VINTAGE

THE CONSTANTS OF NATURE

JOHN D. BARROW

Contents

About the Author

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Also by John D. Barrow

Theories of Everything

The Left Hand of Creation
(With Joseph Silk)

L'Homme et le Cosmos
(With Frank J. Tipler)

The Anthropic Cosmological Principle
(with Frank J. Tipler)

The World Within the World
The Artful Universe
Pi in the Sky
Perché il mondo è matematico?
Impossibility
The Origin of the Universe
Between Inner Space and Outer Space
The Universe that Discovered Itself
The Book of Nothing

To Carol

John D. Barrow

THE CONSTANTS OF NATURE

From Alpha to Omega

VINTAGE

‘Not the power to remember, but its very opposite, the power to forget is a necessary condition for our existence.’

Sholem Ash

Preface

Some things never change. And this is a book about those things. Long ago, the happenings that made it into histories were the irregularities of experience: the unexpected, the catastrophic, and the ominous. Gradually, scientists came to appreciate the mystery of the regularity and predictability of the world. Despite the concatenation of chaotically unpredictable movements of atoms and molecules, our experience is of a world that possesses a deep-laid consistency and continuity. Our search for the source of that consistency looked first to the ‘laws’ of Nature that govern how things change. But gradually we have identified a collection of mysterious numbers which lie at the root of the consistency of experience. These are the constants of Nature. They give the Universe its distinctive character and distinguish it from others we might imagine. They capture at once our greatest knowledge and our greatest ignorance about the Universe. For, while we measure them to ever greater precision, fashion our fundamental standards of mass and time around their invariance, we cannot explain their values. We have never explained the numerical value of any of the constants of Nature. We have discovered new ones, linked old ones, and understood their crucial role in making things the way they are, but the reason for their values remain a deeply hidden secret. To search it out we will need to unpick the most fundamental theory of the laws of Nature, to discover if the constants that define them are fixed and framed by some over-arching logical consistency or whether chance still has a role to play.

Our first glimpses reveal a very peculiar situation. While some constants seem as if they will be fixed, others have the scope to be other than they are, and some seem completely untouched by everything else about the Universe. Do their values fall out at random? Could they really be different? How different could they be if life is to be possible in the Universe?

Back in 1986, my first book, *The Anthropic Cosmological Principle*, explored all the then-known ways in which life in the universe was sensitive to the values of the constants of Nature. Universes with slightly altered constants would be still-born, devoid of the potential to evolve and sustain the sort of organised complexity that we call life. Since that time, cosmologists have found more and more ways in which the Universe could exhibit variations in its defining constants; more and more ways in which life could have failed to emerge in the Universe. They have also begun to take seriously the possibility and actuality of other universes in which the constants of Nature do take different values. Inevitably, we find ourselves in a world where things fell out right. But what was the chance of that happening? Here we shall look at many of these possibilities, connecting them to the curious history of our attempts to understand the values of our constants of Nature.

Recently, one big story about the constants of Nature has produced a focus for media attention and detailed scientific research. It raises the most basic question of all: are the constants of Nature really constant after all? A new method of scrutinizing the constants of Nature over the last II billion years of the Universe’s history has been devised by a group of us. By looking at the atomic patterns barcoded into the light that reaches us from distant quasars we can look and see what atoms were like when the light began its journey billions of years ago. So, were the constants of Nature always the same? The answer, unexpected and shocking, raises new possibilities for the Universe and the laws that govern it. This book will tell you about them.

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I would also like to thank Elizabeth, for surviving at one stage the thought that the book might need to be retitled *A River Runs Through It*, and our three children David, Roger and Louise who were always worried that pocket-money might be a constant of Nature.

