ANCESTORS OF AN INDUSTRY

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INTRODUCTION

THE BIBLICAL EXHORTATION to "praise famous men and our fathers that begat us" is one which Britain may well take to heart, especially in the field of the Sciences. She has ever been too ready to acquiesce in the claims of other nations to lead the world in scientific resource and invention, when history reveals that Britons stand high among the world's scientific pioneers.

This book, which is based on a series of announcements published by I.C.I. during 1948 and 1949, tells the story of British scientific achievement from Robert of Chester, the English monk who in 1144 opened the door of Eastern chemical knowledge to Western Europe, up through the centuries to Sir William Bragg and Lord Rutherford, whose researches in the present century led to the liberation of atomic energy. It has been prepared with the assistance of Dr. E. J. Holmyard, the editor of *Endeavour*, and the illustrations have in nearly every case been based on contemporary portraits. This series of biographical sketches will, it is hoped, serve to remind people, both at home and overseas, that though scientific discovery knows no national frontiers, Britain's contribution to the forward march of science is second to none.

Robert of Chester

1144

Drawn by Robert *Austin*, R.*A.*

Robert of Chester

ROBERT OF CHESTER brought the science of chemistry to Western Europe 800 years ago. Of this remarkable man's origin little is known except that he was probably born at Ketton in Rutland. He was certainly educated at the then flourishing school at Chester, after which, following the custom of the times, he studied at the Moorish universities in Spain. The Moors or Arabs were the world's leading scientists at that period. On 11th February, 1144, Robert completed the translation into Latin of an Arabic treatise on chemistry, ascribed to the Umayyad prince Khalid ibn Yazid. Khalid was one of the earliest Arabic writers on chemistry, and is supposed to have studied the subject under a Christian scholar named Morienus, from Alexandria. Robert's translation was Europe's first chemical textbook, the *Book of the Composition of Alchemy.*

No doubt he also brought with him from Spain one of the flowing Arab robes which, as the "gowns" of British universities, still serve to remind us that a close bond once linked the scholars of East and West. He could no more have dreamed of the place these garments were to occupy in later years than he could have imagined the future of another Arabic treatise he translated. This was a work by a celebrated mathematician, Khwarizmi, on a branch of mathematics developed by the Arabs and still known to us by its Arabic name, algebra. Robert of Chester was also the first to use the word sine (a translation of the corresponding Arabic term) in its present trigonometrical sense. For a time he was Archdeacon of Pamplona, but returning to England about 1147–50 he calculated astronomical tables for the longitude of London. Besides his extensive works in mathematics, Robert made the first Latin translation of the Koran. Europe owes an immeasurable debt to this Englishman. Robert's chemical translation was soon followed by many others, and within a comparatively short time the seedling chemistry had become firmly rooted. But for him, the East's knowledge of chemistry and mathematics might have remained a closed book to the Western world for centuries.

Roger Bacon

1214–1292

Drawn by Michael Ayrton

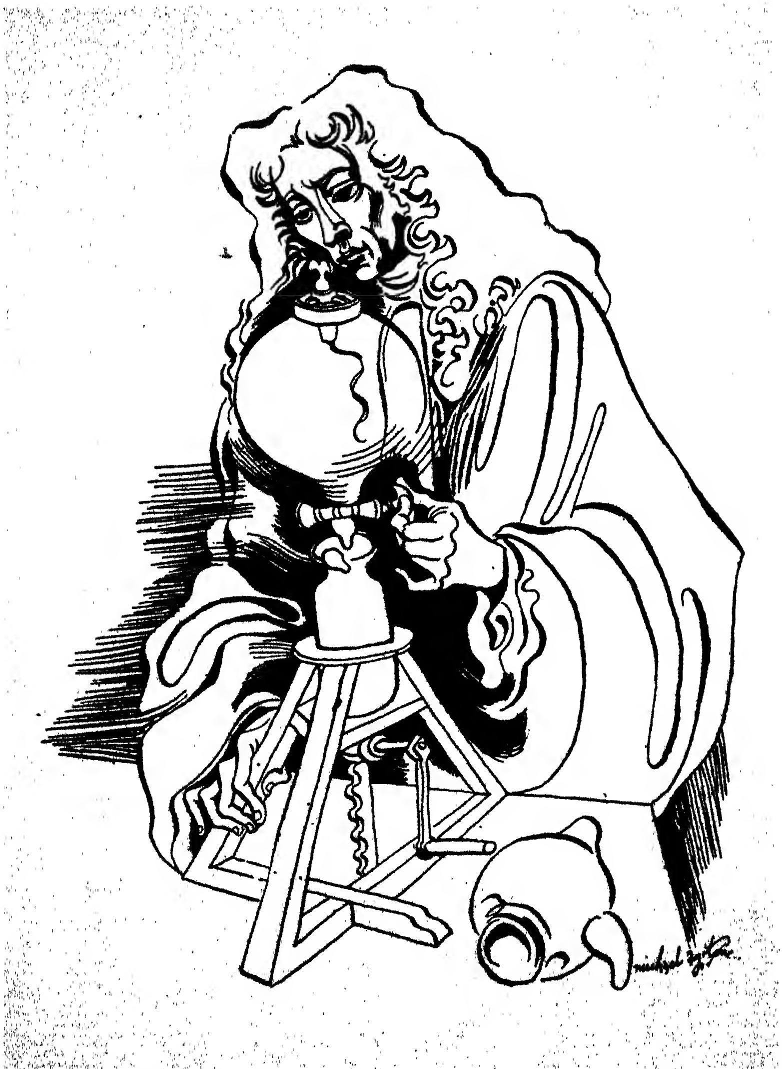
Roger Bacon

ROGER BACON, the "doctor mirabilis" who later acquired a spurious fame as the wonder-working magician Friar Bacon, showed the world for the first time the importance of scientific observation and experiment. This remarkable man was born at Ilchester in Somerset in 1214. After studying at the University of Oxford and in Paris and Italy, he eventually returned to Oxford (where a house traditionally known as his was still standing on Folly Bridge as late as 1789). He became a Franciscan friar in 1251. In an age when science was largely synonymous with the alchemists' search for the philosopher's stone and attempts to transmute base metals into gold, Bacon displayed a scientific vision far in advance of his era. He foresaw the possibility of mechanical flight, the improvement of sight by lenses, the propulsion of ships by engines, and the use of explosives. He has been credited with the discovery of gunpowder, but though this was possibly discovered during his lifetime the cipher passage in one of his books which seems to describe the recipe has been shown to be merely a copyist's error. Some explosive mixture must have been in existence, however, for he complained of the annoyance caused by boys who let off fireworks outside his study.

In all his teaching he insisted on the importance of experiment rather than discussion, and on the necessity for first-hand practical experience of such chemical operations as distillation and calcination. He saw clearly that without practical foundation of this and other kinds, natural science was little more than a collection of words. In alchemy Bacon distinguished between speculative alchemy and practical alchemy; both were to be founded on observation and experiment, but practical alchemy applied some of the results of speculative to definite practical ends. One result of his insistence upon experiment was to enable him to show that air is necessary to sustain combustion. This he did by putting a lighted lamp in a closed vessel and observing that under these conditions the flame was sooner or later extinguished. In many branches of natural philosophy he possessed great acumen in selecting the type of facts whose study was likely to prove fruitful, and in the poise of his general outlook he is worthy to be classed as a scientist rather than an alchemist. He died on 11th June, 1292, leaving as his contribution to science a way of thought which still persists all over the world. Roger Bacon, Englishman, may justly be described as the first modern scientist.

The Hon. Robert Boyle

1627–1691



Drawn by Michael Ayrton

The Hon. Robert Boyle

THE HON. ROBERT BOYLE was the man who formulated the theory on which all chemical reasoning is based—namely, that an element is the simplest form of matter and cannot be resolved into other substances. He first stated his theory in a treatise entitled *The Sceptical Chymist*, first published in London in 1661. Before that time, scientists had clung to Aristotle's hypothesis, dating back to the fourth century B.C., that the four elements were fire, water, earth and air, and that all matter consisted of these in different proportions. Boyle's appreciation of the true nature of an element changed the whole trend of scientific thought. Boyle tells us that after he had gone through the common operations of chemistry and had begun to make some serious reflections upon them he thought it was a pity that instruments that might prove so serviceable to the advancement of natural philosophy should not be more studiously and skilfully used to so good a purpose. Chemistry, he felt, ought not to be a mere handmaid to medicine (as the iatro-chemists or medical chemists maintained) or a slave to the search after the transmutation of base metals into gold (as the alchemists maintained) but a natural philosophy, a systematic investigation of nature with the object of the advancement of knowledge. In *The Sceptical Chymist*, in the form of a dialogue, the modern conception of an element is clearly expressed while previous ones are exploded. The chemists' typical proof that substances consist of fire, air, earth and water lay in pointing out the fact that when a piece of wood is burnt, fire appears, water boils and hisses from the ends of the burning wood, smoke ascends into the air, where it vanishes, thus showing itself to be of the same nature, and the earthy ash is left. Boyle pertinently inquires what proof there is that the fire, air, earth and water really are present in the wood before combustion. Obtaining no convincing answer, he expresses his own opinion that elements are simple bodies, of which all compounds are composed and into which they may ultimately be resolved.

Son of the Earl of Cork, he was born at Lismore Castle, in Ireland, in 1627. At the age of eight, he was sent to school at Eton. Thence he proceeded to Oxford, and spent much of the rest of his life at the university, carrying out scientific work which covered a vast field. Among his achievements were the invention of the first efficient air pump, the preparation of methyl alcohol from wood, and the propounding of Boyle's law, which is still used to describe how the volume of a gas varies with pressure. Before Boyle's time, chemistry was the happy hunting ground of the quack physician and alchemist. His work at Oxford raised it to the status of a dignified branch of natural science. It is not without good reason, therefore, that Robert Boyle is regarded throughout the world as "the father of chemistry."

John Mayow

1643–1679

Drawn by Robert Austin, R.A.

John Mayow

AIR IS NECESSARY both to keep a fire alight and to maintain life. Though this important fact has been known for thousands of years, it was an English chemist and physician, John Mayow, who first proved by practical experiments that only a part of air supports life and that there is a great similarity between breathing and burning. This part of the air, which we now know to be oxygen, Mayow called the "nitro-aerial spirit." He kept a mouse in a jar of air closed by a bladder and observed that the bladder bulged inwards, probably with the contraction of the air inside as the mouse used up the oxygen. He also observed that a mouse alone in a closed jar lived twice as long as a mouse kept in a jar together with a burning lamp, showing that both mouse and lamp were using up the same part of the air. Mayow made advances of considerable importance in the manipulation of gases. He showed that a gas could be transferred from one vessel to another by filling the latter with water, inverting it in a trough of water and bringing the mouth of the first vessel, containing the gas, into the mouth of the other, "care being taken that the mouth of neither of the glasses is raised above the surface of the water." He further emphasized the importance in quantitative work of levelling the water inside and outside the jar containing the gas, in order to get the latter at atmospheric pressure. This he accomplished by means of a siphon tube.

Though Mayow produced some remarkably shrewd theories on chemical affinity and was one of the first chemists to explain how nitric acid is produced by the action of sulphuric acid on nitre, his reputation rests on his work as a practical experimenter. He was born in Cornwall in 1643 and entered Wadham College, Oxford, in 1658. He died in London at the early age of 36, a few months after his election to the Fellowship of the Royal Society. John Mayow, English physician, was one of the several chemists who helped to solve the riddle of combustion—one of the most fundamental reactions in chemistry.

