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Physics

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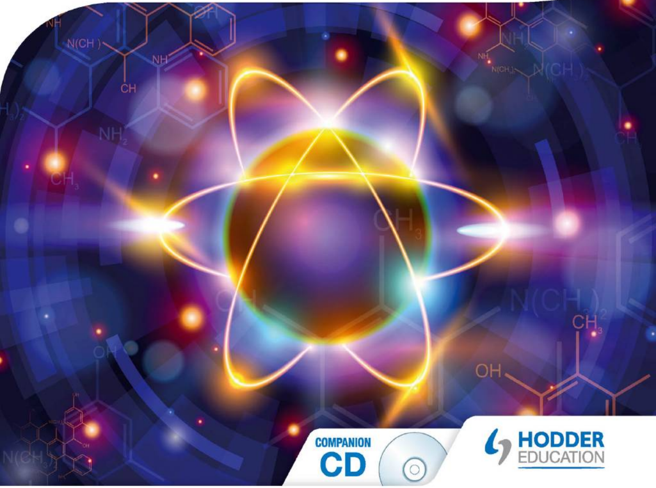
Mike Crundell, Geoff Goodwin and Chris Mee



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Cambridge
International AS and A Level

Physics

Mike Crundell and Geoff Goodwin

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Introduction

This book is a new edition of *International AS and A Level Physics* that has been revised and amended to be compatible with the Physics Syllabus 9702 of Cambridge International Examinations, published in 2014 for first examination in 2016.

The book has been fully endorsed by Cambridge International Examinations and is listed as an endorsed textbook for students studying this syllabus. New material has been included, where necessary, so that the book provides comprehensive cover of the subject content. The content of the book has been re-ordered so that students studying AS physics will find that part of the syllabus as being separate from the second part of the A Level course. In a few places, the content of the book goes slightly beyond the syllabus requirements, either to provide some background information or to arrive at a satisfactory termination of a topic.

All the assessment objectives that are identified in the syllabus are covered in the book. The learning outcomes, as specified in the syllabus, are listed in each topic of the book using the same wording as in the syllabus so that students may identify easily the section of the syllabus that is being covered. The content of each topic is identified by learning outcome, not necessarily presented in sequential numerical order, but according to the most sensible order for learning. For example, in AS Level Topic 6, learning outcome 6.2 (Work) comes before 6.1 (Energy). The chart opposite shows how topics are arranged in the book and how this relates to syllabus coverage.

A new feature of the syllabus is Key concepts. These are the essential ideas, theories, principles or mental tools that help learners to develop a deep understanding of their subject, and make links between different topics. An icon indicates where each Key concept is covered:

Models of physical systems
Physics is the science that seeks to understand the behaviour of the Universe. The development of models of physical systems is central to physics. Models simplify, explain and predict how physical systems behave.

Testing predictions against evidence
Physical models are usually based on prior observations, and their predictions are tested to check that they are consistent with the behaviour of the real world. This testing requires evidence, often obtained from experiments.

Mathematics as a language and problem-solving tool
Mathematics is integral to physics, as it is the language that is used to express physical principles and models. It is also a tool to analyse theoretical models, solve quantitative problems and produce predictions.

Matter, energy and waves
Everything in the Universe comprises matter and/or energy. Waves are a key mechanism for the transfer of energy and are essential to many modern applications of physics.

Forces and fields
The way that matter and energy interact is through forces and fields. The behaviour of the Universe is governed by fundamental forces that act over different length scales and magnitudes. These include the gravitational force and the electromagnetic force.

Key points, definitions and equations are highlighted in coloured panels. There is a summary of the important features that have been covered after each section or topic. Throughout each topic, worked examples are provided so that students may familiarise themselves with the subject matter. The worked examples are followed by questions of similar difficulty, listed under the *Now it's your turn* headings. In addition, there are questions which have a broader context and are of the examination style as regards wording and level of difficulty. Answers to both types of question are provided at the back of the book.

This book has been written specifically for the Cambridge syllabus. However, its coverage of subject matter and style of questions make it suitable for students who are studying towards physics qualifications of other awarding bodies.