J.D.B
Cambridge, April 2002

chapter one

Before the Beginning

> ‘What happens first is not necessarily the beginning.’
>
> Henning Mankell[1]

SAMELINESS

> ‘There is nothing that God hath established in a constant cause of nature, and which therefore is done everyday, but would seem a miracle, and exercise our admiration, if it were done but once.’
>
> John Donne[2]

CHANGE IS A challenge. We live in the fastest moving period of human history. The world around us is driven by forces that make our lives increasingly sensitive to small changes and sudden responses. The elaboration of the Internet and the tentacles of the Worldwide Web have put us in instantaneous contact with computers and their owners all round the world. The threats from unchecked industrial progress have brought about ecological damage and environmental change that appears to be happening faster than even the gloomiest prophets of doom had predicted. Children seem to grow up faster. Political systems realign in new and unexpected ways more quickly and more often than ever before. Even human beings and the information they embody are facing editorial intervention by more ambitious spare-part surgery or the reprogramming of parts of our genetic code. Most forms of progress are accelerating and more and more parts of our experience have become entwined in the surge to explore all that is possible.

In the world of scientific exploration the recognition of the impact of change is not so new. By the end of the nineteenth century it had been appreciated that once upon a time the Earth and our solar system had not existed; that the human species must have changed in appearance and average mental capability over huge spans of time; and that in some broad and general way the Universe should be winding down, becoming a less hospitable and ordered place. During the twentieth century we have fleshed out this skeletal picture of a changing Universe. The climate and topography of our planet is continually changing and so are the species that live upon it. Most dramatically of all, we have discovered that the entire universe of stars and galaxies is in a state of dynamic change, with great clusters of galaxies flying away from one another into a future that will be very different from the present. We have begun to appreciate that we are living on borrowed time. Cataclysmic astronomical events are common; worlds collide. Planet Earth has been hit in the past by comets and asteroids. One day its luck will run out, the shield provided so fortuitously by the vast planet Jupiter, guarding the outer reaches of our solar system, will not be able to save us. Eventually, even our Sun will die. Our Milky Way galaxy will be drawn into a vast black hole deep in its centre. Life like our own will end. Survivors will need to have changed their form, their homes and their nature to such an extent that we would be challenged to call their continued existence ‘living’ by our own standards today.

We have recognised the simple secrets of chaos and unpredictability which beset so many parts of the world around us. We understand our changing weather but we cannot predict it. We have appreciated the similarities between complexities like this and those that emerge from systems of human interaction – societies, economies, choices, ecosystems – and from within the human mind itself.

All these perplexing complexities rush along and seek to convince us that the world is like a runaway roller-coaster, rocking and rolling; that everything we once held to be true might one day be overthrown. Some even see such a prospect as a reason to be suspicious of science[3] as a corrosive effect upon the foundations of human nature and certainty, as though the construction of the physical Universe and the vast schema of its laws should have been set up with our psychological fragility in mind.

But there is a sense in which all this change and unpredictability is an illusion. It is not the whole story about the nature of the Universe. There is both a conservative and a progressive side to the deep structure of reality. Despite the incessant change and dynamic of the visible world, there are aspects of the fabric of the Universe which are mysterious in their unshakeable *constancy*. It is these mysterious unchanging things that make our Universe what it is and distinguish it from other worlds that we might imagine. There is a golden thread that weaves a continuity through Nature. It leads us to expect that certain things elsewhere in space will be the same as they are here on Earth; that they were and will be the same at other times as they are today; that for some things neither history nor geography matter. Indeed, perhaps without such a substratum of unchanging realities there could be no surface currents of change or any complexities of mind and matter at all.

These bedrock ingredients of our Universe are what this book is about. Their existence is one of the last mysteries of science that has challenged a succession of great physicists to come up with an explanation for why they are as they are. Our quest is to discover what they are but we have long known only what to call them. They are the *constants of Nature*. They lie at the root of sameliness in the Universe: why every electron seems to be the same as every other electron.

The constants of Nature encode the deepest secrets of the Universe. They express at once our greatest knowledge and our greatest ignorance about the cosmos. Their existence has taught us the profound truth that Nature abounds with unseen regularities. Yet, while we have become skilled at measuring the values of these constant quantities, our inability to explain or predict their values shows how much we have still to learn about the inner workings of the Universe.

