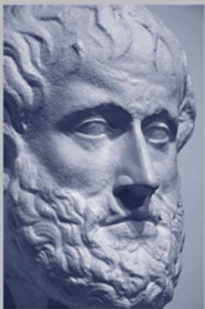

Aristotle
(384 BC–322 BC)

René du Perron Descartes
(1596–1650)

Marie Skłodowska Curie
(1867–1934)

Sir Francis Galton
(1822–1911)

Biographical Encyclopedia *of* Scientists

Third Edition

Edited by
John Daintith

CRC Press
Taylor & Francis Group
A TAYLOR & FRANCIS BOOK

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Preface

This reference book presents biographical entries on important scientists – from the earliest times to the present day. It is an updated version of *A Biographical Encyclopedia of Scientists*, which was published by the Institute of Physics in 1993. This in turn was based o n earlier editions.

In this new edition, we have updated all the entries and added over 200 new biographies. We have also included a simple pronunciation guide in entries where this is appropriate. The respelling system used is shown on page vi. Another added feature of this edition is the inclusion of a selection of quotations by or about certain people. There are also cross references to other entries in the book – these are indicated by SMALL CAPITALS. In the appendix to the book there is a chronology of key events in science, a list of useful web sites, and a subject index.

In compiling such a book there are several difficult decisions to make on the selection of material. The most general one is that of the scope of the book – what areas of knowledge it should cover. This work concentrates on what might be called the 'traditional' pure sciences – physics, chemistry, biology, astronomy, and the earth sciences. It also covers medicine and mathematics, and includes a selection of people who have made important contributions to engineering and technology. A few of the entries cover workers in such fields as anthropology and psychology, and a small number of philosophers have also been allowed in.

Our intention has been to produce a book as much about science itself as about scientists, and this has governed our approach to selecting information: the entries contain basic biographical data – place and date of birth, posts held, etc. – but do not give exhaustive personal details about the subject's family, prizes, honorary degrees, etc. Most of the space has been given to their main scientific achievements and the nature and importance of these achievements. This has not always been easy; in particular, it has not always been possible to explain in relatively simple terms work in the higher reaches of abstract mathematics or modern theoretical physics.

Perhaps the most difficult problem was compiling the entry list. We have attempted to include people who have produced major advances in theory or have made influential or well-known discoveries. A particular difficulty has been the selection of contemporary scientists, in view of the fact that of all scientists who have ever lived, the vast majority are still alive. In this we have been guided by lists of prizes and awards made by scientific societies. It should also be said that the compilers and editors have used their own judgment in choosing what is important or useful. In some cases entries have been added simply because we found them interesting. We hope that the reader will find all the entries useful and share our interest in them.

JD 2008

Pronunciation Guide

A guide to pronunciation is given for foreign names and names of foreign origin; it appears in brackets after the first mention of the name in the main text of the article.

a *as in* bat
ah *as in* palm (pahm)
air *as in* dare (dair), pear (pair)
ar *as in* tar
aw *as in* jaw, ball (bawl)
ay *as in* gray, ale (ayl)
ch *as in* chin
e *as in* red
ee *as in* see, me (mee)
eer *as in* ear (eer)
er *as in* fern, layer
f *as in* fat, phase (fayz)
g *as in* gag
i *as in* pit
I *as in* mile (mIl), by (bI)
j *as in* jaw, age (ayj), gem (jem)
k *as in* keep, cactus (**kak**-tus), quite (kwIt)
ks *as in* ox (oks)
ng *as in* hang, rank (rangk)
o *as in* pot
oh *as in* home (hohm), post (pohst)
oi *as in* boil, toy (toi)
oo *as in* food, fluke (flook)
or *as in* organ, quarter (**kwor**-ter)
ow *as in* powder, loud (lowd)
s *as in* skin, cell (sel)
sh *as in* shall
th *as in* bath
th *as in* feather (**fe*th***-er)
ts *as in* quartz (kworts)
u *as in* buck (buk), blood (blud), one (wun)
u(r) *as in* urn (but without sounding the "r")
uu *as in* book (buuk)
v *as in* van, of (ov)
y *as in* yet, menu (**men**-yoo), onion (**un**-yon)
z *as in* zoo, lose (looz)
zh *as in* treasure (**tre**-zher)

Names of two or more syllables are broken up into small units, each of one syllable, separated by hyphens. The stressed syllable in a word of two or more syllables is shown in **bold** type.

We have used a simple pronunciation system based on the phonetic respelling of names, which avoids the use of unfamiliar symbols. The sounds represented are as follows (the phonetic respelling is given in parentheses after the example word, if this is not pronounced as it is spelled):

The consonants b, d, h, l, m, n, p, r, t, and w have their normal sounds and are not listed in the table.

In our pronunciation guide a consonant is occasionally doubled to avoid confusing the syllable with a familiar word, for example, -iss rather than -is (which is normally pronounced -iz); -off rather than -of (which is normally pronounced -ov).

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A

Abbe, Cleveland (1838–1916) *American meteorologist*

Abbe (**ab**-ee) was born in New York City and educated there at City College; he later taught at the University of Michigan. He then spent two years (1864–66) in Russia at the Pulkovo Observatory under Otto STRUVE. On his return to America he worked as director of the Cincinnati Observatory (1868–70).

Abbe was the first official weather forecaster in America. He was appointed, in 1871, chief meteorologist with the weather service, which was later formed into the U.S. Weather Bureau (1891), and remained in this organization for the rest of his life. He was one of the first scientists to see the revolutionary role the telegraph had to play in weather forecasting and used reports conveyed to him from all over the country.

Abbe published over 300 papers on meteorology and from 1893 he was in charge of the journals published by the U.S. Weather Bureau. He was also responsible for the division of America into time zones in 1883.

Abbe, Ernst (1840–1905) *German physicist*

Abbe (**ab**-ee), who was born in Eisenach in Germany, came from poor parents but managed to become a lecturer at the University of Jena, where in 1886 he collaborated with Carl Zeiss, a supplier of optical instruments to the university, to improve the quality of microscope production. Up till then, this had been an empirical art without rigorous theory to aid design. Abbe's contribution was his knowledge of optical theory. He is known for the *Abbe sine condition* – a necessary condition for the elimination of spherical aberration in an optical system; such a system he described as aplanatic. He also invented the apochromatic lens system (1886), which eliminated both primary and secondary color distortions, and the *Abbe condenser* (1872) – a combination of lenses for converging light onto the specimen in microscopes.

The partnership between Abbe and Zeiss was a productive combination of Zeiss's practical knowledge and Abbe's mathematical and theoretical ability. After Zeiss's death, Abbe became the sole owner of the Zeiss company.

Abegg, Richard (1869–1910) *German physical chemist*

Abegg (**ah**-beg) was born in the German port of Danzig (now Gdańsk in Poland); he studied chemistry at Kiel, Tübingen, and Berlin. He graduated in 1891 as a pupil of Wilhelm Hofmann. Initially an organic chemist, he was attracted by the advances being made in physical chemistry, and in 1894 moved to Göttingen. Here, he worked on electrochemical and related problems and with G. Bodländer produced an important paper on valence, *Die Elektronaffinität* (1869; Electron Affinity). He is remembered for *Abegg's rule* (partially anticipated by Dmitri Mendeleev), which states that each element has two valences: a normal valence and a contravalence, the sum of which is eight. In 1899 he became a professor at Breslau (now Wrocław in Poland) and was about to become the director of the Physico-Chemical Institute there when he was killed in a ballooning accident.

Abel, Sir Frederick Augustus (1827–1902) *British chemist*

> The investigator must associate himself with those who have labored in fields where molecules and atoms rather than multicellular tissues or even unicellular organisms are the units of study.
> —Describing chemical research

Abel was born in London, the son of a well-known musician and the grandson of a court painter to the grand duke of Mecklenberg-Schwerin. Despite this artistic background, Abel developed an early interest in science after visiting his uncle A. J. Abel, a mineralogist and pupil of BERZELIUS. In 1845 he was one of the first of the pupils to study at the Royal College of Chemistry, remaining there until 1851. After a brief appointment as chemical demonstrator at St. Bartholomew's Hospital, London, he succeeded Michael FARADAY in 1852 as a lecturer in chemistry at the Royal Military Academy at Woolwich. In 1854 he became ordnance chemist and chemist to the war department.

Abel's career was thus devoted exclusively to the chemistry of explosives. New and powerful explosives, including guncotton and nitroglycerin, had recently been invented but were unsafe to use. Abel's first achievement was to show

how guncotton could be rendered stable and safe. His method was to remove all traces of the sulfuric and nitric acids used in its manufacture by mincing, washing in soda until all the acid had been removed, and drying. In 1888 he was appointed president of a government committee to find new high explosives. The two existing propellants, Poudre B and ballistite, had various defects, most important of which was a tendency to deteriorate during storage. Together with Sir James DEWAR, Abel introduced the new explosive, cordite, in 1889. This was a mixture of guncotton and nitroglycerin with camphor and petroleum added as stabilizers and preservatives.

Abel was honored for his services by being made a knight in 1891 and a baronet in 1893.

Abel, John Jacob (1857–1938) *American biochemist*

Abel was born in Cleveland, Ohio, the son of a farmer. He was educated at the University of Michigan and Johns Hopkins University. He spent the years 1884–90 in Europe studying at Leipzig, Heidelberg, Würzburg, Vienna, Bern, and Strasbourg, where he gained an MD in 1888. On his return to America he worked briefly at the University of Michigan before being appointed in 1893 to the first chair of pharmacology at Johns Hopkins, a post he retained until his retirement in 1932.

Abel approached biology with a first-rate training in chemistry and with the conviction that the study of molecules and atoms was as important as the observation of multicellular tissues under the microscope. He thus began by working on the chemical composition of various bodily tissues and fluids and, in 1897, succeeded in isolating a physiologically active substance from the adrenal glands, named by him epinephrine, also known as adrenalin. This extract was actually the monobenzoyl derivative of the hormone. It was left to Jokichi TAKAMINE to purify it in 1900.

As early as 1912 Abel clearly formulated the idea of an artificial kidney and in 1914 isolated for the first time amino acids from the blood. He was less successful with his search (1917–24) for the pituitary hormone, being unaware that he was dealing with not one but several hormones. His announcement in 1926 that he had crystallized insulin met with considerable skepticism, especially regarding its protein nature. This work was not generally accepted until the mid 1930s.

After his retirement Abel devoted himself to a study of the tetanus toxin.

Abel, Niels Henrik (1802–1829) *Norwegian mathematician*

> By studying the masters and not their pupils.
> —In reply to a question about how he gained his expertise

Abel (**ah**-bel) was born in Froland, the son of a poor pastor; he was educated in mathematics at the University of Christiana (Oslo). After the death of his father, Abel had to support a large family; he earned what he could by private teaching and was also helped out by his teacher. He was eventually given a grant by the Norwegian government to make a trip to France and Germany to visit mathematicians. In Germany he met the engineer and mathematician August Crelle, who was to be of great assistance to him. Crelle published Abel's work and exerted what influence he could to obtain him a post in Germany. Tragically Abel died just when Crelle had succeeded in getting him the chair in mathematics at Berlin.

With Evariste GALOIS (whom he never met), Abel founded the theory of groups (commutative groups are known as *Abelian groups* in his honor), and his early death ranks as one of the great tragedies of 19th-century mathematics. One of Abel's first achievements was to solve the longstanding problem of whether the general quintic (of the fifth degree) equation was solvable by algebraic methods. He showed that the general quintic is not solvable algebraically and sent this proof to Karl GAUSS, but unfortunately Gauss threw it away unread, having assumed that it was yet another unsuccessful attempt to solve the quintic.

Abel's greatest work was in the theory of elliptic and transcendental functions. Mathematicians had previously focused their attention on problems associated with elliptic integrals. Abel showed that these problems could be immensely simplified by considering the inverse functions of these integrals – the so-called "elliptic functions." He also proved a fundamental theorem, *Abel's theorem*, on transcendental functions, which he submitted to Augustin CAUCHY (and unfortunately fared no better than with Gauss). The study of elliptic functions inaugurated by Abel was to occupy many of the best mathematicians for the remainder of the 19th century. He also made very important contributions to the theory of infinite series.

Abelson, Philip Hauge (1913–2004) *American physical chemist*

> Part of the strength of science is that it has tended to attract individuals who love knowledge and the creation of it … Thus, it is the communication process which is at the core of the vitality and integrity of science.
> —*The Roots of Scientific Integrity* (1963)

Abelson, who was born in Tacoma, was educated at Washington State College and at the University of California at Berkeley, where he obtained his PhD in 1939. Apart from the war years at the Naval Research Laboratory in Washington, he spent most of his career at the Carnegie Institution, Washington, serving as the director of the geophysics laboratory from

1953, and as president from 1971 to 1978. He subsequently became the editor of a number of scientific journals including the important periodical *Science*, which he edited from 1962 to 1985.

In 1940 he assisted Edwin McMILLAN in creating the first transuranic element, neptunium, by bombardment of uranium with neutrons in the Berkeley cyclotron. Abelson next worked on separating the isotopes of uranium. It was clear that a nuclear explosion was possible only if sufficient quantities of the rare isotope uranium-235 (only 7 out of every 1,000 uranium atoms) could be obtained. The method Abelson chose was that of thermal diffusion. This involved circulating uranium hexafluoride vapor in a narrow space between a hot and a cold pipe; the lighter isotope tended to accumulate nearer the hot surface. Collecting sufficient uranium-235 involved Abelson in one of those massive research and engineering projects only possible in war time. In the Philadelphia Navy Yard, he constructed a hundred or so 48-foot (15-meter) precision-engineered pipes through which steam was pumped. From this Abelson was able to obtain uranium enriched to 14 U-235 atoms per 1,000.

Although this was still too weak a mixture for a bomb, it was sufficiently enriched to use in other separation processes. Consequently a bigger plant, consisting of over 2,000 towers, was constructed at Oak Ridge, Tennessee, and provided enriched material for the separation process from which came the fuel for the first atom bomb.

After the war Abelson extended the important work of Stanley MILLER on the origin of vital biological molecules. He found that amino acids could be produced from a variety of gases if carbon, nitrogen, hydrogen, and oxygen were present. He was also able to show (1955) the great stability of amino acids by identifying them in 300-million-year-old fossils and later (1956) identified the presence of fatty acids in rocks.

Abrikosov, Alexei A. (1928–) *Soviet-born American physicist*

Abrikosov was born in Moscow and in 1951 received his PhD from the Kapitsa Institute for Physical Problems, Moscow, for a thesis on the theory of thermal diffusion in plasmas. Four years later the same Institute made him a Doctor of Physical and Mathematical Sciences for his work on quantum electrodynamics at high energies. He worked at several universities and scientific institutions in the Soviet Union and in 1991 he joined the Materials Science Division of the Argonne National Laboratory, Illinois. He is also (since 1965) a professor at Moscow State University.

Most of Abrikosov's work has concerned the theory of solids, including metals, semimetals, semiconductors, and superconductors. For example, he discovered type-II superconductors (which, unlike type-I, remain superconducting in powerful magnetic fields) and explained their magnetic properties, which involves the so-called *Abrikosov vortex lattice*. He continued his research in Argonne, discovering quantum magnetoresistance in certain silver compounds and studying high-temperature superconductors. Such materials have practical applications in medical magnetic resonance imaging (MRI) equipment and particle accelerators. During his long career in science he has received many honors and awards. In 2003 he shared the Nobel Prize for physics with Vitaly GINZBURG and Anthony LEGGETT for their pioneering work on superconductors and superfluids.

Adams, John Couch (1819–1892) *British astronomer*

Adams was born in the small Cornish town of Launceston in the west of England, where his father was a tenant farmer. He developed an early interest in astronomy, constructing his own sundial and observing solar altitudes, and pursuing his astronomical studies in the local Mechanics Institute. He graduated brilliantly from Cambridge University in 1843, and became Lowndean Professor of Astronomy and Geometry in 1858; in 1860 he was appointed director of the Cambridge Observatory.

His fame rests largely on the dramatic events surrounding the discovery of the planet Neptune in 1846. Astronomers had detected a discrepancy between the observed and predicted positions of Uranus and thus it appeared that either NEWTON's theory of gravitation was not as universal as had been supposed, or there was an as yet undetected body exerting a significant gravitational influence over the orbit of Uranus. There is evidence that Adams had decided to work on this problem as early as 1841. He had a general solution to the problem by 1843 and a complete solution by September 1845. It was then that he visited George AIRY, the Astronomer Royal, with a prediction of the exact position of the new planet.

Airy gave little attention to it and was moved to action only when, in June 1846, the French astronomer, Urbain LE VERRIER, also announced the position of a new planet. It was within one degree of the position predicted by Adams the previous year. Airy asked James Challis, director of the Cambridge Observatory, to start looking for the new planet with his large 25-inch (63.5-cm) refractor. Unfortunately Challis decided to cover a much wider area of the sky than was necessary and also lacked up-to-date and complete charts of the area. His start was soon lost and Johann GALLE in Berlin had no difficulty in discovering the planet on his first night of observation. All the fame, prizes, and honors initially went to Le Verrier.

