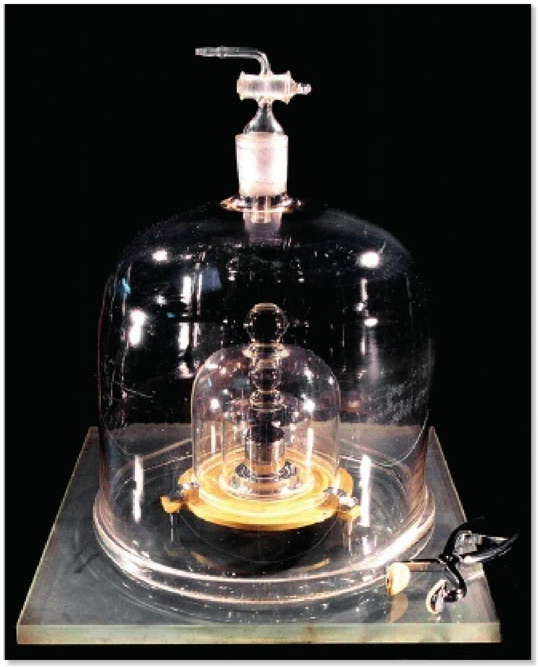


**fig A** The international standard kilogram, officially known as the International Prototype Kilogram, is made from a mixture of platinum and iridium and is held at the Bureau International des Poids et Mesures in Paris. All other masses are defined by comparing with this metal cylinder.

Some measurements we make are of fundamental qualities of things in the Universe. For example, the length of a pencil is a fundamental property of the object. Compare this with the pencil's speed if you drop it. To give a value to the speed, we have to consider a distance moved, and the rate of motion over that distance – we also need to measure time and then perform a calculation. You can see that there is a fundamental difference between the types of quantity that are length and speed. We call the length a **base unit**, whilst the speed is a **derived unit**. At present, the international scientific community uses seven base units, and from these all other units are derived. Some derived units have their own names. For example, the derived unit of force should be $kg\,m\,s^{-2}$, but this has been named the newton (N). Other derived units do not get their own name, and we just list the base units that went together in deriving the quantity. For example, speed is measured in $m\,s^{-1}$.

| Basic quantity | Unit name | Unit symbol |
|---|---|---|
| Mass | kilogram | kg |
| Time | second | s |
| Length | metre | m |
| Electric current | ampere | A |
| Temperature | kelvin | K |
| Amount of substance | mole | mol |
| Luminous intensity | candela | cd |

**table A** The base units.

The choice of which quantities are the base ones is somewhat a matter of arbitrary choice. The scientists who meet to determine the standard unit system have chosen these seven. You might think that electric current is not a fundamental property, as it is the rate of movement of charge. So it could be derived from measuring charge and time. However, scientists had to pick what was fundamental and they chose current. This means that electric charge is a derived quantity found by multiplying current passing for a given time.

## SI units

For each of the base units, a meeting held every four or six years of the General Conference on Weights and Measures, under the authority of the Bureau International des Poids et Mesures in Paris, either alters the definition, or ratifies continuing with the current definitions. As we learn more and more about the Universe, these definitions are gradually moving towards the fundamental constants of nature.

The current definition of each of the seven base units is listed below:

- The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.
- The second is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.
- The metre is the length of the path travelled by light in vacuum during a time interval of $\frac{1}{299\,792\,458}$ of a second.
- The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to $2 \times 10^{-7}$ newton per metre of length.
- The kelvin, unit of thermodynamic temperature, is the fraction $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water.

- The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kg of carbon-12. (When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles or specified groups of such particles.)
- The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency $540 \times 10^{12}$ hertz and that has a radiant intensity in that direction of $\frac{1}{683}$ watt per steradian.

**fig B** A standard metre, made to be exactly the length that light could travel in 1/299 792 458 of a second.

### Learning tip

'Metrology' is the study of the science of measurement, and 'metrics' refers to ways of standardising measuring techniques.

## Derived units

In **table B** you will see many of the derived units that we will study in this book, but this is only a list of those that have their own name.

| Derived quantity | Unit name | Unit symbol | Base units equivalent |
|---|---|---|---|
| Force | newton | N | $kg\,m\,s^{-2}$ |
| Energy (work) | joule | J | $kg\,m^2\,s^{-2}$ |
| Power | watt | W | $kg\,m^2\,s^{-3}$ |
| Frequency | hertz | Hz | $s^{-1}$ |
| Charge | coulomb | C | A s |
| Voltage | volt | V | $kg\,m^2\,s^{-3}\,A^{-1}$ |
| resistance | ohm | Ω | $kg\,m^2\,s^{-3}\,A^{-2}$ |

**table B** Some well known derived units.

## Power prefixes

Sometimes the values we have to work with for some quantities mean that the numbers involved are extremely large or small. For example, the average distance from the Earth to the Sun, measured in metres, is 150 000 000 000 m. Scientists have developed a system for abbreviating such large values by adding a prefix to the unit which tells us that it has been multiplied by a very large or very small amount. In our Earth orbit example, the distance is equivalent to 150 billion metres, and the prefix giga- means multiply by a billion. So the Earth–Sun distance becomes 150 gigametres, or 150 Gm.

| Factor | Name | Symbol | Factor | Name | Symbol |
|---|---|---|---|---|---|
| $10^1$ | deca- | da | $10^{-1}$ | deci- | d |
| $10^2$ | hecto- | h | $10^{-2}$ | centi- | c |
| $10^3$ | kilo- | k | $10^{-3}$ | milli- | m |
| $10^6$ | mega- | M | $10^{-6}$ | micro- | μ |
| $10^9$ | giga- | G | $10^{-9}$ | nano- | n |
| $10^{12}$ | tera- | T | $10^{-12}$ | pico- | p |
| $10^{15}$ | peta- | P | $10^{-15}$ | femto- | f |
| $10^{18}$ | exa- | E | $10^{-18}$ | atto- | a |
| $10^{21}$ | zetta- | Z | $10^{-21}$ | zepto- | z |
| $10^{24}$ | yotta- | Y | $10^{-24}$ | yocto- | y |

**table C** Prefixes used with SI units.

# Questions

1 From **table B**:
(a) Pick any quantity that you have studied before and explain how it can have the base unit equivalent shown.
(b) All of the derived quantity units are named after scientists. What is slightly strange about the way the unit names are written compared with their abbreviations?

2 Write the following in standard form:
(a) 9.2 GW
(b) 43 mm
(c) 6400 km
(d) 44 ns.

3 Write the following using an appropriate prefix and unit symbol:
(a) 3 600 000 joules
(b) 31 536 000 seconds
(c) 10 millionths of an ampere
(d) 105 000 hertz.

# 1.1 2 Estimation

**By the end of this section, you should be able to...**

- estimate values for physical quantities
- use your estimates to solve problems

## Order of magnitude

In physics it can be very helpful to be able to make approximate estimates of values to within an order of magnitude. This means that the power of ten of your estimate is the same as the true value. For example, you are the same height as the ceiling in your classroom, if we consider the order of magnitude. The ceiling may be twice your height, but it would need to be ten times bigger to reach the next order of magnitude.

This is made clearer if we express all values in standard form and then compare the power of ten. You are likely to be a thousand times taller than an ant, so we would say you are three orders of magnitude larger.

typical ant height: 2 mm = $2 \times 10^{-3}$ m

typical human height: 2 m = $2 \times 10^{0}$ m

**fig A** You are three orders of magnitude taller than an ant.

In many situations, physicists are not interested in specific answers, as circumstances can vary slightly and then the specific answer is incorrect. An order of magnitude answer will always be correct, unless you change the initial conditions by more than an order of magnitude. So a physicist could easily answer the question 'What is the top speed of a car?' because we don't really want to know the exact true value. To give an exact answer would depend on knowing the model of car, and the weather and road conditions being considered, and this answer would only be correct for that car on that day. By estimating important quantities, like a typical mass for cars, we can get an approximate – order of magnitude – answer. The reason for doing so would be that it allows us to develop ideas as possible or impossible, and focus on developing the ideas along lines that will eventually be feasible when we get to developing a specific solution. This reduces time and money wasted by pursuing ideas that can never be realised. It is also vital in quickly spotting when we have miscalculated the answer to a question. If we used a sophisticated equation to calculate the answer to the top speed of a particular car in particular conditions, and the answer came out as 300 000 metres per second, we should immediately know that the answer is incorrect, and re-check the calculation.

| Order of magnitude scale | Typical object |
|---|---|
| $1 \times 10^{13}$ m | Size of the solar system |
| $1 \times 10^{11}$ m | Size of Earth's orbit around the Sun |
| $1 \times 10^{8}$ m | Size of Moon's orbit around Earth |
| $1 \times 10^{4}$ m | Diameter of Manchester |
| $1 \times 10^{0}$ m | Human height |
| $1 \times 10^{-3}$ m | Ant height |
| $1 \times 10^{-5}$ m | Biological cell diameter |
| $1 \times 10^{-8}$ m | Wavelength of ultraviolet light |
| $1 \times 10^{-10}$ m | Diameter of an atom |
| $1 \times 10^{-14}$ m | Diameter of an atomic nucleus |

**table A** Examples of object scales changing with powers of ten.

## Fermi questions

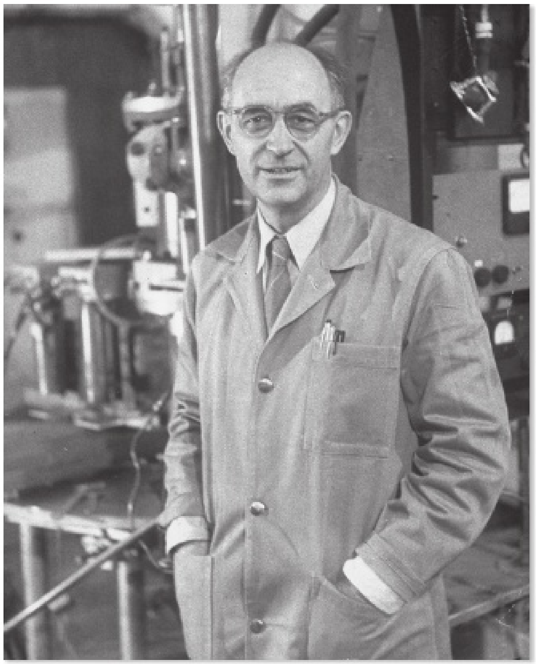


**fig B** Enrico Fermi was one of the developers of both nuclear reactors and nuclear bombs, along with other work on particle physics, quantum physics and statistical mechanics. He was awarded the 1938 Nobel Prize for Physics for the discovery of new radioactive elements and induced radioactivity.