What is the ultimate status of the constants of Nature? Are they truly constant? Are they everywhere the same? Are they all linked? Could life have evolved and persisted if they were even slightly different? These are some of the issues that this book will grapple with. It will look back to the discoveries of the first constants of Nature and the impact they had on scientists and theologians looking for Mind, purpose and design in Nature. It will show what frontier science now believes constants of Nature to be and whether a future Theory of Everything, if it exists, will one day reveal the true secret of the constants of Nature. And most important of all, it will ask whether they are truly constant.

chapter two

Journey Towards Ultimate Reality

> ‘*Franklin:* Have you ever thought, Headmaster, that your standards might perhaps be a little out of date?
> *Headmaster:* Of course they’re out of date. Standards always are out of date. That is what makes them standards.’
>
> Alan Bennett[1]

MISSION TO MARS

> ‘The Mars Climate Orbiter Mishap Investigation Board has determined that the root cause for the loss of the Mars Climate Orbiter spacecraft was the failure to use metric units.’

NASA Mars Climate Orbiter Mishap Investigation Report[2]

IN THE LAST week of September 1998 NASA was getting ready to hit the press agencies with a big story. The Mars Climate Explorer, designed to skim through the upper atmosphere of Mars, was about to send back important data about the Martian atmosphere and climate. Instead, it just crashed into the Martian surface. In NASAs words,

> ‘The MCO spacecraft, designed to study the weather and climate of Mars, was launched by a Delta rocket on

> December 11th, 1998, from Cape Canaveral Air Station, Florida. After a cruise to Mars of approximately 9½ months, the spacecraft fired its main engine to go into orbit around Mars at around 2 a.m. PDT on September 23, 1999. Five minutes into the planned 16-minute burn, the spacecraft passed behind the planet as seen from Earth. Signal reacquisition, nominally expected at approximately 2:26 a.m. PDT did not occur. Efforts to find and communicate with MCO continued up until 3 p.m. PDT on September 24, 1999, when they were abandoned.'[3]

The spacecraft was 60 miles (96.6 km) closer to the Martian surface than the mission controllers thought, and $125 million disappeared into the red Martian dust. The loss was bad enough but when the cause was discovered it looked like a case for the force-feeding of humble pie. Lockheed-Martin, the company controlling the day-to-day operation of the spacecraft, was sending out data about the thrusters in Imperial units, miles, feet and pounds-force, to mission control, while NASA's navigation team was assuming like the rest of the international scientific world that they were receiving their instructions in metric units. The difference between miles and kilometres was enough to send the craft 60 miles off course on a suicidal orbit into the Martian surface.[4]

The lesson of this débâcle is clear. Units matter. Our predecessors have bequeathed us countless everyday units of measurement that we tend to use in different situations for the sake of convenience. We buy eggs in dozens, bid at auctions in guineas, measure horse races in furlongs, ocean depths in fathoms, apples in bushels, coal in hundredweight, lifetimes in years and weigh gemstones in carats. Accounts of all the standards of measurement in past and present existence run to hundreds of pages. All this was entirely satisfactory while commerce was local and simple. But as communities started to trade internationally in ancient times they started to encounter other ways of counting. Quantity was measured differently from country to country and conversion factors were needed, just as we change currency when travelling internationally today. Once international collaboration began on technical projects the stakes were raised.[5] Precision engineering requires accurate inter-comparison of standards. It is all very well telling your collaborators on the other side of the world that they need to make an aircraft component that is precisely one metre long, but how do you know that their metre is the same as your metre?

MEASURE FOR MEASURE – PAROCHIAL STANDARDS

> ‘She does not understand the concept of Roman numerals.
> She thought we just fought World War Eleven.’
>
> Joan Rivers[6]

Originally, standards of measurement were entirely parochial and anthropometric. Lengths were derived from the length of the king’s arm or the span of his hand. Distances mirrored the extent of a day’s journey. Time followed the astronomical variations of the Earth and Moon. Weights were convenient quantities that could be carried in the hand or on the back. Many of these measures were wisely chosen and are still with us today in spite of the official ubiquity of the decimal system. None is sacrosanct. Each is designed for convenience in particular circumstances. Many measures of distance were derived anthropomorphically from the dimensions of human anatomy. The ‘foot’ is the most obvious unit of this sort. Others are no longer so familiar. The ‘yard’ was the length of a tape drawn from the tip of a man’s nose to the farthest fingertip of his arm when stretched horizontally to one side. The ‘cubit’ was the distance from a man’s elbow joint to furthermost fingertip of his outstretched hand, and varies between about 17 and 25 of our inches (0.44–0.64 metres) in the different ancient cultures that employed it.[7] The nautical unit of length, the fathom, was the largest distance-unit defined from the human anatomy, and was defined as the maximum distance between the fingertips of a man with both hands outstretched horizontally to the side.

