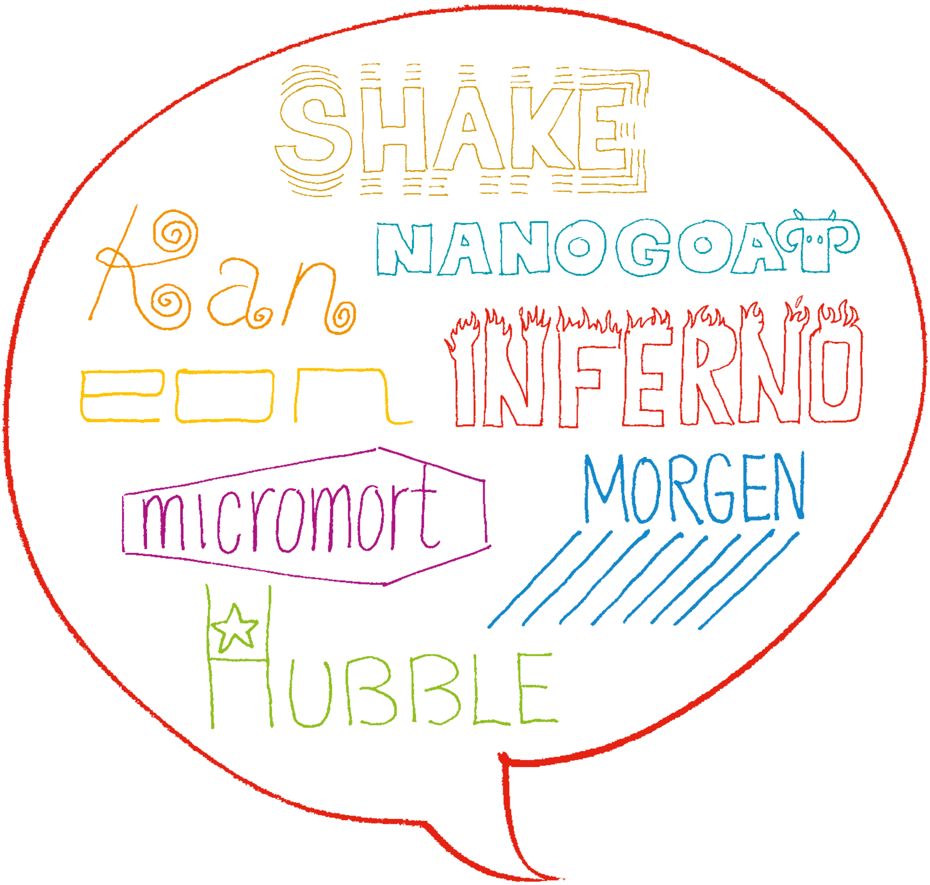
IOP Education | Stories from physics booklet 1

Weird units and wonderful measures

By Richard Brock



IOP Institute of Physics

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Introduction

The story of physics is intertwined with the stories of people. Richard has collected some amazing, amusing and enlightening stories and I am very pleased that the IOP is able to help him to share them. I'm sure that you will be quickly taken in by the stories themselves and their engaging retelling here. They will be of interest to any teacher and are ready to use with students to bring the discipline alive and illustrate its reliance on human ingenuity and frailty.

This booklet is the first in a series and shows how physics has developed from a desire to find define and measure things that can be quantified – and then look for ways of relating them. I am sure that you will enjoy it.

Charles Tracy

IOP Head of Education

Message from the author

I can still vividly recall some of the stories I was told by my physics teachers. I remember hearing about Tycho Brahe's pet elk, his metallic false nose and Newton's many eccentricities. When I became a teacher, I would share these stories with my classes and began to collect more stories, both from talking to teachers and from my reading. Although I am no longer a school teacher, I now have a collection of hundreds of stories about physics and I am still finding new ones.

I am delighted to be working with the Institute of Physics to share these stories more widely with teachers who can, in turn, share them with their classes. Together we are creating a series of booklets which is intended to act as a catalogue of stories for teaching physics.

The history of science, and contemporary research, are full of engaging stories that are rich in humanity. Adding engaging stories which capture the imagination to physics lesson can emphasise the human side of the subject and promote students' engagement with conceptual content.

In the words of educational researcher Fritz Kubli, stories can 'fill voiceless scientific structures with life and enrich physics teaching.'