Sir Isaac Newton

1642–1727

Drawn by Michael Ayrton

Sir Isaac Newton

SIR ISAAC NEWTON, who has been described as the greatest man of science of all time, is best known to the general public for his famous observation of the falling apple. This led him to formulate his Laws of Motion, the fundamental laws on which the branch of mathematical physics known as dynamics is based. His achievements in optics and mathematics have obscured his work as a chemist. Newton's contact with chemistry began when he was at school in Grantham, where he lodged with an apothecary. Throughout his life he displayed great interest in the chemistry of metals, much of his work being of a very practical nature, such as the production of alloys for use on the mirrors of the reflecting telescope he designed.

Newton maintained a private chemical laboratory at Trinity College, Cambridge. His principal service to chemistry was his clarification of the "corpuscular" theory of matter, which he employed to provide a theoretical explanation of Boyle's law (i.e. the density of a gas is proportional to the pressure at a constant temperature). Newton's direct application of the theory to experimentally observed facts paved the way for Dalton's fully developed atomic theory a century later. Newton gave close attention to the problem of chemical attractions and forces, and believed that the particles of a salt in solution diffused evenly through the solvent. The fact that on evaporation of the solution the particles of salt aggregated in regular crystalline forms he explained by assuming them to possess a certain polarity. In general the position of the particles was due to an attractive force, which was very strong in immediate contact, produced chemical action at short distances, and did not extend far from the particles. The strengths of the attraction between various substances varied, and so the vigour of chemical change ranged from mild to violent.

Newton was born at Woolsthorpe, near Grantham, on Christmas Day, 1642. Entering Trinity College, Cambridge, in 1661, he became Professor of Mathematics in the university at the very early age of 27. He was appointed Warden of the Royal Mint in 1696, and Master three years later. Newton's mind was cast in a serious mould. There was a complete lack of humorous books in his library, and his biographer, Brewster, tells us that there is only one record (and that doubtful) of his ever having laughed. The astronomer Halley once joked on what Newton considered a serious subject and was sharply reprimanded for it. On the other hand, Newton was a man of strict probity, and possessed shrewd business ability, a turn for organization, and a determined personality.

Stephen Hales

1677 – 1761

Drawn by Robert Austin, R.A.

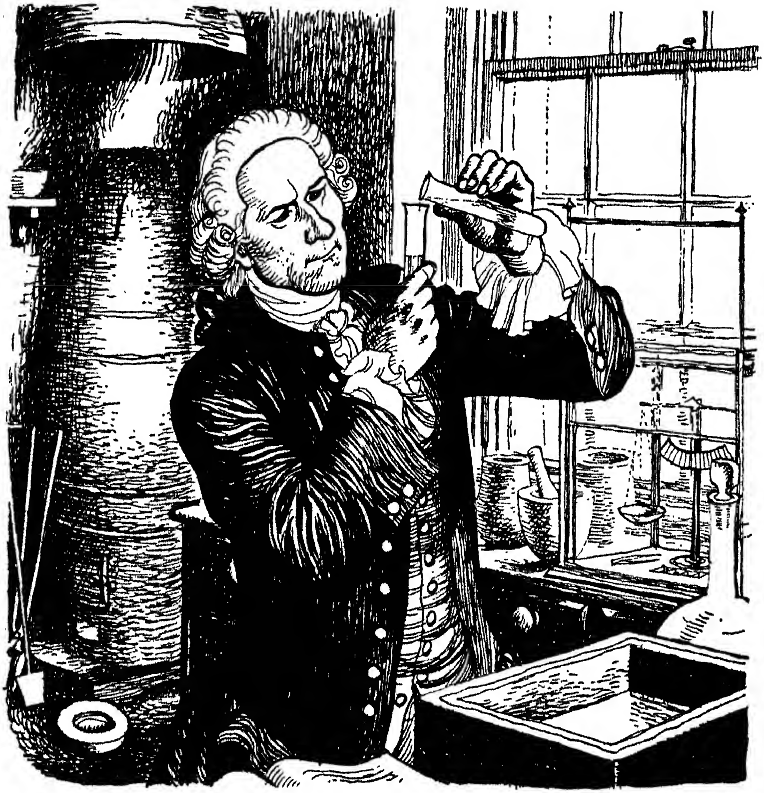
Stephen Hales

STEPHEN HALES, vicar of Teddington in Middlesex, made the important discovery that plants absorb part of their food from the air. Hales invented artificial ventilators and numerous other mechanical contrivances as well as studying animal and plant physiology. From this he turned his attention to chemistry, and in his principal book, *Vegetable Staticks*, published in 1727, he stressed the importance of accurate weighing and measuring in chemical operations. Unfortunately, his quickness to see the need for accurate measurement restricted his vision in other directions. Having observed that plants inspire large quantities of air, he concluded that this air could be recovered, and proceeded to distil, in a gun barrel, a great number of miscellaneous substances, including tallow, hog's blood, peas, oyster shells, tobacco, a fallow deer's horn, camphor, beeswax and honey.

He collected the gases he obtained and made accurate calculations to show the proportion they bore by weight to the original substances. He says, for instance: "and since we are assured that the All Wise Creator has observed the most perfect proportions of number, weight, and measure in the make of all things, the most likely way, therefore, to get any insight into the nature of these parts of the Creation which come within our observation must in all reason be to number, weigh, and measure. And we have much encouragement to pursue this method of searching into the nature of things from the great success which attended any attempts of this kind." For the Creator has "comprehended the days of the earth in a measure and weighed the mountains in scales and the hills in a balance." There is no doubt that Hales unwittingly prepared crude samples of many important chemicals, but he was so engrossed in weighing and measuring, at the expense of accurately observing the substances under experiment, that he failed entirely to appreciate the significance of much of his own work. He dismissed the various gases he had prepared as "air." He died in 1761, and was honoured with a memorial tablet in Westminster Abbey.

John Roebuck

1718–1794



Drawn by Illingworth

John Roebuck

JOHN ROEBUCK, a Birmingham doctor, invented the first commercial method for manufacturing sulphuric acid. One of the most important of all chemicals, it had previously only been made in comparatively small quantities. On the Continent it was prepared by heating various sulphide crystals, a process carried on largely at Nordhausen; this produced a fuming acid. In England sulphuric acid was manufactured by Ward at Richmond, near London, using large glass bell-jars, with a capacity of up to 66 gallons. Roebuck, in 1746, suggested the use of leaden chambers measuring about six feet in each direction, and many such chambers, of greatly increased size, were soon erected in different parts of the country. By 1805 one factory had 360 chambers, each with a capacity of 192 cubic feet. Roebuck's invention of the lead chamber process in 1746 resulted in sulphuric acid being manufactured on a vast scale, and also reduced production costs by 75%.

Born in Sheffield in 1718, Roebuck was the son of a prosperous manufacturer. After taking a degree in medicine at Edinburgh University, he settled down to practise in Birmingham. Applied science became his hobby, and the lead chamber was only one of many improvements in chemical production which he introduced to Birmingham's industries. In 1749 he established his own sulphuric acid works near Edinburgh, and later greatly contributed to Scotland's wealth by founding the Scottish iron industry. By the time of his death in 1794 he had been made a Freeman of Edinburgh and a Fellow of its Royal Society. Roebuck's interests covered an extremely wide sphere, but his enduring claim to fame rests on the chamber process, which with the "contact" process patented in 1831 by another Englishman, Peregrine Phillips, is still used today to meet industry's enormous demands for sulphuric acid.

Joseph Black

1728–1799

Drawn by Michael Ayrton

Joseph Black

JOSEPH BLACK published only three papers on chemical subjects in the course of over fifty years of scientific research, but his work is of such importance that he is regarded as one of the founders of modern chemistry. The most important of his papers, published in 1756, was entitled "Experiments upon Magnesia Alba, Quicklime and some other Alcaline Substances." Black knew that both limestone and the mild alkalis (i.e. sodium and potassium carbonates) effervesce when treated with dilute acids. He assumed that the gas evolved was that which we now call carbon dioxide. He obtained a proof of this assumption by experiments in which he found that no gas is evolved when an acid is added to quicklime, that limestone saturates nearly the same quantity of acid after it is converted into quicklime as before, and that limestone yields the same weight of gas when treated with a dilute acid as when heated strongly in a furnace. He next showed that if a definite weight of limestone was converted into quicklime, the latter could be reconverted into limestone by treatment with a solution of a mild alkali, and the weight of the limestone thus formed was equal to that of the original specimen. The calcium, therefore, had been saturated with carbon dioxide, which must have been provided by the alkali. On exposing the solution of caustic alkali to the air for some time, Black found that it lost the whole of its causticity, and this he explained by assuming that it had absorbed carbon dioxide from the atmosphere. From this remarkable series of experiments Black had thus obtained results that enabled him to explain satisfactorily the whole problem. Limestone was a compound of quicklime and carbon dioxide; when heated it lost the carbon dioxide, quicklime being left. The mild alkalis were compounds of fixed air with substances resembling quicklime but much more soluble in water. When a solution of a mild alkali was treated with quicklime the latter absorbed the carbon dioxide of the former, with production of insoluble limestone. The filtrate was therefore a solution of caustic alkali. In all essentials Black's explanation of these phenomena is identical with our own, and so well reasoned is his paper on the subject that it is regarded as one of the classics of chemical literature.

Born in 1728 in Bordeaux of Scottish parents temporarily resident in France, Joseph Black went to Glasgow University at the age of 18, becoming Professor of Anatomy and Chemistry in 1756, a post he retained for ten years until he took up an appointment at the University of Edinburgh. But it is for his work on the alkalis that this Scottish chemist is remembered. These chemicals, which include such everyday substances as washing soda and bicarbonate of soda, are as essential for industry as the home. Their manufacture is one of the most important branches of the British chemical industry.

Henry Cavendish
1731–1810

Drawn by Michael Ayrton

Henry Cavendish

HENRY CAVENDISH first showed the world how water—the most important of all chemical compounds—could be made synthetically. Cavendish discovered that it was composed of the two gases now called oxygen and hydrogen, and in 1784 prepared water by exploding a mixture of them in a glass vessel. The apparatus which he used is still preserved at the University of Manchester. Cavendish was also the first to weigh the Earth, and the result he obtained was astonishingly accurate. He discovered the composition of nitric acid, and was the first chemist to recognize hydrogen (which he prepared by treating zinc with dilute sulphuric acid) as a definite chemical element. He was the first practical experimenter to find a means of drying a gas, which he accomplished by passing it through pearl ash, and invented the method of storing gases over mercury, an idea that led Priestley to use mercury instead of water in the pneumatic trough, and so resulted in the isolation of many gases that cannot be collected over water owing to their solubility. Cavendish also made a discovery the importance of which was not realized until a century later. He passed electric sparks through a mixture of air and oxygen, and observed that oxides of nitrogen were formed, which he absorbed in caustic alkalis. The sparking was continued, with the addition of further oxygen from time to time, until no further reduction in volume took place, that is, until all the nitrogen had been converted into oxides of nitrogen and absorbed by the alkali. He then added a solution of liver of sulphur to absorb the unused oxygen, and found that he always had left a small bubble of gas, about 1/120th of the volume of the nitrogen in the air used. We now know that this bubble of gas was argon, an element rediscovered in 1895 by Lord Rayleigh and Sir William Ramsay. No more striking testimony to the skill and accuracy of Cavendish's work could be desired. All these discoveries have proved of immense importance.

Though both his parents were English, Henry Cavendish was born at Nice in 1731. He was educated at the University of Cambridge, and from 1760 until his death in 1810 his whole time was devoted to science, and in particular to physics and chemistry. Though he was extremely shy, shunned publicity and never attempted to exploit any of his discoveries, the work of this English chemist has been of great and lasting benefit to science and industry throughout the world.