The movement of merchants and traders around the Mediterranean region in ancient times would have highlighted the different measures of the same anatomical distance. This would have made it difficult to maintain any single set of units. But national tradition and habit was a powerful force in resisting the adoption of another country’s standards.

The most obvious problem with such units is the fact that men and women come in different sizes. Who do you measure as your standard? The king or queen is the obvious candidate. Even so, this results in a recalibration of units every time the throne changes hands. One notable response to the problem of the variation in human dimensions was that devised by David I of Scotland in 1150 to define the Scottish inch: he ordained that it was to be the *average* drawn from measurements of the width of the base of the thumbnail of three men: a ‘mekill’ [big] man, a man of ‘messurabel’ [moderate] stature, and a ‘lytell’ [little] man.

The modern metric system of centimetres, kilograms and litres, and the traditional ‘Imperial’ system of inches, pounds and pints are equally good measures of lengths, weights and volumes so long as you can measure them accurately. That is not the same thing as saying they are equally convenient, though. The metric system mirrors our counting system by having each unit ten times bigger than the next smallest. Imagine having a counting system that had uneven jumps. So, instead of hundreds, tens and units we had a counting system like that used in England for non-technical weights (like human body weights or horse-racing handicaps) with 16 ounces in one pound and 14 pounds in one stone.

The cleaning up of standards of measurement began decisively at the time of the French Revolution at the end of the eighteenth century. Introducing new weights and measures brings with it a certain upheaval in society and is rarely received with unalloyed enthusiasm by the populace. The French Revolution therefore provided an occasion to make such an innovation without adding significantly to the general upheaval of everything else.[8] The prevailing trend of political thinking at the time sided with the view that weights and measures should have an egalitarian standard that did not make them the property of any one nation, nor give any nation an advantage when it came to trading with others. The way to do this was believed to define measure against some agreed standard, from which all rulers and secondary measures would be calibrated. The French National Assembly enacted this into law on 26 March 1791, with the support of Louis XVI and the clear statement of principle submitted by Charles Maurice de Talleyrand:

> ‘In view of the fact that in order to be able to introduce uniformity of weights and measures it is necessary that a natural and unchanging unit of mass be laid down, and that the only means of extending this uniformity to other nations and urging them to agree upon a system of measures is to choose a unit that is not arbitrary and does not contain anything specific to any peoples on the globe.’[9]

Two years later, the ‘metre’[10] was introduced as the standard of length, defined as the ten millionth part of a quarter of the Earth’s meridian.[11] Although this is a plausible way to identify a standard of length it is clearly not very practical as an everyday comparison. Consequently, in 1795, the units were directly related to specially made objects. At first the unit of mass was taken as the gram, defined to be the mass of one cubic centimetre of water at 0 degrees centigrade. Later it was superseded by the kilogram (1000 grams) defined as the mass of 1000 cubic centimetres of water at 4 degrees centigrade. Finally, in 1799, a prototype metre bar[12] was made together with a standard kilogram mass and placed in the archives of the new French Republic. Even today, the reference kilogram mass is known as the ‘Kilogramme des Archives’.

Unfortunately, the new metric units were not at first successful and Napoleon reintroduced the old standards in the early years of the nineteenth century. The European political situation prevented an international harmonisation of standards.[13] It was not until New Year’s Day 1840 that Louis Phillipe made metric units legally obligatory in France. Meanwhile they had already been adopted more universally in the Netherlands, Belgium and Luxembourg twenty-four years earlier, and by Greece in 1832. Britain only allowed a rather restricted use of metric units after 1864 and the USA followed suit two years later. Real progress only occurred in 1870 when the International Metre Commission was established and met in Paris on 8 August for the first time, to coordinate standards and oversee the making of new standard masses and lengths.[14] Copies of the standards were distributed to some of the member states chosen by the drawing of lots. The kilogram was the mass of a special cylinder, 39 mm in height and diameter, made of an alloy of platinum and iridium[15] kept under three glass bell-jars and stored inside a vault at the

International Bureau of Standards in Sèvres near Paris. Its definition is simple:[16]

> ‘The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.’