It is quite common for students to begin learning about physics by being introduced to units. Whilst knowledge of units is important for understanding physics, students can find teaching about measurement abstract and unexciting. This first volume contains a series of stories about units and the ways in which they have been used.

So, let me tell you some stories about physics...

Richard Brock

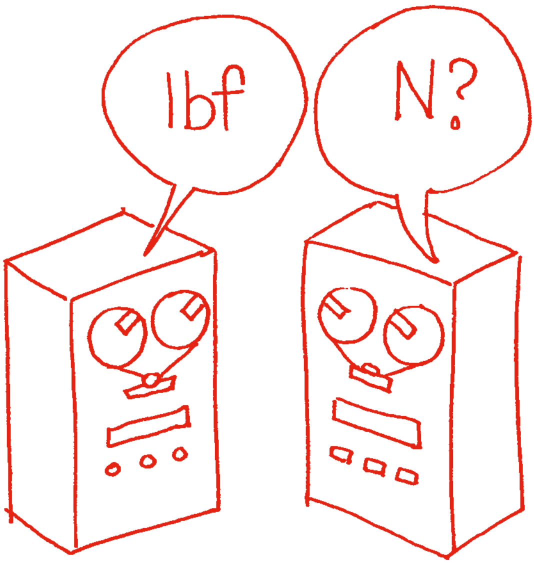
Why getting your units right matters

In December 1998, NASA launched the Mars Climate Orbiter. Its mission was to report data on the Martian atmosphere and climate. The probe was intended to function until 2004 and the construction of the orbiter and its lander were reported to have cost $330 million.

In September 1999, as the spacecraft was about to enter Martian orbit, communication was lost. A subsequent report determined that the Orbiter had most likely been destroyed because it had entered Mars' atmosphere at the wrong angle.

The loss of the Orbiter has been attributed to a mismatch of units. The software that sent commands to the spacecraft from Earth used imperial units whilst the software on the Orbiter worked in metric units.

The Mars Climate Orbiter Mishap Investigation Board reported that the spacecraft was inserted into orbit at the dangerously low altitude of 35 miles above Mars, rather than 140 miles. This was because the imperial unit of force, the pound-force, is equal to 4.45 Newtons so the thrust produced by the orbiter to begin its orbit was incorrect by a factor of 4.45. Ooops!



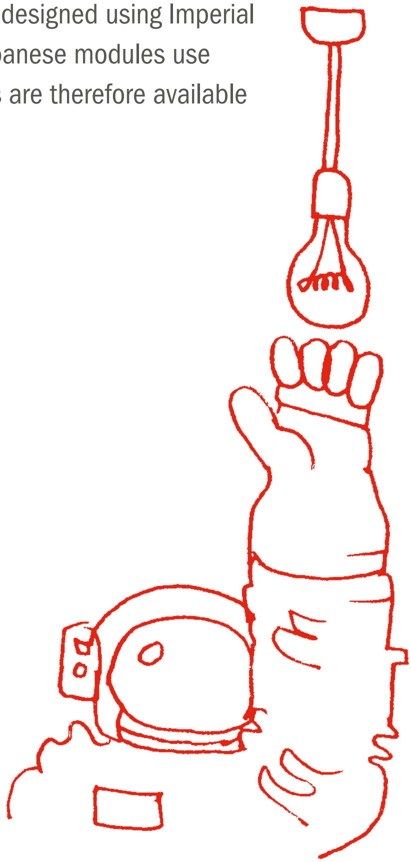
How many sets of tools does an astronaut need to change a light bulb?

Answer: two if you are in the International Space Station (ISS) and don't know which module the bulb is in!

Yet again, space is the arena where units are mismatched. But this time, everyone knows to be prepared.

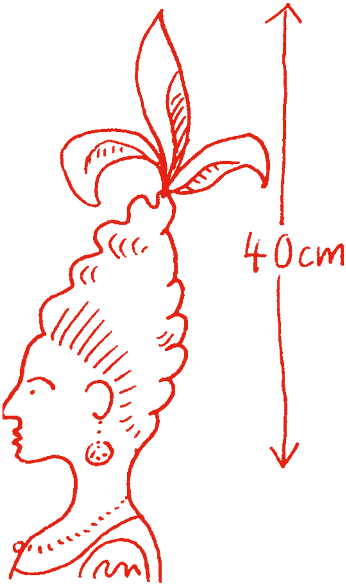
The first component of the ISS was launched into orbit in 1998. It was built by an international consortium which fostered collaboration but also led to some practical quirks.

