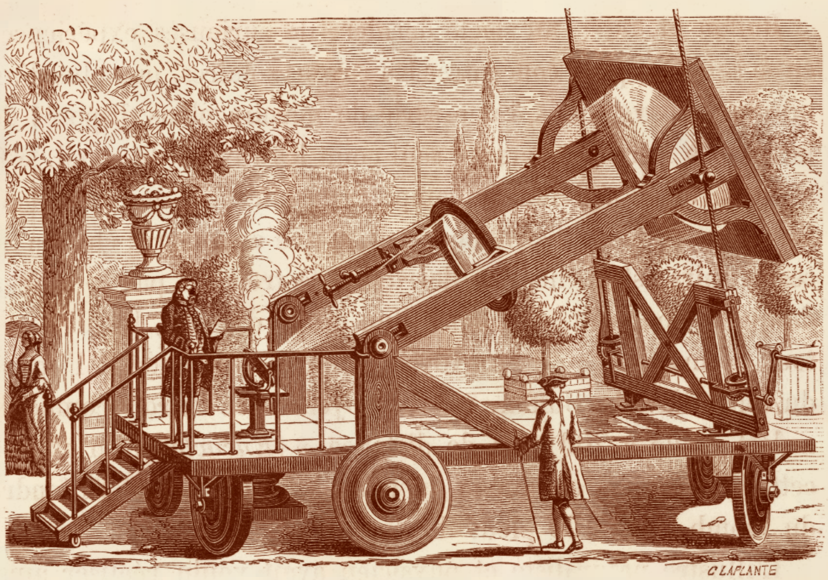
The Scientists



The Scientists

AN EPIC OF DISCOVERY

EDITED BY ANDREW ROBINSON

With 220 illustrations

Thames & Hudson

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ON THE SHOULDERS OF GIANTS

If I have seen further it is by standing on the shoulders of giants.
Isaac Newton in a letter to Robert Hooke, 1676,
citing the French medieval philosopher Bernard of Chartres, d. *c.* 1130

In ancient Rome, the Latin word *scientia* – from which *science* first emerged in Old French during the Middle Ages – meant 'knowledge' in the widest possible sense. Originally, the term encompassed not merely knowledge obtained from studying nature, but every intellectual discipline, including philosophy, politics and theology. Even today, it is common to find phrases such as the 'science of logic', 'political science' and the 'dismal science' (in reference to economics).

In this book, however, 'science' carries its general modern meaning: the collection, classification and analysis of data about the physical universe. This kind of science is as old as the Babylonians, Egyptians and Greeks of the ancient world, not to mention the medieval Arabs, Chinese, Europeans, Indians and Persians of the millennium ending around 1500, whose scientific contributions are increasingly recognized by historians. Yet surprisingly, the modern word to describe those doing such science, 'scientists', is less than two centuries old. Before the mid-19th century, individuals we would now routinely call great scientists, such as the 17th-century figures Johannes Kepler, Galileo Galilei and Isaac Newton, were instead known as 'natural philosophers'. As late as 1799, when the progressively minded Royal

OPPOSITE This plate from the 13th-century French *Bible moralisée* showing God the Father measuring the Universe reflects not only the prevailing belief in the divine origin of the physical world, but also the religious foundations of medieval science.

The oldest surviving world map, dating from 600 BC. It defines the Babylonian world, conceived as a flat disc surrounded by, or floating on, an ocean. Babylon is marked with an oblong, which intersects the bent parallel lines of the River Euphrates. The map is labelled in cuneiform script.

Planisphæri cœleste, a planispheric map of the heavens published in 1670 by the Dutch cartographer Frederik de Wit. By this date, the heliocentric theory of the planetary system was well established, and the Scientific Revolution was well underway.

Institution opened its doors in London, it appointed a 'professor of natural philosophy' to lecture on what we would now call physics.