Joseph Priestley

1733–1804

Drawn by Michael Ayrton

Joseph Priestley

JOSEPH PRIESTLEY, Yorkshireman, Doctor of Divinity, theologian and pamphleteer, owes his fame to chemical discoveries made in his leisure hours as a relaxation from writing sermons and political broadsheets. His first success as a practical chemist was the accidental discovery of soda water. While living next door to a brewery in Leeds, curiosity led him to investigate the process of brewing. In doing so, he found that carbon dioxide gas, which is produced during the brewing of malt beverages, could be dissolved in ordinary water to make "aerated water." The success of this experiment set him on his chemical career, and he acquired a renown which matched his considerable reputation as a theologian.

His appointment as librarian to Lord Shelburne at Bowood in 1773 gave him ample time and opportunity to develop his scientific hobbies, and his most important work was done during the following eight years. In this period he discovered, prepared and studied a vast number of gases—all of them highly important—including oxygen, ammonia, nitrous oxide (the "laughing gas" of the dentist's surgery), hydrogen sulphide, hydrogen chloride and sulphur dioxide. He isolated oxygen in 1774, but completely failed to understand the reaction which yielded it. Chemists at that time believed combustible bodies to contain an elusive substance, phlogiston, which was given up to the air upon combustion. Metals, which could be burned or at least calcined, were regarded as compounds of phlogiston with the appropriate earth or calx. A metal calx was therefore an elementary body and represented what was left of the metal after the phlogiston had been driven off. Priestley heated the calx of mercury with a burning glass and was intensely surprised to obtain a gas with extraordinary powers of supporting combustion. He made various surmises as to its origin, each more improbable than the last. It was left to his French contemporary, Lavoisier, to reveal that a calx is actually a compound of a metal with oxygen, and that what Priestley had done was to decompose mercuric oxide.

During the initial period of the French Revolution Priestley openly expressed sympathy with the revolutionaries, and was one of their warmest advocates in this country. Popular feeling was roused against him, and on 14th July, 1791, the anniversary of the fall of the Bastille, a mob wrecked his house and made a bonfire of his furniture and books. He himself made a hurried escape to London, travelling on the stage coach under an assumed name, and later set sail for New York, where he was well received in scientific and religious circles. He was offered, but declined, the chair of chemistry at Philadelphia, and established himself in Pennsylvania, where he spent the remaining years of his life in retirement. He died in 1804.

John Dalton
1766–1844

Drawn by Michael Ayrton

John Dalton

JOHN DALTON, an English Quaker, was the first to propound the theory that the atom was the smallest particle of matter imaginable—a theory that was not assailed until more than a century later. Even in Dalton's day, the idea that matter was composed of small indivisible particles was not new. A similar theory had been put forward by the Greek philosopher Democritus two thousand years earlier. Sir Isaac Newton had restated it as the "corpuscular theory" a hundred years before Dalton. Where Dalton excelled them was in formulating these theories in a way that explained known chemical processes and enabled deductions to be made which could be submitted to the test of practical experiment. In short, he translated them from philosophical abstractions into a method for accurately forecasting and controlling chemical reactions and manufacturing processes. The main points of his theory were as follows. All matter is composed of a great number of extremely small particles or atoms. To attempt to conceive the number of particles is like attempting to conceive the number of stars in the universe, but if we limit the subject, for instance by taking a given volume of a gas, it is clear that the number of particles must be finite, just as in a given space of the universe the number of stars and planets cannot be infinite. Chemical analysis and synthesis go no further than to the separation of atoms one from another, and to their reunion. In other words, atoms are indestructible and cannot be created or destroyed. Each element has its own distinct variety of atom, and similarly each compound has its own distinct variety of compound atom or ultimate mechanical particle. Dalton further stated that it was important and possible to ascertain the relative weights of different atoms, and he carried out experiments on these lines. Finally he assumed that when elements combine to form compounds, the ultimate particles of the compounds consist of *small* whole numbers of the atoms of the elements concerned. The main difficulty experienced by the atomic theory in its early days was due to lack of knowledge of the actual number of atoms in the ultimate particle of a compound. Dalton himself never overcame the difficulty, which was, however, solved early in the nineteenth century by the Italian scientist Avogadro.

Dalton, the son of a weaver, was born at Eaglesfield in Cumberland in 1766. He went to work at the age of 12, but studied in his spare time to such effect that in 1793 the Manchester Academy appointed him tutor in mathematics and natural science. Six years later he set himself up as a private teacher, devoting his leisure to research and the fashioning of his Atomic Theory, which was first published in 1808 in his book *A New System of Chemical Philosophy*. Dalton's theory, unaltered in its essentials, is still used to explain the laws of chemical combination.

Sir Humphry Davy
1778–1829

Drawn by Michael Ayrton

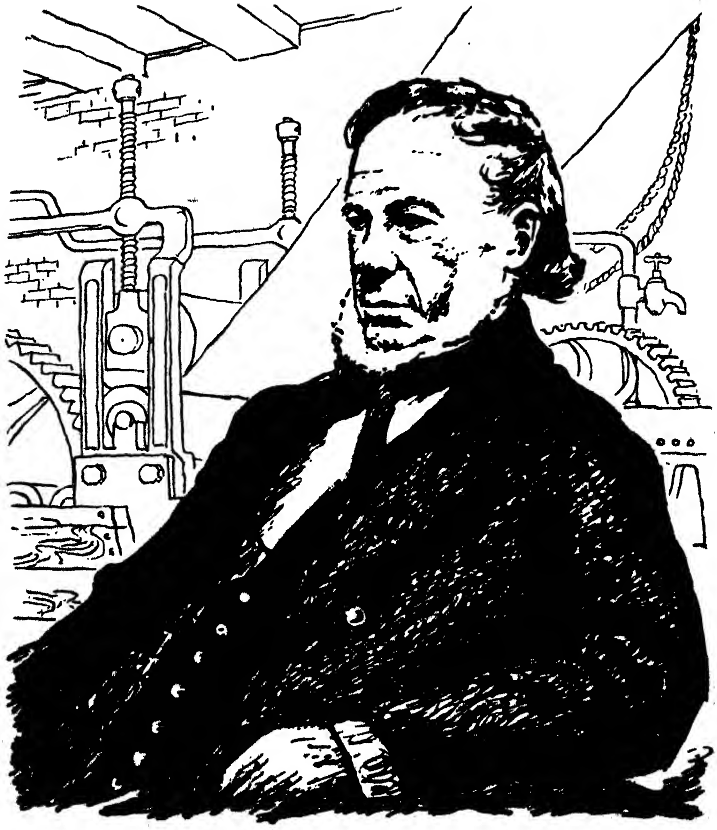
Sir Humphry Davy

SIR HUMPHRY DAVY has been described as being "almost, if not quite, unique as a truly great natural philosopher who also secured a fervent popular acclaim." The miners' safety lamp which he invented, and for which he refused to take out a patent, has saved many thousands of lives and is still known as the "Davy lamp." He also carried out work on the chemistry of tanning and agriculture, but his most important researches were on the application of electricity to chemical problems. Using electrolytic methods he isolated sodium and potassium, and he obtained amalgams of calcium, strontium and barium. His investigations of these reactions led him to suggest that chemical affinity might be electrical in nature. Modern science, nearly a century and a half later, has shown that this is true. An important discovery of Davy's was that chlorine is an element. Up to 1810, when Davy investigated the matter, chlorine was thought to be a compound of the gases we now call hydrogen chloride and oxygen. Davy found, however, that no oxygen could ever be obtained from chlorine, and that when metallic potassium was heated in hydrogen chloride, only hydrogen was evolved. He therefore concluded that chlorine must be an element.

Born in Cornwall in 1778, Davy was apprenticed to an apothecary at the age of 17, but in 1798 his master released him to go to Bristol to study the physiological effects of gases. Almost at once he attracted attention by observing the anaesthetic powers of nitrous oxide ("laughing gas"), and at the age of 23 the Royal Institution appointed him Director of the Laboratory and Assistant Lecturer in Chemistry. Such was his success as a lecturer that he often attracted fashionable audiences of over a thousand, and in 1802 was appointed Professor of Chemistry at the Institution. So great were Davy's achievements that he was made a baronet in recognition of his great services to British science, as well as being presented with a gold medal by Napoleon in spite of the fact that England and France were at war at that time.

John Mercer

1791–1866



Drawn by Felix Kelly

John Mercer

JOHN MERCER has justly been called the father of textile chemistry. In 1844 he investigated the action of caustic soda on cotton, and made observations which, forty years afterwards, enabled Lowe to produce the highly lustred material now known as mercerised cotton. He also made the discovery that cellulose could be dissolved in a solution of copper oxide in ammonia, and so laid the foundation for what later developed into the Bemberg process of manufacturing rayon. Mercer's prolific genius produced many other inventions concerning textile dyeing and printing, many of which came into immediate use.

Born near Blackburn in Lancashire in 1791, John Mercer went to work as a bobbin winder at the Oakenshaw Print Works at the age of 9. Fortunately a fellow employee taught him reading, writing and arithmetic. This enabled young Mercer to read a second-hand copy of *The Chemical Pocket Book* by James Parkinson. With this meagre education Mercer went on to invent a new method of textile printing, and reorganized the Print Works at Oakenshaw where he had been apprenticed as a child. Observations of the effect of chemical reactions on certain photographic salts led him to devise new printing processes on paper and on cambric in varied colours; these he described in a paper to the British Association at Leeds in 1858, and exhibited with the Photographic Society of Vienna. He also found a technical solution to the problem of the mildewing of printed calico. By 1850 he was a partner in Oakenshaw Works, which as a result of his inventions had become a resounding success, while his scientific eminence had been recognized by his election to the Fellowship of the Royal Society. He died in 1866.

James Muspratt

1793–1886

Drawn by Robert *Austin*, R.*A*.

James Muspratt

JAMES MUSPRATT was the founder of the British alkali industry. The manufacture of sodium carbonate, one form of which is the familiar "washing soda," and other alkalis is one of the most important branches of the chemical industry. The first commercial process for making them depended on the use of sulphuric acid and produced hydrochloric acid as a by-product. Ever since James Muspratt opened his works in Liverpool a century and a quarter ago, alkali and mineral acid manufacture have frequently been closely bound together. Muspratt, though born in Ireland, was of English parentage. At the age of 14 he was apprenticed to a wholesale druggist in Dublin, but four years later, in 1811, he gave up commerce and made his way to Spain, where he fought in the Peninsula War. Returning to England, he joined the Royal Navy as a midshipman, but found conditions in his ship so intolerable that he deserted, returned to Ireland, and started a small works where he manufactured potassium ferrocyanide.

Coming to Liverpool in 1822, he set up a plant to produce sulphuric acid, extending it the following year to make sodium carbonate. The method Muspratt used for making sodium carbonate was that invented some thirty years earlier by the French chemist Nicolas Leblanc. It consisted in acting upon salt with sulphuric acid and heating the sodium sulphate so produced with charcoal, or small coal, and limestone. The Leblanc process was worked for most of the nineteenth century, but has now been superseded by the more economical and simpler Solvay process. In 1828, in partnership with Josias Gamble, he built an alkali works at St. Helens in Lancashire. The hydrochloric acid fumes from his works were allowed to escape into the air and did much damage to neighbouring farmers' crops. In 1836 a method of absorbing these objectionable gases was invented by another Englishman, William Gossage. Instead of being allowed to go to waste, the fumes were recovered and proved to be a valuable by-product. Hydrochloric acid manufacture had now been added to that of sulphuric acid and sodium carbonate by James Muspratt and his associates. The foundations of the British heavy chemical industry were complete.