The modules built by the United States are designed using Imperial units, whilst the European, Russian and Japanese modules use metric units. Both metric and imperial tools are therefore available for the astronauts.



Standardising units in Revolutionary France – a scientist's anxiety and the mistaken metre

It is estimated that 250,000 different weights and measures were in use across pre-revolutionary France.



In 1791, the National Assembly attempted to standardise length measurement by defining the metre as one ten-millionth the distance from the equator to the North Pole. Astronomers Pierre Méchain and Jean Baptiste Joseph Delambre were commissioned to measure the meridian between Dunkirk and Barcelona. The surveyors would measure the distance by marking out a hundred triangles, with bases of approximately 36,000 ft, measured by moving standard 12 ft platinum rods over 3000 times.

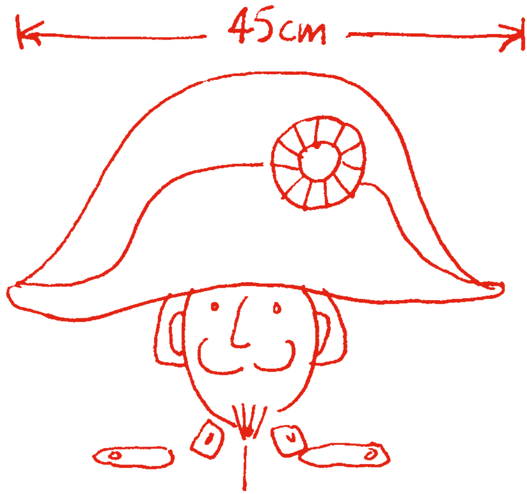
But in the unrest that followed the revolution, the scientists' specialised equipment sparked local peoples' suspicions and both Méchain and Delambre were arrested as potential counter-revolutionaries.

Though freed from arrest, Méchain's work did not go well – he broke his arm and ribs in an accident and he began to notice inconsistencies in his data driving him into depression. He wrote to Delambre: 'After all that has happened I can no longer show myself anywhere and my only wish is to be annihilated'.

Though he initially resisted, Méchain was persuaded to return to Paris to report his findings to a conference, but whilst Delambre presented his data, Méchain refused. Assuming the French scientists had fabricated their research, a Danish delegate left the conference in disgust. Nonetheless, the conference organisers declared the scientists' data sound and used them to calculate the provisional length for the metre. Prototypes were produced based on the measurements, leading to the famous platinum standard rod in 1799.

Despite the honours and awards that followed the conference, Méchain continued to be plagued by doubts over his measurements and sought to collect additional data. In carrying out this research, he died from yellow fever.

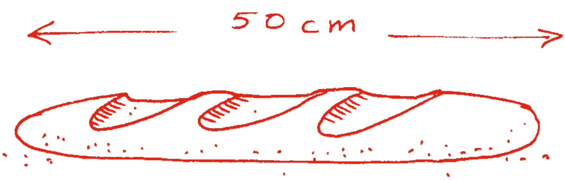
Delambre received his colleague's papers after his death and found them to consist of a mess of undated, unbound pages covered in crossings out, and he had to clean up the data before it could be published.



A quarter of a century after Méchain's death, an astronomer analysing his papers found that Méchain had made mistakes and deliberately changed his data. But these distortions were minor in comparison to measurement uncertainties.

By the 1870s, the error in the measurement of the metre was well known and a debate arose between those who felt the measurement should be changed to its 'true' value and those in favour of continuity. The conservative faction won, arguing that changing the measurement would have led to international disruption

The result is that the metre used today is two parts in 10,000 shorter than the ideal of one ten-millionth the distance from the equator the North Pole (contemporary satellite data show this distance to be 10,002,290 m). Doubtless Méchain would be appalled to know that his error has persisted for centuries.



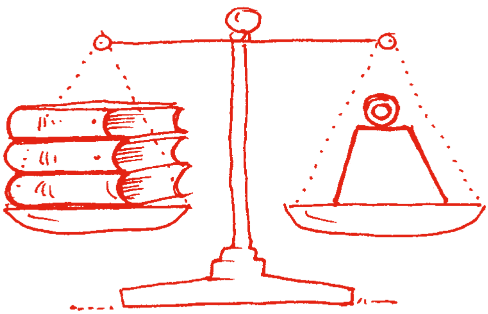
The Great British Mass Standard

Historical accounts report that a mass standard pre-dated the Norman Conquest and was referred to as the pound of the Tower of London. No physical examples of the Tower pound survive, though a bell-shaped brass weight matching the mass of the pound was found in Westminster Abbey in 1842 but has since been lost.