When it was publicly pointed out, by Challis and John HERSCHEL, that Adams's work had priority over Le Verrier's, the shy Adams wanted no part of the controversy that followed. In fact he seemed genuinely uninterested in honors. He declined both a knighthood and the post of Astronomer Royal, which was offered him after Airy's retirement in 1881. He later worked on the planetary perturbations (1866), and on the secular variation of the mean motion of the Moon (1852), both difficult questions of mathematical astronomy. His scientific papers were published by his brother in two volumes, in 1876 and 1901.

Adams, Roger (1889–1971) *American organic chemist*

Born in Boston, Massachusetts, Adams studied chemistry at Harvard, where he obtained his PhD in 1912, and at the University of Berlin. After working briefly at Harvard he joined the staff of the University of Illinois in 1916 and later served as professor of organic chemistry from 1919 until his retirement in 1957.

Adams developed a simple but effective method for catalyzing the hydrogenation of unsaturated organic compounds using finely divided platinum or palladium dioxides, which were reduced to the metal. He also worked out the structure of a number of naturally occurring physiologically active compounds, such as chaulmoogra oil (which was used to treat leprosy) and gossypol (a poisonous constituent of animal feedstuffs derived from cotton). In the late 1930s Adams was asked by the American Narcotics Bureau to examine the chemistry of the marijuana alkaloids and he succeeded in isolating and identifying the active ingredient, tetrahydrocannabinol.

Adams, Walter Sydney (1876–1956) *American astronomer*

> Professor Adams has … killed two birds with one stone. He has carried out a new test of Einstein's general theory of relativity, and he has shown that matter at least 2,000 times denser than platinum is not only possible, but actually exists in the stellar universe.
> —Sir Arthur Eddington, *Stars and Atoms* (1927)

Adams was born in Antioch (now in Turkey). He was the son of missionaries working in Syria, then part of the Ottoman Empire, who returned to America in 1885. Adams graduated from Dartmouth College in 1898 and obtained his MA from the University of Chicago in 1900. After a year in Munich he began his career in astronomy as assistant to George HALE in 1901 at the Yerkes Observatory. He moved with Hale to the newly established Mount Wilson Observatory in 1904 where he served as assistant director, 1913–23, and then as director from 1923 until his retirement in 1946.

At Mount Wilson Adams was able to use first the 60-inch (1.5-m) and from 1917 the 100-inch (2.5-m) reflecting telescopes in whose design and construction he had been closely associated. His early work was mainly concerned with solar spectroscopy, when he studied sunspots and solar rotation, but he gradually turned to stellar spectroscopy. In 1914 he showed how it was possible to distinguish between a dwarf and a giant star merely from their spectra. He also demonstrated that it was possible to determine the luminosity, i.e., intrinsic brightness, of a star from its spectrum. This led to Adams introducing the method of spectroscopic parallax whereby the luminosity deduced from a star's spectrum could be used to estimate its distance. The distances of many thousands of stars have been calculated by this method.

He is however better known for his work on the orbiting companion of Sirius, named Sirius B. Friedrich BESSEL had first shown in 1844 that Sirius must have a companion and had worked out its mass as about the same as our Sun. The faint star was first observed telescopically by Alvan CLARK in 1862. Adams succeeded in obtaining the spectrum of Sirius B in 1915 and found the star to be considerably hotter than the Sun. Adams realized that such a hot body, just eight light-years distant, could only remain invisible to the naked eye if it was very much smaller than the Sun, no bigger in fact than the Earth. In that case it must have an extremely high density, exceeding 100,000 times the density of water. Adams had thus discovered the first "white dwarf" – a star that has collapsed into a highly compressed object after its nuclear fuel is exhausted.

If such an interpretation was correct then Sirius B should possess a very strong gravitational field. According to Einstein's general theory of relativity, this strong field should shift the wavelengths of light waves emitted by it toward the red end of the spectrum. In 1924 Adams succeeded in making the difficult spectroscopic observations and did in fact detect the predicted red shift, which confirmed his own account of Sirius B and provided strong evidence for general relativity.

Addison, Thomas (1793–1860) *British physician*

Addison, who was born in Longbenton, near Newcastle upon Tyne, England, graduated in medicine from Edinburgh University in 1815 and soon afterwards moved to practice in London. He entered Guy's Hospital in 1817, was appointed assistant physician in 1824, and later became physician and joint lecturer with Richard BRIGHT, an eminent contemporary.

Addison was the first to describe, in 1849, the disease caused by pathological changes in the adrenal (suprarenal) glands, which is now known as *Addison's disease*. He described the characteristic anemia, bronzed skin, and other symptoms in his famous paper, *On the Constitutional and Local Effects of Disease of the Supra-Renal Capsules* (1855), and distinguished it from another form of anemia, now called pernicious anemia, which results from other causes entirely. This is sometimes called *Addisonian anemia*.

Addison also wrote papers concerning tuberculosis, skin diseases, the anatomy of the lung, and other topics, which were published in a collected edition in 1868. He collaborated with Bright in writing *Elements of the Practice of Medicine* (1839) of which only the first volume was completed.

An eloquent if rather aloof lecturer, Addison's fame as a physician came largely after his death.

Adhemar, Alphonse Joseph (1797–1862) *French mathematician*

Adhemar (ad-ay-**mar**), who was born and died in Paris, France, was a private mathematics tutor who also produced a number of popular mathematical textbooks.

His most important scientific work was his *Les Revolutions de la mer* (1842; The Upheavals of the Sea) in which he was the first to propose a plausible mechanism by which astronomical events could produce ice ages on Earth. It had been known for some time that while the Earth moved in an elliptical orbit around the Sun it also rotated about an axis that was tilted to its orbital plane. Because the orbit is elliptical and the Sun is at one focus, the Earth is closer to the Sun at certain times of year. As a result, the southern hemisphere has a slightly longer winter than its northern counterpart. Adhemar saw this as a possible cause of the great Antarctic icesheet for, as this received about 170 hours less solar radiation per year than the Arctic, this could just be sufficient to keep temperatures cold enough to permit the ice to build up.

Adhemar was also aware that the Earth's axis does not always point in the same direction but itself moves around a small circular orbit every 26,000 years. Thus he postulated a 26,000-year cycle developing in the occurrence of glacial periods, but his views received little support.

Adler, Alfred (1870–1937) *Austrian psychologist*

> It is one of the triumphs of human wit...to conquer by humility and submissiveness...to cause pain to others by one's own suffering,...to make oneself small in order to appear great...such are often the expedients of the neurotic.
> —*The Neurotic Constitution* (1912)

Adler (**ad**-ler or **ahd**-ler) was born in Penzing, Austria, the son of a corn merchant, and was educated at the University of Vienna, where he obtained his MD in 1895. After two years at the Vienna General Hospital he set up in private practice in 1898.

In about 1900 Adler began investigating psychopathology and in 1902 he became an original member of Sigmund FREUD's circle, which met to discuss psychoanalytical matters. His disagreements with Freud began as early as 1907 – he dismissed Freud's view that sexual conflicts in early childhood cause mental illness – and he finally broke away from the psychoanalytic movement in 1911 to form his own school of individual psychology. Adler tended to minimize the role of the unconscious and sexual repression and instead to see the neurotic as overcompensating for his or her "inferiority complex," a term he himself introduced. His system was fully expounded in his *Practice and Theory of Individual Psychology* (1927). In 1921 Adler founded his first child-guidance clinic in Vienna, which was to be followed by over 30 more before the Nazi regime in Vienna forced their closure in 1932. From 1926 onward he began to spend more and more time in America, finally settling there permanently in 1932 and taking a professorship of psychiatry at the Long Island College of Medicine, New York, a post he retained until his death from a heart attack while lecturing in Aberdeen in Scotland.

Adrian, Edgar Douglas, Baron Adrian of Cambridge (1889–1977) *British neurophysiologist*

Adrian, a lawyer's son, was born in London and studied at Cambridge University and St. Bartholomew's Hospital, London, where he obtained his MD in 1915. He returned to Cambridge in 1919, was appointed professor of physiology in 1937, and became the master of Trinity College, Cambridge, in 1951, an office he retained until his retirement in 1965. He was raised to the British peerage in 1955.

Adrian's greatest contribution to neurophysiology was his work on the nerve impulse. When he began it was known that nerves transmit nerve impulses as signals, but knowledge of the frequency and control of such impulses was minimal. The first insight into this process came from Adrian's colleague Keith LUCAS, who demonstrated in 1905 that the impulse obeyed the "all-or-none" law. This asserted that below a certain threshold of stimulation a nerve does not respond. However, once the threshold is reached the nerve continues to respond by a fixed amount however much the stimulation increases. Thus increased stimulation, although it stimulates more fibers, does not affect the magnitude of the signal itself.

It was not until 1925 that Adrian advanced beyond this position. By painstaking surgical techniques he succeeded in separating individual nerve fibers and amplifying and recording the small action potentials in these fibers. By studying the effect of stretching the sternocutaneous muscle of the frog, Adrian demonstrated how the nerve, even though it transmits an impulse of fixed strength, can still convey a complex message. He found that as the extension increased so did the frequency of the nerve impulse, rising from 10 to 50 impulses per second. Thus he concluded that the message is conveyed by changes in the frequency of the discharge. For this work Adrian shared the 1932 Nobel Prize for physiology or medicine with Charles SHERRINGTON.

Aganice (Aglaonike or **Aglaonice**) (*fl.* ?3rd–1st century BC) *Egyptian sorceress*

Aganice was a natural philosopher and sorceress who is said to have originated from Thessaly in Greece and been associated with the court of the Pharaoh Sesostris III (ruled 1878–1843 BC) in ancient Egypt. However, there is no hard evidence for this, and some modern authors assert that she may have lived much earlier, or simply belong to the canon of ancient mythology. Her status stemmed from a supposed ability to predict lunar and solar eclipses, and to convince gullible audiences that she had the power to make the Moon disappear. According to the Greek biographer Plutarch, she was the daughter of Hegetor and "thoroughly conversant with the periods of the Full Moon when it is subject to eclipse, and knowing beforehand when the Moon was due to be overtaken by the Earth's shadow, imposed upon audiences of women and made them all believe that she drew down the Moon." Some modern astronomers have taken this as evidence for a series of dark lunar eclipses in the first century BC, whereas others dispute that such eclipses were common, casting doubt on the credibility of Aganice's reputation. In any case, her name is lent to a Greek expression for a braggart: "Yes, as the Moon obeys Aganice."

Agassiz, Jean Louis Rodolphe (1807–1873) *Swiss–American biologist*

> The world has arisen in some way or another. How it originated is the great question, and Darwin's theory, like all other attempts to explain the origin of life, is thus far merely conjectural. I believe he has not even made the best conjecture possible in the present state of our knowledge.
> —*Evolution and Permanence of Type* (1874)

Generally considered the foremost naturalist of 19th-century America, Agassiz (**ag**-a-see) was born in Motier-en-Vuly, Switzerland. He was educated at the universities of Zurich, Heidelberg, and Munich, where he studied under the embryologist Ignaz DÖLLINGER. At the instigation of Georges CUVIER, he cataloged and described the fishes brought back from Brazil by C. F. P. von Martius and J. B. von Spix (*Fishes of Brazil*, 1929), following this with his *History of the Freshwater Fishes of Central Europe* (1839–42) and an extensive pioneering work on fossil fishes, which eventually ran to five volumes: *Recherches sur les poissons fossiles* (1833–43; Researches on Fossil Fishes). These works, completed while Agassiz was professor of natural history at Neuchâtel (1832–46), established his reputation as the greatest ichthyologist of his day. Agassiz's best-known discovery, however, was that of the Ice Ages. Extensive field studies in the Swiss Alps, and later in America and Britain, led him to postulate glacier movements and the former advance and retreat of ice sheets; his findings were published in *Etudes sur les glaciers* (1840; Studies on Glaciers).

A successful series of lectures given at Boston, Massachusetts, in 1846 led to his permanent settlement in America. In 1847 he was appointed professor of zoology and geology at Harvard, where he also established the Museum of Comparative Zoology (1859). Agassiz's subsequent teachings introduced a departure from established practice in emphasizing the importance of first-hand investigation of natural phenomena, thus helping to transform academic study in America. His embryological studies led to a recognition of the similarity between the developing stages of living animals and complete but more primitive species in the fossil record. Agassiz did not, however, share Darwin's view of a gradual evolution of species, but, like Cuvier, considered that there had been repeated separate creations and extinctions of species – thus explaining changes and the appearance of new forms. Unfortunately, one of Agassiz's most influential pronouncements was that there were several species, as distinct from races, of man: an argument used by slavers to justify their subjugation of Black people as an inferior species. His ambitious *Contributions to the Natural History of the United States* (4 vols., 1857–62) remained uncompleted at his death.

Agre, Peter (1949–) *American cell biologist*

Agre was born in Northfield, Minnesota, and in 1970 gained his BA in chemistry from Augsburg College, Minneapolis. He then switched to medicine and attended Johns Hopkins University School of Medicine in Baltimore, where he qualified as MD in 1974. He spent his medical residency at Case Western University and gained a clinical fellowship at the University of North Carolina at Chapel Hill. He then returned to Johns Hopkins for a research fellowship in the cell biology department, becoming a faculty member in the department of medicine in 1984. In 1993 he became professor of biological chemistry and professor of medicine at Johns Hopkins School of Medicine, specializing in blood disorders.

For body cells to function, there has to be a way in which substances such as water and various ions can pass through the wall of the cell to maintain an even pressure within it – the cell's outer membrane must contain pores. From the mid-1980s Agre's main area of research was to discover the nature of these pores and thus how water molecules cross the cell wall. In 1988 he isolated a protein from the outer membrane of red blood cells, and within two years he demonstrated that this protein forms a channel through which water molecules can travel. Agre named the protein *aquaporin*. The 1991 discovery is now known as aquaporin-1 and various other types of aquaporins have since been found in a wide range of other cells of bacteria, plants, and animals. At last there was an explanation of, for example, how osmosis takes place in plant cells and how blood cells in the kidney reabsorb water from primary urine. The discovery was important in the understanding and possible treatment of kidney disease. For his discovery of water channels in cells, Agre shared the 2003 Nobel Prize for chemistry with the American cell biologist Roderick MACKINNON, who had earlier discovered ion channels.

Agricola, Georgius (1494–1555) *German metallurgist*

Agricola (a-**grik**-o-la) was born Georg BAUER (**bow**-er) but, as was the custom of the day, he Latinized his name (Agricola and Bauer both mean "farmer"). Beyond his place of birth – Glauchau in Germany – little is known about him until his entry into the University of Leipzig in 1514. He later pursued his studies of philosophy and medicine in Italy at Bologna, Padua, and Venice (1523–27). In 1527 he was engaged as physician to the Bohemian city of Joachimsthal – the center of a rich mining area – moving in 1534 to another celebrated mining town, Chemnitz, near his birthplace. Here he became burgomaster in 1545. He wrote seven books on geological subjects but these were also so illuminating of other subjects that he was known in his lifetime as "the Saxon Pliny."

His most famous work, *De re metallica* (1556; On the Subject of Metals), concentrates on mining and metallurgy with a wealth of information on the conditions of the time, such as management of the mines, the machinery used (e.g., pumps, windmills, and water power), and the processes employed. The book is still in print having the unique distinction of being translated and edited (1912) by a president of the United States, Herbert Hoover, with Lou Henry Hoover (his wife).

Agricola is often regarded as the father of modern mineralogy. In the Middle Ages, the subject was based on accumulated lore from the Orient, the Arabs, and antiquity. Stones were believed to come in male and female form, to have digestive organs, and to possess medicinal and supernatural powers. Agricola began to reject these theories and to provide the basis for a new discipline. Thus in his *De ortu et causis subterraneorum* (1546; On the Origin and Cause of Subterranean Things) he introduced the idea of a lapidifying juice (or *succus lapidescens*) from which stones condensed as a result of heat. This fluid was supposedly subterranean water mixed with rain, which collects earthy material when percolating through the ground.

Agricola also, in *De natura fossilium* (1546; On the Nature of Fossils), introduced a new basis for the classification of minerals (called "fossils" at the time). Although far from modern, it was an enormous improvement on earlier works. Agricola based his system on the physical properties of minerals, which he listed as color, weight, transparency, taste, odor, texture, solubility, combustibility, and so on. In this way he tried to distinguish between earths, stones, gems, marbles, metals, building stone, and mineral solutions, carefully describing his terms, which should not be assumed to be synonymous with today's terms, in each case.

Aiken, Howard Hathaway (1900–1973) *American computer pioneer*

Born in Hoboken, New Jersey, Aiken graduated from the University of Wisconsin and began work with the Madison Gas and Engineering Company in 1923. He moved to Westinghouse Electric, Chicago, in 1927 but decided ten years later to pursue an academic career. He was awarded his Harvard PhD in 1939 and was immediately appointed to the faculty, becoming professor of applied mathematics and director of the computation laboratory in 1946, positions he held until his retirement in 1961.