Michael Faraday

1791–1867

Drawn by Michael Ayrton

Michael Faraday

MICHAEL FARADAY'S fame rests on those of his researches which laid the foundations of electrical engineering. Less known, but almost equally important, are his achievements as a chemist. He found out how to liquefy chlorine and certain other gases, isolated hexachloroethane, an important industrial solvent, and prepared the naphthalene sulphonic acids which are used in textile dyeing. His most important chemical work, however, was the discovery of benzene, a colourless liquid which forms the starting point for manufacturing practically all synthetic dyes, as well as aspirin, saccharin and many substances used in medicine. This discovery laid the foundation upon which another British chemist, Sir William Perkin, was able to build the modern synthetic dyestuffs industry. In the realm of physical chemistry Faraday did fundamental work upon electrolysis. He introduced the use of the words ion, cation, and anion, and discovered what has since been known as Faraday's law, namely that the mass of any individual product liberated in electrolysis is directly proportional to the quantity of electricity passed through the electrolyte, and secondly, that the masses of various products liberated in electrolysis by the passage of the same quantity of electricity are in the exact ratio of their chemical equivalents. Upon these facts the whole science of electrochemistry is based, and when we remember the industrial applications of electrolytic methods we realize the incomparable significance of Faraday's work. It also had great theoretical importance, since it led chemists to reflect upon the possible electric nature of chemical reaction, a hypothesis which has since proved fully justified.

Faraday was born at Newington Butts, London, in 1791. He came of poor parents who apprenticed him to a bookbinder at the age of 13, his early scientific education being obtained by reading the books brought in for binding. A customer gave a ticket for Davy's chemical lectures at the Royal Institution, where Faraday obtained employment as a laboratory assistant in 1813. By 1825 he had become Director of the Laboratory and eight years later was appointed first Fullerian Professor of Chemistry, a post he retained until his death in 1867. Faraday's chemical researches were of immense importance, the isolation of benzene alone having proved of great value to mankind all over the world. Faraday himself was never interested in the practical applications of his scientific work, but pursued his investigations purely in the search for knowledge. "For nearly forty years he went every working day to his laboratory with some new question to put experimentally to Nature, and he never paused until he had sufficient answer 'Yea' or 'Nay' to his query."

William Gossage

1799–1877

Drawn by Robert Austin, R.*A*.

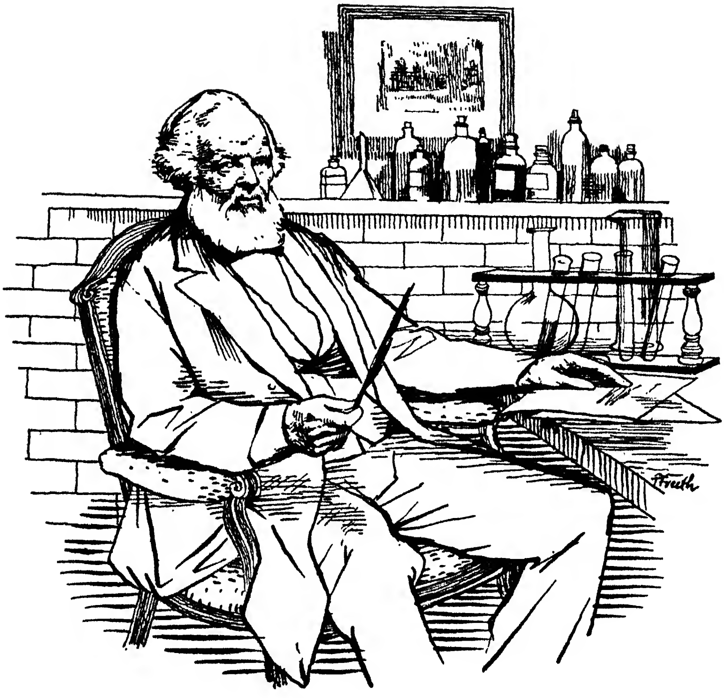
William Gossage

WILLIAM GOSSAGE'S name is generally associated with the mottled soap he patented in 1857. Not so well known, but far more important, were the "towers" which he invented in 1836 to absorb the hydrogen chloride evolved during the manufacture of alkali by the Leblanc process. This gas, liberated in increasing quantities as the industry expanded, caused great damage in the neighbourhood of alkali works. By converting it into hydrochloric acid, Gossage not only ended what was becoming a dangerous nuisance, but enabled an important mineral acid to be made cheaply and in enormous quantities from what had been regarded simply as industrial waste.

Born in Lincolnshire in 1799, William Gossage spent his youth assisting his uncle, a chemist and druggist in Chesterfield. He then went into business for himself in Leamington, but gave it up to enter a salt and alkali works at Stoke Prior, Worcestershire. In 1850 he moved to Widnes, Lancashire, where he made soap as well as alkali. His inventive powers seemed inexhaustible. Starting in 1823, his patents followed each other in a continuous stream for over forty years. Nearly all were concerned with improvements in the manufacture of heavy chemicals, and some were far ahead of their time. For example, owing to engineering difficulties, his method of recovering the manganese dioxide used in making chlorine did not come into use until thirty years after he invented it. Gossage also devised improved methods for the manufacture of sulphuric acid; he proposed, for instance, that vertical chambers should be substituted for horizontal ones, and that from the roof of the chambers there should be showers of liquid sulphuric acid to assist in diffusing the gases contained in the chamber. His ideas, in fact, closely resembled those put into practice by Glover and Gay-Lussac. Gossage died at Bowdon, Cheshire, in 1877. His practical genius played a very important part in developing the British heavy chemical industry.

Thomas Clark

1801–1867



Drawn by Thomas Freeth

Thomas Clark

THOMAS CLARK, a Scottish doctor, made the important discovery that hard water can be softened by chemical means. A common cause of what is known as "temporary" hardness is the presence of dissolved calcium bicarbonate. This can be removed by boiling, the "hardness" being turned into insoluble calcium carbonate—familiar to most people as the "fur" in kettles. Temporary hardness not only wastes soap, but is a serious defect in water used for industrial purposes. The "fur" deposited inside boilers and pipes reduces their efficiency and leads to undue fuel consumption. Clark discovered that the correct quantity of lime added to temporarily hard water causes chemical reactions which change both the lime itself and the unwanted calcium bicarbonate into an insoluble carbonate. This can be removed, leaving the water soft, and suitable for use in steam boilers and for industrial processes.

The interesting point about Clark's process of softening water is that lime by itself would render water hard, but by adding it to water containing calcium bicarbonate in the calculated proportion both the calcium compounds are eliminated: one might almost call it a homeopathic method of treatment. When the temporary hardness of water is due to the presence of magnesium bicarbonate, Clark's process can still be used to soften it, but double the amount of lime must be used; this precipitates the magnesium in the form of the unstable hydroxide. Clark also invented a method for investigating the hardness in water, by titrating it with a standard soap solution until a permanent lather is obtained.

Clark was born in Ayr in 1801. Thirty years later he obtained an M.D. at Glasgow University, but instead of practising medicine he went to work at the St. Rollox chemical works. In 1833 he was appointed Professor of Chemistry at Marischal College, Aberdeen, where he remained until his retirement twenty-seven years later. He died in 1867, but his memory is perpetuated in "Clark's Method" of water softening, which is still in use.

Peregrine Phillips

1831

Drawn by Robert *Austin,* R.*A.*

Peregrine Phillips

PEREGRINE PHILLIPS invented the contact process for making sulphuric acid. This depends upon the fact that if a mixture of sulphur dioxide and oxygen is passed over a heated catalyst the two gases combine, at least in part, to form sulphur trioxide, which when dissolved in water forms sulphuric acid. Phillips had affirmed that an instantaneous combination of sulphur dioxide and oxygen of the air could be effected by passing a mixture of sulphur dioxide and a sufficient supply of air through tubes containing evenly divided platinum heated to a strong yellow heat. Though this process was patented as early as 1831, it was not developed commercially until seventy years later, when it revolutionized sulphuric acid manufacture. Today, half the world's output is made in this way. Although his discovery ranks among the most important advances ever made in chemical manufacture, surprisingly little is known about Phillips himself. Even the dates and places of his birth and death are uncertain. The only indisputable fact about his life is the date of his patent.

A Peregrine Phillips, believed to be the inventor's father, opened a tailor's shop in Bristol in 1803, but forsook tailoring in 1824 to go into partnership with John Thorne, a vinegar manufacturer of the same city. Peregrine Phillips junior—the inventor—was also a member of the firm, but he appears to have renounced his share about the same time as he took out his patent. The wording of this document shows that he must have had both a good technical education and a capacity for hard work, but nothing is known as to where he acquired his knowledge or whether he ever tried to exploit his patent commercially. The year after he had taken it out, the vinegar business was sold, and Peregrine Phillips, though still a young man, was never heard of again.

Thomas Graham

1805–1869

Drawn by Nicolas Bentley

Thomas Graham

THOMAS GRAHAM was the first to investigate the manner in which charcoal absorbs gases. His work on the subject has been of immense practical value. The gas mask—a safety device as important in industry as in war—depends mainly on the ability of a charcoal filter to absorb gas. Most industrial solvents are recovered by similar charcoal filters. Graham did a vast amount of research on filters and the properties of liquids and gases, but is best known for the formulation of Graham's law, which makes it possible to calculate the relative rate at which gases of different densities will pass through small apertures. Graham also worked on colloids and osmosis, and his investigation of the phosphates showed that the ortho-, pyro- and metaphosphates were salts of three isomeric phosphoric anhydrides coming from three distinct acids. Among Graham's other researches may be mentioned those of the occlusion of hydrogen by metals, the absorption of dissolved salts on charcoal, supersaturation, hydrated salts and oxides, and the alcoholates of salts.

A Scotsman, he was born in Glasgow in 1805, and began his scientific studies at Glasgow University. His intellectual brilliance was such that at the early age of 25 he became Professor of Chemistry at Anderson's College. Seven years later he moved to London to take up a similar appointment at University College. His career there lasted for eighteen years, during which he gained the reputation of being the most distinguished chemist of his day. He was elected first President of the Chemical Society when only 36. Graham is rightly regarded as one of the fathers of physical chemistry, but he also possessed business acumen to a rare degree. In this he resembled Sir Isaac Newton, and, like Newton before him, he was appointed Master of the Royal Mint, a position he took up in 1855. After six years, the research chemist in him reasserted itself, and he retired to devote himself to scientific investigations, which continued until his death in 1869.

W. H. Fox Talbot

1800–1877

Drawn by Tom Purvis

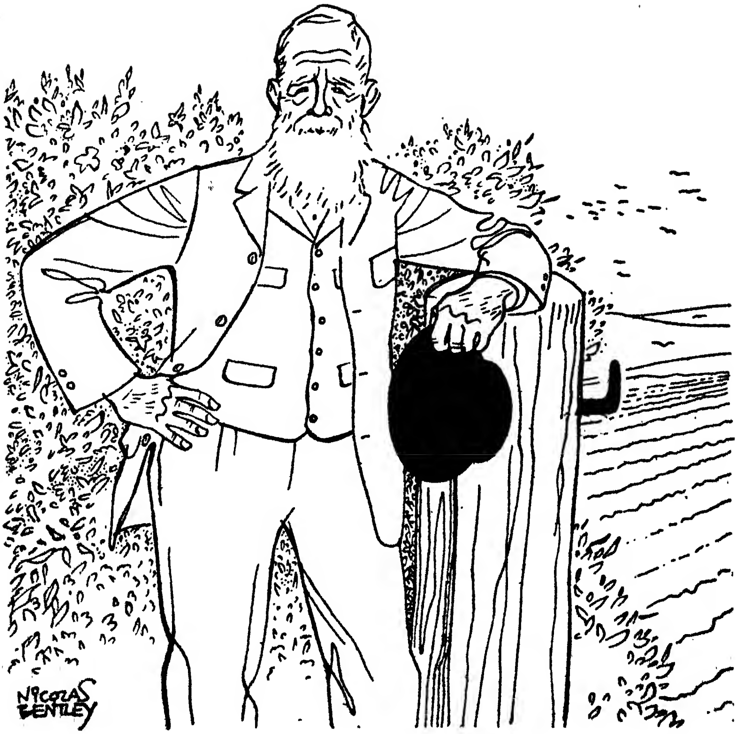
W. H. Fox Talbot

W. H. FOX TALBOT is universally acknowledged to have been the father of modern photography. Though he did not take the first photograph, he invented the Calotype process, which made it possible for any number of positives or "prints" to be made from a single negative. It is on this process that all modern photography has been built. Born at Melbury in Dorset in 1800, Fox Talbot was a man with remarkably wide interests. Though primarily a mathematician, a subject in which he took an honours degree at Cambridge University in 1821, he was also a chemist, a botanist and a philologist. He spoke fluent French, and could read German, Hebrew, Gaelic, Welsh, Polish, Wendish (an obscure Slavonic language) and Russian. With Sir Henry Rawlinson he was a pioneer translator of the Assyrian cuneiform inscriptions. His mathematical attainments earned him the Fellowship of the Royal Society in 1831, and he represented the Chippenham Division of Wiltshire in the Parliament that passed the Reform Bill of 1832.