Enrico Fermi was an Italian physicist who lived from 1901 to 1954. He was a pioneer in championing the power of estimation. What have become known as **Fermi questions** are seemingly specific questions, to which only an order of magnitude answer is expected. It is common for the question to appear improbably difficult, in that we do not have nearly enough information to work out the answer. During a nuclear bomb test in 1945, at a distance of about ten miles, Fermi estimated the strength of the explosion by dropping some pieces of paper as the blast reached him. His answer was about 50% of that later calculated using sophisticated mathematics and detailed measurements. This is typical of the sort of accuracy of answer we are looking for with an estimate – he was correct to the nearest order of magnitude.

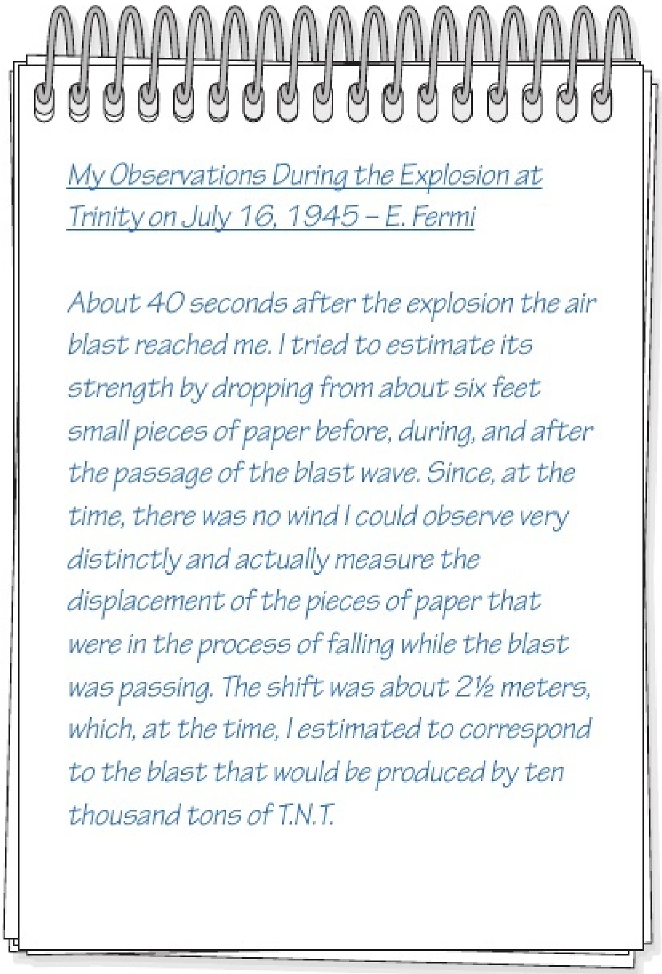



**fig C** An impressive estimation of the strength of a nuclear bomb, based on very little real data.

The trick is for you to work out what steps would need to be taken to reach the answer, if any information you asked for could be made available. Then, where we don't have all the data needed, make an educated estimate for the numbers missing. Making sensible assumptions is the key to solving Fermi questions.

**WORKED EXAMPLE**

Probably the most famous example of a Fermi question was this challenge to a class:

'How many piano tuners are there in Chicago?'

The only piece of information he provided was that the population of Chicago was 3 million.

*Step 1:* How many pianos in Chicago?

If each household is 4 people, then there are:

$\frac{3\,000\,000}{4} = 750\,000$ households

If one household in ten owns a piano, then there are:

$\frac{750\,000}{10} = 75\,000$ pianos

*Step 2:* How many pianos per piano tuner?

Assume each piano needs tuning once annually. Further assume a piano tuner works 200 days a year, and can service 4 pianos a day. Each tuner can service: $200 \times 4 = 800$ pianos.

*Step 3:* How many tuners?

Each piano tuner can deal with 800 pianos, and there are 75 000 pianos in total. So there are: $\frac{75\,000}{800} = 94$ piano tuners.

Your answer to Fermi would be 'There are 100 piano tuners in Chicago'. This is not expected to be the exactly correct answer, but it will be correct to order of magnitude. We would not expect to find that Chicago has only 10 piano tuners, and it would be very surprising if there were 1000.

## Questions

1 Give an order of magnitude estimate for the following quantities:
- (a) the height of a giraffe
- (b) the mass of an apple
- (c) the reaction time of a human
- (d) the diameter of a planet
- (e) the temperature in this room.

2 Answer the following Fermi questions, showing all the steps and the assumptions and estimates you make.
- (a) How many tennis balls would fit into Winchester Cathedral?
- (b) How many atoms are there in your body?
- (c) How many drops of water are there in the English Channel?
- (d) In your lifetime, how much will you earn in total?
- (e) How many Fermi questions could Enrico Fermi have answered whilst flying from Rome to New York?

# TOPIC 2
## Mechanics

# CHAPTER 2.1 Motion

## Introduction

How could we calculate how fast a plane is flying, in what direction it is going and how long it will take to reach a certain destination? If you were a pilot, how would you know what force to make the engines produce and where to direct that force so your plane moves to your destination? There is an amazing number of calculations that need to be done to enable a successful flight, but the basis on which all of it is worked out is simple mechanics.

This chapter explains the multiple movements of objects. It looks at how movement can be described and recorded, and then moves on to explaining why movement happens. It covers velocity and acceleration, including how to calculate these in different situations.

We only consider objects moving at speeds that could be encountered in everyday life. At these speeds (much less than the speed of light) Sir Isaac Newton succinctly described three laws of motion. With knowledge of basic geometry, we can identify aspects of movement in each dimension.

Newton's laws of motion have been constantly under test by scientists ever since he published them in 1687. Within the constraints established by Einstein in the early twentieth century, Newton's laws have always correctly described the relationships between data collected. You may have a chance to confirm Newton's laws in experiments of your own. With modern ICT recording of data, the reliability of such experiments is now much improved over traditional methods.

### All the maths you need

- Units of measurement (*e.g. the newton, N*)
- Using Pythagoras' theorem, and the angle sum of a triangle (*e.g. finding a resultant vector*)
- Using sin, cos and tan in physical problems (*e.g. resolving vectors*)
- Using angles in regular 2D structures (*e.g. interpreting force diagrams to solve problems*)
- Changing the subject of an equation (*e.g. re-arranging the SUVAT equations*)
- Substituting numerical values into algebraic equations (*e.g. calculating the acceleration*)
- Plotting two variables from experimental or other data, understanding that $y = mx + c$ represents a linear relationship and determining the slope of a linear graph (*e.g. verifying Newton's second law experimentally*)
- Estimating, by graphical methods as appropriate, the area between a curve and the $x$-axis and realising the physical significance of the area that has been determined (*e.g. using a speed–time graph*)

## What have I studied before?

- Using a stopwatch to measure times
- Measuring and calculating the speed of objects
- Gravity making things fall down, and giving them weight
- Measuring forces, calculating resultant forces
- The motion of objects as a result of forces acting on them

## What will I study later?

- Kinetic energy and gravitational potential energy
- Interconverting gravitational potential and kinetic energy
- Work and power
- Momentum and the principle of conservation of momentum
- Wave movements
- Fluid movements and terminal velocity
- The meaning and calculation of impulse (A level)

## What will I study in this chapter?

- The definitions of and equations for: speed, distance, displacement, time, velocity, acceleration
- Graphs of motion over time
- The classification of scalars and vectors
- Adding and resolving vectors
- Newton's laws of motion
- Kinematics equations
- Moments (turning forces)

# 2.1 1 Velocity and acceleration

**By the end of this section, you should be able to...**

- explain the distinction between scalar and vector quantities
- distinguish between speed and velocity and define acceleration
- calculate values using equations for velocity and acceleration

**fig A** Charlene Thomas has accelerated to a high speed.

Movement is fundamental to the functioning of our universe. Whether you are running to catch a bus or want to calculate the speed needed for a rocket to travel to Mars or the kinetic energy of an electron in an X-ray machine, you need to be able to work out how fast things are moving.

## Rate of movement

One of the simplest things we can measure is how fast an object is moving. You can calculate an object's **speed** if you know the amount of time taken to move a certain distance:

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

$$v = \frac{d}{t}$$

However, the calculation for speed will only tell you how fast an object is moving. Often it is also vitally important to know in what direction this movement is taking the object. When you include the direction in the information about the rate of movement of an object, this is then known as the **velocity**. So, the velocity is the rate of change of **displacement**, where the distance in a particular direction is called the 'displacement'.

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

$$\mathbf{v} = \frac{s}{t}$$

OR $$\mathbf{v} = \frac{\Delta s}{\Delta t}$$

**Learning tip**

The upper case symbol for the Greek letter delta, Δ, is used mathematically to mean a change in a quantity. For example, $\Delta s$ means the change in the displacement of an object, to be used here to calculate its velocity.