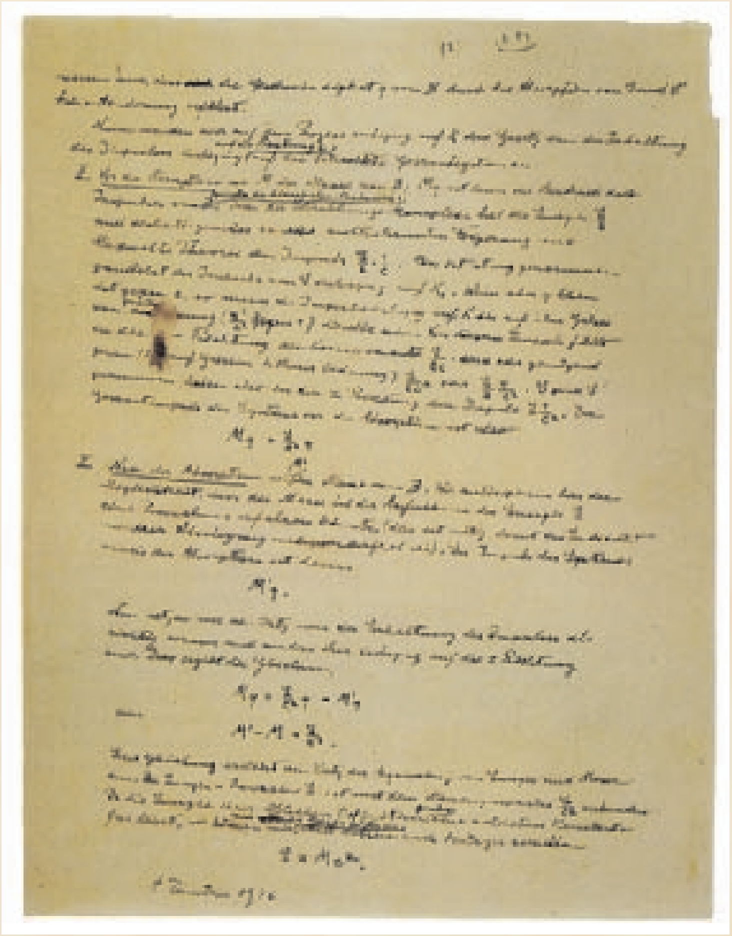
THE BIRTH OF A PROFESSION

'Scientist' was coined only in 1833, at a meeting of the newly founded British Association for the Advancement of Science in Cambridge. One of the attendees, the poet Samuel Taylor Coleridge, had raised the question of what name to give to the fast-increasing tribe of professional experts in various scientific disciplines: an umbrella term that would cover anatomists, astronomers, biologists, botanists, chemists, geologists, palaeontologists, physicists, zoologists and others. According to the report of the ensuing discussion, 'philosopher' was rejected as 'too wide and too lofty a term', whereas 'savant' was regarded as 'rather assuming' – and also too specifically French; and so the association's polymathic secretary, William Whewell, a mineralogist, historian of science and future master of Trinity College – where Newton had once studied – proposed 'scientist', by analogy with 'artist'. Although the new name was 'not generally palatable' to the meeting, it immediately caught on in the United States, was gradually adopted in Britain, and was

universally used by the first half of the 20th century, during which science and technology came to dominate, and even to define, the modern world.

Notwithstanding science's new prestige, 'The whole of science is nothing more than a refinement of everyday thinking', claimed Albert Einstein in 1936, when he was already regarded as the most original scientist since Newton. This was a mischievous paradox typical of a man with a genius for discovering simplicity in complexity. True if you were Einstein, maybe – but for most of us it is a scarcely credible statement. Come off it, one cannot help thinking. What have our everyday thought processes got to do with the thinking of great scientists like Einstein, especially the esoteric mathematical subtleties of 20th-century physicists?

Physics, in its long evolution towards unifying more and more of the physical universe on the basis of fewer and fewer fundamental ideas, seems to have moved further and further away from everyday thinking with each passing decade. Most non-physicists learn to use some of the technological by-products of pure research in physics: computers, mobile phones, the World Wide Web, and the like. But general relativity – Einstein's theory that explains black holes and the accuracy



The original manuscripts of Einstein's 1905 papers on the theory of relativity no longer exist, and just three documents remain that contain his famous formula, $E = mc^2$, in his own hand. This one dates from 1946, when Einstein copied it out for a science magazine, which published it under the title '$E = mc^2$: the most urgent problem of our time'.

of the satellite GPS – and quantum theory – which underlies plasma televisions and lasers – appear to have nothing in common with everyday experience. Earlier key scientific ideas, such as Archimedes' principle of displacement and flotation, Newton's laws of motion and gravitation, Michael Faraday's concept of the magnetic field and Charles Darwin's principle of evolution by natural selection, are comparatively accessible to everyday thinking; we can even do simple experiments at home to demonstrate the truth of them with objects immersed in water, falling coins, patterns of iron filings and moving compass needles. Not so with relativity and quantum theory.