In 1937 Aiken began to look for support to build an electromechanical calculator to reduce the time and effort spent in the numerical solution of differential equations. He obtained backing from IBM in 1939. The result, known as Harvard Mark 1 or ASCC (Automatic Sequence-Controlled Calculator), was completed in 1943. It was 8 feet tall, 50 feet long, weighed 5 tons, and contained 750,000 parts. The Mark 1, which operated decimally, was programmed by punched tape. It was driven by a long metal shaft, which was in turn operated by the main sequence-control mechanism. Consequently, it could calculate no faster than the speed of its mechanical parts. Although essentially obsolete at the time of its appearance, it continued in use. It was employed for calculating mathematical tables for a further sixteen years.

Aiken went on to build a larger Mark II version for the U.S. Navy in 1948. Two further machines were built by Aiken. Both of these were operated by electronic circuits, rather than mechanically: the Mark III in 1949, again for the Navy, and the Mark IV in 1952 for the Air Force.

Airy, Sir George Biddell (1801–1892)
British astronomer

> I had made considerable advance … in calculations on my favourite numerical lunar theory, when I discovered that, under the heavy pressure of unusual matters (two transits of Venus and some eclipses) I had committed a grievous error in the first stage of giving numerical value to my theory. My spirit in the work was broken, and I have never heartily proceeded with it since.
> —Describing his theoretical work on the orbital motion of the Moon

Airy, the son of a tax collector, was born in Alnwick in the north-east of England. He attended school in Colchester before going to Cambridge University in 1819. He met with early success, producing a mathematical textbook in 1826 and numerous papers on optics. He became Lucasian Professor of Mathematics at Cambridge in 1826 and two years later was made Plumian Professor of Astronomy and director of the Cambridge Observatory. In 1835 he was appointed Astronomer Royal, a post he held for 46 years.

Airy was a very energetic, innovative, and successful Astronomer Royal. He reequipped the observatory, installing an altazimuth for lunar observation in 1847, a new transit circle and zenith tube in 1851, and a 13-inch (33-cm) equatorial telescope in 1859. He created a magnetic and meteorological department in 1838, began spectroscopic investigations in 1868, and started keeping a daily record of sunspots with the Kew Observatory heliograph in 1873. In optics he investigated the use of cylindrical lenses to correct astigmatism (Airy was astigmatic) and examined the disklike image in the diffraction pattern of a point source of light (in an optical device with a central aperture) now called the *Airy disk*. Also named for him is his hypothesis of isostasy: the theory that mountain ranges must have root structures of lower density, proportional to their height, in order to maintain isostatic equilibrium.

Despite his many successes he is now mainly, and unfairly, remembered for his lapses. When John ADAMS came to him in September 1845, with news of the position of a new planet, Airy unwisely ignored him, leaving it to others to win fame as the discoverers of Neptune. He also dismissed Michael FARADAY's new field theory.

Aitken, Robert Grant (1864–1951) *American astronomer*

Born in Jackson, California, Aitken obtained his BA in 1887 and his MA in 1892 from Williams College, Massachusetts. He began his career at the University of the Pacific, then in San Jose, as professor of mathematics from 1891 until 1895 when he joined the staff of Lick Observatory, Mount Hamilton, California. He remained at Lick for his entire career, serving as its director from 1930 until his retirement in 1935.

Aitken did much to advance knowledge of binary stars, i.e., pairs of stars orbiting about the same point under their mutual gravitational attraction. He described over 3,000 binary systems and published in 1932 the comprehensive work *New General Catalogue of Double Stars Within 120° of the North Pole*. He also produced the standard work *The Binary Stars* (1918).

Akers, Sir Wallace Allen (1888–1954)
British industrial chemist

Akers, the son of a London accountant, was educated at Oxford University. He first worked for the chemical company Brunner Mond from 1911 to 1924 and, after four years in Borneo with an oil company, returned in 1928. By then Brunner Mond had become part of ICI. From 1931 he was in charge of the Billingham Research Laboratory and from 1944 was the company director responsible for all ICI research.

In World War II Akers worked under Sir John Anderson, the government minister responsible for work on the atom bomb. He was put in charge of Tube Alloys, the Ministry of Supply's front for secret nuclear work. It was Akers who led the mission of British scientists in 1943 to America to work out details of collaboration, although he proved unacceptable to the Americans and was replaced by James CHADWICK. Akers returned to head Tube Alloys in the UK.

After the war one of his main tasks was the setting up of the Central Research Laboratory for ICI at Welwyn near London, later named the Akers Research Laboratory. He was knighted in 1946.

Al-Battani (*or* **Albategnius**) (*c.* 858–929)
Arab astronomer

> Nobody is known in Islam who reached similar perfection in observing the stars and in scrutinizing their motions.
> —Ibn al-Qifti (13th century)

Al-Battani (al-ba-**tah**-nee) was the son of a maker of astronomical instruments in Harran (now in Turkey). He worked mainly in Raqqah on the Euphrates (now ar-Raqqah in Syria) and was basically a follower of PTOLEMY, devoting himself to refining and perfecting the work of his master. He improved Ptolemy's measurement of the obliquity of the ecliptic (the angle between the Earth's orbital and equatorial planes), the determination of the equinoxes, and the length of the year. He also corrected Ptolemy in various matters, in particular in his discovery of the movement of the solar perigee (the Sun's nearest point to the Earth) relative to the equinoxes. His work was widely known in the medieval period, having been translated by PLATO of Tivoli in about 1120 as *De motu stellarum* (On Stellar Motion), which was finally published in Nuremberg in 1537.

Albertus Magnus, St. (*c*. 1200–1280) *German scholastic philosopher*

Albert Magnus was the son of a German lord, his real name being Count von Bollstädt. Born in the south German town of Lauingen, he studied at the University of Padua and then became, in 1223, a member of the Dominican order against his family's wishes. He continued his studies throughout Europe and then taught theology. From about 1245 he lectured in Paris, where the philosopher and theologian Thomas Aquinas became one of his pupils, and in 1248 he was sent to Cologne to establish a Dominican study center, returning to Paris in 1254.

Albertus Magnus's voluminous writings, including treatises on theology, physics, and natural history, were generally Aristotelian in spirit, though he stressed the importance of direct observation of nature rather than strict adherence to textual authority. He also conducted alchemical experiments and in his *De mineralibus* (1569; On Minerals) he claimed to have tested alchemical gold "and found after six or seven ignitions that it was converted to powder."

He retired, in 1270, to his convent at Cologne. He was made a doctor of the Church and canonized in 1931.

Albinus, Bernhard Siegfried (1697–1770) *German anatomist*

Albinus (al-**bI**-nus) was born in Frankfurt an der Oder in Germany and was educated at the University of Leiden, where he subsequently held professorships in anatomy and surgery and later medicine. A popular lecturer on his subject, Albinus also carried out his own studies of human anatomy, and is chiefly known for his detailed classification of contemporary and traditional knowledge in this field. He published, with his former teacher Hermann BOERHAAVE, the complete works of Andreas VESALIUS, and also edited a new edition of the works of Hieronymus FABRICIUS. His own work, in which he emphasized the importance of illustrating the "anatomical norm," was published in 1747 in *Tabulae sceleti et musculorum corporis humani* (Plates of the Skeleton and Muscles of the Human Body), which contains numerous excellent drawings.

Albright, Arthur (1811–1900) *British chemist and industrialist*

Albright came from a Quaker family in the village of Charlbury, near Oxford, England. He was first apprenticed as an apothecary in Bristol and became a partner in the Birmingham firm of John and Edward Sturge, manufacturing chemists. In 1844 the partners established a new plant at Selly Oak to produce white phosphorus for the match industry. This was manufactured from calcium phosphate, derived from imported bones, and sulfuric acid.

White phosphorus was a difficult material to handle, being toxic and spontaneously flammable. Another allotropic form – red phosphorus – was discovered in 1845 by Anton SCHRÖTTER. Albright bought the patents and improved the process for producing red phosphorus. A larger factory was opened at Oldbury. J. E. Lundström of Sweden showed, in 1855, how Albright's phosphorus could be used in the production of safety matches. In this system the chlorate was confined to the tip of the match and the phosphorus was used only on the box.

In 1855 Albright's partnership with the Sturges was dissolved and he joined with J. W. Wilson in the following year, eventually forming the chemical company Albright and Wilson.

Alcmaeon (about 450 BC) *Greek philosopher and physician*

Alcmaeon (alk-**mee**-on) was born in Croton (now Crotone in Italy). Details of his work come from the surviving fragments of his book and through references by later authors, including ARISTOTLE. He was probably influenced by the school of thought founded by PYTHAGORAS in Croton and originated the notion that health was dependent on maintaining a balance between all the pairs of opposite qualities in the body, i.e., wet and dry, hot and cold, etc. Imbalance of these qualities resulted in illness. This theory was later developed by HIPPOCRATES and his followers.

Alcmaeon performed dissections of animals and possibly of human cadavers also. He demonstrated various anatomical features of the eye and ear, including their connections with the brain, and correctly asserted that the brain was the control center of bodily functions and the seat of intelligence.

Alder, Kurt (1902–1958) *German organic chemist*

Alder (**ahl**-der), who was born in Königshütte, Germany (now Chorzów in Poland), studied chemistry in Berlin and Kiel, receiving his doctorate in 1926 under Otto DIELS. In 1928 Diels and Alder discovered an important type of organic chemical reaction in which a compound containing two double carbon–carbon bonds separated by a single carbon–carbon bond adds to a compound containing a double carbon–carbon bond. The resulting molecule contains an aromatic ring structure with alternating double and single bonds. Alder was professor of chemistry at Kiel (1934), chemist with I. G. Farben at Leverkusen (1936), and director of the Chemical Institute at the University of Cologne (1940). In 1950 Diels and Alder jointly received the Nobel Prize for chemistry for their discovery of what is now known as the Diels–Alder reaction.

Aldrovandi, Ulisse (1522–1605) *Italian naturalist*

Aldrovandi (al-droh-**van**-dee) was educated at Bologna (where he was born and died) and Padua, where he obtained a medical degree in 1553. He was professor of botany and natural history at Bologna and in 1567 founded the Bologna Botanic Gardens. Under the patronage of popes Gregory XIII and Sixtus V, Aldrovandi traveled over a great part of Europe observing natural phenomena and collecting specimens, which he planned to incorporate in a multivolume natural history. Only four volumes appeared during his lifetime, *Ornithologiae* (3 vols., 1599; Ornithology), and *De animalibus insectis* (1602; On Insects). Other volumes appeared posthumously and include works on fish and whales (1613), monsters (1640), serpents and dragons (1640), and quadrupeds (1613; 1616; 1621; 1637).

Aldrovandi was in no sense a modern zoologist. The many-headed hydra and the basilisk appear on his pages along with cows and goats. Further, while he could write at great length about creatures, 31 pages for example on the peacock, little of this would be recognized today as relevant to zoology. Much of the material is linguistic, covering the names of, for example, the peacock in various languages together with synonyms for the bird and its use in proverbs. Much also is concerned with the emblematic appearance and significance as it is found on coins, medals, and coats of arms.

Alembert, Jean Le Rond d' *See* D'ALEMBERT, JEAN LE ROND.

Alferov, Zhores Ivanovich (1930–) *Russian physicist*

Alferov (**al**-fe-rof) was born in Vitebsk, Belorussia (then part of the Soviet Union), and educated at the Lenin Electrochemical Institute in St. Petersburg (then Leningrad). Since 1953 he has been a staff member of the A. F. Ioffe Physico-Technical Institute in St. Petersburg, being director from 1987 to the present time. Since 1995 Alferov has also been a member of the Russian parliament (the Duma), being reelected in 2007 as a member of the Communist Party.

Since the early 1960s Alferov has been one of the leading figures in the development of the physics and technology of layered semiconductor structures known as semiconductor heterostructures, including applications to lasers, solar cells, and light-emitting diodes (LED). This work has had a major impact on information technology because it has enabled information systems based on semiconductor heterostructures to be built that have the desirable features of being both fast and very small. It is necessary for information systems to be fast because large amounts of information have to be transferred in a short time. It is very useful for information systems to be small so that they can then be used in homes, offices, or even briefcases or pockets.

Fast small transistors based on semiconductor heterostructures have many technological applications, including radio-link satellites and the base stations of mobile telephones. The same type of technology is used in the laser diodes that drive the flow of information in the fiber-optical cables used in the Internet. Other technological applications of semiconductor heterostructures include CD players, bar-code readers, and light-emitting diodes.

Alferov has been awarded many prizes for his pioneering work in semiconductor heterostructures, culminating in the Nobel Prize for physics in 2000, which he shared with Herbert KROEMER and Jack KILBY for their related work.

Alfvén, Hannes Olof Gösta (1908–1995) *Swedish physicist*

Alfvén (**al**-ven), who was born in Norrkoeping, Sweden, was educated at the University of Upsala where he received his PhD in 1934. He subsequently worked at the Royal Institute of Technology, Stockholm, where he served as professor of the theory of electricity (1940–45), professor of electronics (1945–63), and professor of plasma physics (1963–73).

Alfvén is noted for his pioneering theoretical research in the field of magnetohydrodynamics – the study of conducting fluids and their interaction with magnetic fields. This work, for which he shared the 1970 Nobel Prize for physics with Louis NEEL, was mainly concerned with plasmas, i.e., ionized gases containing positive and negative particles. He investigated the interactions of electrical and magnetic fields and showed theoretically that the magnetic field, under certain circumstances, can move with the plasma. In 1942 he postulated the existence of waves in plasmas; these *Alfvén waves* were later observed in both liquid metals and ionized plasmas.

Alfvén also applied his theories to the motion of particles in the Earth's magnetic field and to the properties of plasmas in stars. In 1942, and later in the 1950s, he developed a theory of the origin of the solar system. This he assumed to have formed from a magnetic plasma, which condensed into small particles that clustered together into larger bodies. His work is also applicable to the properties of plasmas in experimental nuclear fusion reactors. Alfvén's books include *Cosmical Electrodynamics* (1950), which collects his early work, *On the Origin of the Solar System* (1954), and *On the Evolution of the Solar System* (1976, with G. Arrhenius).

In his later years Alfvén argued against the current orthodoxy of the big-bang theory of the origin of the universe. Space, he argued, is full of immensely long plasma filaments. The electromagnetic forces produced have caused the plasma to condense into galaxies. As for the expansion of the universe, he attributed this to the energy released by the collision of matter and antimatter. Whereas Alfvén's critics charged him with vagueness, he responded by arguing that cosmologists derive their theories more from mathematical considerations than from laboratory experiments.

Alhazen (*or* **Abu Ali Al-Hassan Ibn Al Haytham**) (*c*. 965–1038) *Arabian scientist*

> Now the known things are of five kinds: the known in number, the known in magnitude, the known in ratio, the known in position, and the known in species … In the examples of analysis we give in the present treatise we shall prove the known things used, whether or not we have found them in other works.
> —*Opticae Thesaurus* (1572; The Treasury of Optics)

Born in Basra (now in Iraq), Alhazen (al-ha-**zen**) was one of the most original scientists of his time. About a hundred works are attributed to him; the main one was translated into Latin in the 12th century and finally published in 1572 as *Opticae Thesaurus* (The Treasury of Optics). This was widely studied and extremely influential. It was the first authoritative work to reject the curious Greek view that the eye sends out rays to the object looked at. Alhazen also made detailed measurements of angles of incidence and refraction. He studied spherical and parabolic mirrors, the camera obscura, and the role of the lens in vision. While the Greeks had had a good understanding of the formation of an image in a plane mirror, Alhazen tackled the much more difficult problem of the formation of images in spherical and parabolic mirrors and offered geometrical solutions. It is difficult to think of any other writer who had surpassed the Greeks in any branch of the exact sciences by the 14th let alone the 11th century. He was, however, unfortunate in his relationship with the deranged caliph al-Hakim. Having rashly claimed that he could regulate the flooding of the Nile, he was forced to simulate madness to escape execution until the caliph died in 1021.

Al-Khwarizmi, Abu Ja'far Muhammad Ibn Musa (*c*. 800–*c*. 847) *Arab mathematician, astronomer, and geographer*

> With my two algorithms, one can solve all problems – without error, if God wills it!
> —*Algebra*

Al-Khwarizmi (al-**kwah**-riz-mee) takes his name from his birthplace, Khwarizm (now Khiva in Uzbekistan). His importance lies chiefly in the knowledge he transmitted to others. Very little is known about his life except that he was a member of the academy of sciences in Baghdad, which flourished during the rule (813–33) of caliph al-Ma'mun. Al-Khwarizmi's main astronomical treatise and his chief mathematical work, the *Algebra*, are dedicated to the caliph. The *Algebra* enlarged upon the work of DIOPHANTUS and is largely concerned with methods for solving practical computational problems rather than algebra as the term is now understood. Insofar as he did discuss algebra, al-Khwarizmi confined his discussion to equations of the first and second degrees.