The British Imperial units, like the yard and the pound, were defined similarly and standard prototypes were kept by the National Physical Laboratory in England and the National Bureau of Standards in Washington DC.

This trend for standardisation saw the creation of scientific units of measurement. As a result we habitually measure lengths, masses and times in multiples of metres, kilograms and seconds. One unit of each gives a familiar quantity that is easily imagined: a metre of cloth, a kilogram of potatoes. This convenience of size witnesses at once to their anthropocentric pedigree. But its inconvenience also becomes obvious when we start to use these units to describe quantities that are super- or sub-human in scale. The smallest atoms are 10 billion times smaller than a metre. The Sun is more than 10^{30} kilograms in mass. In Figure 2.1 we show the span of sizes and masses of significant objects in the Universe with ourselves added for perspective. We sit in between the huge astronomical distances and masses and the sub-atomic scale of the most elementary particles of matter.

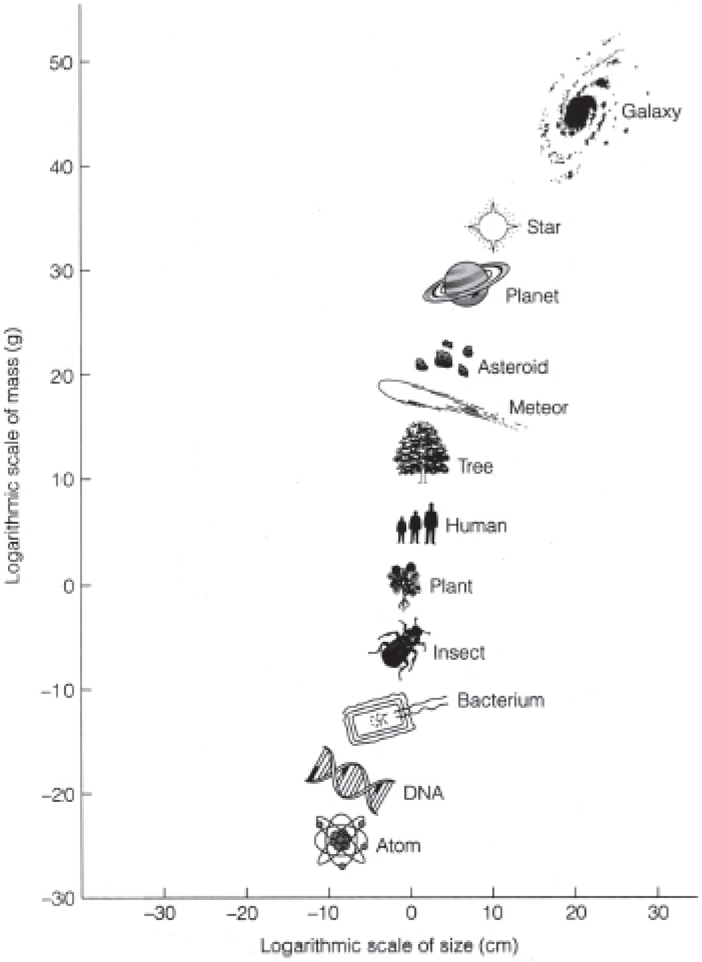
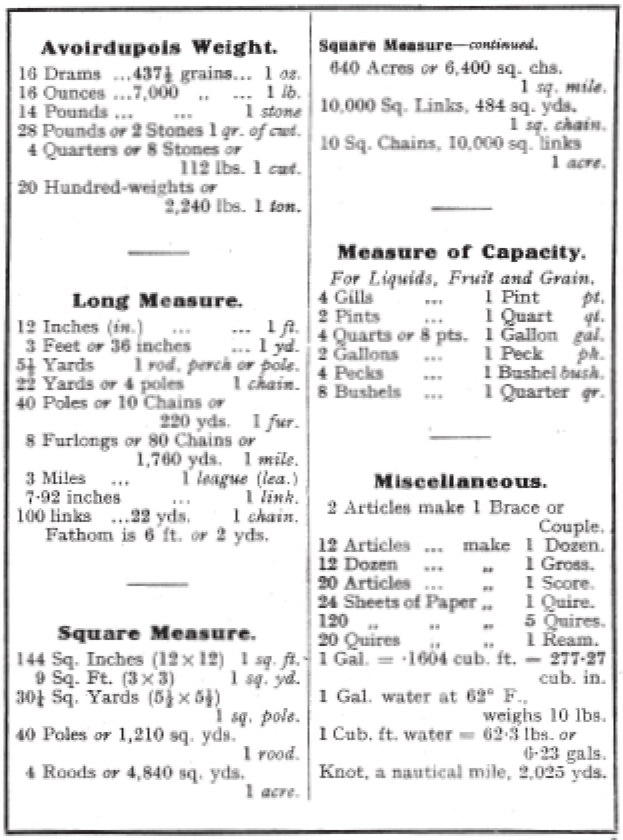