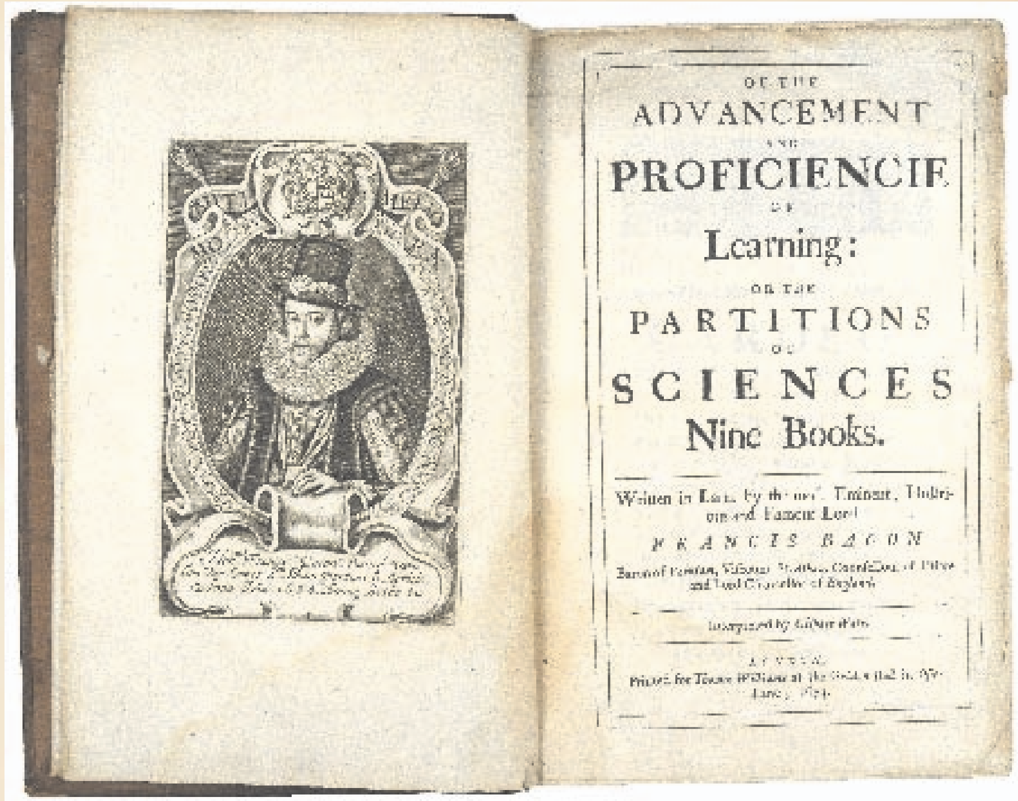
THE INFLUENCE OF THE ANCIENTS

Modern science owes much, of course, to ancient Greeks of the calibre of Archimedes, Aristotle, Democritus, Euclid, Eratosthenes and Ptolemy. To these mathematicians and natural philosophers who observed nature and thought for themselves two millennia and more ago, we owe, for example, the earliest systematic classification of animals, the perception that matter is made of atoms, the invention of geometry, the idea that light travels in straight lines, the first estimate of the Earth's circumference and the concept of latitude and longitude. Here the ancients' thinking was marvellously fruitful.

However, the ancient Greeks also (with one or two enlightened exceptions such as Aristarchus of Samos) believed that the Sun and the planets revolved around the Earth in perfect circles, and that the more massive a body was, the faster it would fall when dropped. Aristotle's 'everyday thinking', it would seem, led him to the conclusion in his *Mechanics* that 'The moving body comes to a standstill when the force which pushes it along can no longer so act to push it' – a grossly inaccurate conception of mass and force. A more massive body should fall faster because, said Aristotle, it had a greater tendency to seek the centre of the Earth – which is also simple to demonstrate as wrong. His concept of 'motion' included not only pushing and pulling, but also combining and separating and waxing and waning. A fish swimming and an apple falling from a tree were, obviously enough, in motion – but so too were a child growing into an adult and a fruit ripening. Thus, common sense led Aristotle, who was not a great experimenter (unlike Archimedes), into a hopeless conceptual muddle about the simplest facts of mechanics.

Yet such was the prestige of the Greeks in philosophy that Aristotle's ideas about the physical world dominated European intellectual life right up to the time of Newton in the 17th century, and even to the time of Darwin, who deeply admired Aristotle's observations on animals. In the 1620s, the English natural philosopher Francis Bacon, whose writings were soon to be instrumental in the launch in 1660 of the world's oldest surviving scientific society – London's Royal Society – remarked critically of his predecessors that, 'All the philosophy of nature which is now

OPPOSITE
This French engraving of the ancient Greek mathematician and inventor Archimedes, who lived during the 3rd century BC, dates from the 17th century.