His astronomical work, *Zij al-sindhind*, is also based largely on the work of other scientists. As with the *Algebra*, its chief interest is as the earliest Arab work on the subject still in existence.

Al-Khwarizmi's other main surviving works are a treatise on the Hindu system of numerals and a treatise on geography. The Hindu number system, with its epoch-making innovations, for example the incorporation of a symbol for zero, was introduced to Europe via a Latin translation (*De numero indorum*; On the Hindu Art of Reckoning) of al-Khwarizmi's work. Only the Latin translation remains but it seems certain that al-Khwarizmi was the first Arab mathematician to expound the new number system systematically. The term "algorithm" (a rule of calculation) is a corrupted form of his name. His geographical treatise marked a considerable improvement over earlier work, notably in correcting some of the influential errors and misconceptions that had gained currency owing to PTOLEMY's *Geography*.

Allbutt, Sir Thomas Clifford (1836–1925) *British physician and medical historian*

Allbutt was born in Dewsbury in Yorkshire, England, and studied natural sciences at Cambridge University, graduating in 1860. He then studied medicine at St. George's Hospital, London, gaining his MB in 1861. He was appointed physician to Leeds General Infirmary in 1864 where, in 1866, he invented the short clinical thermometer, which was a great advance on previous highly cumbersome instruments. His major interest was cardiology and he was the first to describe the effects of syphilis on the cerebral arteries. His *System of Medicine* (8 vols. 1896–99) became an important medical text. In 1892 he was appointed professor of medicine at Cambridge, where he lectured and wrote several notable works on the history of medicine, including *Greek Medicine in Rome* (1921).

Allen, Edgar (1892–1943) *American endocrinologist*

Allen, the son of a physician, was born in Canon City, Colorado, and educated at Brown University. After war service he worked at Washington University, St. Louis, before being appointed (1923) to the chair of anatomy at the University of Missouri. In 1933 he moved to a similar post at Yale and remained there until his death.

In 1923 Allen, working with Edward DOISY, began the modern study of the sex hormones. It was widely thought that the female reproductive cycle was under the control of some substance found in the corpus luteum, the body formed in the ovary after ovulation. Allen thought rather that the active ingredient was probably in the follicles surrounding the ovum. To test this he made an extract of the follicular fluid and found that on injection it induced the physiological changes normally found only in the estrous cycle. Allen had in fact discovered estrogen although it was only identified some six years later by Adolf BUTENANDT.

Allen, James Alfred Van *See* VAN ALLEN, JAMES ALFRED.

Alpher, Ralph Asher (1921–2007) *American physicist*

Alpher was born in Washington, DC, and educated there at George Washington University; he obtained his BS in 1943 and his PhD in 1948. He spent the war as a physicist with the U.S. Navy's Naval Ordnance Laboratory in Washington followed by a period (1944–55) with the applied physics laboratory of Johns Hopkins University, Baltimore. In 1955 Alpher joined the staff of the General Electric Research and Development Center, Schenectady, New York, remaining with them until his retirement in 1986.

At George Washington, Alpher came under the influence of the physicist George GAMOW with whom he collaborated in a number of papers. They produced, with Hans BETHE, a major paper on the origin of the chemical elements, sometimes called the *Alpher–Bethe–Gamow theory*, which was incorporated into Gamow's modern form of the big-bang theory of the origin of the universe, published in 1948. It is said that Bethe's name was added to make the title sound like "alpha-beta-gamma," the first three letters of the Greek alphabet. In the theory it was supposed that the universe was initially very hot and dense and was composed entirely of neutrons. The neutrons decayed to protons (hydrogen nuclei), which could then capture neutrons to form deuterium nuclei. A further series of reactions produced helium. It was also proposed that a further succession of reactions, mainly the capture of neutrons, could produce other elements. Calculations on the abundance of the elements as predicted by the theory were performed by Alpher and Robert C. Herman. Although it is accepted that hydrogen and helium were indeed formed in the primitive universe by such a process, heavier elements are now known to be synthesized in the stars.

The same year, 1948, saw the publication of a remarkable paper by Alpher and Herman in which they predicted that the big bang should have produced intense radiation that gradually lost energy as the universe expanded and by now would be characteristic of a temperature of about 5 kelvins (–268°C). Unlike its later and independent formulation by Robert DICKE in 1964, the 1948 paper had surprisingly little impact. Alpher did approach a number of radar experts but was informed that it was then impossible to detect such radiation. When it was discovered by Arno PENZIAS and Robert WILSON in 1964–65 its effect was to initiate a major revolution in cosmology and astrophysics.

In 1953 Alpher and James Follin performed calculations that took account of the change in the relative numbers of protons and neutrons in the early Universe. This has been described as one of the first modern attempts to analyze the early history of the Universe. In 2001 Alpher and Herman published a book, *Genesis of the Big Bang*, on their work together and with Gamow on this topic.

Alpini, Prospero (1553–1617) *Italian botanist and physician*

Alpini (al-**pee**-nee), who was born in Venice, Italy, studied medicine at Padua University, receiving his MD in 1578. He became physician to Giorgio Emo, the Venetian consul in Egypt, and between 1580 and 1583 traveled widely in Egypt and the Greek Islands. This enabled him to make an extensive study of the Egyptian and Mediterranean floras, and he was the first European to describe the coffee and banana plants and a genus of the ginger family, later named *Alpinia*. He also studied the date palm and was the first to fertilize dates artificially, having realized that this palm has separate male and female trees. In 1593 Alpini was appointed professor of botany at Padua and he also became director of the Botanic Gardens there, introducing many Egyptian plants.

Alter, David (1807–1881) *American inventor and physicist*

Alter was born in Westmoreland County, Pennsylvania. Largely self-taught, he graduated from the Reformed Medical College in New York in 1831. During his lifetime Alter experimented at home using apparatus constructed by himself. He worked on a wide range of subjects but was little recognized for his achievements. His best work was on spectrum analysis, suggesting that each element had its own characteristic spectrum that would enable qualitative analysis to be carried out. This was later proved correct by Gustav KIRCHHOFF and Robert BUNSEN. Alter's inventions included a new method for purifying bromine, a process for obtaining oil from coal, an electric clock, and an electric telegraph that would spell out words with the aid of a pointer.

Altman, Sidney (1939–) *American chemist*

Born in Montreal, Canada, Altman was educated at the University of Colorado, Boulder, where he obtained his PhD in 1967. He moved to Yale in 1971, becoming professor of biology in 1980 and a naturalized U.S. citizen in 1984.

In 1982 Thomas CECH at Colorado had shown that RNA sometimes served as a biocatalyst – a role previously thought to be exclusive to protein enzymes. Cech's work was on a reaction in which the RNA was a self-catalyst. Altman set out to investigate other catalytic activity of RNA.

He worked with ribonuclease-P, an enzyme composed of both RNA and a protein, which catalyzes the processing of transfer RNA (tRNA). For the enzyme to work at the cellular level, it was thought that both protein and RNA were needed. It could, however, be possible that the RNA was merely a kind of structural support for the protein enzyme. Altman found that, *in vitro*, ribonuclease-P alone could splice the tRNA molecule at the correct place; the unaccompanied protein displayed no such activity.

Final proof came when a recombinant DNA template was used to produce only the RNA part of the ribonuclease-P. The artificial RNA still catalyzed the appropriate activity without any associated protein whatsoever. Altman had thus helped to break down the previously unquestioned dogma that molecules could either carry information, like RNA, or catalyze chemical reactions, like proteins, but they could not do both. The discovery could also throw light on the puzzle that if proteins are needed to assemble RNA, and RNA to assemble proteins, then how did the process ever get started? The answer could lie in the catalytic activity of RNA itself.

For his work on ribonuclease-P Altman shared the 1989 Nobel Prize for chemistry with Thomas Cech.

Alvarez, Luis Walter (1911–1988) *American physicist*

> There is no democracy in physics. We can't say that some second-rate guy has as much right to opinion as Fermi.
> —Quoted by D. S. Greenberg in *The Politics of Pure Science* (1967)

Alvarez, the son of a research physiologist, was born in San Francisco and educated at the University of Chicago where he gained his PhD in 1936. He moved soon after to the University of California, Berkeley. Apart from wartime work on radar at the Massachusetts Institute of Technology Radiation Laboratory (1940–43) and on the Manhattan Project at Los Alamos (1943–45), Alvarez spent his entire career at Berkeley, serving as professor of physics from 1945 until his retirement in 1978.

In 1938 Alvarez reported his first major discovery, namely, the phenomenon of orbital electron capture. In 1936 Hans BETHE had argued that an excited nucleus could decay by capturing one of its own orbiting electrons, a process known as K-capture as the electron is taken from the innermost (K) electron shell. Alvarez succeeded in detecting the process experimentally by identifying the characteristic x-rays emitted during K capture as a result of electrons moving from outer orbits into the vacant K orbit.

Alvarez followed this by making (1939) the first measurement, with Felix BLOCH, of the neutron's magnetic moment. He also demonstrated that hydrogen-3 (tritium) was radioactive, work which proved to be of significance in the later development of the hydrogen bomb.

While working on radar during the war Alvarez had what he later described as one of his most valuable ideas. If radar could be used to track approaching aircraft then, he argued, the same information should be adequate to guide a pilot to a safe landing in bad weather. There were many obstacles to be overcome before GCA (Ground Controlled Approach) could be adopted. By early 1943, however, Alvarez was able to talk down a distant plane he could follow only on radar.

Soon after he moved to Los Alamos where he worked on the problem of detonating the bomb. It was necessary for 32 detonators to fire simultaneously. Alvarez was an observer in a follow-up plane of the Hiroshima bomb.

After the war Alvarez remained as creative as ever. His most important work was in the field of particle physics. By the early 1950s experimentalists had begun to find it difficult to track particles. Cloud chambers took too long to operate, emulsions could only pick up charged particles, and consequently much was being missed. In April 1953 Alvarez was introduced by Donald GLASER to the idea that particles passing through a small glass bulb containing diethyl ether would produce bubble tracks. The chamber operated by suddenly reducing the pressure causing the liquid to "boil" and leave a bubble track where a particle had passed.

Alvarez immediately began to design a much larger bubble chamber using liquid hydrogen as a fluid. After a few test runs with some small chambers Alvarez proposed to build a 72-inch model at a cost of $2.5 million. It first came into operation in March 1959 and was used to discover a large number of elementary particles. For his work in this field Alvarez was awarded the 1968 Nobel Prize for physics.

In 1962 Alvarez first saw the Giza pyramids in Egypt. Ever capable of seeing a problem calling for scientific analysis, he wondered if there were any hidden chambers in the Cephren pyramid as there were in the other Giza structures. If the pyramid was radiated with muons, more muons would pass through the less dense plane of a hidden chamber and would show up clearly on a scatter plot. After several years' persuasion of politicians and officials Alvarez's team made the appropriate measurement in 1968. At first it seemed that the pyramid contained a massive chamber and Alvarez excitedly made plans to tunnel into the tomb. Calculations quickly showed, however, that no such chamber could exist as it would have caused a collapse long ago. Eventually a computer error was detected. After several years' work Alvarez conceded that the Cephren pyramid was quite solid.

Pyramid archaeology was not the only excursion taken by Alvarez outside conventional physics. In 1977 his son Walt, a geologist, showed him a rock from Gubbio in the Italian Apennines. It was aged 65 million years and consisted of two layers of limestone, one from the Cretaceous, the other from the Tertiary, separated by a thin clay strip. During the rock's formation the dinosaurs had flourished and passed into extinction.

Alvarez was intrigued by the presence in the clay of unusually high concentrations of iridium. No more than about 0.03 parts per billion are normally to be found in the Earth's crust. The geologists, however, reported that there was 300 times as much iridium in the clay layer than in the surrounding limestone samples (an example of what is now known as the "iridium anomaly"). The clay, it was calculated, had formed over a mere 1,000 years, and was located in time at the KT boundary (K = *Kreide*, German for Cretaceous, T = Tertiary). Could the thin strip of clay and its iridium content throw any light on the mass extinctions that were taking place during its formation?

He first suggested that the iridium could have come from a nearby supernova explosion. This was soon rejected after a fruitless search in the clay for traces of plutonium–244, another supernova byproduct. Alvarez began to consider another possibility, namely, a collision with a large asteroid. It would certainly bring along with it the observed iridium, but it was not immediately apparent how the asteroid could produce a global extinction. Further reflection suggested that an asteroid 10 kilometers in diameter would throw sufficient dust into the atmosphere to darken the sky for several years. This in turn would prevent photosynthesis, destroy plant life and, along the way, all other dependent creatures.

Alvarez published his theory in 1980 and spent much of the remaining decade of his life explaining and defending his views. Some geologists objected that dinosaurs had become extinct some 20,000 years before the iridium layer was deposited. Others claimed that prolonged darkness would have been as damaging to marine as to terrestrial life, whereas marine life suffered no comparable mass extinction. Despite these and other objections Alvarez's impact theory survived the 1980s as the most favored account of the death of the dinosaurs.

Alvarez left a vivid account of his life in his *Alvarez, Adventures of a Physicist* (1987).

Alzheimer, Alois (1864–1915) *German psychiatrist*

Alzheimer (**ahlts**-hI-mer or **awlts**-hI-mer) was born in Markbreit in Germany and studied medicine at the universities of Würzburg and Berlin. After working in hospitals in Frankfurt and Heidelberg, he joined the Munich Psychiatric Clinic of Emil Kraepelin (1856–1926) as head of the anatomy department. He worked in Munich from 1904 until 1912 when he was appointed professor of psychiatry and neurology at the University of Breslau (now Wrocław in Poland).

In 1907 Alzheimer treated a 51-year-old woman with a growing memory loss. Her condition rapidly deteriorated into severe dementia. On autopsy, he identified a number of pathological conditions including shrinking of the cortex and the presence of neurofibrillary tangles and neuritic plaques. The plaques and tangles were distinctive enough to warrant a diagnosis of senile dementia or, as it later became known, *Alzheimer's disease*.

Amagat, Emile Hilaire (1841–1915) *French physicist*

Born at Saint-Satur, Amagat (am-a-**ga**) obtained his doctorate in 1872 from Paris and became a professor of physics at the Faculté Libre des Sciences at Lyons and eventually a full member of the French Academy of Sciences.

He is noted for his work on the behavior of gases. He started work plotting isotherms of carbon dioxide at high pressures, expanding the results of Thomas Andrews; this research was published in 1872 as his doctoral thesis. In 1877 followed a publication on the coefficient of compressibility of fluids, showing conclusively that this decreased with an increase in pressure, a result contradicting the results of other scientists. Between 1879 and 1882 Amagat investigated a number of gases, publishing data on isotherms and reaching the limit of pressures obtainable using glass apparatus – about 400 atmospheres. To get yet further Amagat invented a hydraulic manometer that could produce and measure up to 3200 atmospheres. (This manometer was later used in firearms factories for testing purposes.)

Amaldi, Edoardo (1908–1989) *Italian physicist*

Amaldi (am-**al**-dee) was born in Carpaneto in Italy; in 1929 he graduated from the University of Rome, where he had studied under Enrico FERMI. Together with Fermi and others he discovered that fast-moving neutrons are slowed down (moderated) by substances containing hydrogen, and can thus be brought to energies at which they more easily interact with nuclei. He also contributed to the study of tau mesons, hyperons, and antiprotons.

In 1937 he was made professor of general physics at the University of Rome, and from 1952 until 1954 he was secretary-general of the European Organization for Nuclear Research. He also served as president of the International Union of Pure and Applied Physics (1957–60) and president of the Istituto Nazionale di Fisica Nucleare (1960–65).

Amaldi played a key role in the creation and development of CERN (Conseil européen pour la Recherche nucléaire; European Laboratory for Particle Physics). On a visit to Europe in 1948 Luis ALVAREZ had asked Amaldi why the Europeans did not "do physics jointly" and build, as several American universities had done, a large accelerator. Amaldi began to lobby for such a project and persuaded a reluctant UK to enter, having overcome, in a stormy meeting, the strong objections of Lord Cherwell. When, in 1952, eleven governments set up CERN Amaldi was offered the post of director general. He refused, accepting instead the position of vice director in charge of administration, returned to his university post in 1954, and concentrated on research into the detection of gravitational waves.

Ambartsumian (*or* **Ambartsumyan), Viktor Amazaspovich** (1908–1996) *Armenian astrophysicist*

Ambartsumian (am-bart-**soo**-mee-an) was born in Tbilisi (now in Georgia), the son of a distinguished Armenian philologist. He graduated from the University of Leningrad in 1928 and did graduate work at Pulkovo Observatory, near Leningrad, from 1928 to 1931. He was professor of astrophysics from 1934 to 1946 at Leningrad and held the same post at the State University at Yerevan in Armenia from 1947 until his death. In 1946 he organized the construction, near Yerevan, of the Byurakan Astronomical Observatory, having been appointed its director in 1944. He remained as director until 1988.