Figure 2.1 *The mass and size ranges of some important ingredients of the Universe. Our choice of centimetres and grams as units places us close to the centre of things*.

Despite the introduction of universal metric standards by international commissions and government ministers, the ordinary worker took little notice of edicts about units, especially in Britain where a huge multiplicity of special units were in play throughout every branch of industry and commerce. By the middle of the nineteenth century, the industrial revolution had created diverse human subcultures of engineers and brewers, accountants and metalworkers, timekeepers and ship workers, all of whom needed ways of measuring the materials that they managed and manipulated. The result was an explosion of units of measure. Every type of material began to have its own standard of strength and tolerance, quantity and weight. Not only were these units anthropocentric they were profession-centric as well. Brewers liked one choice of volume measure, water engineers another; jewellers measured weight differently to sailors and architects. When I was a child there was a common brand of lined exercise book that would be used for making notes at school. They always had red or blue covers and the outside back cover of the book listed all the peculiar Imperial measures of length, area, capacity and weight (see Figure 2.2).



Avoirdupois Weight.

16 Drams ...437½ grains... 1 *oz.*
16 Ounces ...7,000 ,, ... 1 *lb.*
14 Pounds ... ... 1 *stone*
28 Pounds *or* 2 Stones 1 *qr. of cwt.*
4 Quarters *or* 8 Stones *or* 112 lbs. 1 *cwt.*
20 Hundred-weights *or* 2,240 lbs. 1 *ton.*

Long Measure.

12 Inches (*in.*) ... ... 1 *ft.*
3 Feet *or* 36 inches ... 1 *yd.*
5½ Yards 1 *rod, perch or pole.*
22 Yards *or* 4 poles 1 *chain.*
40 Poles *or* 10 Chains *or* 220 yds. 1 *fur.*
8 Furlongs *or* 80 Chains *or* 1,760 yds. 1 *mile.*
3 Miles ... 1 *league* (*lea.*)
7·92 inches ... 1 *link.*
100 links ...22 yds. 1 *chain.*
Fathom is 6 ft. *or* 2 yds.

Square Measure.

144 Sq. Inches (12 × 12) 1 *sq. ft.*
9 Sq. Ft. (3 × 3) 1 *sq. yd.*
30¼ Sq. Yards (5½ × 5½) 1 *sq. pole.*
40 Poles *or* 1,210 sq. yds. 1 *rood.*
4 Roods *or* 4,840 sq. yds. 1 *acre.*

Square Measure—*continued.*

640 Acres *or* 6,400 sq. chs. 1 *sq. mile.*
10,000 Sq. Links, 484 sq. yds. 1 *sq. chain.*
10 Sq. Chains, 10,000 sq. links 1 *acre.*

Measure of Capacity.

For Liquids, Fruit and Grain.

4 Gills	...	1 Pint	*pt.*
2 Pints	...	1 Quart	*qt.*
4 Quarts *or* 8 pts.		1 Gallon	*gal.*
2 Gallons	...	1 Peck	*pk.*
4 Pecks	...	1 Bushel	*bush.*
8 Bushels	...	1 Quarter	*qr.*

Miscellaneous.