OF THE
ADVANCEMENT
AND
PROFICIENCIE
OF
Learning:
OR THE
PARTITIONS
OF
SCIENCES
Nine Books.

Written in Latin by the most Eminent, Illustrious and Famous Lord
FRANCIS BACON
Baron of Verulam, Viscount St. Alban, Consilior of Estate and Lord Chancellor of England.

Interpreted by Gilbert Wats.

LONDON,
Printed for Thomas Williams at the Golden Ball in Osier-Lane, 1674.

The philosopher Francis Bacon's book generally known as *The Advancement of Learning*, was first published in 1605. By the time that this 1674 edition appeared, Bacon's published works had played a key role in the founding of the Royal Society in London.

received, is either the philosophy of the Grecians, or that other of the alchemists.... The one is gathered out of a few vulgar observations, and the other out of a few experiments of a furnace. The one never faileth to multiply words, and the other ever faileth to multiply gold.'

INTELLECT AND OBSERVATION

But challenges to Aristotle's view of the world were underway. In 1543, on his deathbed, Nicolaus Copernicus published *De revolutionibus orbium coelestium*, his heliocentric picture of the Solar System with the Earth and other planets revolving around the Sun. This challenge to both everyday perception and biblical scripture was greeted with much scepticism by natural philosophers and, in due course, resistance from the Catholic Church – but eventually, the grand idea caught on that the Earth was no longer at the centre of the world, as it had been since the time of the Greeks, although Copernicus still adhered to the ancient view that the planetary orbits were circular.

Then, in 1609, Kepler, using the first accurate observational data on the planetary motions, compiled by Tycho Brahe, made an educated guess that the planetary orbits around the Sun were not circles but ellipses – one of the geometrical forms

discovered by the ancient Greeks – and with this mental leap Kepler conceived his laws of planetary motion. These enabled him to calculate astronomical tables, and hence the positions of the planets at any time in the past, present or future, which fitted well with astronomers' observations. As Einstein remarked on the tercentenary of Kepler's death in 1930, 'Kepler's marvellous achievement is a particularly fine example of the truth that knowledge cannot spring from experience alone but only from the comparison of the inventions of the intellect with observed fact.'


PARS QVARTA. 169

APPARET igitur ex certissimis observationibus, quod via Planetae in aura aetheria non sit circulus, sed figurae ovalis, & quod libretur in diametro parvi circelli, hoc modo; Si post aequales arcus eccentri, Planeta pro distantiis circumferentialibus, γα, δα, εα, ζα, hoc est, γα, ια, λα, ζα, quibus circuli perfectio innititur, distantias diametrales, γα, κα, μα, ζα, conficiat; ubi ad oculum patet, de semicirculi eccentrici perfectione rescindi tantae latitudinis lunulam, quanta est quolibet loco differentia distantiarum diversarum, puta ικ, λμ. Hoc jam obtento, non rationibus a priori, sed observationibus, uti jam dixi; jam speculationes Physicae procedent rectius quam hactenus. *** Etenim libratio haec sese accommodat ad spacium in eccentrico confectum, non quidem rationabili seu mentali aliquo modo, ut mens Planetae aequales arcus eccentrici imperfecti c b, b e, e f, adnumeret aequalibus partibus librationis γκ, κμ, μξ: sunt enim hae inaequales; sed modo naturali, qui nititur non aequalitate angulorum b e c, e a b, f e e, sed ** fortitudine anguli d e c, e b c, f b c, perpetuo crescentis, quae fortitudo fere sequitur sinum Geometris dictum: ubi ascensus continua imminutione lensim in descensum mutatur, probabilius, quam si subito Planeta proram convertere diceretur; quod quidem diximus cap. XXXIX etiam experimentis observationum repugnare clarissime. Cum igitur mensura librationis hujus, dignum admodum naturalem intendat: causa quoque naturalis erit; nempe non mens Planetae, sed naturalis, aut forte, corporalis aliqua facultas.

Ac cum sit nobis cap: XXXIX. ex optimis rationibus in praesuppositis, non posse Planetam transitionem facere de loco in locum, nuda contentione virium insitarum, nisi adjuventur aut informentur illae a vi extranea; cogitandum igitur, si quo pacto, ipsi etiam virtuti Solari, transcribamus hanc librationem ex parte. Id molientes, ad remos nostros jam supra cap: XXXIX. introductos relegabimur. Sit enim flumen aliquod circulare c d e . f g h . in eo sit

Z 3 nauta

A page from Johannes Kepler's *Astronomia nova* (A new astronomy), published in 1609. The book contains the earliest mention of elliptical planetary orbits around the Sun, and a statement of Kepler's first and second laws of planetary motion.