Ambartsumian's work was mainly concerned with the evolution of stellar systems, both galaxies and smaller clusters of stars, and the processes taking place during the evolution of stars. The idea of a stellar "association" was introduced into astronomy by Ambartsumian in 1947. Associations are loose clusters of hot stars that lie in or near the disk-shaped plane of our galaxy. They must be young, no more than a few million years old, as the gravitational field of the galaxy will tend to disperse them. This must mean that star formation is still going on in the galaxy.

He also argued in 1955 that the idea of colliding galaxies proposed by Rudolph MINKOWSKI and Walter BAADE to explain such radio sources as Cygnus A would not produce the required energy. Instead, he proposed that the source of energy was gigantic explosions occurring in the dense central regions of galaxies and these would be adequate to provide the 10^{55} joules emitted by the most energetic radio sources.

Amdahl, Gene Myron (1922–) *American computer engineer*

The son of a South Dakota farmer, Amdahl was educated at South Dakota State College and, following war service, the University of Wisconsin, where he received his doctorate in 1952. Shortly after, he joined IBM to work on the design of their new mainframe computers, the 701, 704, and 709. Amdahl left IBM in 1955 in a disagreement over the minor role he had been assigned in the development of their new model, the 7030. He returned to IBM in 1960, after working for the Ford subsidiary Aeronautics on systems design, and began work on the IBM 360 series. This was one of the first models to incorporate integrated circuits and proved to be one of the most successful mainframes ever produced.

In 1965 Amdahl was made an IBM Fellow, a five-year appointment allowing him to work on any project he chose. During this period he founded the IBM Advanced Computing Systems Lab in Menlo Park, California.

Before the expiry of his fellowship Amdahl resigned once more. This time the disagreement arose over IBM's traditional policy of pricing mainframes on the basis of their computing power rather than their cost. Such an approach, Amdahl argued, gave IBM no incentive to build more powerful machines. In 1970 he founded the Amdahl Corporation with the aim of designing IBM-compatible mainframes. Large-scale integration chips were just coming into use and, while previously designers had struggled to link 25–30 circuits on a chip, Amdahl aimed to have 100. Within three years Amdahl's new computer, the Amdahl 470, three times more powerful than the IBM 360s but no more expensive at $3.5 million, had created sales of $320 million. IBM responded with price cuts and Amdahl consequently sold his company in 1979 to Fujitsu.

He immediately started his second company, Trilogy, using the new technology of wafer-scale integration which, in theory, should allow 2,000 chips to be replaced by 20 wafers. Amdahl was predicting sales of $1 billion within two years. The technology, however, was too new and the models proved to be less powerful than expected. They also had a tendency to short-circuit and came onto the market three years behind schedule. Amdahl left the mainframe business and conceded the market to IBM. Trilogy merged with Elxsi in 1985.

Amdahl subsequently founded other companies: Amdor International (in 1987) and Commercial Data Servers (in 1995). Since 2004 he has been on the board of advisors of Massively Parallel Technologies.

Amici, Giovanni Battista (1786–1863)
Italian astronomer and instrument maker

Amici (a-**mee**-chee) was professor of mathematics at the University of Modena and in 1835 became the director of the observatory at the Royal Museum in Florence. He made great improvements in the design of parabolic mirrors for reflecting telescopes, and constructed and designed prismatic spectroscopes. In 1840 he made two achromatic objective lenses with diameters of 9.5 and 11 inches (24 and 28 cm), which were used by Giovanni DONATI. He also made advances in microscopy, improving the compound microscope and using it to study plant reproduction.

Amontons, Guillaume (1663–1705)
French physicist

Amontons (a-mon-**ton**), a Parisian, who had been deaf since childhood, invented and perfected various scientific instruments. In 1687 he made a hygrometer (an instrument for measuring moisture in the air); in 1695 he produced an improved barometer; and in 1702–03 a constant-volume air thermometer. In 1699 he published the results of his studies on the effects of change in temperature on the volume and pressure of air. He noticed that equal drops in temperature resulted in equal drops in pressure and realized that at a low enough temperature the volume and pressure of the air would become zero – an early recognition of the idea of absolute zero. These results lay largely unnoticed and the relationship between temperature and pressure of gases was not reexamined until the next century (by scientists such as Jacques CHARLES).

Amontons also published in 1699 the results of his studies on friction, which he considered to be proportional to load.

Ampère, André Marie (1775–1836)
French physicist and mathematician

Ampère (ahm-**pair**) was born in Lyons, France, where his father was a wealthy merchant. He was privately tutored, and to a large extent self-taught. His genius was evident at an early age. He was particularly proficient at mathematics and, following his marriage in 1799 he was able to make a modest living as a mathematics teacher in Lyons. In 1802 he moved first to Bourg-en-Bresse to take up an appointment, then to Paris as professor of physics and chemistry at the Ecole Centrale.

His first publication was on the statistics of games of chance *Considérations sur la théorie mathématique de jeu* (1802; Considerations on the Mathematical Theory of Games) and his work at Bourg led to his appointment as professor of mathematics at the Lyceum of Lyons, and then in 1809 as professor of analysis at the Ecole Polytechnique in Paris. His talents were recognized by Napoleon, who in 1808 appointed him inspector general of the newly formed university system – a post Ampère held until his death.

Ampère's most famous scientific work was in establishing a mathematical basis for electromagnetism. The Danish physicist Hans Christian OERSTED had made the important experimental discovery that a current passing through a wire could cause the movement of a magnetic compass needle. Ampère witnessed a demonstration of electromagnetism by François ARAGO at the Academy of Science on 11 September 1820. He set to work immediately on his own investigations, and within seven days was able to report the results of his experiments.

In a succession of presentations to the academy in the next four months, he developed a mathematical theory to explain the interaction between electricity and magnetism, to which he gave the name "electrodynamics" (now more commonly: electromagnetism) to distinguish it from the study of stationary electric forces, which he christened "electrostatics."

Having recognized that electric currents in wires caused the motion of magnets, and that a magnet can affect another magnet, he looked for evidence that electric currents could influence other electric currents. The simplest example of this interaction is found by arranging for currents to flow through two parallel wires. Ampère discovered that if the currents passed in the same direction the wires were attracted to each other, but if they passed in opposite directions the wires were repelled. From this he went on to consider more complex configurations of closed loops, helices, and other geometrical figures, and was able to provide a mathematical analysis that allowed quantitative predictions.

In 1825 he had been able to deduce an empirical law of forces (*Ampère's law*) between two current-carrying elements, which showed an inverse-square law (the force decreases as the square of the distance between the two elements, and is proportional to the product of the two currents). By 1827 he was able to give a precise mathematical formulation of the law, and it was in this year that his most famous work *Mémoirs sur la théorie mathématique des phénomènes electrodynamiques uniquement déducte de l'expérience* (Notes on the Mathematical Theory of Electrodynamic Phenomena, Solely Deduced from Experiment) was published.

Besides explaining the macroscopic effects of electromagnetism, he attempted to construct a microscopic theory that would fit the phenomenon, and postulated an electrodynamic molecule in which electric-fluid currents circulated, giving each molecule a magnetic field.

In his honor, the unit of electric current is named for him, and in fact the ampere is defined in terms of the force between two parallel current-carrying wires.

Anaxagoras of Clazomenae (about 500 BC–428 BC) *Greek philosopher*

Anaxagoras (an-ak-**sag**-o-rus) left his birthplace in Asia Minor (now Turkey) in about 480 BC and taught in Athens during its most brilliant period under Pericles, who was himself one of Anaxagoras's pupils. In about 450 BC he was exiled to Lampsacus after being prosecuted for impiety by the enemies of Pericles.

Although he wrote a book, *On Nature*, only fragments of his writings survive; his work is known through later writers, notably ARISTOTLE and Simplicius, and is open to contradictory interpretations. The difficulty consists in reconciling his principle of homoemereity, which states that matter is infinitely divisible and retains its character on division, with his statement "there is a portion of everything in everything." His work can be seen as a criticism of the Eleatic school of PARMENIDES and ZENO of Elea, who had argued against plurality and even motion.

Anaxagoras's astronomy was more rational than that of his predecessors; he stated that the Sun and stars were incandescent stones, that the Moon derived its light from the Sun, and he gave the modern explanation for eclipses of the Sun and Moon.

Anaximander of Miletus (*c*. 611 BC–*c*. 547 BC) *Greek philosopher*

> Anaximander...said that a certain infinite nature is first principle of the things that exist. From it come the heavens and the worlds in them.
> —Hippolytus, *Refutation of All Heresies* (2nd century AD)

Anaximander (a-nak-si-**man**-der), who was born and died in Miletus (now in Turkey), belonged to the first school of natural philosophy and was the pupil of THALES. He wrote one of the earliest treatises but none of his writings survive and his work is known only through later writers, notably ARISTOTLE and THEOPHRASTUS.

Anaximander criticized Thales's idea that water was the basic element of the universe by pointing out that no one element gains the upper hand and that "they make retribution and pay the penalty to one another … according to the ordering of time." From this he deduced that the primal matter was what he called the *apeiron* or the indefinite. This idea was later developed by the atomists. He was the first to realize that the Earth did not have to float on water or be supported in any way; he stated that it was in equilibrium with the other bodies in the universe.

Anaximander was the first philosopher to speculate on the origin of man. He is also credited with the first determinations of the solstices and equinoxes and the production of the first map of the world as he knew it. He was the first to recognize that the Earth's surface is curved but believed it was curved only in the north–south direction and consequently represented the Earth as a cylinder.

Anaximenes of Miletus (about 546 BC) *Greek philosopher*

Anaximenes (an-ak-**sim**-e-neez) was the last of the great Milesian philosophers. He was probably a pupil of ANAXIMANDER of Miletus and, like THALES before him, he identified one of the tangible elements as the primal substance. For Anaximenes this was air, which by processes of condensation and rarefaction could produce every other kind of matter. He used the rather mystical argument that since air is the breath of life for man it must also be the main principle of the universe.

Anderson, Carl David (1905–1991) *American physicist*

Anderson, the son of Swedish immigrants, was born in New York City and educated at the California Institute of Technology where he obtained his PhD in 1930 and where he remained for his entire career, serving as professor of physics from 1939 until his retirement in 1978.

Anderson was deeply involved in the discovery of two new elementary particles. In 1930 he began to study cosmic rays by photographing their tracks in a cloud chamber and noted that particles of positive charge occurred as abundantly as those of negative charge. The negative particles were clearly electrons but those of positive charge could not be protons (the only positive particles known at the time) as they did not produce sufficient ionization in the chamber. Eventually Anderson concluded that such results "could logically be interpreted only in terms of particles of a positive charge and a mass of the same order of magnitude as that normally possessed by a free negative electron." It was in fact the positron or positive electron, whose existence he announced in September 1932. In the following year his results were confirmed by Patrick BLACKETT and Giuseppe OCCHIALINI and won for Anderson the 1936 Nobel Prize for physics.

In the same year Anderson noted some further unusual cosmic-ray tracks. As they appeared to be made by a particle more massive than an electron but lighter than a proton it was at first thought to be the particle predicted by Hideki YUKAWA that was thought to carry the strong nuclear force and hold the nucleus together. The particle was initially named the "mesotron" or "yukon." However, this identification proved to be premature, as its interaction with nucleons was found to be so infrequent that it could not possibly perform the role described by Yukawa. From 1938 the particle became known as the meson, and the confusion was partly dispelled in 1947 when Cecil POWELL discovered another and more active meson, to be known as the pi-meson or pion to distinguish it from Anderson's mu-meson or muon. While the role of the pion is readily explained, that of Anderson's muon is still far from clear.

Anderson, Philip Warren (1923–) *American physicist*

Anderson was born in Indianapolis and obtained his BS (1943), MS (1947), and PhD (1949) at Harvard University, doing his doctoral thesis under John VAN VLECK. The period 1943–45 was spent at the Naval Research Laboratory working on antenna engineering. Upon receiving his doctorate, Anderson joined the Bell Telephone Laboratories at Murray Hill, New Jersey, where he worked until 1984. He is currently Joseph Henry Professor of Physics at Princeton.

Anderson's main research has been in the physics of the solid state, incorporating such topics as spectral-line broadening, exchange interactions in insulators, the JOSEPHSON effect, quantum coherence, superconductors, and nuclear theory. Under Van Vleck he worked initially on elucidating the phenomenon of pressure broadening of lines in microwave, infrared, and optical spectroscopy. In 1959 he developed a theory to explain "superexchange" – the coupling of spins of two magnetic atoms in a crystal through their interaction with a nonmagnetic atom located between them. He went on to develop the theoretical treatments of antiferromagnetics, ferroelectrics, and superconductors.

In 1961 Anderson conceived a theoretical model to describe what happens where an impurity atom is present in a metal – now widely known and used as the *Anderson model*. Also named for him is the phenomenon of *Anderson localization*, describing the migration of impurities within a crystal. In the 1960s Anderson concentrated particularly on superconductivity and superfluidity, predicting the existence of resistance in superconductors and (with Pierre Morel) pointing out the nature of the possible superfluid states of ^{3}He. In 1971 he returned to disordered media, working on low-temperature properties of glass and later studying spin glasses and high-temperature superconductivity.

Along with his Harvard tutor Van Vleck and the British physicist Nevill MOTT, Anderson shared the 1977 Nobel Prize for physics "for their fundamental theoretical investigation of the electronic structure of magnetic and disordered systems."

In the late 1980s Anderson became a controversial figure in the physics community by arguing before Congress that the proposed SSC (Superconducting Super Collider) to be built in Texas at a cost of $8 billion would yield neither practical benefits nor any fundamental truths that could not be gained elsewhere and more cheaply. When Congress killed the plan in 1993 Anderson commented that he was only sorry that Congress had allowed the project to go on so long.

Anderson, Thomas (1819–1874) *British organic chemist*

Born in the port of Leith in Scotland, where his father was a physician, Anderson also studied medicine, gaining his MD from Edinburgh in 1841. His main interest, however, lay in chemistry which he pursued in 1842 with BERZELIUS in Sweden and with LIEBIG in 1843 in his famous Giessen Laboratory. Anderson was appointed Regius Professor of Chemistry at the University of Glasgow in 1852.

Anderson's most important work was concerned with the chemistry of pyridine (C_5H_5N), a heterocyclic compound, which he extracted in 1851 from bone oil. He had earlier (1849) extracted the related substances, lutidine (C_5H_3N), picoline (C_5H_4N), and collidine (C_5H_2N). Anderson went on to suggest that he had discovered an homologous series in which the radical C_5H_n was being substituted for H_3 in the ammonia molecule. The pyridines are used as powerful and versatile organic solvents capable of dissolving fats, mineral oils, and rubber.

Anderson also did much to introduce the "agricultural chemistry" of Liebig into Scotland. He worked from 1848 as a chemist with the Highland and Agricultural Society, for which he determined the chemical composition of such staples as turnip, wheat, and beans. Anderson wrote one of the earliest texts on the subject in his *Elements of Agricultural Chemistry* (1860).

Andrade, Edward Neville da Costa (1887–1971) *British physicist*

Born in London, Andrade was educated at University College, London, and at Heidelberg where he obtained his PhD in 1911. He then worked with Ernest RUTHERFORD at Manchester before joining the Royal Artillery in 1914. After the war he was appointed professor of physics at the Artillery College, Woolwich, and moved to a similar chair at University College, London, in 1928. Andrade resigned in 1950 to take up the directorship of the Royal Institution, a post he held until his retirement in 1952.

Andrade worked mainly on the physics of metals and the viscosity of liquids. On the former subject he made the first serious scientific study of creep in metals while on the latter subject he investigated the effect of an electric field on viscosity. In addition to writing a number of popular works on science, Andrade was also widely known as a student of 17th-century physics. He was an expert on Robert HOOKE and as chairman in 1947 of the Royal Society Newton letters committee he played an important role in beginning the monumental task of the publication of Newton's letters, a task requiring 40 years for its completion (from 1938).

Andreessen, Marc (1971–) *American computer scientist*

Andreesen (**an**-dree-sen) was born in New Lisbon, Wisconsin, and was educated at the University of Illinois at Urbana.

In his senior year at Illinois he worked at the National Center for Supercomputer Applications (NCSA), a high-tech think tank, where he came across the Internet, then in its early days. He immediately realized that a browser that could be easily used would be very useful. In a few weeks Andreessen, together with Eric BINA and some colleagues from NCSA, produced an operational browser called *Mosaic*.

In 1994 Andreessen and Jim Clark founded a company called Mosaic Corp. with the intention of making Internet browsers. They soon changed the name to Netscape Communications after legal objections to the previous name by the University of Illinois. Andreessen and his team, including Bina, produced an improved version of Mosaic, which they called *Navigator*. Navigator was initially very successful but was eclipsed when Microsoft introduced its own browser *Internet Explorer*. In 1998 Andreessen became technology officer of America Online (AOL), which had bought out Netscape. He left AOL in 1999 with the intention of playing a more direct role in the development of the Internet. He is currently involved in a number of projects including Ning, a platform for creating social websites and networks.