2 Articles make 1 Brace or Couple.

12 Articles	...	make	1 Dozen.
12 Dozen	...	,,	1 Gross.
20 Articles	...	,,	1 Score.
24 Sheets of Paper		,,	1 Quire.
120 ,,	,,	,,	5 Quires.
20 Quires	,,	,,	1 Ream.

1 Gal. = ·1604 cub. ft. = 277·27 cub. in.
1 Gal. water at 62° F., weighs 10 lbs.
1 Cub. ft. water = 62·3 lbs. *or* 6·23 gals.
Knot, a nautical mile, 2,025 yds.

Figure 2.2 *A typical set of miscellaneous weights and measures from an English self-help book of the 1950s.*[17]

For the engineer and the practical person of affairs this was convenient, useful and no doubt very profitable. But for anyone seeking an integrated natural philosophy it made human knowledge appear fragmented and idiosyncratic. A visitor from another planet would be perplexed by the need for different measures of weight when buying gold, apples or sealing wax.

MAINTAINING UNIVERSAL STANDARDS

> 'There was a crooked man who built a crooked house.'
>
> Nursery rhyme

By the second half of the nineteenth century, engineers, industrialists and scientists were becoming overwhelmed by the profusion of *ad hoc* units and measures. The industrial revolution had accelerated the development of every imaginable industry. Manufacturing, machining, measuring, designing, building – these were the rages of the age and they spawned more and more units.

Within the halls of science the existence of standard lengths and masses was not entirely satisfactory for the purist either. Every time standard masses were handled with their special tongs their mass would be very slightly changed. It would vary slightly as atoms were evaporated from their surfaces or dust deposited from the atmosphere. They were not really constant.[18] Nor were they universal. Suppose that a signal had been received from an engineer on another planet asking us how big we were. It would be no use sending an answer in metres or kilograms and then responding to the inevitable reply, 'What are they?' by telling our extraterrestrial correspondent that they were objects kept in glass containers in Paris. Unfortunately the quest for universal standards had created examples which were neither standard nor universal.

Within science the driving force for rationalisation came from the study of electricity and magnetism. Different systems of units were in use by different groups of scientists and had different relationships with the traditional metric units for mass, length, time and temperature.

The first general response to these problems came from Lord Rayleigh and James Clerk Maxwell. In his Presidential address to the British Association for the Advancement of Science in 1870 Maxwell advocated the introduction of standards which are not tied to special objects, like standard metres[19] or kilograms kept in special conditions. For standards like these can never really be constant. The standard mass in Paris will lose and gain molecules all the time. Measures of time that are defined, like the day, by the rotation of the Earth or, like the year, by its orbit of the Sun likewise cannot be constant. As the rotation of the Earth slows, and our solar circuit changes, so these standards will very slowly drift. They may be defined in extrahuman terms but they are not candidates for ultimate standards. Maxwell had spent a good deal of time studying the behaviour of molecules in gases and was very impressed by the way in which each molecule of hydrogen was the same as all the others. This was quite different to dealing with large, everyday objects where every one was different. Maxwell saw an opportunity to use the sameness of molecules to define standards absolutely:

> ‘Yet, after all, the dimensions of our earth and its time of rotation, though, relatively to our present means of comparison, very permanent, are not so by any physical necessity. The earth might contract by cooling, or it might be enlarged by a layer of meteorites falling on it, or its rate of revolution might slowly slacken, and yet it would continue to be as much a planet as before.
>
> But a molecule, say of hydrogen, if either its mass or its time of vibration were to be altered in the least, would no longer be a molecule of hydrogen.

> If, then, we wish to obtain standards of length, time, and mass which shall be absolutely permanent, we must seek them not in the dimensions, or the motion, or the mass of our planet, but in the wave-length, the period of vibration, and the absolute mass of these imperishable and unalterable and perfectly similar molecules [i.e. atoms].[20]

Maxwell was specially interested in molecules for many philosophical purposes. He recognised the significance of there existing populations of identical building blocks for all the material bodies we see around us. If we take any piece of pure iron it will be composed of a collection of identical iron molecules. The fact that these molecules appear to be identical is a remarkable feature of the world. Maxwell contrasted this invariance with the changeability and evolution of living things predicted by Charles Darwin’s theory of evolution by natural selection. Maxwell pointed to the molecules of Nature as entities that were not subject to selection, adaptation or mutation. His challenge was to find a way to exploit this immutability and universality in the way that we define our units of measurement. In this way we would be able to take a step away from the bias introduced by the imperatives of human convenience towards the deep invariances of physical reality.