This fresco on the walls of Pisa cathedral, painted in 1841, shows Galileo Galilei observing the movement of a pendulum. It is alleged that Galileo watched the swinging of the cathedral's chandeliers when formulating his law of the pendulum, which he published in 1602.

Around the same time as Kepler, Galileo Galilei overturned Aristotle's erroneous notions of motion through physical, quantitative experiments with moving objects and falling weights. He showed that a body moving at a constant speed – that is, uniformly – does not require to be 'pushed' by a force, as Aristotle had claimed. For example, a marble set rolling at a given speed on a perfectly horizontal, frictionless floor will continue to move at that speed. (In the real world, the force of friction will eventually bring it to a stop.) And he demonstrated that the speed of a freely falling body does not depend on its mass. Hence the cannonballs of different mass that he allegedly dropped from the Leaning Tower of Pisa at the same instant were found to hit the ground at the same time, not at different times (as Aristotle would have predicted). 'Pure logical thinking cannot yield us any knowledge of the empirical world; all knowledge of reality starts from experience and ends in it. Propositions arrived at by purely logical means are completely empty as regards reality', wrote Einstein some three centuries later. 'Because Galileo saw this, and particularly because he drummed it into the scientific world, he is the father of modern physics – indeed, of modern science altogether.'

'DISCOVERERS OF UNDISCOVERED THINGS'

Mainly for this reason, *The Scientists* begins with articles on Copernicus, Kepler and Galileo – the progenitors of the Scientific Revolution of the 16th and 17th centuries that undoubtedly laid the foundations of present-day science. However, the rest of the book does not follow a purely chronological progression, century by century, preferring instead to emphasize the development of scientific thinking over time in particular fields such as cosmology. Thus, the six sections start with science at the largest scale – that of the Universe – and then progressively reduce the scale, to that of the Earth (section two), of molecules and matter (section three) and of the

subatomic world (section four). Sections five and six are devoted to the living world of plants and animals, including of course the human body and mind. Although all of the core scientific disciplines are covered along the way, including psychology, other disciplines with a scientific element, such as mathematics, medicine, archaeology and anthropology, have been omitted so as to keep the book to a manageable size, with the exception of three articles on the physicians-cum-physiologists William Harvey and Jan IngenHousz, and the archaeologists-cum-anthropologists of human origins Louis and Mary Leakey. Also omitted, again for lack of space, are applied scientific thinkers such as Christopher Wren, James Watt and Thomas Edison, whose chief achievements lay in architecture, engineering, technology or invention.

Every article mingles a scientist's life with his or her science. For all the supposed objectivity of the scientific method, the progress of science has always been driven by strong personalities. The biographies (and autobiographies) of great scientists often illuminate their motivations and sometimes offer clues as to the sources of their breakthroughs. Who can resist the anecdote of Archimedes, the king's gold crown and the overflowing bathtub? Or Newton's reported comment about gravity and the falling apple? Or Einstein's own description of his teenaged thought experiment about chasing a light ray? Or James Watson's rumbustious account of the decoding of the structure of DNA in *The Double Helix* – a book at first condemned by Watson's collaborator Francis Crick for its personalizing of scientific research, but in due course grudgingly admired by him for its truthfulness.

Apart from their love of science, do the forty or so great scientists chosen here share anything in common? Their nationalities, family backgrounds, education and training, personalities, religious beliefs, working methods and the circumstances of their greatest discoveries differ enormously. But in one respect, at least, they do appear to be alike: all of them worked habitually and continually at science and were prolifically productive. The French mathematician, theoretical physicist, engineer and philosopher of science Henri Poincaré (a seminal influence on Einstein's theory of special relativity) published 500 papers and 30 books; Einstein himself produced 240 publications; Sigmund Freud had 330. As Darwin observed to his son late in life, 'I have been speculating last night what makes a man a discoverer of undiscovered things, and a most perplexing problem it is. Many men who are very clever – much cleverer than the discoverers – never originate anything. As far as I can conjecture, the art consists in habitually searching for causes or meaning of everything which occurs. This implies sharp observation and requires as much knowledge as possible of the subject investigated.' Newton, when asked how he had discovered the law of gravity, replied pithily, 'By thinking on it continually.' All of the great scientists in this book would, one senses, have said amen to that.