Andrews, Roy Chapman (1884–1960) *American naturalist and paleontologist*

Andrews was born in Beloit, Wisconsin, and was educated there at Beloit College. After graduating, he took up a post at the American Museum of Natural History, New York. His early interest lay in whales and other aquatic mammals, and these he collected assiduously on a number of museum-sponsored expeditions to Alaska, North Korea, and the Dutch East Indies (Indonesia) between 1908 and 1913. It was largely through Andrews's efforts that the collection of cetaceans at the American Museum of Natural History became one of the most complete in the world.

Andrews is best known for his discovery of previously unknown Asiatic fossils. Most of his findings were made on three expeditions to Asia, which he led as chief of the Asiatic Exploration Division of the American Museum of Natural History. The first of these was to Tibet, southwestern China, and Burma (1916–17); he then visited northern China and Outer Mongolia (1919), and central Asia (1921–22 and 1925). The third Asian expedition produced major finds of fossil reptiles and mammals, including remains of the largest known land mammal, the Paraceratherium (formerly called Baluchitherium), an Oligocene relative of the modern rhinoceros, which stood some 17–18 feet (5.5 m) at the shoulder. In Mongolia, Andrews discovered the first known fossil dinosaur eggs. He was also able to trace previously unknown geological strata, and unearthed evidence of primitive human life on the central Asian plateau.

Andrews was appointed director of the American Museum of Natural History in 1935, but resigned in 1942 in order to devote himself entirely to writing about his travels and discoveries.

Andrews, Thomas (1813–1885) *Irish physical chemist*

> There exists for every liquid a temperature at which no amount of pressure is sufficient to retain it in the liquid form.
> —Quoted by W. A. Miller in *Elements of Chemistry* (1863)

The son of a linen merchant from Belfast (now in Northern Ireland), Andrews studied chemistry under Thomas Thomson at Glasgow, under Jean DUMAS in Paris, and under Justus von LIEBIG at Giessen. He also studied medicine at Edinburgh and obtained his MD in 1835. He practiced medicine in Belfast before becoming vice-president of Queen's College, Belfast, in 1845 and professor of chemistry in 1849.

Andrews made experimental studies on the heat evolved in chemical reactions and also showed that ozone is an allotrope of oxygen. He was a brilliant experimentalist and his work on the liquefaction of gases brought order to a confused subject. Andrews performed a famous series of experiments on the variation of the volume of carbon dioxide gas with pressure. He studied the behavior of the gas at different temperatures, and showed that there was a certain temperature – the critical temperature – above which the gas could not be liquefied by pressure alone. This work, which was published as *On the Continuity of the Liquid and Gaseous States of Matter* (1869) led to the liquefaction of those gases previously held to be "permanent" gases.

Anfinsen, Christian Boehmer (1916–1995) *American biochemist*

> Anfinsen was a true pioneer in the field of protein structure and protein folding.
> —Daniel Nathans

Born in Monessen, Pennsylvania, Anfinsen was educated at Swarthmore College, the University of Pennsylvania, and Harvard, where he obtained his PhD in 1943. He taught at Harvard Medical School from 1943 to 1950, when he moved to the National Heart Institute at Bethesda, Maryland, where from 1952 to 1962 he served as head of the laboratory of cellular physiology. In 1963 Anfinsen joined the National Institute of Arthritis and Metabolic Diseases at Bethesda, where he was appointed head of the laboratory of chemical biology. In 1982 he became professor of biology at Johns Hopkins University.

By 1960 Stanford MOORE and William STEIN had fully determined the sequence of the 124 amino acids in ribonuclease, the first enzyme to be so analyzed. Anfinsen, however, was more concerned with the shape and structure of the enzyme and the forces that permit it always to adopt the same unique configuration. The molecule of ribonuclease – a globular protein – consists of one chain twisted into a ball and held together by four disulfide bridges. By chemical means, the sulfur bridges can be separated so that the enzyme becomes a simple polypeptide chain with no power to hydrolyze ribonucleic acid, i.e., it becomes denatured. Once the bridges are broken they can be reunited in any one of 105 different ways. Anfinsen found that the minimum of chemical intervention – merely putting the enzyme into a favorable environment – was sufficient to induce the ribonuclease to adopt the one configuration that restores enzymatic activity.

The important conclusion Anfinsen drew from this observation was that all the information for the assembly of the three-dimensional protein must be contained in the protein's sequence of amino acids – its primary structure. He went on to show similar behavior in other proteins. For this work Anfinsen shared the 1972 Nobel Prize for physiology or medicine with Moore and Stein.

Ångström, Anders Jonas (1814–1874) *Swedish physicist and astronomer*

Ångström (**ang**-strom or **awng**-stru(r)m) was born the son of a chaplain in Lögdö, Sweden. He studied and taught physics and astronomy at the University of Uppsala, where he obtained his doctorate (1839) and later became professor of physics (1858), a position he held up to his death.

Ångström was one of the pioneers of spectroscopy. His most important work was *Optiska Undersökningar* (1853; Optical Investigations), in which he published measurements on atomic spectra, particularly of electric sparks. He noted spectral lines that were characteristic of both the gas and the electrodes used. Ångström applied EULER's theory of resonance to his measurements and deduced that a hot gas emits light at precisely the same wavelength at which it absorbs light when it is cool. In this he anticipated the experimental proof of Gustav KIRCHHOFF. He was also able to show the composite nature of the spectra of alloys.

Having established the principles of spectroscopy in the laboratory, Ångström turned his attention to the Sun's spectrum, publishing *Recherches sur le spectre solaire* (1868; Researches on the Solar Spectrum) in which he made the inference that hydrogen was present in the Sun. In this work he also reported the wavelengths of some 1,000 FRAUNHOFER lines measured to six significant figures in units of 10^{-8} centimeters. Since 1905 his name has been officially honored as a unit of length used by spectroscopists and microscopists; 1 angstrom (Å) = 10^{-8} centimeters. His map of the *Normal Solar Spectrum* (1869) became a standard reference for some 20 years. Ångström was also the first to examine the spectrum of the aurora borealis and to measure the characteristic bright yellow–green light sometimes named for him.

Anning, Mary (1799–1847) *British fossil hunter*

Anning was born in Lyme Regis, Dorset, on the south coast of England, the daughter of a cabinetmaker. Her father died in 1810, leaving his widow and two surviving children in debt. To make a meager living, the family turned to hunting for fossils along the cliffs bordering the small seaside town, and selling them to collectors and museums. From this modest beginning, and in spite of her poverty and low social class, Mary Anning defied the conventions of her age to become well known and respected among the male-dominated scientific community. In 1817 Lieutenant-Colonel Thomas Birch, an affluent amateur collector of fossils, became the family's patron, and he arranged to sell his own collection for the benefit of the Anning family. During this time, Mary was effectively running the family fossil business, acquiring a wealth of anatomical knowledge about the specimens she gathered and prepared for sale, and becoming a prominent figure in Lyme and beyond. She is credited with several major discoveries of prehistoric marine reptiles, including the first fossil ichthyosaur (in about 1809–1811; now in the Natural History Museum, London), and also the first plesiosaur (in 1821). Although many of Anning's finds were sold on with little or no credit given to their discoverer, her reputation grew, and with it came scientific recognition and reward. From 1838 she received an annuity from the British Association for the Advancement of Science, and shortly before her death she was named as the first honorary member of the newly founded Dorset County Museum.

Antoniadi, Eugène Michael (1870–1944) *Greek–French astronomer*

Antoniadi (an-ton-**yah**-dee) was born in Constantinople (now Istanbul, Turkey). He established quite early a reputation as a brilliant observer and in 1893 was invited by Camille FLAMMARION to work at his observatory at Juvisy near Paris. From 1909 he worked mainly with the 33-inch (84-cm) refracting telescope at the observatory at Meudon. He became a French citizen in 1928.

In his two works *La Planète Mars* (1930; The Planet Mars) and *La Planète Mercure* (1934; The Planet Mercury), Antoniadi published the results of many years' observations and presented the best maps of Mars and Mercury to appear until the space probes of recent times. With regard to Mars he took the strong line: "Nobody has ever seen a genuine canal on Mars," attributing the "completely illusory canals," "seen" by astronomers such as Percival LOWELL and Flammarion, to irregular natural features of the Martian surface. Antoniadi also observed the great Martian storms of 1909, 1911, and 1924 noting, after the last one, that the planet had become covered with yellow clouds and presented a color similar to Jupiter.

On Mercury his observations made between 1914 and 1929 seemed to confirm Giovanni SCHIAPARELLI's rotation period of 88 days, identical with the planet's period of revolution around the Sun. The effect of this would be for Mercury always to turn the same face to the Sun, in the same way as the Moon always turns the same face to the Earth. Antoniadi cited nearly 300 observations of identifiable features always in the same position, as required by the 88-day rotation period.

However, radar studies of Mercury in 1965 revealed a 59-day rotation period for Mercury. This time is however very close to half the synodic period of Mercury (116 days) so that when the planet returns to the same favorable viewing position in the sky, at intervals of 116 days, it does present the same face to observers.

Antoniadi also wrote on the history of astronomy, publishing *L'Astronomie Egyptienne* (Egyptian Astronomy) in 1934.

Apker, Leroy (1915–1978) *American physicist*

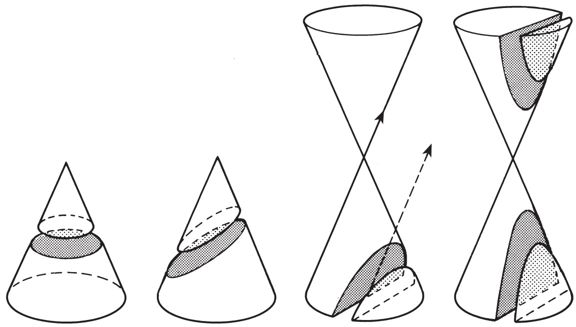
Apker was born in Rochester, New York, and educated there at the University of Rochester; he obtained his PhD in 1941. He later joined the staff of General Electric where he worked as a research associate.

Apker worked on the photoelectric effect applied to semiconductors and ionic crystals. A particular aspect of his work was photoemission from the alkali-metal halides, such as potassium iodide. Crystals of these compounds can contain a type of defect involving a missing negative ion replaced by an electron – called a "color center" (because such defects color the crystal). Apker studied the photoemission from such crystals, and the interaction of excitons with color centers causing the ejection of electrons.

Apollonius of Perga (*c*. 262 BC–*c*. 190 BC) *Greek mathematician and geometer*

Apollonius (ap-o-**loh**-nee-us) moved from his birthplace Perga (now in Turkey) to study in the Egyptian city of Alexandria, possibly under pupils of EUCLID. Later he taught in Alexandria himself. One of the great Greek geometers, Apollonius's major work was in the study of conic sections and the only one of his many works to have survived is his eight-book work on this subject, the *Conics*. Apollonius's work on conics makes full use of the work of his predecessors, notably Euclid and CONON of Samos, but it is a great advance in terms of its thoroughness and systematic treatment. The *Conics* also contains a large number of important new theorems that are entirely Apollonius's creation. He was the first to define the parabola, hyperbola, and ellipse. In addition, he considered the general problem of finding normals from a given point to a given curve (i.e., lines at right angles to a tangent at a point on the curve).

Apart from the geometrical work that has



CONIC SECTIONS Apollonius showed that the circle, ellipse, parabola, and hyperbola could be generated by different sections of a conical surface.

survived, Apollonius is known to have contributed to optics – in particular to the study of the properties of mirrors of various shapes. This work, however, is now lost.

Appel, Kenneth (1932–) *American mathematician*

Appel, who was born in Brooklyn, New York City, was educated at the University of Michigan, where he completed his PhD in 1959. After working for two years at the Institute for Defense Analysis at Princeton, he joined the faculty of the University of Illinois, Urbana, where he served as professor of mathematics from 1991 to 1993. He then took up the chairmanship of the mathematics department at the University of New Hampshire until 2002.

In 1976, in collaboration with Wolfgang HAKEN, Appel announced the solution to one of mathematics long-standing unsolved problems, the four-color map problem. In 1852 Francis Guthrie had noticed that it seemed to be possible to color any map, assuming countries with common borders were colored differently, with no more than four colors. Guthrie was sufficiently intrigued by the point to raise it with the mathematician de Morgan and ask for a proof of the conjecture. De Morgan found the problem unexpectedly difficult, as did succeeding generations of mathematicians.

Appel and Hagen used a variation of a method first tried by Arthur Kempe in 1879. It depends on the fact that maps must contain certain unavoidable configurations – Appel and Hagen recognized 1,482 of these. They then used a computer to show that all of these could be reduced to four-color configurations. They began work in 1972, but it was not until 1976 that they were satisfied with their analysis and their program. It took more than 1,200 hours of computer time to prove the theorem.

Appert, Nicolas-François (1749–1841) *French inventor*

Appert (a-**pair**), who was born in Chalôns-sur-Marne, France, was a chef, confectioner, and distiller who invented the canning of food. In 1795 he started to experiment with sealed containers, using corked glass sealed with wax. He succeeded in preserving fruits, soups, marmalades, etc., for several years. To claim a 12,000-franc award in 1810 he published his findings in *L'art de conserver, pendant plusiers années, toutes les substances animal et végétales* (The Art of Preserving All Kinds of Animal and Vegetable Substances for Several Years). He used the money to set up the first commercial cannery in the world, the House of Appert, at Massy, which was open from 1812 to 1833.

Appleton, Sir Edward Victor (1892–1965) *British physicist*

Appleton was born in Bradford, England, and studied physics at Cambridge University from 1910 to 1913. During World War I, while he was serving in the Royal Engineers, he developed the interest in radio that was to influence his later research. After the war he returned to Cambridge and worked in the Cavendish Laboratory from 1920. In 1924 he was appointed Wheatstone Professor of Experimental Physics at King's College, London.

Here, in his first year, he used a BBC transmitter to conduct a famous experiment, which established beyond doubt the presence of a layer of ionized gas in the upper atmosphere capable of reflecting radio waves. The existence of such a layer had been postulated by Oliver HEAVISIDE and Arthur KENNELLY to explain MARCONI's transatlantic radio transmissions. By varying the frequency of a transmitter in Bournemouth and detecting the signal some 140 miles (225 km) away in Cambridge, he showed that interference occurred between direct (ground) waves and waves reflected off the layer (sky waves). Furthermore, the experiment measured the height of the layer, which he estimated at 60 miles (96 km). He proceeded to do theoretical work on the reflection or transmission of radio waves by an ionized layer and found, using further measurements, a second layer above the Heaviside–Kennelly layer. The *Appleton layer* undergoes daily fluctuations in ionization and he established a link between these variations and the occurrence of sunspots.

In 1936 he became the Jacksonian Professor of Natural Philosophy at Cambridge, and during the war years until 1949 he was secretary of the department of scientific and industrial research, in which period he led research into radar and the atomic bomb.

For his great achievements in ionospheric physics he was knighted in 1941 and in 1947 won the Nobel Prize for physics. From 1949 until his death he was principal of Edinburgh University.

Arago, Dominique François Jean (1786–1853) *French physicist*

> To get to know, to discover, to publish – this is the destiny of a scientist.
> —Quoted by A. L. MacKay in *A Harvest of a Quiet Eye* (1977)

Born in Estagel, France, Arago (a-ra-**goh** or **a**-ra-goh) was educated at the Ecole Polytechnique in Paris and then spent some years in Spain, where he accompanied Jean Baptiste BIOT on a measurement of an arc of meridian. On his return to Paris in 1809 he was elected to the Académie des Sciences and received the chair of analytical geometry at the Ecole Polytechnique. In 1830 he succeeded J. B. J. FOURIER as the permanent secretary of the Ecole Polytechnique. Arago worked in a number of branches of physics.

His first investigations concerned the polarization of light and in 1811 he discovered chromatic polarization. He was a vigorous defender of A. J. FRESNEL's wave theory of light against the criticisms of LAPLACE and Biot, who both supported the corpuscular theory. In 1838 he described an experiment to decide the issue by comparing the speed of light in air with that in a denser medium. Shortly before Arago's death, Léon FOUCAULT and Armand FIZEAU proved that the experiment supported the wave theory.

Arago also worked on electromagnetism, showing that a coil of wire carrying a current could act as a magnet. He also found that a rotating copper disk could deflect a magnetic needle suspended above it. (This arrangement, known as *Arago's disk*, depends on magnetic induction.)

In astronomy, Arago discovered the Sun's chromosphere. He also played a part in the discovery of Neptune by Urbain LE VERRIER.

Arago was a fierce republican and, from 1830 onward, he was involved in political life as deputy for the Pyrenées Orientales. In 1848 he became a government minister and, among other measures, abolished slavery in the French colonies.

Arber, Werner (1929–) *Swiss microbiologist*

Arber (**ar**-ber), who was born in Gränichen, Switzerland, graduated from the Swiss Federal Institute of Technology in 1953 and gained his PhD from the University of Geneva in 1958. He spent a year at the University of Southern California before returning to Geneva where he became professor of molecular genetics in 1965. In 1971 Arber moved to Basel to take the chair of molecular biology.