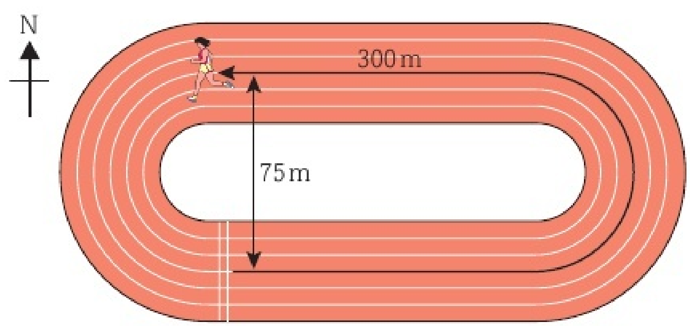



**fig B** The displacement due north is only 75 m, whilst the actual distance this athlete has run is 300 m. So the velocity due north is much less than the actual speed.

## Scalars and vectors

A quantity for which the direction must be stated is known as a **vector**. If direction is not important, the measurement is referred to as a **scalar** quantity. Therefore, velocity is a vector and speed is a scalar; distance is a scalar and displacement is a vector.

Scalar and vector quantities are not limited to measurements related to movement. Every measured quantity can be classified as needing to include the direction (vector, e.g. force) or as being sufficiently stated by its magnitude only (scalar, e.g. mass).

### Learning tip

Vector notation means that vectors are written in **bold** type to distinguish them from scalar variables.

## Average and instantaneous speed

In most journeys, it is unlikely that speed will remain constant throughout. As part of her training programme, the athlete in **fig A** wants to keep a record of her speed for all races. From rest, before the starting gun starts the race, she accelerates to a top speed. However, the race timing will be made from start to finish, and so it is most useful to calculate an average speed over the whole race. **Average speed** is calculated by dividing the total distance for a journey by the total time for the journey. Thus it averages out the slower and faster parts of the journey, and even includes stops.

**Instantaneous speed** can be an important quantity, and we will look at how to measure it in the next topic.


**fig C** Most speed checks look at instantaneous speed, but CCTV allows police to monitor average speed over a long distance.

## Acceleration

**Acceleration** is defined as the rate of change of velocity. Therefore, it must include the direction in which the speed is changing, and so acceleration is a vector quantity. The equation defining acceleration is:

$$\text{acceleration (m s}^{-2}) = \frac{\text{change in velocity (m s}^{-1})}{\text{time taken to change the velocity (s)}}$$

$$\boldsymbol{a} = \frac{\boldsymbol{v} - \boldsymbol{u}}{t}$$

OR

$$\boldsymbol{a} = \frac{\Delta \boldsymbol{v}}{\Delta t}$$

where $\boldsymbol{u}$ is the initial velocity and $\boldsymbol{v}$ is the final velocity.

The vector nature of acceleration is very important. One of the consequences is that if an object changes only the direction of its velocity, it is accelerating, *whilst remaining at a constant speed*. Similarly, deceleration represents a negative change in velocity, and so could be quoted as a negative acceleration.

# Questions

1 The athlete in **fig A** has taken 36 seconds from the start to reach the 300 m mark as shown. Calculate:

(a) her average speed during this 36 seconds

(b) her average velocity due north during this 36 seconds

(c) her average velocity due east during this 36 seconds.

2 A driver in a car travelling at about 25 mph (40.2 km $h^{-1}$) sees a cat run onto the road ahead.

(a) Convert 40.2 km $h^{-1}$ into a speed in m $s^{-1}$.

(b) The car travels 16.5 m whilst the driver is reacting to the danger. What is his reaction time?

(c) The car comes to a stop in 2.5 s. What is its deceleration?

3 An electron in an X-ray machine is accelerated from rest to half the speed of light in $1.7 \times 10^{-15}$ s. Calculate:

(a) the speed the electron reaches in m $s^{-1}$

(b) the acceleration the electron experiences.

### Learning tip

Whilst accelerations can (very briefly) be extraordinarily high, like that for the electron in question 3(b), no speed or velocity can ever be greater than the speed of light, which is $3 \times 10^8$ m $s^{-1}$. If you calculate a speed that is higher than this, check your calculation again as it must be wrong.

### Key definitions

**Speed** is the rate of change of distance.

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

$$v = \frac{d}{t}$$

**Velocity** is the rate of change of displacement.

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

$$\boldsymbol{v} = \frac{\boldsymbol{s}}{t} \text{ OR } \boldsymbol{v} = \frac{\Delta \boldsymbol{s}}{\Delta t}$$

**Displacement** is the vector measurement of distance in a certain direction.

A **vector** quantity must have both magnitude and direction.

A **scalar** quantity has only magnitude.

**Average speed** is calculated by dividing the total distance for a journey by the total time for the journey:

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

**Instantaneous speed** is the speed at any particular instant in time on a journey, which can be found from the gradient of the tangent to a distance–time graph (see **Section 2.1.2**) at that time.

**Acceleration** is the vector defined as the rate of change of velocity.

$$\text{acceleration (m s}^{-2}) = \frac{\text{change in velocity (m s}^{-1})}{\text{time taken to change the velocity (s)}}$$

$$\boldsymbol{a} = \frac{\boldsymbol{v} - \boldsymbol{u}}{t} \text{ OR } \boldsymbol{a} = \frac{\Delta \boldsymbol{v}}{\Delta t}$$

# 2.1 2 Motion graphs

**By the end of this section, you should be able to...**

- interpret displacement–time graphs, velocity–time graphs and acceleration–time graphs
- make calculations from these graphs
- understand the graphical representations of accelerated motion

One of the best ways to understand the movements of an object whilst on a journey is to plot a graph of the position of the object over time. Such a graph is known as a **displacement–time graph**. A **velocity–time graph** will also provide detail about the movements involved. A velocity–time graph can be produced from direct measurements of the velocity or generated from calculations made using the displacement–time graph.

## Displacement–time graphs

If we imagine a boating trip on a river, we could monitor the location of the boat over the hour that it has been rented for and plot the displacement–time graph for these movements. Depending on what information we want the graph to offer, it is often simpler to draw a distance–time graph in which the direction of movement is ignored.

The graphs shown in **fig A** are examples of plotting position against time, and show how a distance–time graph cannot decrease with time. A displacement–time graph could have parts of it in the negative portions of the *y*-axis, if the movement went in the opposite direction at some points in time.

The simplest thing we could find from these graphs is how far an object has moved in a certain time. For example, in **fig A**, both the graphs show that in the first 15 minutes the boat moved 150 m. Looking at the time from 40 to 48 minutes, both show that the boat travelled 120 m, but the displacement–time graph is in the negative region of the *y*-axis, showing the boat was moving downriver from the starting point – the opposite direction to the places it had been in the first 40 minutes.

During the period from 20 to 25 minutes, both graphs have a flat line at a constant value, showing no change in the distance or displacement. This means the boat was not moving – a flat line on a distance–time (*d*–*t*) graph means the object is stationary. From 20 to 25 minutes on the velocity–time (*v*–*t*) graph of this journey (see **fig B**) the line would be at a velocity of $0\,\mathrm{m\,s^{-1}}$.

### Speed and velocity from *d*–*t* graphs

The **gradient** of the *d*–*t* graphs in **fig A** will tell us how fast the boat was moving. Gradient is found from the ratio of changes in the *y*-axis divided by the corresponding change on the *x*-axis, so:

for a distance–time graph:

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

$$v = \frac{d}{t}$$

for a displacement–time graph:

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

$$v = \frac{\Delta s}{\Delta t}$$

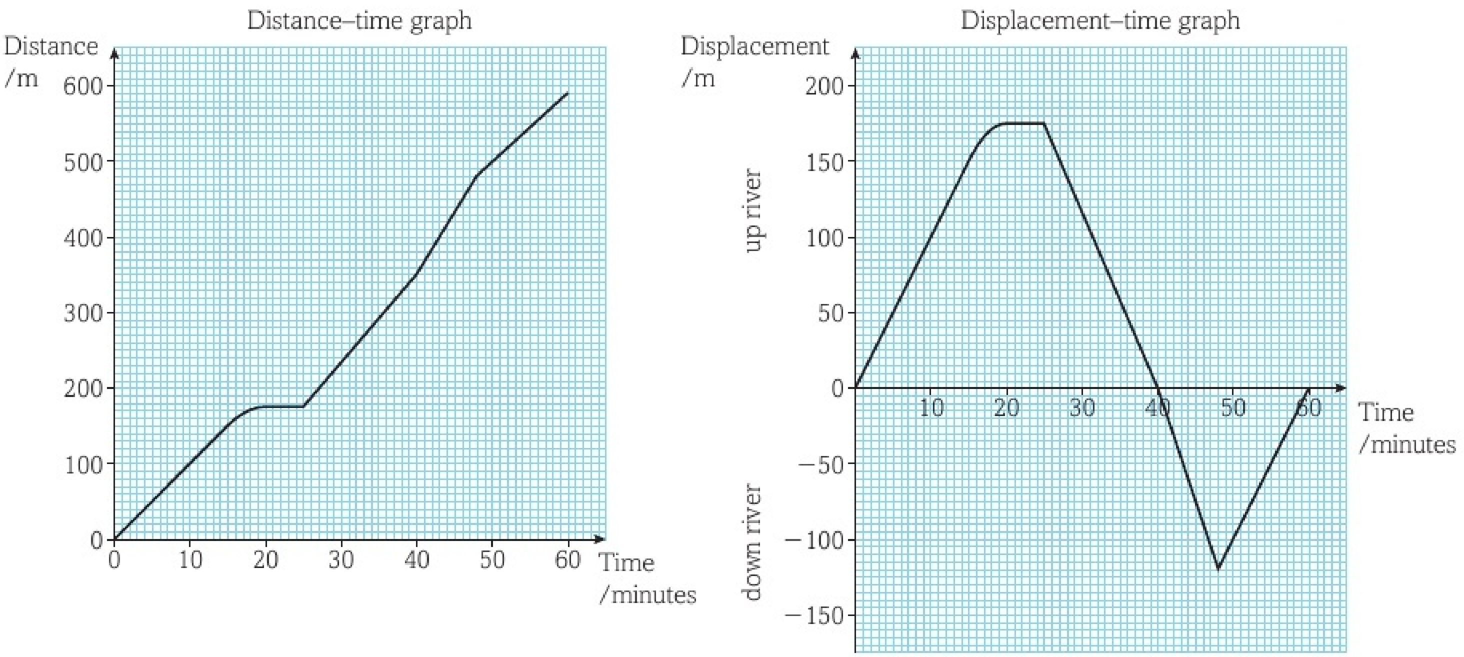



**fig A** A comparison of the displacement–time graph of the boating trip up and down a river with its corresponding distance–time graph.