In 1854 he threw open his patents on the Calotype process, taken out fourteen years earlier, and thus initiated the developments which have led from the daguerrotype to the great photographic industry of today. Photography is not only one of the amenities of life: it is also of indispensable service to science, industry and defence. From astronomy to banking, from archaeology to medicine, it would be difficult to find a human activity into which the use of photography has not come at some point or another. Britain may take pride in the fact that, in addition to Fox Talbot's contributions, much of the fundamental work on photography was carried out by British scientists. Thomas Wedgwood, for example, used silver nitrate paper to obtain profile and stencil pictures; Sir Humphry Davy employed silver chloride for profile printing; and Sir John Herschel introduced "hypo" (sodium thiosulphate) for fixing.

Sir John Bennet Lawes

1814–1900



Drawn by Nicolas Bentley

Sir John Bennet Lawes

SIR JOHN BENNET LAWES, squire of Rothamsted in Hertfordshire, founded the world's oldest agricultural research station in his native village. Financing it at first largely out of his own pocket, he later endowed the station with money derived from his process for making superphosphate. This discovery led to the development of the modern fertilizer industry. The world consumption of superphosphate at the present time is over 16 million tons per annum.

Born in 1814, Lawes was attracted to chemistry even as a boy. He had his own laboratory, first in a bedroom and then in a barn. Educated at Eton and Brasenose College, Oxford, he passed his life at Rothamsted, and although his early success with superphosphate made the young squire a chemical manufacturer, his dominating interest was always agricultural research. His experimental work, carried out over a period of fifty-eight years in partnership with Sir Henry Gilbert, laid the foundations of agricultural chemistry. He did much work on the manufacture of citric and tartaric acids, and discovered methods of extracting the latter from low-grade argol or wine-lees, thus providing a new source of income for the wine-producing countries, where this material had hitherto been to a great extent a troublesome waste product. Just before his death he gave

£100,000 to ensure the continued existence of the Rothamsted Experimental Station, and constituted the Lawes Agricultural Trust. During the last half-century the Station has been considerably extended, and the investigations carried out there cover all the many branches of the application of science to agriculture. When he died in 1900, Lawes had been given a baronetcy, had been elected to the Fellowship of the Royal Society, and had received the Albert Medal of the Royal Society of Arts. No man ever did more to ensure the world's food supply than this great farmer-scientist.

John Glover
1817–1902

Drawn by Robert Austin, R.A.

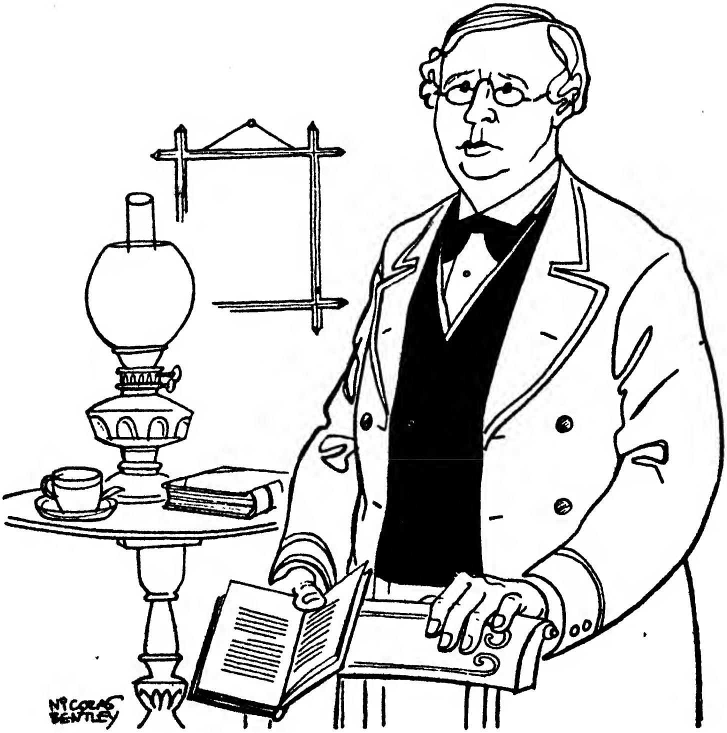
John Glover

JOHN GLOVER greatly improved the commercial manufacture of sulphuric acid. Next to water, sulphuric acid is the most important of all chemicals. Its use is so widespread that the volume of its production is often taken as a barometer of general industrial activity. In 1859 Glover built the first of the "Glover Towers," now such a familiar feature of the chemical works of Lancashire. The functions and advantages of the Glover towers were many. They resulted in a great saving of fuel and sodium nitrate; the concentrating plant was no longer required; the hot gases passing through the tower were cooled and carried steam into the chambers; and the acid was denitrated and concentrated. He declined to take out a patent for his invention and was always ready to show visitors and even competitors how it worked. A Glover tower built in 1868 concentrated 73,000 tons of sulphuric acid to a specific gravity of 1·75 entirely by the combustion of 15,400 tons of pyrites. The original cost of erecting the tower was £450, and the annual cost of repair over a six-year period was £11.

Born at Wallsend, near Newcastle-on-Tyne, in 1817, John Glover was apprenticed to a plumber, but studied chemistry at the local Mechanics' Institute to such effect that he secured the post of junior chemist in a Tyneside chemical works. There he invented an improved method of manufacturing alum, and at the age of 25 became manager of a works making sulphuric acid, hydrochloric acid and magnesium carbonate. While thus employed he thought out and constructed the first of his towers. In 1861 he became a partner in the Carville Chemical Works, where he remained until his retirement in 1882. He had a high opinion of the value of scientific discipline, and in a speech to the Newcastle-on-Tyne Chemical Society he said: "I believe that such of you as devote yourselves to purely scientific investigations, from the promptings of a pure and devoted love, may not, as your reward, gain material wealth, but will have formed what is of infinitely greater value, a noble character and capacity for enjoyment which wealth cannot give you."

Henry Deacon

1822–1876



Drawn by Nicolas Bentley

Henry Deacon

HENRY DEACON was an Englishman who, in 1868, found a new method of obtaining chlorine from hydrochloric acid gas, at that time a by-product of alkali manufacture. He made hydrochloric acid gas and mixed it with air, passing the mixture over a heated copper salt, which acted as a catalyst. The oxygen in the air oxidized the hydrochloric acid to form steam and chlorine. The chlorine so obtained was of course diluted by the atmospheric nitrogen, but could be used directly for bleaching and for the manufacture of bleaching powder. His method, known as the Deacon Process, was eventually used all over the world. Side by side with another process, also invented by an English chemist, Deacon's invention made possible the commercial production of chlorine. This important heavy chemical is used in bleaching, for the manufacture of disinfectants, cleaning fluids and industrial solvents. Municipalities employ it for sterilizing water supplies. Chlorine and its derivatives are essential to the chemical engineering and textile industries.

Deacon was born in London in 1822. His parents were extremely poor, but they were fortunate in enjoying the friendship of Michael Faraday. The great scientist took upon himself the supervision of the boy's brief education at a Quaker school in Tottenham. He left at the age of 14 and was apprenticed to an engineering firm, but soon afterwards it went bankrupt. He then moved to Lancashire, having his indentures transferred to Nasmyth and Gaskell, but at the age of 26 forsook engineering to become manager of Pilkington Brothers' glass-works at St. Helens. He abandoned glass a few years later when offered the managership of a small alkali works at Widnes. Subsequently he set up works of his own in partnership with William Pilkington and later with Gaskell—his former employers. He died of typhoid fever at the comparatively early age of 54

A. W. Williamson

1824–1904

Drawn by Michael Ayrton

A. W. Williamson

A. W. WILLIAMSON played a prominent part in the establishment of science degrees at London University, an event which has had a profound influence on the development of science in Great Britain. Though Williamson's greatest contribution to chemistry was as a teacher—he was professor of chemistry at University College for thirty-eight years—he was also a research worker. His achievements in this field included a masterly study of ether and the mechanism of etherification. This work was a model of scientific method, and not only solved the particular problems concerned but very largely contributed to the general chemical theory of valency. Williamson also had ideas about the constitution of salts which foreshadowed fundamental conceptions of the ionic theory. He did much work on methods of gas analysis, which are partly responsible for the excellence of domestic gas supplies today.

Williamson was born in Wandsworth in 1824. After studying chemistry and mathematics in both Germany and France, he was elected to the Professorship of Chemistry at University College in 1849. His eminence as a teacher and research worker was recognized by the Royal Society when he was awarded its royal medal in 1862, and he was twice President of the Chemical Society. He was also actively interested in the British Association, of which he was President in 1873 and General Treasurer from 1874 to 1891. He was a Fellow of the Royal Society of Edinburgh and an honorary member of the Royal Irish Academy, as well as the recipient of many academic honours. By the time of his death in 1904 his tremendous activity in both the academic and industrial spheres had established him as one of the great figures in contemporary chemistry.

Sir Edward Frankland

1825–1899

Drawn by W. Kassemoff

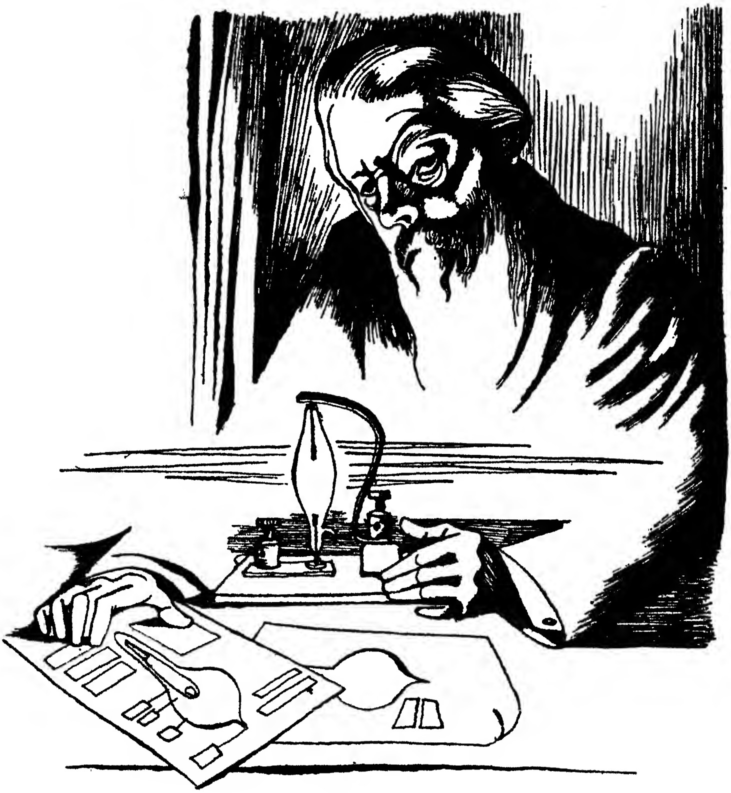
Sir Edward Frankland

SIR EDWARD FRANKLAND was among the first to develop the theory of valency, which explains how the atoms that constitute all matter are held together. "When the formulae of inorganic chemical compounds are considered, even a superficial observer is impressed with the general symmetry of their construction. The compounds of nitrogen, phosphorus, antimony, and arsenic, especially, exhibit the tendency of these elements to form compounds containing 3 or 5 atoms of other elements; and it is in these proportions that their affinities are best satisfied: thus in the ternal group we have NO_3, NH_3, NI_3, NS_3, PO_3, PH_3, PCl_3, SbO_3, SbH_3, $SbCl_3$, AsO_3, AsH_3, $AsCl_3$, etc.; and in the five-atom group, NO_5, NH_4O, NH_4I, PO_5, PH_4I, etc. Without offering any hypothesis regarding the cause of this symmetrical grouping of atoms, it is sufficiently evident, from the examples just given, that such a tendency or law prevails, and that, no matter what the character of the uniting atoms may be, the combining power of the attracting element, if I may be allowed the term, is always satisfied by the same number of these atoms." This theory of valency played an important part in the subsequent growth of chemistry. With Sir Norman Lockyer, British astronomer, Frankland discovered the existence of helium in the sun. In addition he was one of the leading authorities on water supply, and instituted a system for the periodic examination of water for bacteria which brought him widespread renown. In pure chemistry he investigated organometallic compounds and the luminosity of flames.