In the early 1950s Giuseppe Bertani reported a phenomenon he described as "host-controlled variation" in which phages (the viruses that infect bacteria) successfully growing on one host found it difficult to establish themselves on a different bacterium. In 1962, he proposed that bacteria possess highly specific enzymes capable of destroying invading phages by cutting up their DNA. The existence of such "restriction enzymes," as they came to be called, was later established by Hamilton SMITH.

It turned out that, as Arber had proposed, the enzymes attack the invading DNA at a specific site, always cutting them at exactly the same place. It was this property that endowed restriction enzymes with such interest for if strands of DNA could be so manipulated to be cut at particular known points, it only needed the power to join such strands together in desired combinations for genetic engineering to be a reality. As restriction enzymes were found to leave DNA strands "sticky" and ready to combine with certain other "sticky" strands it was soon apparent to molecular biologists that genetic engineering was at last a practical proposition.

For his work on restriction enzymes Arber shared the 1978 Nobel Prize for physiology or medicine with Smith and Daniel NATHANS.

Archimedes (287 BC–212 BC) *Greek mathematician*

> Give me a lever long enough, and a firm place to stand on, and with my own weight I will move the Earth.
> —*On the Lever*

The father of Archimedes (ar-ki-**mee**-deez) was an astronomer and he himself inherited an interest in the subject. He was educated in Alexandria and spent most of the rest of his life in his birthplace, Syracuse, under the patronage of King Hieron. Archimedes was without question the greatest mathematician and scientist that classical Greek civilization produced and is usually considered to be one of the greatest mathematicians of all time. He was held in very high regard even by his contemporaries, and Karl Friedrich GAUSS thought that only Isaac NEWTON was Archimedes's equal as a mathematician. Archimedes was as much an applied mathematician as a pure mathematician. He was very much interested in putting his theoretical discoveries to practical use and is known to have been skilled in making his own equipment and carrying out his own experiments. It is no exaggeration to describe Archimedes as the creator of the science of mechanics. Naturally before his time many isolated facts had been discovered, but it was only with him that mechanics became a unified body of theory capable of yielding new and unexpected practical applications.

Archimedes was able to find methods for determining the center of gravity of a variety of bodies. He also gave the first general theory of levers, and organized a practical demonstration to show how, with a suitable series of levers, a very small force is capable of moving a very large weight. He amazed his contemporaries by arranging for the king of Syracuse to move a large ship simply by pressing a small lever. In connection with his work on levers Archimedes made one of his famous statements, "Give me a firm place to stand on and I will move the Earth." Archimedes also had a practical interest in optics, although no writings of his on the subject have come down to us. He put all this newfound theoretical knowledge to deadly effect when Syracuse was besieged by the Romans, by designing and building a variety of war machines. Among these were enormous mirrors to focus the Sun's rays and set fire to the Roman ships, and a variety of catapults.

Archimedes also successfully applied his scientific discoveries in hydrostatics. He designed all sorts of pumps, and the Archimedean waterscrew is still widely used. But his most famous practical success was in solving a problem presented to him by King Hieron. Hieron wished to know whether a newly made crown, which was supposed to be of pure gold was, as he suspected, partly silver. Archimedes solved the problem by grasping the concept of relative density. By immersing successively the crown itself and pieces of gold and silver of equal weight in full containers of water and observing the amount of water each displaced, Archimedes was able to show that the crown was indeed not made of pure gold. One of the famous stories associated with Archimedes tells how this occurred to him when he was getting into his bath and observed how the more of his body was immersed the more water overflowed from the bath. He saw instantly how to solve his problem, leaped from the bath, and rushed through the streets, stark naked, shouting "Eureka!" (I have found it).

Archimedes's work in applied mathematics and science ensured his great contemporary fame, but some of his greatest work was probably in his more esoteric researches in pure mathematics. Like all Greek mathematicians, his interest was primarily concentrated on geometry. Arithmetic was greatly hampered by a very cumbersome system of notation. Although Archimedes himself invented a much improved system for notation of very large numbers, algebra had yet to be invented, in Europe at least. Archimedes's most profound achievement was to perfect the "method of exhaustion" for calculating the areas and volumes of curved figures. The method involves successively approximating the figure concerned by inscribed and circumscribed polygons. This method essentially used the concept of limit – a concept that took some time for later European mathematicians to grasp. Archimedes used this method to determine an approximate value for π, which was not to be improved on for many centuries.

Archimedes was put to death by a Roman soldier when the Romans, under general Marcellus, finally successfully besieged Syracuse. The killing was against the orders of Marcellus who respected Archimedes and wished for him to be protected. Archimedes was apparently drawing mathematical symbols in the sand when killed.

Argelander, Friedrich Wilhelm August

(1799–1875) *German astronomer*

Born in the Baltic port of Memel (now Klaipeda in Lithuania), Argelander (ar-ge-**lahn**-der) was the son of a wealthy Finnish merchant and a German mother. He was educated at Königsberg, where his interest in astronomy was aroused by the lectures of Friedrich BESSEL. Argelander began his career in 1820 as an assistant in Bessel's Königsberg Observatory. In 1823 he moved to the Åbo Observatory in Finland, then part of Russia. The observatory burned down in 1827 and Argelander began the design and construction of a new observatory in Helsinki, which was completed in 1832. In 1836 he was appointed professor of astronomy at Bonn. Here Friedrich Wilhelm IV built for Argelander an impressive new observatory. They were in fact old friends. In 1806, following Prussia's defeat by Napoleon, Friedrich Wilhelm, then the crown prince, had sought refuge in the Argelander home in Memel, East Prussia.

Argelander's name continues to be known by astronomers for his compilation of the *Bonner Dorchmusterung* (1859–63; 3 vols; Bonn Survey), still the largest and most comprehensive of prephotographic catalogs. Under Bessel he had begun a survey of the sky from 15°S to 45°N. This was extended at Bonn to an area from 90°N to 2°S and when complete listed the positions of 324,198 stars down to the ninth magnitude. His work was continued by his successor, E. Schonfeld, who in the *Southern Bonner Dorchmusterung* (1886; Southern Bonn Survey) added a further 133,659 stars taken from the southern skies (2°S–23°S).

Aristarchus of Samos (*c.* 320 BC–*c.* 250 BC) *Greek astronomer*

Little is known of the life of Aristarchus (a-ri-**star**-kus), but ARCHIMEDES reported that Aristarchus had proposed that, while the Sun and the fixed stars are motionless, the Earth moves around the Sun on the circumference of a circle. Just what led Aristarchus to this view and how firmly he held it is not known. It received no support until the late medieval period.

One short work of Aristarchus has survived – *On the Sizes and Distances of the Sun and Moon*. In this work he calculated that the Earth is about 18 times further away from the Sun than from the Moon. His method was to use the fact that when the Moon is exactly in the second quarter it will form a right-angled triangle with the Earth and the Sun, and the relative lengths of the sides of the triangle can be determined by angular measurement. Aristarchus's method is correct, but his measurement was inaccurate (the Sun is roughly 400 times further away). Despite the size of the error it was nevertheless the first attempt to come to grips with astronomical distances by something more sophisticated than revelation or guesswork.

Aristotle (384 BC–322 BC) *Greek philosopher, logician, and scientist*

> Every science and every inquiry, and similarly every activity and pursuit, is thought to aim at some good.
> —*The Nicomachean Ethics,* Bk I

Aristotle (**a**-ri-stot-el), the son of Nicomachus, physician at the court of Mayntas II of Macedon, was born in Chalcis and moved to Athens in 367 BC, where he was a member of the academy until PLATO's death in 347. For the next 12 years he worked in Assos in Asia Minor, Mytilene on Lesbos, and, from 342 until 335, in Macedon as the tutor of the young Alexander the Great. Unfortunately little is known of this legendary relationship apart from the fact that Alexander took with him on his campaigns a copy of Homer's *Iliad* annotated by Aristotle. Also, Plutarch quotes a letter from Alexander rebuking his former tutor for publishing his *Metaphysics* and revealing to all what had been privately and, he assumed, exclusively taught to him. Following Alexander's accession to the throne of Macedon in 335 Aristotle returned to Athens to found his own school, the Lyceum. When, however, Athens, with little cause to love the power of Macedon, heard of the death of Alexander (323) they turned against Aristotle and accused him, as they had SOCRATES earlier in the century, of impiety. To prevent Athens from "sinning twice against philosophy" he moved to Chalcis where he died the following year.

Aristotle not only developed an original and systematic philosophy but applied it in a deliberate manner to most areas of the knowledge of his day. The resulting treatises on such subjects as physics, cosmology, embryology, and mineralogy acquired a considerable authority, becoming for medieval scholars if not the last word on any subject then invariably the first. Aristotelian science was not overthrown until the great scientific revolution of the 16th and 17th centuries.

In cosmology Aristotle basically accepted the scheme in which the Earth was at the center of the universe with the planets and fixed stars moving around it with uniform speed in perfectly circular orbits. (He also believed, on empirical grounds, that the Earth was round.) But Aristotle was not content simply to construct models of the universe and faced the problem of how to account for the various forms of motion. He began by accepting that matter was composed of the four elements of EMPEDOCLES – earth, water, fire, and air. Left to themselves the elements would either fall freely, like earth and water, or rise naturally like air and fire. This for Aristotle was natural motion, self-explanatory and consisting simply of bodies freely falling or rising to their natural place in the universe. For a stone to fall to the ground no one had to push or pull it but merely to remove all constraints for it to fall in a straight line to the Earth.

But the heavenly bodies do not move up or down in straight lines. Therefore, Aristotle concluded, they must consist of a fifth element, aether (or *quinta essentia* to the medieval schoolmen), whose natural motion was circular. Thus in the Aristotelian universe different bodies obey different laws; celestial and terrestrial bodies move differently because the laws of motion are different in the heavens from those operating below the Moon. Nor was this the only distinction. For Aristotle the heavens were, with their supposed regularity, incorruptible, without change or decay; such processes were only too apparent on the Earth.

Aristotle also produced a number of volumes on biological problems. In particular his *De partibus animalium* (On the Parts of Animals) and his *De generatione animalium* (On the Generation of Animals) show a detailed knowledge of the fauna of the Mediterranean world and a concern to understand their anatomy and physiology. Over 500 species of animal are referred to by Aristotle. He was also a keen observer and had obviously made empirical investigations on the development of the chick embryo for example, noting the appearance of its heart on the fourth day. In fact some of his observations were only confirmed by zoologists in the

19th century and had for long been thought to be as erroneous as his physics.

In embryology he was also able to refute by dissection the view that the sex of the embryo is determined by its site in the womb. He also argued against the doctrine of pangenesis, that the seed comes from the whole of the body, as he also did against the classical version of preformationism, that the embryo contains all parts already preformed. His physiology, which could not be obtained so readily from simple dissection, was less acute. Respiration was thought to cool the body, an exercise unnecessary for fish who could cool themselves merely by drawing water through their gills.

He, further, produced a rudimentary taxonomy that went to some length to show that divisions based on number of limbs turned out to be obviously arbitrary. Instead, he proposed that mode of reproduction be used. This gave him the basic division between viviparous (exclusively mammalian) and the oviparous, subdivided into birds and reptiles laying proper eggs and the fishes laying "imperfect eggs." He added the insects, who lay no eggs at all but simply produce larvae.

If Aristotle had produced only his *Organon* – works on logic – he would have been considered a prolific and powerful thinker. His style of logic lasted unchallenged even longer than his physics for it was not until 1847 that George BOOLE laid the foundations of a more modern logic and it was not until the present century that non-Aristotelian logics were systematically developed.

Arkwright, Sir Richard (1732–1792) *British inventor*

> In the evening I walked to Cromford and saw the children coming from their work out of one of Mr. Arkwright's manufactories. I was glad to see them look in general very healthy and many with fine, rosy complexions.
> —Joseph Farington, *Diary of Joseph Farington* (ed. James Greig 1922)

Arkwright was born in the town of Preston in northern England. Apprenticed to a barber at the age of 18, he became a wigmaker. Through travel and self-education he developed an interest in spinning machinery and in 1769 he patented a water-powered machine that, unlike previous machines, produced a cotton yarn strong enough for use as warp. This machine was used in the horse-driven mill he established at Nottingham (1768) to produce machine-spun yarn. In 1771 he set up a water-powered mill in Cromford, Derbyshire, and in the following years established a number of factories employing machinery for all processes of textile manufacture from carding to spinning. This established the cotton industry as the main industry in the north of England. He was knighted in 1786 and died a wealthy man.

Armstrong, Henry Edward (1848–1937) *British chemist and teacher*

The son of a London provisions merchant, Armstrong studied under FRANKLAND at the Royal College of Chemistry and completed his doctorate in 1870 under Adolph KOLBE at Leipzig. A man of great energy and wide interests, he was a pioneer of British technical education, a prolific researcher, and leader of a major school of chemical research. After various teaching posts in London, he was appointed (1884–1911) professor at the Central Technical College in London (forerunner of the Imperial College of Science and Technology). He served on many committees and was secretary (1883–93) and later president (1893–95) of the Chemical Society.

Armstrong's research work covered many fields, including aromatic substitution, crystallography, stereochemistry, terpenes, and enzymes. He proposed the quinone theory of color and the work carried out by his school on orientation and isomeric change in naphthalene derivatives, although little regarded in Britain, was of fundamental importance to the German dyestuffs industry.

Arnald of Villanova (*c.* 1235–1313) *Spanish alchemist*

Arnald (**ar**-nald), who was born in Valencia, Spain, was educated in Paris and Montpellier, and studied medicine at Naples. He became a famous physician much in demand by popes and monarchs. In 1285 he became a professor at the University at Montpellier, but came into conflict with the Church in 1299 and was charged with heresy in Paris. He was imprisoned but finally released about 1303 and died at sea between Naples and Genoa in about 1313.

Arnald was one of the first scholars to mention alcohol. In medicine he used it to extract the "virtues of herbs," which became known as tinctures. Some of his other medical ideas were less progressive: he wrote at length on the efficacy of seals and amulets claiming to be able to provide one that would defend its wearer from witchcraft, storms, quinsy, inflammation of the brain, and financial difficulties.

He produced many works on medicine, most notably *Medicinalium introductionum speculum* (An Introductory View of Medicine), and also works on theology and chemistry. The many alchemical works, including *Rosarium philosophorum* (A Rose Garden of Philosophers), that were attributed to him and that had considerable influence in the following centuries are now thought not to be his work.

Arrhenius, Svante August (1859–1927) *Swedish physical chemist*

> These new theories [of Arrhenius] … suffered from the misfortune that nobody really knew where to place them. Chemists would not recognize them as chemistry; nor physicists as physics. They have in fact built a bridge between the two.
> —Per Theodor Cleve (1903)

Arrhenius (ar-**ray**-ni-us) was born in Wijk, near Uppsala, Sweden. He originally went to Uppsala University to study chemistry, changing later to physics. Finding the standard mediocre, he transferred to Stockholm in 1881 to do research under the physicist Erik Edlund, working initially on electrical polarization and then on the conductivity of solutions (electrolytes).

At the time it was known that solutions of certain compounds conduct electricity and that chemical reactions could occur when a current was passed. It was thought that the current decomposed the substance. In 1883 Arrhenius proposed a theory that substances were partly converted into an active form when dissolved. The active part was responsible for conductivity. In the case of acids and bases, he correlated the strength with the degree of decomposition on solution. This work was published as *Recherches sur la conductibilité galvanique des electrolytes* (1884; Researches on the Electrical Conductivity of Electrolytes) and submitted as his doctoral dissertation. The paper's great merit was not recognized by the Swedish authorities and he was awarded only a fourth-class doctorate. Arrhenius sent his work to several leading physical chemists, including Jacobus VAN'T HOFF, Friedrich OSTWALD, and Rudolf CLAUSIUS, who were immediately impressed. This led to a period of travel and work in various European laboratories in the period 1885–91.

In 1887 van't Hoff showed that although the gas law ($pV = RT$) could be applied to the osmotic pressure of solutions, certain solutions behaved as if there were more molecules than expected. Arrhenius immediately realized that this was due to dissociation – a conclusion confirmed by further experimental work and published in the classic paper *Über die Dissociation der in Wasser gelösten Stoffe* (1887; On the Dissociation of Substances in Water). The idea that electrolytes were dissociated even without a current being passed proved difficult for many chemists but the theory has stood the test of time.

This work won Arrhenius a high international reputation but only limited acclaim in Sweden. Despite this he returned to Stockholm in 1891 as lecturer at the Technical Institute and in 1895 became professor there. In 1903 he was awarded the Nobel Prize for chemistry, and in 1905 he became the director of the Nobel Institute, a post he held until shortly before his death.

Arrhenius is also remembered for the *Arrhenius equation*, which relates the rate of a chemical reaction to the temperature. He was a man of wide-ranging intellect and besides developing his work on solutions, he worked on cosmogony and on serum therapy, being especially interested in the relation between toxins and antitoxins. He also investigated the greenhouse effect by which carbon dioxide regulates atmospheric temperature and calculated the changes that would have been necessary to have produced the Ice Ages.