For example, the first 15 minutes of the boating trip in **fig A** represents a time of 900 seconds. In this time, the boat travelled 150 m. Its velocity is:

$$v = \frac{\Delta s}{\Delta t} = \frac{150}{900} = 0.167 \text{ m s}^{-1} \textit{ upriver}$$

## Velocity–time graphs

A velocity–time graph will show the velocity of an object over time. We calculated that the velocity of the boat on the river was 0.167 m s$^{-1}$ upriver for the first 15 minutes of the journey. Looking at the graph in **fig B**, you can see that the line is constant at +0.167 m s$^{-1}$ for the first 15 minutes.

Also notice that the velocity axis includes negative values, so that the difference between travelling upriver (positive *y*-axis values) and downriver (negative *y*-axis values) can be represented.

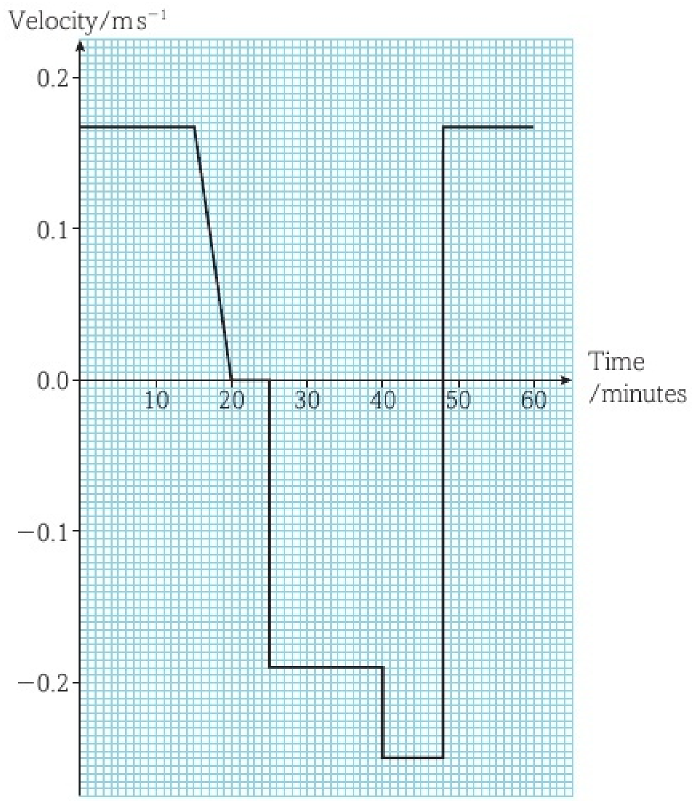



**fig B** Velocity–time graph of the boating trip.

## Acceleration from *v*–*t* graphs

Acceleration is defined as the rate of change in velocity.

In order to calculate the gradient of the line on a ***v***–*t* graph, we must divide a change in velocity by the corresponding time difference. This exactly matches with the equation for acceleration:

$$\text{gradient} = \frac{\Delta \boldsymbol{v}}{\Delta t} = \frac{\boldsymbol{v} - \boldsymbol{u}}{t} = \text{acceleration}$$

For example, between 15 and 20 minutes on the graphs, the boat slows evenly to a stop. The acceleration here can be calculated as the gradient:

$$\text{gradient} = \frac{\Delta \boldsymbol{v}}{\Delta t} = \frac{\boldsymbol{v} - \boldsymbol{u}}{t} = \frac{0 - 0.167}{5 \times 60} = \frac{-0.167}{300} = -0.0006 \text{ m s}^{-2}$$

So the acceleration is: $a = -0.6 \times 10^{-3}$ m s$^{-2}$.

## Distance travelled from *v*–*t* graphs

Speed is defined as the rate of change in distance:

$$v = \frac{d}{t}$$

$$\therefore \quad d = v \times t$$

As the axes on the ***v***–*t* graph represent velocity and time, an area on the graph represents the multiplication of velocity × time, which gives distance. So to find the distance travelled from a ***v***–*t* graph, find the area between the line and the *x*-axis.

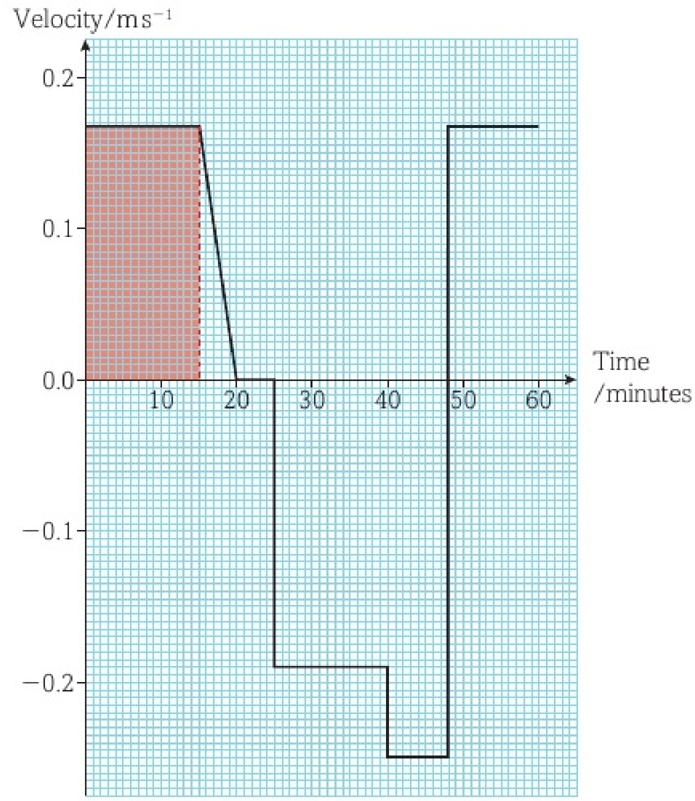



**fig C** In the first 15 minutes (900 seconds) the distance travelled by the boat moving at 0.167 m s$^{-1}$ is given by the area between the line and the *x*-axis: $d = v \times t = 0.167 \times 900 = 150$ m.

If we are only interested in finding the distance moved, this also works for a negative velocity. You find the area from the line up to the time axis. This idea will still work for a changing velocity. Find the area under the line and you have found the distance travelled. For example, from 0 to 20 minutes, the area under the line, all the way down to the *x*-axis, is a trapezium, so we need to find that area. To calculate the whole distance travelled in the journey for the first 40 minutes, we would have to find the areas under the four separate stages (0–15 minutes; 15–20 minutes; 20–25 minutes; and 25–40 minutes) and then add these four answers together.

## Investigation

**Finding the acceleration due to gravity by multiflash photography**

Using a multiflash photography technique, or a video recording that can be played back frame by frame, we can observe the falling motion of a small object such as a marble. We need to know the time between frames.

From each image of the falling object, measure the distance it has fallen from the scale in the picture. A carefully drawn distance–time graph will show a curve as the object accelerates. From this curve, take regular measurements of the gradient by drawing tangents to the curve. These gradients show the instantaneous speed at each point on the curve.

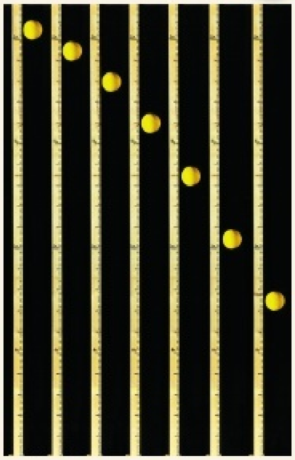


**fig D** Multiflash photography allows us to capture the accelerating movement of an object falling under gravity.

Plotting these speeds on a velocity–time graph should show a straight line, as the acceleration due to gravity is a constant value. The gradient of the line on this ***v***–*t* graph will be the acceleration due to gravity, ***g***.

## Acceleration–time graphs

These graphs show how the acceleration of an object changes over time. In many instances the acceleration is zero or a constant value, in which case an acceleration–time (***a***–*t*) graph is likely to be of relatively little interest. For example, the object falling in our investigation above will be accelerated by gravity throughout. Assuming it is relatively small, air resistance will be negligible, and the ***a***–*t* graph of its motion would be a horizontal line at $a = -9.81\ \text{m s}^{-2}$. Compare this with your results to see how realistic it is to ignore air resistance.

For a larger object falling for a long period, such as a skydiver, then the acceleration will change over time as the air resistance increases with speed. The weight of a skydiver is constant, so the resultant force will be decreasing throughout, meaning that the acceleration will also reduce (see **Section 1.1.5**). The curve would look like that in **fig E**.

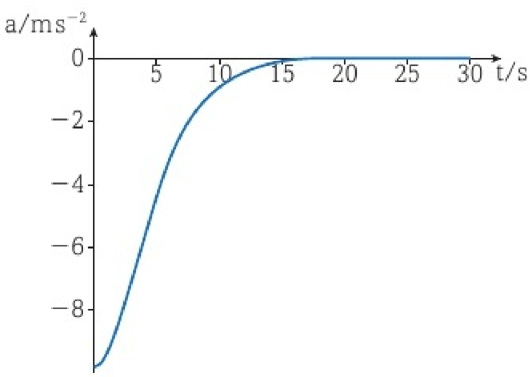



**fig E** Acceleration–time graph for a skydiver.

See **Section 4.1.4** for more details on falling objects and terminal velocity.