Born in Churchtown, Lancashire, in 1825, Frankland was apprenticed to a druggist in Lancaster until he went to London at the age of 20 to study chemistry. In 1851 he was appointed professor of chemistry at Owens College, Manchester. Returning to London in 1857, he held appointments at St. Bartholomew's Hospital, the Royal Institution and the Royal School of Mines. He was President of the Chemical Society from 1871 to 1873, and of the Institute of Chemistry from 1877 to 1880. The Royal Society awarded him its highest honour—the Copley Medal—in 1894. Frankland was knighted in 1897, two years before his death.

Sir Joseph Wilson Swan

1828–1914



Drawn by Michael Ayrton

Sir Joseph Wilson Swan

SIR JOSEPH WILSON SWAN laid the foundations of two great modern industries. He was one of the inventors of the carbon filament lamp, forerunner of the modern electric light bulb. He was also the first to produce a practical artificial silk. This he made by dissolving nitrocellulose in acetic acid and squirting it through a small orifice into a coagulating fluid, thus forming a long continuous thread. Some of these threads were crocheted into lace which was shown at the Inventions Exhibition of 1885 as "Artificial Silk." Swan was much preoccupied with his lamp—which was patented in 1880—and did not exploit his new fibre. It was developed by others and gave rise to the modern rayon industry. Swan made improvements in the collodion process invented by Frederick Scott Archer, and produced excellent collodion for photography. He observed that the sensitiveness to light of an emulsion of silver bromide in gelatine was increased by heat, and following up this observation he invented the dry photographic plate. Up to that time, photographic plates had to be used wet, so Swan's invention was a great improvement in convenience. Swan also patented the first really practicable carbon printing process, and in 1879 he patented bromide paper.

Born in Sunderland in 1828, Swan worked as assistant to a firm of manufacturing chemists in that town, later becoming a partner in another firm at Newcastle-on-Tyne. His numerous inventions and discoveries earned him the Fellowship of the Royal Society in 1894, and a knighthood ten years later. But the millions of electric light bulbs in use all over the world are a greater tribute to the genius of this British scientist than the honours he received during his lifetime.

Sir William Crookes

1832–1919

Drawn by Robert *Austin,* R.*A.*

Sir William Crookes

SIR WILLIAM CROOKES is best known to the layman for his startling prophecy, in 1898, that exhaustion of the Chilean nitrate deposits would lead to world starvation unless alternative sources of nitrogen compounds were discovered. Among scientists he is recognized as one of the fathers of spectroscopy—the analysis of light into its component wavelengths. This has many important applications, especially in industry, where it enables routine tests to be made with great speed and accuracy. Crookes also discovered thallium, an element resembling lead, and invented the Crookes tube, which was the forerunner of the modern X-ray tube. He carried out much work on the nature and constitution of the rare earths, the study of which led him to suggest that all elements were produced by evolution from one fundamental type of matter. He further investigated radioactivity and invented the spinthariscope, by means of which the presence of traces of radioactive material can be detected by the production of phosphorescence on a zinc sulphide screen. To the general public he is known for his invention of safety glass, which effectively shields the eyes of workers from harmful rays.

A Londoner, Crookes was born in 1832, and was educated at Chippenham Grammar School in Wiltshire. He studied at the Royal College of Chemistry and was later employed in the meteorological department of the Radcliffe Observatory, Oxford. Returning to London in 1856, he started publication of *The Chemical News*, a journal of which he remained editor-proprietor for nearly half a century. He wrote many books on chemical subjects, and his *Select Methods of Chemical Analysis* long remained a standard work on the subject. He was frequently consulted by the Government on scientific matters, and at various times served as President of the Royal Society, the British Association, and the Institution of Electrical Engineers. He was knighted in 1897, and was one of the original members of the Order of Merit.

Sir Henry E. Roscoe
1833–1915

Drawn by Tom Purvis

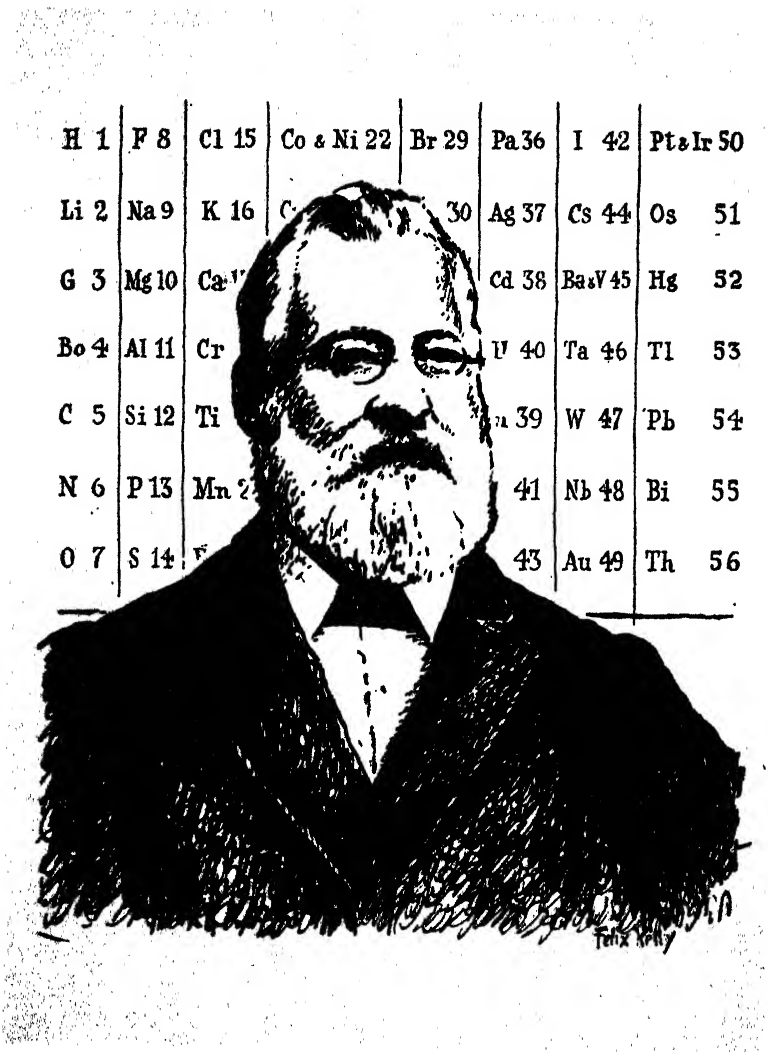
Sir Henry E. Roscoe

SIR HENRY E. ROSCOE was the first chemist to isolate vanadium, a metal used for toughening steel. Vanadium compounds had been known for many years, but Roscoe showed that what Berzelius had thought to be the metal itself was actually vanadium nitride. He made many unsuccessful attempts to prepare vanadium by the reduction of its oxides, and then tried to reduce the bichloride in a current of hydrogen. There were many difficulties, but by placing the chloride in platinum boats in a heated porcelain tube, and passing over it carefully dried oxygen-free hydrogen, he was finally able to isolate vanadium as a brilliant silver-white lustrous metal. The discovery of vanadium has been of great importance in manufacturing the hard steels needed to make tools and the springs and axles of railway engines and motor cars. Small quantities of vanadium are also used in dyeing, and in producing paints and medicines. Roscoe was one of the first to realize the importance of popularizing science, and in 1862 organized a series of Science Lectures for the People. Delivered by himself and other leading scientists, they were a huge success, and in printed form had a world-wide circulation.

Roscoe was born in London in 1833, but his family moved to Liverpool when he was 9 years old, and he spent almost his whole life in the North. He returned to London to take his honours degree in chemistry, and for a short time studied abroad. At the early age of 24 he was appointed Professor of Chemistry at Owens College, Manchester. Like so many other scientists of his day, Roscoe took an active part in public life. He was knighted in 1884, and represented South Manchester in the House of Commons from 1885 to 1895. He died in 1915, leaving behind him a record of great practical achievement and a number of chemical textbooks which have been translated into almost every important language of Europe and the Orient.

J. A. R. Newlands

1837–1898



Drawn by Felix Kelly

J. A. R. Newlands

J. A. R. NEWLANDS was the first man to appreciate that the chemical elements fall naturally into families and groups. These, he found, have similar properties, which are related to their atomic weights. Newlands also noticed that, if the elements were arranged in a certain way, the same physical and chemical properties reappeared after each interval of eight. He therefore called his discovery the Law of Octaves. The important conception of a periodic regularity of properties was significant, but at that time the nature of the significance was not appreciated. Newlands' scheme was necessarily imperfect, and made no allowance for the existence of elements still to be discovered; moreover, elements with no similarity with one another sometimes occupied corresponding positions in different octaves. But, developed by others later, the Law of Octaves eventually emerged as the Periodic Table, which has proved of immense practical value and enabled the existence of unknown elements to be predicted with remarkable accuracy.

A Londoner, born in 1837 of Scottish and Italian parentage, Newlands was educated at the Royal College of Chemistry. He fought with Garibaldi in Italy, but returned to London to practise as an analytical chemist. Later he taught chemistry at Southwark Grammar School and elsewhere, but finally became chief chemist in a sugar refinery at Victoria Docks. Though his Law of Octaves was laughed at when he first propounded it to the Chemical Society in 1864, time proved him to be right. In 1887 he was awarded the Davy Medal of the Royal Society for the discovery which, for twenty-three years, had earned him little but ridicule. Newlands died in 1898.