Whilst the Magna Carta called for further harmonisation – ‘There shall be standard measures of wine, ale, and corn (the London quarter), throughout the kingdom’ – standardisation came slowly. James Watt complained of the problem when communicating with scientists in Europe: ‘I had a great deal of trouble in reducing the weights and measures to speak the same language; and many of the German experiments become still more difficult from their using different weights and different divisions of them in different parts of that empire’.

Watt’s imperialist solution to the issue was for all nations to adopt the pound as a unit of measurement arguing: ‘for the utility is so evident, that every thinking person must immediately be convinced of it’. However, he was not entirely satisfied with the existing system and proposed redefining the pound so it consisted of 10 ounces or 10,000 grains.

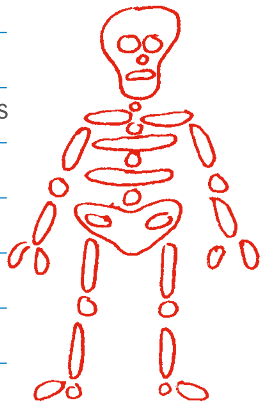
In 1834, the Imperial prototype masses were destroyed in a fire at the Houses of Parliament and in 1844 a new platinum prototype was produced. The British pound prototype was kept in a temperature controlled vault and lifted using an ivory fork.



Magnificent Multipliers

The following list may be an amusing way in which to introduce and discuss prefix multipliers :

Prefix name	Multiplier	Suggested collection	Proposed new unit
Atto	10^{-18}	10^{-18} boys	1 attoboy
Femto	10^{-15}	10^{-15} bismols	1 femtobismol
Pico	10^{-12}	10^{-12} boos	1 picoboo
Nano	10^{-9}	10^{-9} goats	1 nanogoat
Micro	10^{-6}	10^{-6} scopes	1 microscope
Milli	10^{-3}	10^{-3} cents	1 millicent
Kilo	10^{3}	2×10^{3} mocking birds	2 Kilomockingbirds
Mega	10^{6}	10^{6} phones	1 Megaphone
Giga	10^{9}	10^{9} los	1 Gigalo
Tera	10^{12}	10^{12} bulls	1 Terabull
Peta	10^{15}	10^{15} crouches	1 Peta Crouch
Exo	10^{18}	10^{18} skeletons	1 Exoskeleton



Rude units

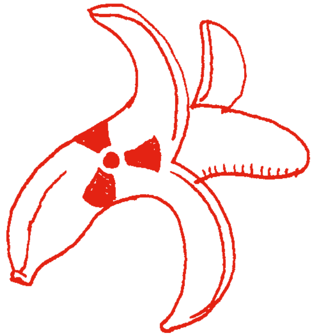
Austin Sendek, a physics student at the University of California has started a campaign to establish ‘hella’ as the SI prefix for 10^{27}. In response, B Todd Huffman wrote a letter to *Physics World*, suggesting ‘tini’ (pronounced with an ‘ee’ sound) for 10^{-27}, insi (pronounced ‘eensey’) for 10^{-30} and winsi (pronounced ‘weensey’) for 10^{-33}.

He concluded, “I have tried to think of prefixes that would come in on the high end beyond ‘hella’ but unfortunately I could think of nothing that could not be interpreted as a rude word.”

Unusual units

Banana equivalent dose (BED)

A unit used to provide an everyday measure of radiation dose. A single banana produces an ionising radiation dose of around 0.1 μSv which has been set as the value of the banana equivalent dose. The ionising radiation dose given by a range of sources can be expressed in BEDs:



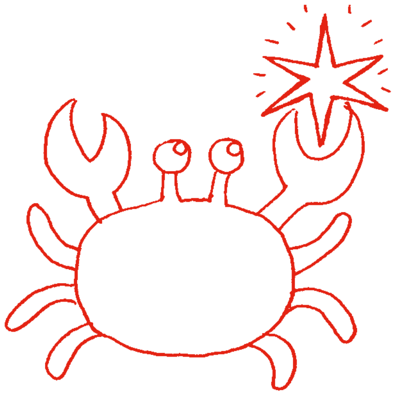
Source	Banana Equivalent Dose	Average loss in life expectancy
Dental X-ray	50	3 minutes
Eating 135 g of Brazil nuts	50	3 minutes
Flight from London to New York	700	37 minutes
Year of normal background dose	27,000	1 day
Exposure limit for nuclear workers	200,000	7 days
Acute radiation effects, including nausea and drop in white blood cell count	10 million	1 year
Spending 10 minutes close to Chernobyl reactor core after meltdown	500 million	50 years

Barn

A unit used to measure the cross-sectional area of atomic nuclei. It was devised in 1942 by MG Holloway and CP Baker and arises from the expression 'as big as a barn door' implying that, to a subatomic particle, the nucleus of an atom is an unmissable target. A barn represents an area of 10^{-28} m^2 and the terms microbarn, nanobarn and femtobarn are used by particle physicists.

Crab

The Crab Nebula contains a pulsar which is one of the brightest objects in the sky at X-ray and gamma-ray wavelengths. The nebula has become a standard for the measurement of the X-ray intensity of astronomical bodies. For example, an object with an intensity one thousandth of the nebula may be reported to measure 1 millicrab.



Dirac

Due to his laconic style, the Cambridge colleagues of Nobel-prize winning physicist Paul Dirac are said to have defined one Dirac as a rate of speaking equal to one word per hour.

Decimal hour, second and minute

In post-revolutionary France, a decimal time system was introduced. The day was divided into ten decimal hours, each of 100 minutes, leading to a decimal minute of 1.4 standard minutes and a decimal second lasting 0.86 standard seconds. The decimal time system lasted only two years from its implementation. Clocks and watches that indicated decimal time were produced. In fact, the mathematician and astronomer Pierre-Simon Laplace had his watch converted to decimal time and his work used the new time units. You can see decimal time pieces in the collection of the Musée des Artes et Métiers in Paris.

Garn

A unit of space sickness jokingly used by NASA. Astronaut Senator Jack Garn was reported to have suffered one of the most extreme cases of space sickness on the Space Shuttle in 1985. The Garn represents the maximum level of sickness that it is possible to reach – most astronauts reach a level of a tenth of a Garn.

Grave

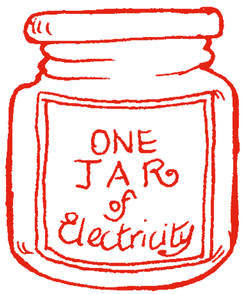
The group of scientists, including French chemist Antoine-Laurent de Lavoisier, who developed the system of measures that evolved into the modern metric system, originally proposed the grave as a unit of mass equivalent to the mass of 1 litre of water at the ice point. However, during the French revolution, Lavoisier was executed, and the new commission decided on the 'gramme' which was defined as the mass of water with a volume of one cubic centimetre.

Inferno, eon and Hubble

In a paper published shortly before his death in 1968, Soviet-American theoretical physicist and cosmologist George Gamov proposed a new set of units for cosmologists, including the inferno (10^9 K), the eon (10^9 years) and the Hubble (10^9 light years).

Jar

An obsolete unit of capacitance. The unit is believed to be one of the oldest electrical units, introduced in 1834 by Sir William Harris. A jar represents the capacitance of an early Leiden jar, with 9 $\times 10^8$ jars being equivalent to 1 farad. The unit was used by the Royal Navy in the *Admiralty Handbook of Wireless Telegraphy* as late as 1938.



Kan

A story, which may be apocryphal, is that a rival of American physicist Robert Millikan suggested that the unit of conceit should be the kan. The kan was defined as a large amount of conceit so for everyday measurements the millikan would be more appropriate.

Micromort

A unit to quantify risk that is equivalent to a one-in-a-million chance of death. For example, travelling in a car carries a risk of 250 miles per micromort whereas walking has a greater risk per distance at 7 miles per micromort. Horse riding is rated at 0.5 micromorts compared to 8 micromorts for hang-gliding, assuming constant risk within the activity and over time. On the theme of fatalities, the **Darwin** has been proposed as the probability that one undergraduate student will suffer a fatal injury if left to their own devices in carrying out a practical.