## Questions

1 Describe in as much detail as you can, including calculated values, what happens in the bicycle journey shown on the *d*–*t* graph in **fig F**.

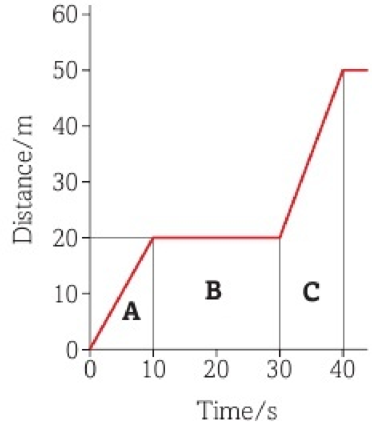



**fig F** Distance–time graph of a bike journey.

2 Describe in as much detail as you can, including calculated values, what happens in the car journey shown on the ***v***–*t* graph in **fig G**.

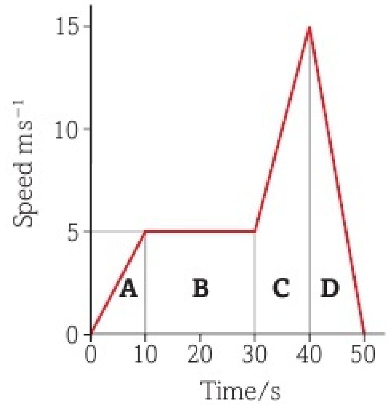



**fig G** Velocity–time graph of a car journey.

3 From **fig B**, calculate the distance travelled by the boat from 40 to 60 minutes.

### Learning tip

Remember that the gradient of a distance–time graph represents speed or velocity, so if the line is curved, the changing gradient indicates a changing speed, which you can describe as the same as the changes in gradient.

### Key definitions

A **displacement–time graph** is a graph showing the positions visited on a journey, with displacement on the *y*-axis and time on the *x*-axis.

A **velocity–time graph** is a graph showing the velocities on a journey, with velocity on the *y*-axis and time on the *x*-axis.

# 2.1 3 Adding forces

**By the end of this section, you should be able to...**

- add two or more vectors by drawing
- add two perpendicular vectors by calculation

Forces are vectors. This means that measuring their magnitude is important, but equally important is knowing the direction in which they act. In order to calculate the overall effect of multiple forces acting on the same object, we can use vector addition to work out the **resultant force**. This resultant force can be considered as a single force that has the same effect as all the individual forces combined.

## Adding forces in the same line

If two or more forces are acting along the same line, then combining them is simply a case of adding or subtracting their magnitudes depending on their directions.

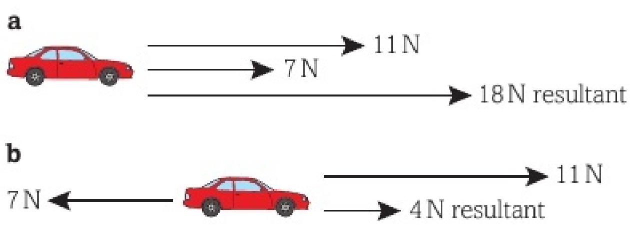



**fig A** Adding forces in the same line requires a consideration of their comparative directions.

## Adding perpendicular forces

The effect on an object of two forces that are acting at right angles (perpendicular) to each other will be the vector sum of their individual effects. We need to add the sizes with consideration for the directions in order to find the resultant.

**fig B** These two rugby players are each putting a force on their opponent. The forces are at right angles, so the overall effect would be to move him in a third direction, which we could calculate.

### Magnitude of the resultant force

To calculate the resultant magnitude of two perpendicular forces, we can draw them, one after the other, as the two sides of a right-angled triangle and use Pythagoras' theorem to calculate the size of the hypotenuse.

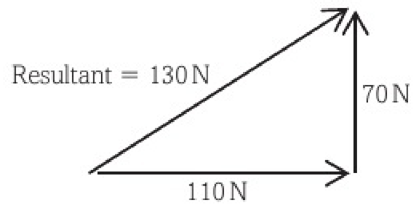



**fig C** The resultant force here is calculated using Pythagoras' theorem: $F = \sqrt{(70^2 + 110^2)} = 130\text{ N}$

### Direction of the resultant force

As forces are vectors, when we find a resultant force it must have both magnitude and direction. For perpendicular forces (vectors), trigonometry will determine the direction.

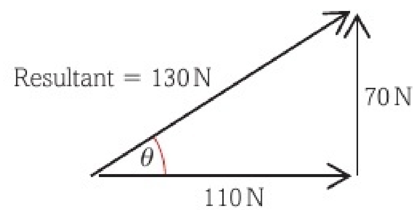



**fig D** The resultant force here is at an angle up from the horizontal of: $\theta = \tan^{-1}\left(\frac{70}{110}\right) = 32°$

**Learning tip**

Always take care to state where the angle for a vector's direction is measured. For example, in **fig D**, the angle should be stated as 32° *up from the horizontal*. This is most easily expressed on a diagram of the situation, where you draw in the angle.

## Adding two non-perpendicular forces

The geometry of perpendicular vectors makes the calculation of the resultant simple. We can find the resultant of any two vectors by drawing one after the other, and then the resultant will be the third side of the triangle from the start of the first one to the end of the second one. A scale drawing of the vector triangle will allow measurement of the size and direction of the resultant.

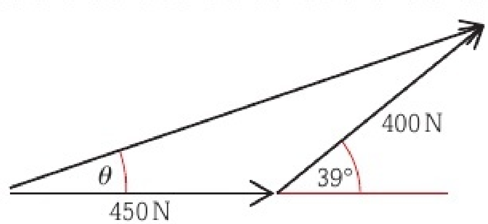



**fig E** The resultant force here can be found by scale drawing of the two forces, and then measurement of the resultant on the drawing using a ruler and a protractor.

### The parallelogram rule

There is another method for finding the resultant of two non-perpendicular forces (or vectors) by scale drawing, which can be easier to use. This is called the parallelogram rule. Draw the two vectors to scale – at the correct angle and scaled so their length represents the magnitude – starting from the same point. Then draw the same two vectors again parallel to the original ones, so that they form a parallelogram, as shown in **fig F**. The resultant force (or vector) will be the diagonal across the parallelogram from the starting point.

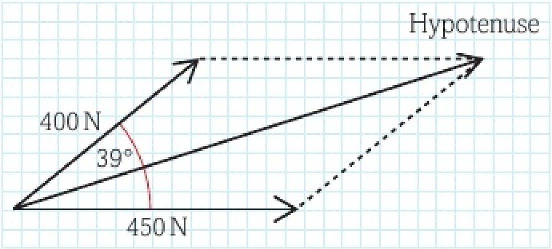



**fig F** Finding the resultant vector using the parallelogram rule.

**Learning tip**

The vector addition rules shown on these pages work for all vectors, not just forces. They are useful only for co-planar vectors, which means vectors that are in the same plane. If we have more than two vectors that are in more than one plane, add two vectors together first, in their plane, and then add the resultant to the next force using these rules again. Keep doing this until all the vectors have been added in.

## Free-body force diagrams

If we clarify what forces are acting on an object, it can be simpler to calculate how it will move. To do this, we usually draw a **free-body force diagram**, which has the object isolated, and all the forces that act on it drawn in at the points where they act. Forces acting on other objects, and those other objects, are not drawn. For example, **fig G** could be said to be a free-body force diagram of the rugby player being tackled in **fig B**, and this would lead us to draw **fig C** and **fig D** to make our resultant calculations.

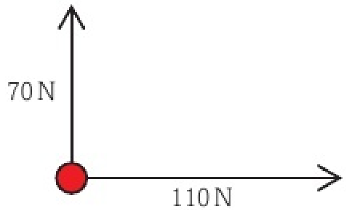



**fig G** Free-body force diagram of a rugby player (red circle). The forces from the tacklers are marked on as force arrows.

## Questions

1 Work out the resultant force on a toy car if it has the following forces acting on it:
- rubber band motor driving forwards 8.4 N
- air resistance 0.5 N
- friction 5.8 N
- child's hand pushing forward 10 N.

2 As a small plane takes off, the lift force on it is 6000 N vertically upwards, whilst the thrust is 2800 N horizontally forwards. What is the resultant of these forces on the plane?

3 Draw a free-body force diagram of yourself sitting on your chair.

4 (a) Draw the scale diagram of **fig E**, and work out what the resultant force would be.
(b) Use the parallelogram rule, as in **fig F**, to check your answer to part (a).

5 In order to try and recover a car stuck in a muddy field, two tractors pull on it. The first acts at an angle of 20° left of the forwards direction with a force of 2250 N. The second acts 15° to the right of the forwards direction with a force of 2000 N. Draw a scale diagram of the situation and find the resultant force on the stuck car.

**Key definitions**

**Resultant force** is the total force (vector sum) acting on a body when all the forces acting are added together accounting for their directions.

A **free-body force diagram** of an object has the object isolated, and all the forces that act on it are drawn in at the points where they act, using arrows to represent the forces.

# 2.1 4 Moments

**By the end of this section, you should be able to...**

- calculate the moment of a force
- apply the principle of moments
- find the centre of gravity of an object

Forces on an object could act so that the object does not start to move along, but instead rotates about a fixed pivot. If the object is fixed so that it cannot rotate, it will bend.