Mike Crundell
Geoff Goodwin
July 2014

Syllabus structure relating to book topics

Syllabus section	**International A/AS Level Physics AS Level Topics**	**International A/AS Level Physics A Level Topics**
1. Physical quantities and units	1. Physical quantities and units	
2. Measurement techniques	2. Measurement techniques	
3. Kinematics	3. Kinematics	
4. Dynamics	4. Dynamics	
5. Forces, density and pressure	5. Forces, density and pressure	
6. Work, energy, power	6. Work, energy, power	
7. Motion in a circle		7. Motion in a circle
8 Gravitational fields		8 Gravitational fields
9. Deformation of solids	9. Deformation of solids	
10. Ideal gases		10. Ideal gases
11. Temperature		11. Temperature
12. Thermal properties of materials		12. Thermal properties of materials
13. Oscillations		13. Oscillations
14. Waves	14. Waves *covers 14.1, 14.2, 14.3, 14.4 and 14.5*	14. Ultrasound *covers 14.6*
15. Superposition	15. Superposition *also covers 14.3b*	
16. Communication		16. Communication
17. Electric fields	17. Electric fields *covers 17.1 and 17.2*	17. Electric fields *covers 17.3, 17.4 and 17.5*
18. Capacitance		18. Capacitance
19. Current of electricity	19. Current of electricity *covers 19.1, 19.2 and 19.3*	19 & 20 Electronic sensors *covers 19.4*
20 D.C. circuits	20 D.C. circuits *covers 20.1, 20.2 and 20.3 a, b*	19 & 20 Electronic sensors *covers 20.3 c, d*
21. Electronics		21. Electronics
22. Magnetic fields		22. Magnetic fields
23. Electromagnetic induction		23. Electromagnetic induction
24. Alternating currents		24. Alternating currents
25. Quantum physics		25. Quantum physics
26. Particle and nuclear physics	26. Particle and nuclear physics *covers 26.1 and 26.2*	26. Particle and nuclear physics *covers 26.3 and 26.4*

1 Physical quantities and units

By the end of this topic, you will be able to:

1.1 (a) understand that all physical quantities consist of a numerical magnitude and a unit
(b) make reasonable estimates of physical quantities included in the syllabus

1.2 (a) recall the following SI base quantities and their units: mass (kg), length (m), time (s), current (A), temperature (K), amount of substance (mol)
(b) express derived units as products or quotients of the SI base units and use the named units listed in the syllabus as appropriate
(c) use SI base units to check the homogeneity of physical equations
(d) use the following prefixes and their symbols to indicate decimal submultiples or multiples of both base and derived units:
- pico (p)
- nano (n)
- micro (μ)
- milli (m)
- centi (c)
- deci (d)
- kilo (k)
- mega (M)
- giga (G)
- tera (T)

(e) understand and use the conventions for labelling graph axes and table columns

1.3 (a) distinguish scalar and vector quantities and give examples of each
(b) add and subtract coplanar vectors
(c) represent a vector as two perpendicular components

Note: amount of substance (mol) is only used in the A level course but is included here for completeness.

Starting points

- Accurate **measurement** is very important in the development of physics.
- Physicists begin by observing, measuring and collecting data.
- These data are analysed to discover whether they fit into a pattern.
- If there is a pattern and this pattern can be used to explain other events, it becomes a **theory**.
- The process is known as the **scientific method** (see Figure 1.1).

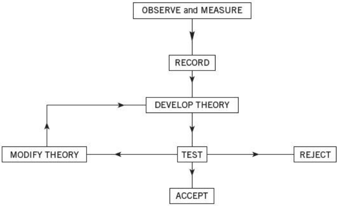

Figure 1.1 Block diagram to illustrate the scientific method

1.1 Physical quantities

Figure 1.2 Brahe (1546–1601) measured the elevations of stars; these days a modern theodolite is used for measuring angular elevation.

A **physical quantity** is a feature of something which can be measured, for example, length, weight, or time of fall. Every physical quantity has a numerical value and a unit. If someone says they have a waist measurement of 50, they could be very slim or very fat depending on whether the measurement is in centimetres or inches! Take care – it is vital to give the unit of measurement whenever a quantity is measured or written down.

Large and small quantities are usually expressed in scientific notation, i.e. as a simple number multiplied by a power of ten. For example, 0.000 34 would be written as 3.4×10^{-4} and 154 000 000 as 1.54×10^{8}. There is far less chance of making a mistake with the number of zeros!

Figure 1.3 The elephant is large in comparison with the boy but small compared with the jumbo jet.

1.2 SI quantities and base units

In very much the same way that languages have developed in various parts of the world, many different systems of measurement have evolved. Just as languages can be translated from one to another, units of measurement can also be converted between systems. Although some conversion factors are easy to remember, some are very difficult. It is much better to have just one system of units. For this reason, scientists around the world use the **Système International (SI)** which is based on the metric system of measurement.

Figure 1.4 The mass of this jewel could be measured in kilograms, pounds, carats, grains, etc.

If a quantity is to be measured accurately, the unit in which it is measured must be defined as precisely as possible.

SI is founded on seven fundamental or **base units**.

The base quantities and the units with which they are measured are listed in Table 1.1. For completeness, the candela has been included, but this unit will not be used in the A/AS course. The mole will only be used in the A Level course.