Morgen

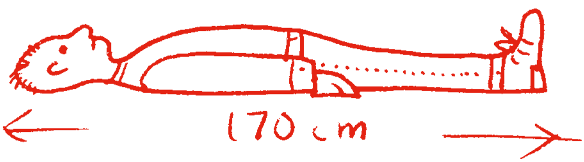
A measure of area somewhere in the range of 2,168 m^2 to 6,643 m^2. It arises from the Germanic word for morning and refers to the amount of land that could be ploughed in one morning. When the Dutchman Peter Minuit bought the island of Manhattan, its area was given as 11,000 morgens.

Shake

In nuclear and astrophysics contexts, the shake is equal to 10 ns and is thought to originate from the phrase 'two shakes of a lamb's tail.' The unit refers to the period between one nucleus ejecting a neutron and the consequent fission of a second nucleus.

Smoot

A unit of length defined as the height of MIT undergraduate Oliver R. Smoot in 1958. New entrants to a fraternity at MIT were set the task of measuring the length of Harvard Bridge. Smoot laid down on the deck of the bridge, his fellow initiates chalked his height (170 cm) on the surface and he repeated the process to measure the length of the bridge as just over 360 Smoots. A plaque on the bridge commemorates the measurement. Smoot went on to became the Chairman of the American National Standards Institute.



For more stories about physics, follow Richard on Twitter:
@RBrockPhysics

A full set of references for this booklet are available on the Stories about Physics forum on TalkPhysics at
talkphysics.org/groups/stories-about-physics

Dr Richard Brock

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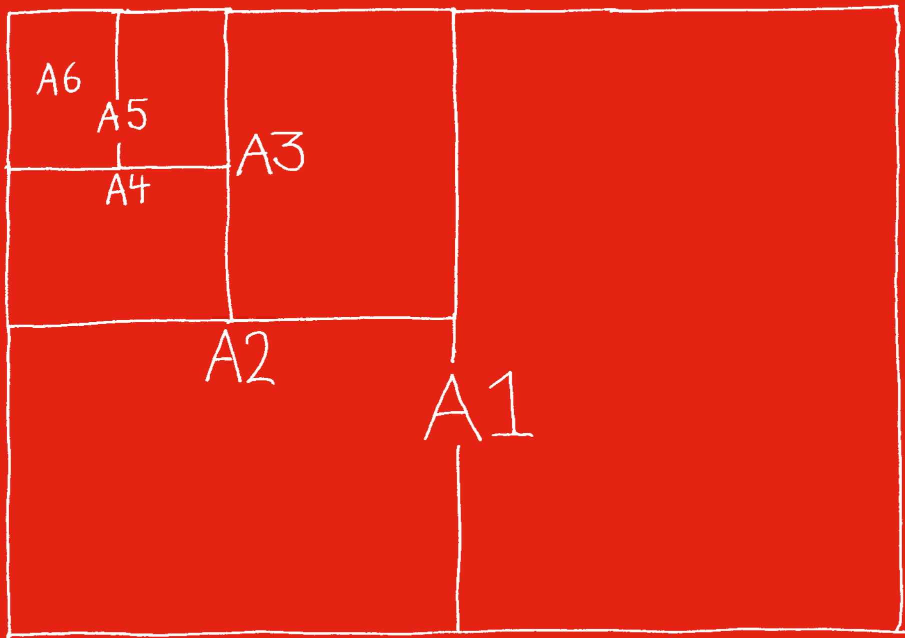
After teaching physics in secondary schools for 8 years, Richard studied for a PhD in physics education and now teaches and conducts research at King's College London.

The Institute of Physics (IOP)

The Institute of Physics is the professional and learned society for physics in the UK and Ireland, inspiring people to develop their knowledge, understanding and enjoyment of physics.

We work with a range of partners to support and develop the teaching of physics in schools; we encourage innovation, growth and productivity in business, including addressing significant skills shortages; and we provide evidence-based advice and support to governments in the UK and Ireland. Our members come from across the physics community, whether in industry, academia, the classroom, technician roles or in training programmes as an apprentice or a student.

However our reach goes well beyond our membership to all who have an interest in physics and the contribution it makes to our culture, our society and the economy. We are a world-leading science publisher and we are proud to be a trusted and valued voice for the physics community.



This booklet measures 210 mm in height x 148 mm in diameter. This format is otherwise known as A5 and is one of the formats within the ISO 216 paper size system. They are all progressively half the area of the previous lower number. They are as follows: A0, A1, A2, A3, A4, A5, A6, A7, A8, A9 and A10.