## Moment of a force

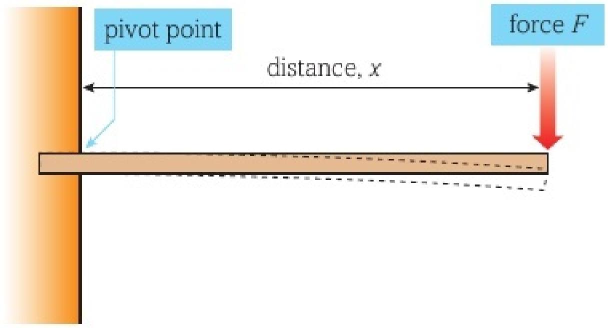



**fig A** A force acts on a beam fixed at a point. The moment of a force causes rotation or, in this case, bending.

The tendency to cause rotation is called the moment of a force. It is calculated from:

moment (Nm) = force (N) × perpendicular distance from the pivot to the line of action of the force (m)

moment = $Fx$

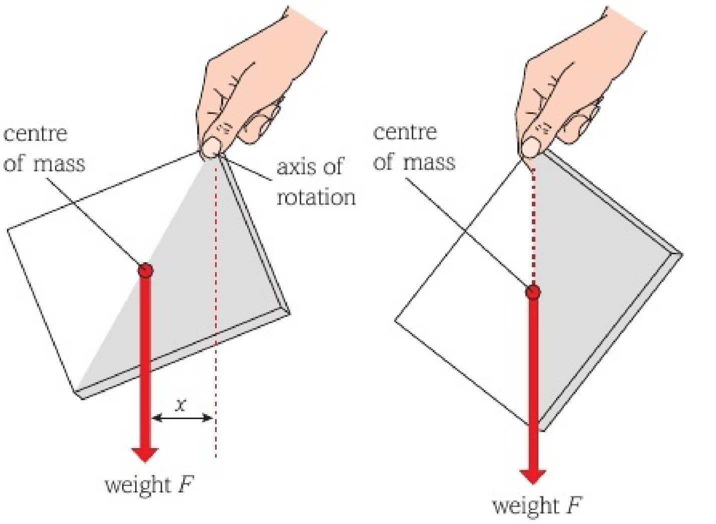



**fig B** The calculation of moment only considers the perpendicular distance between the line of action of the force and the axis of rotation, through the pivot point. When free to rotate, a body will turn in the direction of any net moment.

## Principle of moments

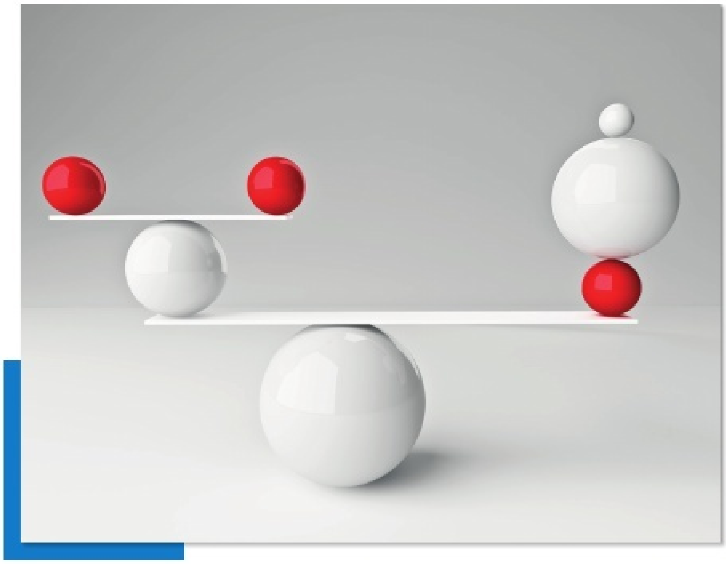


**fig C** Balanced moments create an equilibrium situation.

If we add up all the forces acting on an object and the resultant force, accounting for their directions, is zero, then the object will be in **equilibrium**. Therefore it will remain stationary or, if it is already moving, it will carry on moving at the same velocity. The object could keep a constant velocity, but if the moments on it are not also balanced, it could be made to start rotating. The **principle of moments** tells us that if the total of all the moments trying to turn an object clockwise is equal to the total of all moments trying to turn an object anticlockwise, then it will be in rotational equilibrium. This means it will either remain stationary, or if it is already rotating it will continue at the same speed in the same direction.

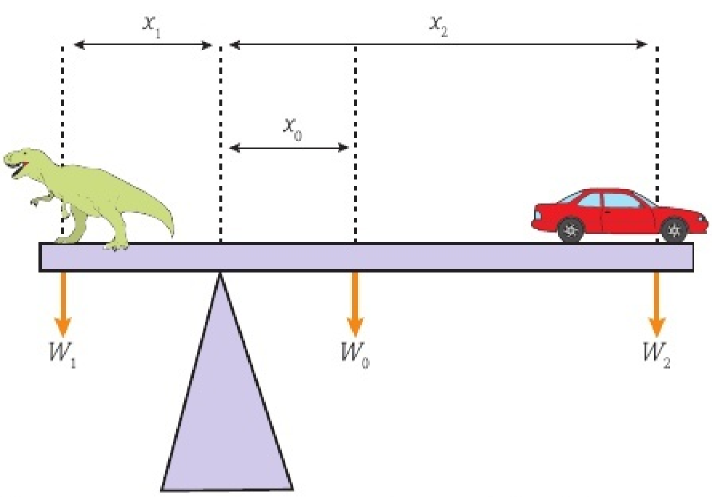



**fig D** As the metre-long beam is balanced, the sum of all the clockwise moments must equal the sum of all the anticlockwise moments.

**WORKED** EXAMPLE

In **fig D**, we can work out the weight of the beam if we know all the other weights and distances. The beam is uniform, so its weight will act from its centre. The length of the beam is 100 cm. So if $x_1$ = 20 cm, then $x_0$ must be 30 cm, and $x_2$ = 80 cm. The dinosaur ($W_1$) weighs 5.8 N and the toy car's weight ($W_2$) is 0.95 N.

In equilibrium, principle of moments:

sum of clockwise moments = sum of anticlockwise moments

$$W_1 x_1 = W_0 x_0 + W_2 x_2$$

$$5.8 \times 0.20 = W_0 \times 0.30 + 0.95 \times 0.80$$

$$\therefore \quad W_0 = \frac{1.16 - (0.76)}{0.30}$$

$$W_0 = 1.3\text{ N}$$

**Learning tip**

In order to calculate the sum of the moments in either direction, each individual moment must be calculated first and these individual moments then added together. The weights and/or distances *cannot* be added together and this answer used to calculate some sort of combined moment.

## Centre of gravity

The weight of an object is caused by the gravitational attraction between the Earth and each particle contained within the object. The sum of all these tiny weight forces appears to act from a single point for any object, and this point is called the **centre of gravity**. For a symmetrical object, we can calculate the position of its centre of gravity, as it must lie on every line of symmetry. The point of intersection of all lines of symmetry will be the centre of gravity. **Fig E** illustrates this with two-dimensional shapes, but the idea can be extended into three dimensions. For example, the centre of gravity of a sphere is at the sphere's centre.

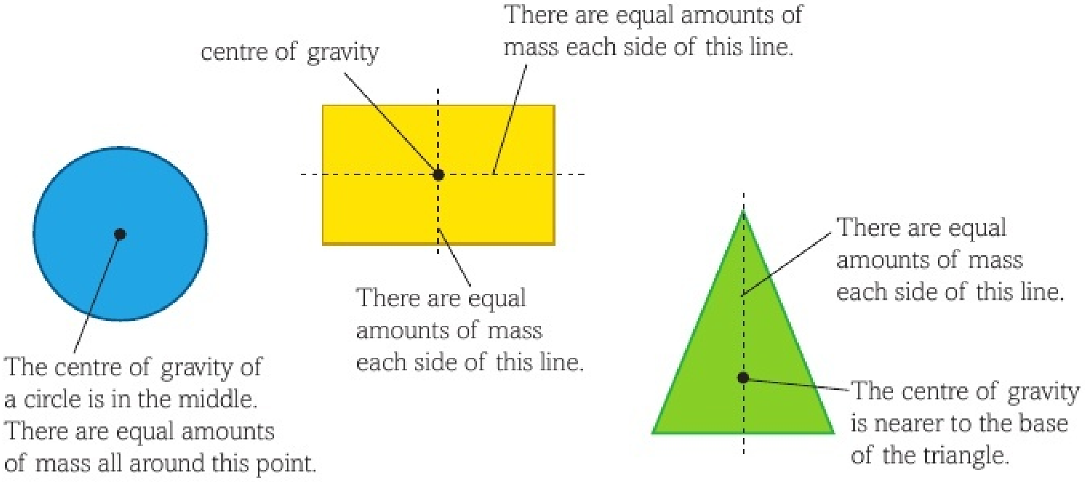



**fig E** The centre of gravity of a symmetrical object lies at the intersection of all lines of symmetry.

**Learning tip**

You can consider the terms 'centre of gravity' and 'centre of mass' to mean the same thing. They are identical for objects that are small compared to the size of the Earth.

### Irregular objects

The centre of gravity of an irregularly shaped object will still follow the rule that it is the point at which its weight appears to act on the object. A Bunsen burner, for example, has a heavy base, and so the centre of gravity is low down near that concentration of mass, as there will be a greater attraction by the Earth's gravity to this large mass.