Table 1.1 The base quantities and units

quantity	unit	symbol
mass	kilogram	kg
length	metre	m
time	second	s
electric current	ampere (amp)	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

Each quantity has just one unit and this unit can have **multiples** and **sub-multiples** to cater for larger or smaller values. The unit is given a **prefix** to denote the multiple or sub-multiple (see Table 1.2). For example, one thousandth of a metre is known as a millimetre (mm) and 1.0 millimetre equals 1.0×10^{-3} metres (m).

Table 1.2 The more commonly used prefixes

prefix	symbol	multiplying factor
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

Beware when converting units for areas and volumes!

$$1\,\text{mm} = 10^{-3}\,\text{m}$$

Squaring both sides $\quad 1\,\text{mm}^2 = (10^{-3})^2\,\text{m}^2 = 10^{-6}\,\text{m}^2$

and $\quad 1\,\text{mm}^3 = (10^{-3})^3\,\text{m}^3 = 10^{-9}\,\text{m}^3$

Note also that $\quad 1\,\text{cm}^2 = (10^{-2})^2\,\text{m}^2 = 10^{-4}\,\text{m}^2$

and $\quad 1\,\text{cm}^3 = (10^{-2})^3\,\text{m}^3 = 10^{-6}\,\text{m}^3$

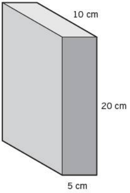

Figure 1.5 This box has a volume of $1.0 \times 10^3\,\text{cm}^3$.

The box in Figure 1.5 has a volume of $1.0 \times 10^3\,\text{cm}^3$ or $1.0 \times 10^6\,\text{mm}^3$ or $1.0 \times 10^{-3}\,\text{m}^3$.

A distance of thirty metres should be written as 30 m and not 30 ms or 30 m s. The letter s is **never** included in a unit for the plural. If a space is left between two letters, the letters denote different units. So, 30 m s would mean thirty metre seconds and 30 ms means 30 milliseconds.

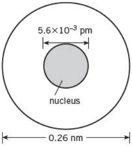

Figure 1.6 Atom of gold

Example

Calculate the number of micrograms in 1.0 milligram.

$$1.0\,g = 1.0 \times 10^3\,mg$$

$$\text{and } 1.0\,g = 1.0 \times 10^6 \text{ micrograms } (\mu g)$$

$$\text{so, } 1.0 \times 10^3\,mg = 1.0 \times 10^6\,\mu g$$

$$\text{and } 1.0\,mg = (1.0 \times 10^6)/(1.0 \times 10^3) = \mathbf{1.0 \times 10^3\,\mu g}$$

Now it's your turn

1 Calculate the area, in cm^2, of the top of a table with sides of 1.2 m and 0.9 m.
2 Determine the number of cubic metres in one cubic kilometre.
3 Write down, using scientific notation, the values of the following quantities:
(a) 6.8 pF,
(b) 32 μC,
(c) 60 GW.
4 How many electric fires, each rated at 2.5 kW, can be powered from a generator providing 2.0 MW of electric power?
5 An atom of gold, Figure 1.6, has a diameter of 0.26 nm and the diameter of its nucleus is 5.6×10^{-3} pm. Calculate the ratio of the diameter of the atom to that of the nucleus.

Derived units

All quantities, apart from the base quantities, can be expressed in terms of **derived units**.

Derived units consist of some combination of the base units. The base units may be multiplied together or divided by one another, but never added or subtracted.

See Table 1.3 for examples of derived units. Some quantities have a named unit. For example, the unit of force is the newton, symbol N, but the newton can be expressed in terms of base units. Quantities which do not have a named unit are expressed in terms of other units. For example, specific latent heat (Topic 12) is measured in joules per kilogram ($J\,kg^{-1}$).

Table 1.3 Some examples of derived units which may be used in the A/AS course

quantity	unit	derived unit
frequency	hertz (Hz)	s^{-1}
velocity	$m\,s^{-1}$	$m\,s^{-1}$
acceleration	$m\,s^{-2}$	$m\,s^{-2}$
force	newton (N)	$kg\,m\,s^{-2}$
energy	joule (J)	$kg\,m^2\,s^{-2}$
power	watt (W)	$kg\,m^2\,s^{-3}$
electric charge	coulomb (C)	A s
potential difference	volt (V)	$kg\,m^2\,s^{-3}\,A^{-1}$
electrical resistance	ohm (Ω)	$kg\,m^2\,s^{-3}\,A^{-2}$
specific heat capacity	$J\,kg^{-1}\,K^{-1}$	$m^2\,s^{-2}\,K^{-1}$

Example

What are the base units of speed?

Speed is defined as $\frac{distance}{time}$ and so the unit is $\frac{m}{s}$.

Division by a unit is shown using a negative index, that is, s^{-1}.

The base units of speed are $\mathbf{m\,s^{-1}}$.