Sir William Perkin

1838–1907

Drawn by Robert *Austin,* R.*A.*

Sir William Perkin

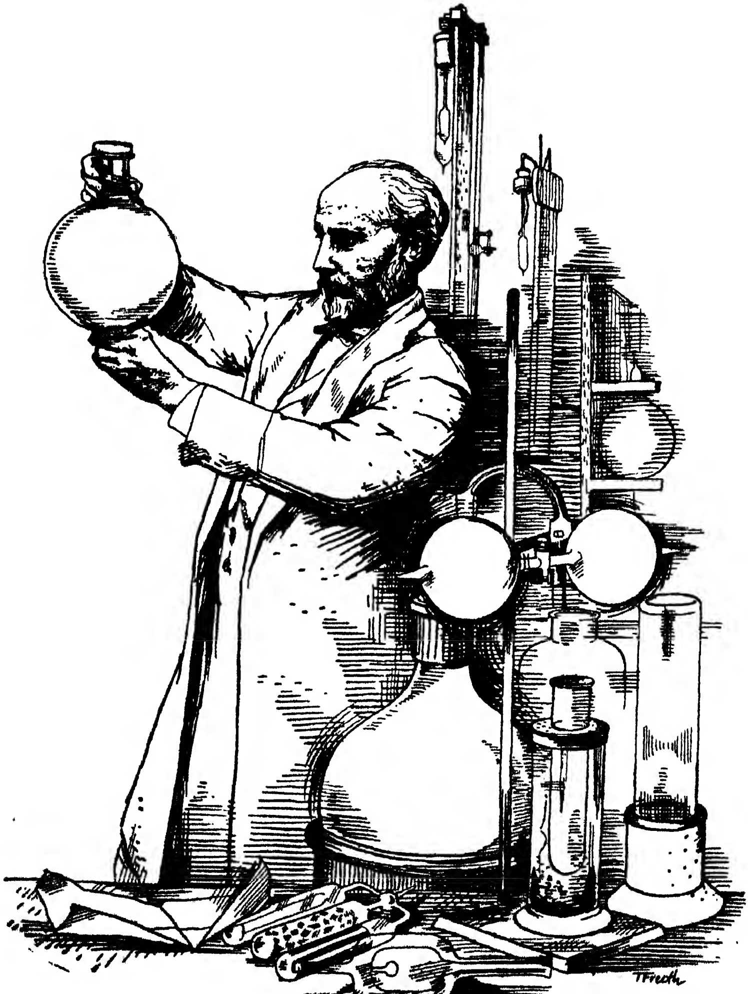
SIR WILLIAM PERKIN founded the modern synthetic dyestuffs industry. He began his chemical career as an assistant at the Royal College of Chemistry, but his first great discovery was actually made in his spare time in a rough laboratory at home when he was no more than 18. This took place in 1856, when Perkin was trying to prepare quinine artificially. He failed to produce synthetic quinine, but by oxidizing crude aniline with potassium dichromate obtained a dark solid which turned out to be a good purple dye. It was, in fact, mauve, the first of the great family of aniline dyes. Perkin took out a patent for the manufacturing process and, in 1857, set up a factory near Harrow. This was the beginning of the aniline dye industry, which has since become of key importance to the whole world.

Born in London in 1838, Perkin was educated at the City of London School before proceeding to the Royal College of Chemistry, where he studied under A. W. Hoffmann and later became his assistant. As well as discovering aniline purple he also invented processes for manufacturing alizarin (the red dye of madder root) and coumarin (the odoriferous principle of woodruff and tonka bean). Achieving financial independence as a result of his discoveries, he was able to devote his attention to pure chemical research, during which he discovered the useful

Perkin Reaction for the synthesis of unsaturated acids, and made a comprehensive study of the magnetic rotatory power of many substances. He also worked on the formation of carbon rings, the chemistry of camphor and the terpenes, and the constitution of berberine and other alkalis. He was President of the Chemical Society in 1883 and of the Society of Chemical Industry in 1884. He was knighted in 1906, the jubilee of his discovery of the first aniline dye.

Sir James Dewar

1842–1923



Drawn by Thomas Freeth

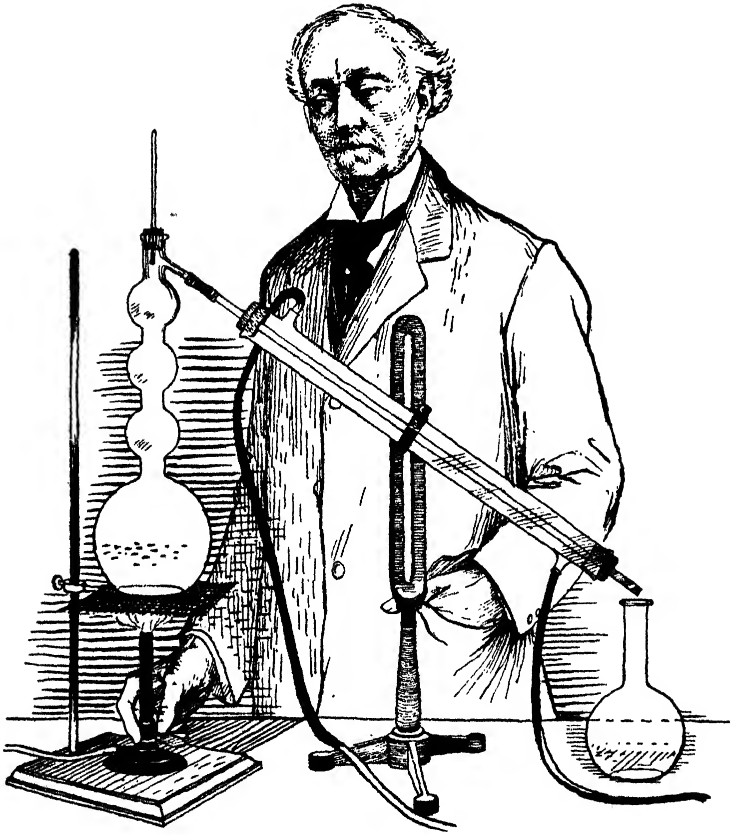
Sir James Dewar

SIR JAMES DEWAR is best known for his invention of the Dewar flask. This, in its modern form of the "Thermos" and other vacuum flasks, is found today in most households. Dewar invented the flasks to aid him in his experiments on the liquefaction of gases—he was the first to liquefy hydrogen in bulk, and afterwards to solidify it. Having liquefied various gases, he found difficulty in keeping them cold enough to prevent evaporation. The Dewar flask solved his problem. A series of investigations which he made into the properties of matter at low temperatures has also proved of great importance in both science and industry. Moreover, with Sir Frederick Abel, Dewar was co-discoverer of cordite, an important propellant explosive. He made some valuable contributions to organic chemistry, and worked on the physiological action of life, the measurement of high temperatures, the physical and chemical properties of iron and nickel carbonyls, the properties of thin films, and specific inductive capacities, as well as making a long series of spectroscopic observations.

Dewar was a Scotsman born in 1842. He was educated at Dollar Academy and the University of Edinburgh, and continued his studies at Ghent. Returning to England, he became Jacksonian professor of natural experimental philosophy at Cambridge in 1874, and two years later was appointed Fullerian professor at the Royal Institution. Dewar was noted for his great manipulative skill, which he is said to have developed as the result of a childish accident. Devoted from very early days to music, he was learning to play the flute, but the accident prevented him from continuing. As a compensation he took to building violins, and so acquired the manual skill for which he was afterwards noted. He was President of the Chemical Society in 1897 and of the British Association in 1902. He was awarded the Rumford Medal of the Royal Society, and among the foreign scientific bodies which honoured him were the French Academy of Sciences, the Italian Society of Sciences, and the Smithsonian Institution.

W. A. Tilden

1842–1926



Drawn by Thomas Freeth

W. A. Tilden

W. A. TILDEN noticed that when isoprene, a clear, oily liquid obtained from acetylene, is allowed to stand for a long time, it turns into a rubber-like substance. This observation was the key to the manufacture of synthetic rubber, and has become of immense commercial value. Yet at the time—and for many years afterwards—it remained simply a chemical curiosity, owing to the low price of natural rubber. His early work was concerned with chlorides and other vegetable products, and later, with W. A. Shenstone, he studied nitrosyl chloride. While engaged in this investigation he discovered that nitrosyl chloride would react with pinene to form a nitroso-chloride, a discovery which in due course led to a useful method for the identification of terpenes. Tilden carried out much work on physical chemistry, and his fluent prose style was seen to advantage in his numerous books and original papers. He was also a chemical historian, and his biographical volume *Famous Chemists* is still regarded as a standard reference book.

Born in London in 1842, Tilden served an apprenticeship to a pharmacist. When qualified, he became the demonstrator at the Pharmaceutical Society's School, a post he held until appointed Senior Chemistry Master at Clifton College, Bristol. At Clifton Tilden did valuable work in raising the status of science as an educational subject, and the greater consideration subsequently accorded to it was largely his work. In 1880 he moved to Birmingham, and in 1894 he was appointed Professor of Chemistry at the Royal College of Science, London, where he remained until his retirement in 1919. He died in 1926 at the age of 84.

Sir William Ramsay

1852–1916

Drawn by W. Kassemoff

Sir William Ramsay

SIR WILLIAM RAMSAY was the discoverer of a whole new family of elements—an achievement unparalleled in the entire history of chemistry. The first of his discoveries was made in 1894, when, with Lord Rayleigh, he isolated argon, a rare gas that exists in small quantities in the air. Argon is obtained by passing air over heated copper to remove the oxygen, while carbon dioxide and moisture are removed with caustic alkali and concentrated sulphuric acid respectively. The residual nitrogen is then repeatedly passed over heated magnesium, leaving a gas consisting mainly of argon. Later, Ramsay and his assistants succeeded in isolating helium, neon, krypton, and xenon, which are also present in the atmosphere but in even smaller amounts. Nowadays the rare gases are conveniently obtained by the fractional distillation of liquid air. At first these gases were mere chemical curiosities, but now, half a century later, they are of great industrial importance. Argon is the gas used in the modern gas-filled electric light bulb. The electric discharge lamp depends on neon to such an extent that few recognize it today by any name other than that of "neon sign." Helium is also employed in these lamps, in addition to its well-known use, instead of hydrogen, for providing buoyancy for lighter-than-air craft. Ramsay also carried out much work on the densities of various substances at different temperatures and pressures, and devised a method of determining the molecular weights of liquids by measurement of their surface tension, worked on radioactivity, and showed that radium emanation spontaneously changed into helium. On the theoretical side he suggested an electronic explanation of valency.

Ramsay was born in Glasgow in 1852. He was a first-class athlete, musician, and linguist, as well as being professor of chemistry at Bristol and later at University College, London. He was knighted in 1902, and was awarded the Nobel Prize in 1904. In 1913 he presided over the International Association of Chemical Societies, where his flair for languages enabled him to address his cosmopolitan audience in English, French, German and Italian. He died in 1916.

Sir J. J. Thomson

1856–1940

Drawn by Tom Purvis

Sir J. J. Thomson

SIR J. J. THOMSON showed that electricity was conducted through gases at low pressure by a stream of negatively charged particles, afterwards named electrons. The charge on an electron is the smallest quantity of electricity that can exist, and electrons are so minute that 1,800 of them weigh only as much as one hydrogen atom. Thomson also carried out work on positive rays, and in this way detected the fact that there are two separate varieties or isotopes of the gas neon, an observation which led to far-reaching results on isotopes in general. He further measured the ratio of charge to mass of electric particles, and investigated the motion of vortex rings. An accomplished mathematician, he was interested in the application of dynamics to physics and chemistry.

At the Cavendish Laboratory Thomson founded a new school of physics dealing with the structure of the atom. The work of this school led to the present conception of the atom as a nucleus round which revolve electrons, and to the discovery of the fission of the uranium nucleus, which made the atomic bomb possible.

Thomson was born near Manchester in 1856, and was educated at Owens College (now the Victoria University of Manchester) and Trinity College, Cambridge, which he entered as a Minor Scholar in 1876. While still in his twenties he was elected Cavendish Professor of Experimental Physics, the most distinguished post of its kind in the world. He retained this appointment until he became Master of Trinity in 1918. He was awarded the Nobel Prize for Physics in 1906 and before his death in 1940 had received a knighthood and the Order of Merit.