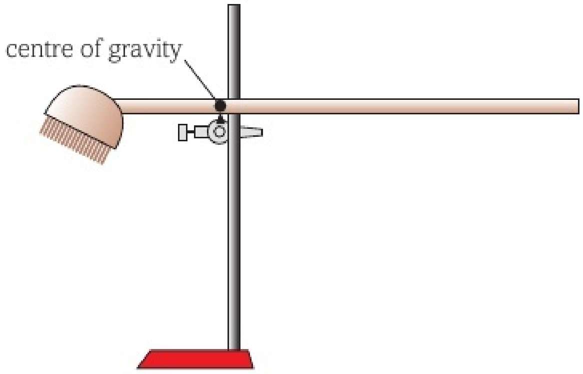



**fig F** Balancing a broom on its centre of gravity.

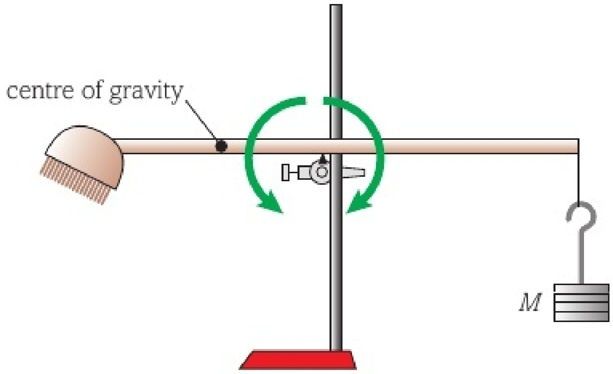



**fig G** Finding the centre of gravity of an irregular rod (broom).

## Investigation

**Finding the centre of mass of an irregular rod**

In this investigation, we use the principle of moments to find the centre of gravity of a broom. As it is not a symmetrical object, the location of the centre of gravity is not easy to determine just by looking at the broom. With the extra mass at the brush head end, the centre of gravity will be nearer that end.

If you can balance the broom on a knife edge, then the centre of gravity must lie above the knife edge. As the perpendicular distance from the line of action to the weight is zero, the moment is zero so the broom sits in equilibrium.

You will probably find it difficult to balance the broom exactly, so you can use an alternative method. First you measure the mass of the broom ($M$) using a digital balance. Then you use a set of hanging masses (of mass $m$) to balance the broom more in the middle of the handle, as in **fig G**. When the broom is balanced, you measure the distance ($d$) from the hanging masses to the pivot). You calculate the distance ($x$) from the pivot to the centre of gravity of the broom using the principle of moments:

clockwise moment = anticlockwise moment

$$m\boldsymbol{g} \times d = M\boldsymbol{g} \times x$$

$$\therefore \quad x = \frac{md}{M}$$

Note: Do not get into the habit of using only the mass in moments calculations, as the definition is *force* times distance. It just happens that in this case $\boldsymbol{g}$ cancels on each side.

# Questions

1 What is the moment of a 252 N force acting on a solid object at a perpendicular distance of 1.74 m from an axis of rotation of the object?

2 A child and her father are playing on a seesaw. They are exactly balanced when the girl (mass 46 kg) sits at the end of the seesaw, 2.75 m from the pivot. If her father weighs 824 N, how far is he from the pivot?

3 The weight of the exercise book in the left-hand picture in **fig B** causes a rotation so it moves towards the second position. Explain why it does not continue rotating but comes to rest in the position of the second picture.

4 If the same set-up as shown in **fig D** was used again, but the toy car was replaced with a banana weighing 1.4 N, find out where the banana would have to be positioned for the beam to balance – calculate the new $x_3$.

## Key definitions

A body is in **equilibrium** if there is zero resultant force and zero resultant moment. It will have zero acceleration.

The **principle of moments** states that a body will be in equilibrium if the sum of clockwise moments acting on it is equal to the sum of the anticlockwise moments.

An object's **centre of gravity** is the point through which the weight of an object appears to act.

# 2.1 5 Newton's laws of motion

**By the end of this section, you should be able to...**

- recall Newton's laws of motion and use them to explain the acceleration of objects
- make calculations using Newton's second law of motion
- identify pairs of forces involved in Newton's third law of motion

WP Sir Isaac Newton was an exceptional thinker and scientist. His influence over science in the West is still enormous, despite the fact that he lived from 1642 to 1727. Probably his most famous contribution to science was the development of three simple laws governing the movement of objects subject to forces.

**fig A** Isaac Newton was an MP and Master of the Royal Mint in addition to being a professor at Cambridge University and President of the Royal Society. He is buried in Westminster Abbey.

## Newton's first law of motion

If an object is stationary there needs to be a resultant force on it to make it move. We saw how to calculate resultant forces in **Section 2.1.3**. If the object is already moving then it will continue at the same speed in the same direction unless a resultant force acts on it. If there is no resultant force on an object – either because there is zero force acting or all the forces balance out – then the object's motion is unaffected.

**fig B** A stationary object will not move unless it is acted upon by a resultant force.

## Newton's second law of motion

This law tells us how much an object's motion will be changed by a resultant force. For an object with constant mass, it is usually written mathematically:

$$\Sigma F = m\boldsymbol{a}$$

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

For example, this relationship allows us to calculate the acceleration due to gravity ($\boldsymbol{g}$) if we measure the force ($\boldsymbol{F}$) accelerating a mass ($m$) downwards.

$$F = ma = mg$$

$$\therefore \quad g = \frac{F}{m}$$

## Investigation

### Newton's second law investigation

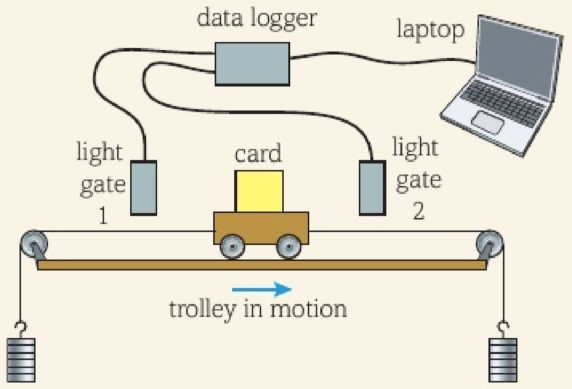



**fig C** Experimental set-up for investigating the relationship between ***F***, *m* and ***a***.

You can use the set-up shown in **fig C**, or a similar experiment on an air track, to measure the acceleration for various values of the resultant force acting on the trolley whilst you keep its mass constant (**table A**). By plotting a graph of acceleration against resultant force, a straight line will show that acceleration is proportional to the resultant force. You could also plot a graph for varying masses of trolley whilst you keep the resultant force constant (**table B**).

| Force/N | Acceleration/m s$^{-2}$ |
|---|---|
| 0.1 | 0.20 |
| 0.2 | 0.40 |
| 0.3 | 0.60 |
| 0.4 | 0.80 |
| 0.5 | 1.00 |
| 0.6 | 1.20 |

**table A** Values of acceleration for different forces acting on a trolley.

| Mass/kg | Acceleration/m s$^{-2}$ |
|---|---|
| 0.5 | 1.00 |
| 0.6 | 0.83 |
| 0.7 | 0.71 |
| 0.8 | 0.63 |
| 0.9 | 0.55 |
| 1.0 | 0.50 |

**table B** Values of acceleration resulting from an applied force of 0.5 N when the mass of the trolley is varied.

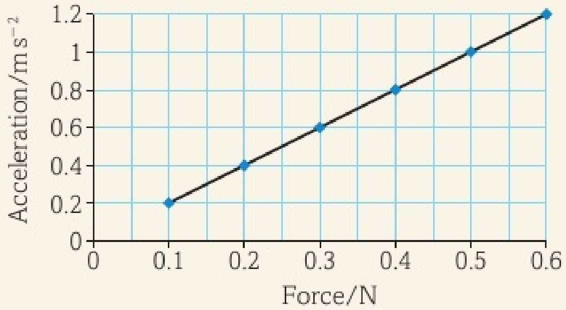



**fig D** Graph of results from the first investigation into Newton's second law. Acceleration is directly proportional to force.

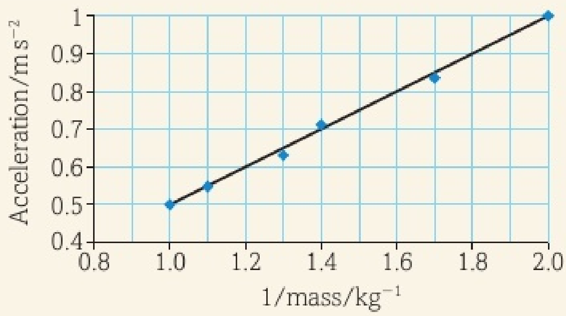



**fig E** Graph of results from the second investigation into Newton's second law. The *x*-axis represents the derived data of '1/mass', so the straight best-fit line shows that acceleration is inversely proportional to mass. Note that there is no need for a graph to start at the origin: choose axes scales that will best show the pattern in the data by making the points fill the graph paper.

Experimental verification of Newton's second law is well established. The investigation shown in **fig C** demonstrates that:

$$a = \frac{F}{m}$$

## Learning tip

### Straight-line graphs

Physicists are always trying to arrange their experimental data into graphs that produce a straight best-fit line. This proves a linear relationship between the experimental variables, and can also give us numerical information about the quantities involved.

The equation for a straight line is:

$$y = mx + c$$

'*m*' in the equation is the gradient of the straight line, and '*c*' is the value on the *y*-axis where the line crosses it, known as the *y*-intercept.

If we plot experimental data on a graph and get a straight best-fit line, then this proves the quantities we plotted on *x* and *y* have a linear relationship. It is referred to as 'directly proportional' (or simply 'proportional') only if the line also passes through the origin, meaning that $c = 0$.

The graphs in **fig D** and **fig E** demonstrate experimental verification of Newton's second law. In each case, the third variable in the equation was kept constant as a control variable. For example, in **fig D** the straight best-fit line, showing that $y \propto x$, proves that $a \propto F$, and the gradient of the best-fit line would represent the reciprocal of the mass that was accelerated and was kept constant throughout, as a control variable. In this example $c = 0$, which means that the proportional relationships are simple:

$$y = mx$$

$$a = \frac{F}{m}$$

As both the above equations represent the graph in **fig D**, it follows that the gradient, *m*, equals the reciprocal of the mass, $1/m$. It is just coincidence that the symbol '*m*' for gradient, and '*m*' for mass are the same letter in this example.