In 1905 the red light emitted by hot cadmium atoms[21] was first used as a standard against which to define a unit of length called the Angstrom (denoted by 1Å and equal to 10^{-10} metre). One wavelength of the cadmium light was equal to 6438.4696 Å. This was a key step because for the first time it defined a standard of length in terms of a universally constant feature of Nature. The wavelength of the light emitted by cadmium[22] is fixed by the constants of Nature alone. If we wanted to tell an extraterrestrial physicist our size, we could do it by saying what we mean by 2.8 billion wavelengths of red cadmium light.[23]

A BRILLIANT IDEA!

> '"Where did the matter come from?"
>
> "What is the difference? … The secret of the universe is apathy. The earth, the sun, the rocks, they're all indifferent, and this is a kind of passive force. Perhaps indifference and gravitation are the same."'
>
> Isaac Bashevis Singer[24]

In 1874, an unusual Irish physicist called George Johnstone Stoney found himself having to make sense of the Babel of practical units. He had been invited to deliver a lecture on units of measurement at the annual meeting of the British Association for the Advancement of Science in Belfast.[25] This annual meeting still exists today but is now devoted to showcasing the developments in science for the general public, the Press and young people. But in Stoney's day it was the foremost science conference in the world, a place where great discoveries would be made public and the Press would report on great debates between leading scientists and commentators. Today there are so many specialised scientific conferences, workshops, meetings, discussions, panel discussions and round tables that there is no longer any place for a meeting that covers all of science at a technical level – it would be impossibly big, impossibly lengthy, and well nigh unintelligible to most of the participants much of the time.

Stoney was an eccentric and original thinker. He was the first person to show how to deduce whether or not other planets in the solar system possessed a gaseous atmosphere, like the Earth, by calculating whether their surface gravity was strong enough to hold on to one. But his real passion was reserved for his most treasured idea – the ‘electron’. Stoney had deduced that there must exist a basic ingredient of electric charge. By studying Michael Faraday’s experiments on electrolysis Stoney had even predicted[27] what its value must be – a prediction subsequently confirmed by J.J. Thomson who discovered the electron in Cambridge in 1897[28] and announced his discovery to the Royal Institution on 30 April. To this basic quota of electric charge Stoney eventually gave the name ‘electron’ and the symbol *E* in 1891[29] (after first calling it[30] the ‘electrine’ in 1874) and he never missed an opportunity to publicise its properties and potential benefits for science.[31]

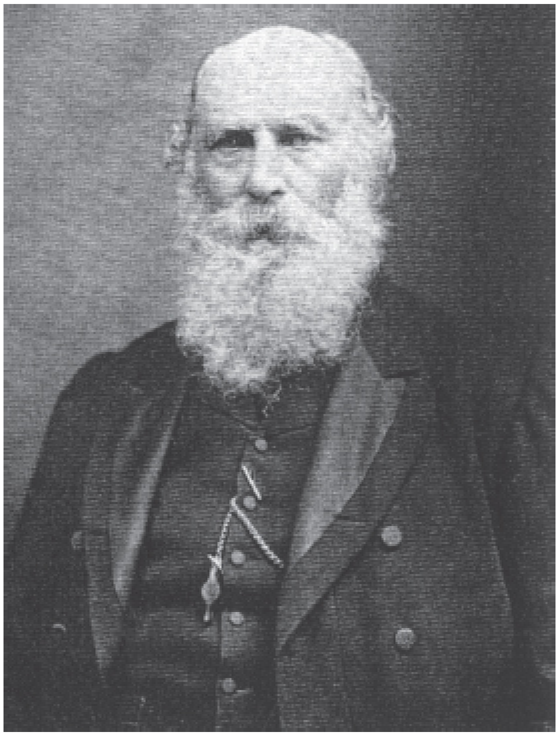


Figure 2.3 *The Irish physicist George Johnstone Stoney (1826–1911).*[26]

Stoney was also an older distant cousin of the famous mathematician, computer scientist and code-breaker, Alan