John Stewart MacArthur

1857–1920

Drawn by Robert *Austin,* R.*A.*

John Stewart MacArthur

JOHN STEWART MACARTHUR made only one notable contribution to metallurgy, but within twenty years it trebled the world's gold output. In 1886, when still a comparatively unknown chemist engaged on research in Glasgow, he was called in to report on a process for extracting gold from its ores. The process had failed, and MacArthur declared it to be unworkable. His researches enabled him to offer an alternative, the now famous MacArthur-Forrest cyanide process, which he had worked out in conjunction with two Scottish physicians named Forrest. This enabled gold to be extracted from low-grade ores. The ore is crushed to a fine powder and dissolved in a weak solution of sodium cyanide. From this solution the gold is precipitated by the addition of zinc in the form of shavings or dust, and is then melted down and cast into ingots. As much as 95% of the gold in the ore is thus recovered. The MacArthur-Forrest process revolutionized the gold industry, and saved the Rand mines from virtual extinction. Today all the great South African mines treat the ore by the cyanide process, and few mines in other parts of the world could operate profitably without it.

MacArthur was born in 1857, and at the age of 14 entered the laboratories of the Tharsis Sulphur and Copper Company in Glasgow as an apprentice chemist. He left them in

1885 to join the Drs. Forrest in research on gold and silver extraction. By 1889 the MacArthur-Forrest cyanide process was being tested on a plant scale in New Zealand, and a year later in South Africa. Though MacArthur had further success—in the manufacture of radium compounds and luminous paints—it is for his great contribution to gold-mining that he is remembered. In 1902 he was awarded the Gold Medal of the Institution of Mining and Metallurgy, in recognition of his work on the cyanide process. He died in Pollokshields, Glasgow, in 1920.

Sir Frederick Gowland Hopkins

1861–1947

Drawn by C. Walter Hodges

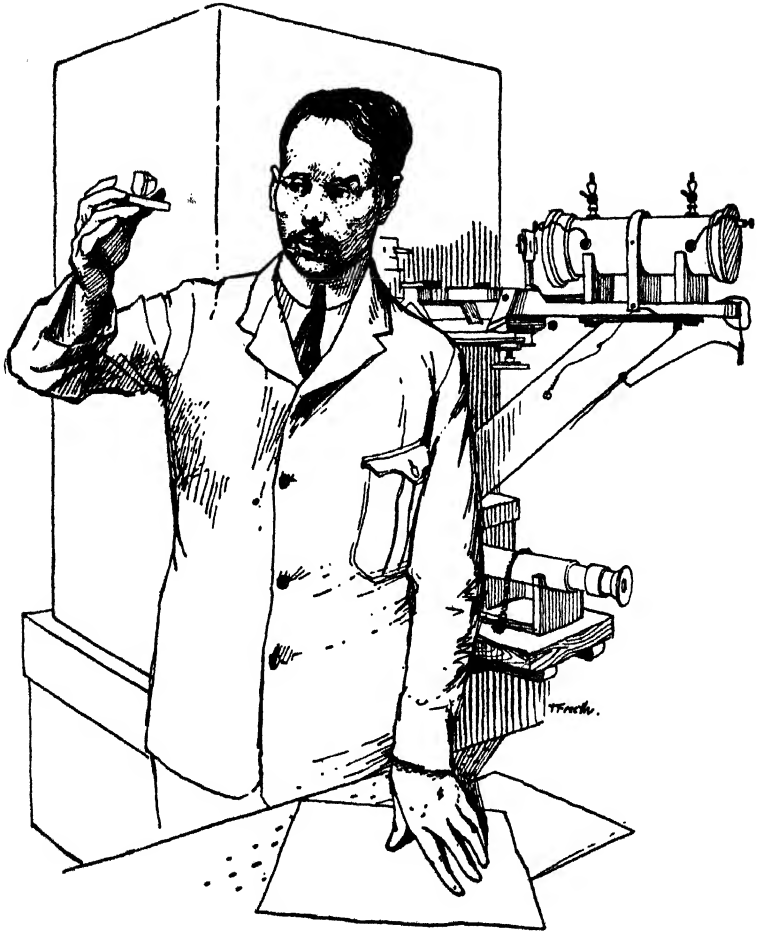
Sir Frederick Gowland Hopkins

SIR FREDERICK GOWLAND HOPKINS revolutionized the chemistry of nutrition, for his early research work led to the discovery of vitamins. At the turn of the century Hopkins succeeded in isolating a vitally important amino-acid, tryptophane, a discovery which went far to explain the structure of those body-building compounds, the proteins. Further research convinced him that no animal could exist on a diet consisting only of pure proteins, fats and carbohydrates (starchy foods), and by 1906 he was already on the track of the accessory food factors now known as vitamins.

Born at Eastbourne in 1861, Hopkins was educated privately, and started work as a clerk in an insurance office in London at the age of 17. He soon gave up this appointment to become assistant to an analytical chemist and study for the examinations of the Institute (now Royal Institute) of Chemistry. He passed so well that by the time he was 22 he had become assistant to the Lecturer on Forensic Medicine at Guy's Hospital. In 1888 he entered Guy's Medical School as a student. Ten years later he was invited to Cambridge, where he became a Fellow and Science Tutor at Emmanuel College. In 1918 Hopkins received the Royal Medal of the Royal Society, and seven years later he was knighted. In 1929 he was awarded the Nobel Prize for his work in biochemistry, and the following year became President of the Royal Society. Hopkins held this position until 1935, when he was awarded the Order of Merit. He died in 1947.

H. G. J. Moseley

1887–1915



Drawn by Thomas Freeth

H. G. J. Moseley

H. G. J. MOSELEY, whose brilliantly promising career came to a tragic end on the Gallipoli beaches when he was only 28, carried out important researches on radioactivity and will always be remembered for his discovery that the atomic nucleus has an electrical charge the size of which is characteristic of the atom. The numerical value of this charge is known as the atomic number. Moseley used the Braggs' crystal method to measure the wavelength of the X-rays emitted by various elements. The X-ray spectrum of an element is not continuous, but consists of a number of lines, associated in groups called the K, L, and M series. In comparing the X-ray spectra of different elements, taking a corresponding line in the same series in each, Moseley found a quantitative relationship, involving not only the atomic weight but the atomic number. It varies by one unit in passing from one element to the next in the periodic table. When the series of atomic numbers was investigated it was found that there were certain gaps, and this led to the search for new elements to fill the gaps; thus hafnium was discovered in 1923 and rhenium in 1925. The method of arranging elements in ascending order of atomic number permitted a complete survey, and permits also the addition of the new man-made elements such as plutonium. Moseley's discovery has been of the greatest importance in the subsequent development of atomic physics.

The son of a distinguished zoologist, Moseley was born at Weymouth, Dorset, in 1887. After a brilliant career at Eton and Trinity College, Oxford, he became a lecturer in physics at Manchester University. He resigned this appointment two years later, when he was elected to the John Harling Fellowship. His labours were interrupted by the outbreak of war in 1914, but not before he had accomplished the researches which were destined to have a dramatic effect on the course of the second world war.

Sir William Bragg

1862–1942

Drawn by Tom Purvis

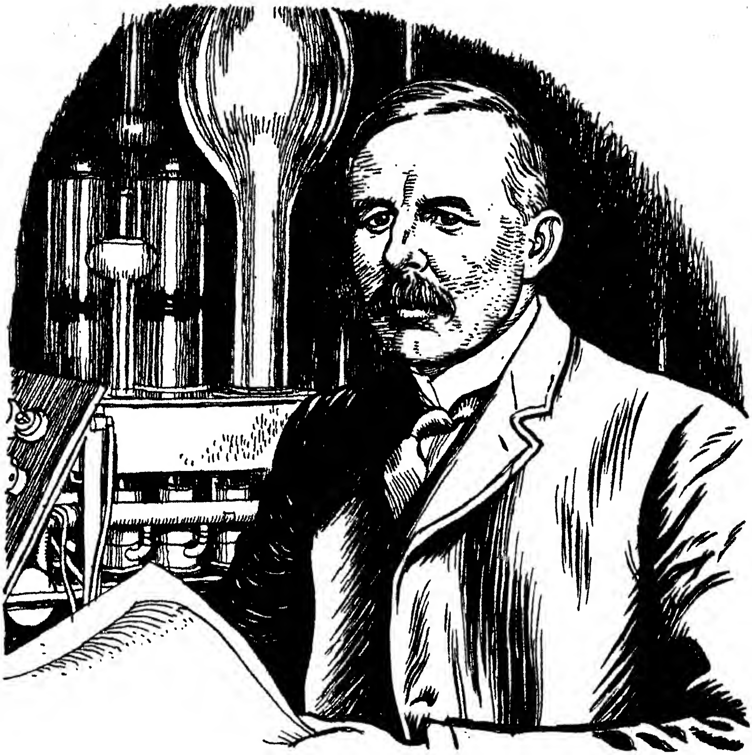
Sir William Bragg

SIR WILLIAM BRAGG, together with his son, Sir Lawrence Bragg, was the originator of the modern technique of the X-ray analysis of crystals which has proved invaluable in unravelling the atomic structure of solid substances. He showed that X-rays suffer reflection from crystal surfaces at definite angles of incidence, and if the X-rays are all of the same wavelength the series of directions along which reflection will occur are obtained from a general equation in which one factor is the distance between planes in the crystal corresponding to the densest arrangement of the atoms. By this means he was able to show how the atoms are arranged in crystals and even to throw light on their arrangement in such substances as silk, rayon, cotton and nylon. On the basis of Bragg's work it is possible to follow polymerization in synthetic plastics and the like, and what began as a purely academic piece of research has, as so often happens, become an indispensable instrument to the industrial and manufacturing chemist. Bragg also carried out work on radioactivity and showed that the alpha rays from different radioactive substances travel different distances through different media, and that their range is closely connected with the atomic weights of the atoms in the medium penetrated. During the war of 1914–18 he acted in an advisory capacity to the Admiralty, more particularly with regard to the problem of detecting submarines.

Born in Cumberland in 1862 and educated at King William's College, Isle of Man, Bragg graduated as third wrangler at Cambridge in 1884. He held important academic appointments in Australia, Leeds and London, including the Directorship of the Davy-Faraday research laboratory at the Royal Institution, where much of his work was carried out. He was an honorary Fellow of Trinity College, Cambridge, and President of the Physical Society and of the British Association. He and his son were jointly awarded the Nobel Prize for physics in 1915, and they were honoured by universities and learned societies in all parts of the world. He received his knighthood in 1920, and the Order of Merit in 1931. He died in 1942.

Lord Rutherford

1871–1937



Drawn by Illingworth

Lord Rutherford

LORD RUTHERFORD was one of the great pioneers in the field of atomic physics. In 1911 he put forward the revolutionary theory that all atoms have a central core or nucleus with a positive electrical charge, which accounts for virtually the entire weight of the atom. This nucleus is surrounded by one or more electrons (charges of negative electricity) revolving in orbits that are relatively enormous compared with the nucleus.

Further research by physicists working under Rutherford's direction showed that the nuclei of all atoms are built up of positively charged protons, or nuclei of the hydrogen atom, and electrically neutral particles called neutrons. They discovered how to chip off part of the nucleus, and so to transmute one element into another. They also established that this chipping liberated relatively vast amounts of energy "locked up" in the nucleus. At that time this did not constitute a method of obtaining useful energy, because the amount of energy used to break up the nuclei exceeded the amount given out. It did, however, indicate the possibility, which has become fact with the fission of the uranium nucleus. These British discoveries were fundamental, and all recent developments in the atomic field would have been impossible without them.

Born at Nelson, New Zealand, in 1871, Ernest Rutherford was elected to the Chair of Physics at McGill University, Montreal, when only 27, and ten years later to the corresponding post at Victoria University, Manchester. In 1919 he succeeded his old master, Sir J. J. Thomson, in the Cavendish professorship of Experimental Physics at Cambridge—the world's outstanding post in physical research. He was created a knight in 1914, and a baron six years before his death in 1937.