Note that graphs in physics are causal relationships. In **fig D**, the acceleration is caused by the force. It is very rare in physics that a graph would represent a statistical correlation, and so phrases such as 'positive correlation' do not correctly describe graphs of physics experiments.

Similarly, it is very rare that a graph of a physics experiment would be correctly drawn if the points are joined 'dot-to-dot'. In most cases a best-fit line should be drawn, as has been done in **fig E**.

## Newton's third law of motion

'When an object A causes a force on another object B, then object B causes an equal force in the opposite direction to act upon object A'. For example, when a skateboarder pushes off from a wall, they exert a force on the wall with their hand. At the same time, the wall exerts a force on the skateboarder's hand. This equal and opposite reaction force is what they can feel with the sense of touch, and as the skateboard has very low friction, the wall's push on them causes acceleration away from the wall. As the wall is connected to the Earth, the Earth and wall combination will accelerate in the opposite direction. The Earth has such a large mass that its acceleration is imperceptible. That's Newton's second law again: acceleration is inversely proportional to mass; huge mass means tiny acceleration.

**fig F** When the boot puts a force on the football, the football causes an equal and opposite force on the boot. The footballer can feel the kick because they feel the reaction force from the ball on their toe.

### Learning tip

Identifying Newton's third law of force pairs can confuse people. To find the two forces, remember they must always act on different objects, and must always have the same cause. In **fig F**, it is the mutual repulsion of electrons in the atoms of the football and the boot that cause the action and reaction.

## Questions

1 In terms of Newton's laws of motion:

(a) Explain why this book will sit stationary on a table.

(b) Describe and explain what will happen if your hands then put an upwards force on the book that is greater than its weight.

(c) Explain why you feel the book when your hands put that upwards force on it.

2 (a) Calculate the gradient of the best-fit line on the graph in **fig D** and thus work out the mass of the trolley that was accelerated in the first investigation.

(b) State what quantity the gradient of the line on the graph in **fig E** represents. Calculate the value of that quantity.

3 Calculate the acceleration in each of the following cases:

(a) A mass of 12.0 kg experiences a resultant force of 785 N.

(b) A force of 22.2 N acts on a 3.1 kg mass.

(c) A 2.0 kg bunch of bananas is dropped. The bunch weighs 19.6 N.

(d) During a tackle, two footballers kick a stationary ball at the same time, with forces acting in opposite directions. One kick has a force of 210 N, the other has a force of 287 N. The mass of the football is 430 g.

### Key definitions

**Newton's first law of motion:**

An object will remain at rest, or in a state of uniform motion, until acted upon by a resultant force.

**Newton's second law of motion:**

If an object's mass is constant, the resultant force needed to cause an acceleration is given by the equation:

$$\sum \boldsymbol{F} = m\boldsymbol{a}$$

**Newton's third law of motion:**

For every action, there is an equal and opposite reaction.

# 2.1 6 Kinematics equations

**By the end of this section, you should be able to...**

- recall the simple kinematics equations
- calculate unknown variables using the kinematics equations

**Kinematics** is the study of the movement of objects. We can use equations, commonly known as the SUVAT equations, to find out details about the motion of objects accelerating in one dimension.

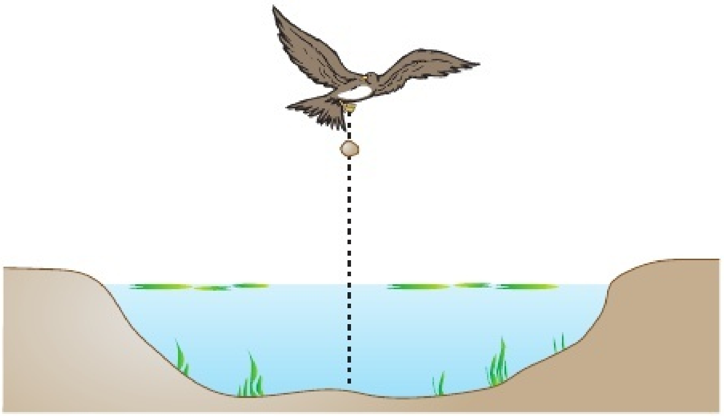


**fig A** Kinematics is the study of the description of the motion of objects. The equations could be used to make calculations about the stone falling through the air, and separately about its motion through the water. The acceleration in air and in water will be different as the resultant force acting in each will be different.

## Zero acceleration

If an object has no resultant force acting on it then it does not accelerate. This is **uniform motion**. In this situation, calculations on its motion are very easy, as they simply involve the basic speed equation:

$$v = \frac{s}{t}$$

The velocity is the same at the beginning and end of the motion, and if we need to find the displacement travelled, it is a simple case of multiplying velocity by time:

$$s = v \times t$$

## Constant acceleration

There are equations that allow us to work out the motion of an object that is moving with a constant acceleration. They are often called the SUVAT equations because of the variables involved, and the first step is to define those five variables:

$\boldsymbol{s}$ – displacement (m)
$\boldsymbol{u}$ – initial velocity ($m\,s^{-1}$)
$\boldsymbol{v}$ – final velocity ($m\,s^{-1}$)
$\boldsymbol{a}$ – acceleration ($m\,s^{-2}$)
$t$ – time (s)

Each equation uses four of the variables, which means that if we know the values of any three variables, we can find out the other two.

## Acceleration redefined

By re-arranging the equation that defined acceleration, we come to the usual expression of the first SUVAT equation:

$$v = u + at$$

For example, if a stone is dropped off a cliff (see **fig B**) and takes three seconds to hit the ground, what is its speed when it does hit the ground?

Identify the three things we know:

- falling under gravity, so $\boldsymbol{a} = \boldsymbol{g} = 9.81\,m\,s^{-2}$ (constant acceleration, so SUVAT can be used)
- starts at rest, so $\boldsymbol{u} = 0\,m\,s^{-1}$
- time to fall $t = 3\,s$

$$v = u + at = 0 + 9.81 \times 3 = 29.43$$

$$v = 29.4\,m\,s^{-1}$$

**Learning tip**

Often the acceleration will not be explicitly stated, but the object is falling under gravity, so:

$$a = g = 9.81\,m\,s^{-2}$$

**Learning tip**

Often the initial velocity will not be explicitly stated, but the object starts 'at rest'. This means it is stationary at the beginning, so:

$$u = 0\,m\,s^{-1}$$

## Distance from average speed

As SUVAT only works with *uniform* acceleration, the average speed during any acceleration will be halfway from the initial velocity to the final velocity. Therefore the distance travelled is the average speed multiplied by the time:

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

For example, for the same stone dropping off the cliff as in the previous example, we could work out how high the cliff is.

Identify the three things we know:

- final velocity came to be $\boldsymbol{v} = 29.4\,m\,s^{-1}$
- starts at rest, so $\boldsymbol{u} = 0\,m\,s^{-1}$
- time to fall $t = 3\,s$

$$s = \frac{(u + v)}{2} \times t = \frac{(0 + 29.4)}{2} \times 3 = 44.1$$

$$s = 44.1\,m$$

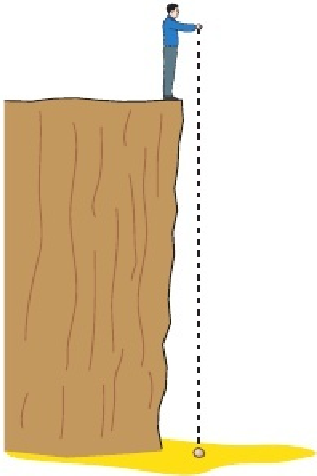


**fig B** Calculations about falling objects are very common.

## Combining equations

We can combine the equations

$$v = u + at$$

and

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

By substituting the first of these equations into the second, we get the combination equation:

$$s = \frac{(u + (u + at))}{2} \times t = \frac{(2ut + at^2)}{2}$$

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

We can use this equation to check again how high the stone was dropped from:

- falling under gravity, so $a = g = 9.81\ \text{m s}^{-2}$
- starts at rest, so $u = 0\ \text{m s}^{-1}$
- time to fall $t = 3\ \text{s}$

$$s = ut + \tfrac{1}{2}at^2 = (0 \times 3) + (\tfrac{1}{2} \times 9.81 \times 3^2) = 44.1$$

$$s = 44.1\ \text{m}$$

Notice that the answer must come out the same, as we are calculating for the same cliff. This highlights the fact that we can use whichever equation is most appropriate for the information given.

## Combining equations another way

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

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

and $v = u + at$

By substituting the first of these equations into the second, we get the combination equation:

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

$$\therefore \quad v(u + v) = u(u + v) + 2as$$

$$\therefore \quad vu + v^2 = u^2 + uv + 2as \qquad vu = uv \textit{ so subtract from each side}$$

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

Check again what the stone's final velocity would be:

- falling under gravity, so $a = g = 9.81\ \text{m s}^{-2}$
- starts at rest, so $u = 0\ \text{m s}^{-1}$
- height to fall $s = 44.1\ \text{m}$

$$v^2 = u^2 + 2as = 0^2 + (2 \times 9.81 \times 44.1) = 865$$

$$\therefore \quad v = \sqrt{865} = 29.4$$

$$v = 29.4\ \text{m s}^{-1}$$

Notice that the answer must come out the same as previously calculated, and this again highlights that there are many routes to reach the answer.

| SUVAT equation | Quantity not used |
| --- | --- |
| $v = u + at$ | distance |
| $s = \frac{(u + v)}{2} \times t$ | acceleration |
| $s = ut + \frac{1}{2}at^2$ | final velocity |
| $v^2 = u^2 + 2as$ | time |

**table A** Each of the SUVAT equations is useful, depending on the information we are given. If you know three quantities, you can always find a fourth by identifying which equation links those four quantities and re-arranging that equation to find the unknown.