Aschoff, Karl Albert Ludwig (1866–1942) *German pathologist*

Educated at Bonn, Berlin (his birthplace), and Strasbourg, Aschoff (**ah**-shoff) was later professor of pathological anatomy, firstly at Marburg (1903–06) and then at Freiburg, where he remained for the rest of his career. He carried out investigations of a number of human pathological conditions, including jaundice, appendicitis, cholecystitis, tuberculosis, and thrombosis. In 1904 he described the inflammatory nodules located in the muscle of the heart and associated with rheumatism (*Aschoff's bodies*). He recognized the bacteria-engulfing activity of the phagocytes in various tissues and named them the reticuloendothelial system. The pathological institute that Aschoff built up at Freiburg-im-Breisgau was attended by students from all over the world.

Aselli, Gaspare (*c.* 1581–1625) *Italian anatomist*

Aselli (ah-**sel**-ee), who was born into a prosperous family in Cremona, Italy, was educated at the University of Pavia, where he later served as professor of anatomy and surgery.

In 1622 while dissecting a recently fed dog he noticed various white vessels spread throughout the intestines. As they exuded a milky fluid when pricked he called them the "lacteals" or the "albas venas." He claimed to trace them to the liver and not unnaturally assumed them to be the vessels transporting the chyle, broken down food products, to the liver to be changed into blood – a process demanded by the current physiology of GALEN. Aselli's observations were fully described in the posthumously published work, *De lactibus* (1627; On the Lacteals), a work that also contained the first colored anatomical illustrations.

It was not until 1651 that Jean PECQUET showed that lacteals did not go to the liver.

Aspect, Alain (1947–) *French physicist*

Alain Aspect was educated at the École Normale Supérieure de Cachan. In 1981–82 at Orsay in Paris, Aspect and his coworkers performed a series of experiments involving coincidence measurements on polarized photons, designed to check the inequalities put forward by John BELL in 1964. Bell's inequalities allow for an experimental test of whether there are local hidden variables in quantum mechanics. It is generally believed by physicists that the *Aspect experiment* provided proof that hidden variables are not involved. Aspect is currently working on Bose–Einstein condensates.

Astbury, William Thomas (1889–1961)
British x-ray crystallographer and molecular biologist

> [Molecular biology] is concerned particularly with the forms of biological molecules and with the evolution, exploitation, and ramification of these forms in the ascent to higher and higher levels of organization.
> —Harvey Lectures, 1950–1951

William Astbury was born in Longton, England, were his father was a potter. In 1916 he won a scholarship to Cambridge University, to study chemistry, physics, and mathematics, and graduated in 1921 after spending two years of the war doing x-ray work for the army. He then joined William Henry BRAGG's brilliant group of crystallographers, first at University College, London, and from 1923 at the Royal Institution. In 1945 Astbury was appointed to the new chair of biomolecular structure at Leeds.

Astbury's early structural studies were carried out on tartaric acid but in 1926 Bragg asked him to prepare some x-ray photographs of fibers for his lectures. The results stimulated an interest in biological macromolecules that Astbury retained for the rest of his life. In 1928 he moved to the University of Leeds as lecturer in textile physics and by 1930 had produced an explanation of the extensibility of wool in terms of two keratin structures: α-keratin in which the polypeptides were hexagonally folded (unextended wool) and β-keratin in which the chain was drawn out in zigzag fashion. A popular account of this work was given in *Fundamentals of Fibre Structure* (1933).

The keratin structure established his reputation, and he quickly extended his studies to other fibers and proteins. He showed that the globular proteins consisted of three-dimensionally folded chains that could be denatured and drawn out into protein fibers. This work laid the foundation for the x-ray structural investigations of hemoglobin and myoglobin. The hexagonal α-keratin structure dominated British crystallographic protein studies until 1951, when it was shown to be incorrect by Linus PAULING who demonstrated the α-helical structure of polypeptide chains.

In 1935 Astbury began to study nucleic acids by x-ray crystallography, and in 1938 he and his research student Florence Bell produced the first hypothetical structure of DNA.

Aston, Francis William (1877–1945)
British chemist and physicist

Aston was born in Harborne, England, the son of a metal merchant. He was educated at Mason College, the forerunner of Birmingham University, where he studied chemistry. From 1898 until 1900 he did research on optical rotation. He left Birmingham in 1900 to work in a Wolverhampton brewery for three years. During this time he continued with scientific research in a home laboratory, where he worked on the production of vacua for x-ray discharge tubes. This work came to the notice of J. H. POYNTING of the University of Birmingham who invited Aston to work with him. He remained at Birmingham until 1910 when he moved to Cambridge as research assistant to J. J. THOMSON. He became a research fellow at Cambridge in 1920 and stayed there for the rest of his life, apart from the war years spent at the Royal Aircraft Establishment, Farnborough. Aston's main work, for which he received the Nobel Prize for chemistry in 1922, was on the design and use of the mass spectrograph, which was used to clear up several outstanding problems and became one of the basic tools of the new atomic physics.

Thomson had invented an earlier form of spectrograph in which a beam of positive rays from a discharge tube passed through a magnetic and an electric field, which deflected the beam both horizontally and vertically. All particles (ions) with the same mass fell onto a fluorescent screen in a parabola. Aston improved the design by using a suitable magnetic field, so that ions of the same mass were focused in a straight line rather than a parabola. Different ions were deflected by different amounts, and the spectrograph produced a photographic record of a series of lines, each corresponding to one type of ion. The deflections allowed accurate calculation of the mass of the ions.

Aston's first spectrograph was ready in 1919 and with it he was soon able to throw light on one outstanding problem about the nature of the elements. In 1816 William PROUT had put forward his hypothesis that all elements are built up from the hydrogen atom and that their atomic weights are integral multiples of that of hydrogen. Although receiving considerable support it was eventually rejected when it was found that many elements have nonintegral weights (e.g., chlorine: 35.453). Frederick SODDY in 1913 had introduced the idea of isotopes, that is, the same chemical element in different forms having differing weights. Aston established that isotopes are not restricted to radioactive elements but are common throughout the periodic table. He also saw that they could explain Prout's hypothesis. Thus he found that neon was made from the two isotopes ^{20}Ne and ^{22}Ne in the proportion of 10 to 1. This will give a weighted average of 20.2 for a large number of neon atoms. The value of 35.453 for chlorine can be similarly explained. The whole-number rule is his principle that atoms have a mass that is equivalent to a whole number of hydrogen atoms.

Aston then went on to determine as many atomic weights as accurately as his instruments would allow. His first spectrograph was only suitable for gases but by 1927 he had introduced a new model capable of dealing with solids. From 1927 to 1935 he resurveyed the atomic weights of the elements with his new instrument.

In the course of this activity he found some minor discrepancies with the whole-number rule. Thus the atomic weight of hydrogen is given not as 1 but 1.008, of oxygen–16 as 15.9949 and of oxygen–17 as 16.99913. Aston attempted to show why these values are so tantalizingly close to the integral values of Prout – why the isotopes of oxygen are not simple 16 and 17 times as massive as the hydrogen atom. He argued that the missing mass is in fact, by the mass–energy equivalence of EINSTEIN, not really missing but present as the binding energy of the nucleus. By dividing the missing mass by the mass number and multiplying by 10,000, Aston went on to calculate what was later called the "packing fraction" and is a measure of the stability of the atom and the amount of energy required to break up or transform the nucleus.

Thus contained in Aston's work were the implications of atomic energy and destruction and he believed in the possibility of using nuclear energy – he also warned of the dangers. He lived just long enough to see the dropping of the first atomic bomb in August 1945.

Atanasoff, John Vincent (1904–1995)

American physicist and computer pioneer

Atanasoff was born in Hamilton, New York, and educated at the universities of Florida, Iowa, and Wisconsin, where he gained his PhD in 1930. He taught at the Iowa State University from 1930 until 1942, when he moved to the Naval Ordnance Laboratory at White Oak, Maryland. After World War II, Atanasoff worked for various technical companies, eventually serving as president of Cybernetics Inc. from 1961 until 1982.

The son of a Bulgarian immigrant who was an electrical engineer, Atanasoff was introduced to calculation at the age of nine when his father gave him a slide rule. This was of little use when, in 1930, he was trying to complete his thesis on the electrical properties of helium. Not even a desk calculator could significantly lighten the extensive computations. He began to think about how things could be improved. By 1937 he had opted for a machine that operates digitally, uses capacitors to store binary numbers, and calculates by logic circuits. Working with his assistant, Clifford Berry, Atanasoff built a prototype in 1939 of the suitably named ABC (Atanasoff–Berry Computer). This was good enough to raise sufficient funds to build an operating machine, which was completed in 1942.

Although the ABC was the first device to incorporate a number of key notions, it was unsatisfactory as a working machine. It was slow, could not be programmed, had to be controlled at all times, and suffered from a number of systematic errors. Clearly, it could be improved but the outbreak of war in 1942 took Atanasoff away to other duties. By the time he was free to work on the ABC other workers had seized the initiative. Atanasoff's work long lay forgotten.

This was corrected in a 1973 court case involving two American companies. Sperry Rand had bought the patent to ENIAC and was seeking to charge royalties to other computer manufacturers. Honeywell Inc. resisted, claiming that ENIAC was derived from the ABC and from information passed to ENIAC's designer, John MAUCHLY, by Atanasoff in the early 1940s. Atanasoff gave evidence and the judge found that ENIAC was not the first "automatic electronic digital computer," and that it was "derived from one Dr. John Vincent Atanasoff."

Audubon, John James (1785–1851)

American ornithologist and naturalist

The illegitimate son of a French sea captain and his Creole mistress, Audubon (**aw**-de-bon) was born in Les Cayes on the Caribbean island of Haiti and was brought up in Nantes in his father's family. He studied painting in Paris, spending six months in the studio of Jacques Louis David. In 1803, to escape conscription into Napoleon's army, Audubon was sent to Pennsylvania where his father owned a farm. Neither the farm nor any of Audubon's other business interests flourished and he was declared bankrupt in 1819 and imprisoned.

No doubt one cause of Audubon's commercial failure was the time spent hunting and observing birds and other animals in the wild. The first hint that his skills as an artist and naturalist could be combined to make money came in 1810 when Alexander Wilson passed through Louisville, Louisiana, where Audubon was operating a general store. Wilson was looking for subscribers to his lavishly illustrated *American Ornithology* (9 vols; 1808–14).

By 1820 Audubon had decided to publish his own collection of animals and birds. He spent a further four years traveling through Louisiana and Mississippi shooting specimens. As no American publisher appeared to be interested in his work, Audubon took his paintings to Britain in 1826. He eventually found a printer in Edinburgh willing to work on his "double elephant size" engravings (39″ × 29″). Sets of five plates were sold to subscribers for about

$10 to finance the next set. In this way 200 full sets of *Birds of America* (1827–38) were published in Britain in 87 parts with 435 plates. Full sets are rarely available for sale – when auctioned they are unlikely to raise less than a million dollars.

Audubon returned to America in 1839, where he bought an estate on the Hudson and began to prepare his *Viviparous Quadrupeds of North America* (3 vols; 1845–48).

Auenbrugger von Auenbrugg, Joseph Leopold (1722–1809) *Austrian physician*

Born in Graz in Austria, Auenbrugger (**ow**-en-broo-ger) learned medicine at the University of Vienna and subsequently worked (1751–62) at the Spanish Hospital, Vienna, where he became chief physician. In the course of his work, he noticed how the note made by tapping the chest altered between healthy and diseased patients and described how this technique of chest percussion could be used to diagnose congestion of the lungs and other conditions. Auenbrugger published his findings in *Inventum novum* (1761; A New Discovery) but their value was slow in gaining recognition. Only after a French translation by Jean-Nicholas CORVISART in 1808 did chest percussion achieve widespread application. It is still used today.

Auenbrugger became one of Vienna's most celebrated physicians and was ennobled by Emperor Joseph II in 1784.

Auer, Karl, Baron von Welsbach (1858–1929) *Austrian chemist*

Auer (**ow**-er) was born in Vienna, the son of the director of the Imperial Printing Press. He was educated at the Vienna Polytechnic and at Heidelberg University, where he was a pupil of Robert BUNSEN.

In 1885 he made a major contribution to knowledge of the lanthanoid (rare-earth) elements. In 1840, Carl MOSANDER had isolated a new "element" called didymium. Auer showed (1885) that this contained, on fractionation, green and rose-red portions. He named them *praseodymia* ("green twin") and *neodymia* ("new twin").

Auer was also one of the first to find some use for the rare-earth elements. Gas had been in use as an illuminant since the beginning of the century and, although an improvement on the early oil lamps, it had many disadvantages of its own. It was expensive, hot, smoky, and smelly. Auer realized that it would be better to use the gas to heat a solid that would itself provide light, rather than use the luminosity of the flame. He used a mantle over the flame, impregnated with thorium oxide and a small amount of cerium. The *Welsbach mantle*, patented in 1885, delayed the end of gas lighting for a few years. Unfortunately for Auer, his invention was too late for, in 1879, EDISON had managed to burn an electric bulb for 40 continuous hours.

Later, in 1898, Auer tried to improve the electric lamp by replacing its carbon filament by metallic osmium, which has a melting point of 2,700°C. Once more he failed, for the future lay with tungsten, which has a higher melting point of 3,410°C.

He was more successful with the so-called *Auer metal* – an alloy consisting mainly of cerium with other lanthanoid elements. It is also called Mischmetal (German: mixed metal) and is used for flints in cigarette lighters.

Auger, Pierre Victor (1899–1993) *French physicist*

Auger (**ow**-zher or **ow**-ger) was born in Paris and educated there at the Ecole Normale Supérieure, where he obtained his doctorate in 1926. He was later appointed to the staff of the University of Paris and after serving there as professor of physics from 1937 became director of higher education for France in 1945. From 1948 until 1960 he was director of the science department of UNESCO; he left UNESCO to become president of the French Space Commission but in 1964 he took the post of director-general of the European Space and Research Organization, a post he retained until his retirement in 1967.

Auger worked mainly on nuclear physics and cosmic rays. In 1925 he discovered the *Auger effect* in which an excited atom emits an electron (rather than a photon) in reverting to a lower energy state. In 1938 Auger made a careful study of "air showers," a cascade of particles produced by a cosmic ray entering the atmosphere and later known as an *Auger shower*. Auger had an interest in the popularization of science. He also published volumes of poetry.

Averroës (1126–1198) *Spanish–Muslim physician and philosopher*

> Knowledge is the conformity of the object and the intellect.
> —*Destructio destructionum* (Refuting Refutations)

Averroës (a-**ve**-roh-eez), also known simply as The Commentator to the Latin West, or Ibn Rushd (from his full name, Abu Al-Walid Muhammad Ibn Ahmad Ibn Rushd), came from a family of jurists and was born in Cordoba in Moorish Spain. He himself trained in law and medicine and later served as *qadi* or judge in Seville and Cordoba. In 1182 he was appointed physician to the court of caliph Abu Ya'qub Yusuf in Marrakesh and to his son, Abu Yusuf Ya'qub, in 1195 but was recalled shortly before his death.

In the field of medicine Averroës produced his *Kulliyat fi al tib* (General Medicine) between 1162 and 1169. He is however better known for his great commentaries on ARISTOTLE but, above all, for his *Tahafut al-Tahafut* (The Incoherence of the Incoherence), a strong attack on the Muslim philosopher al-Ghazzali's *Tahafut al-Falasifah* (The Incoherence of the Philosophers). The work was more influential in the Latin Christian West than in the Muslim East, and its contents paved the way for the medieval separation of faith and reason.

Avery, Oswald Theodore (1877–1955) *American bacteriologist*

Avery was born in Halifax, the capital of Nova Scotia, Canada. Educated at Colgate University, he received his BA in 1900 and his medical degree in 1904. After a time at the Hoagland Laboratory, New York, as a lecturer and researcher in bacteriology, he joined the Rockefeller Institute Hospital (1913–48). While investigating the pneumococcus bacteria responsible for causing lobar pneumonia, Avery found that the bacteria produced soluble substances, derived from the cell wall and identified as polysaccharides, that were specific in their chemical composition for each different type of pneumococcus. This work provided a basis for establishing the immunologic identity of a cell in biochemical terms.

In 1932 Avery started work on the phenomenon of transformation in bacteria. It had already been shown that heat-killed cells of a virulent pneumococcus strain could transform a living avirulent strain into the virulent form. In 1944 Avery and his colleagues Maclyn MCCARTY and Colin MACLEOD extracted and purified the transforming substance and showed it to be deoxyribonucleic acid (DNA). Previously it had been thought that protein was the hereditary material and thus Avery's work was an important step toward the eventual discovery, made nine years later by James WATSON and Francis CRICK, of the chemical basis of heredity.

Avicenna (*or* **Abu-'Ali Al-Husayn Ibn-Sina**) (980–1037) *Persian physician and philosopher*

> Writing about erotics is a perfectly respectable function of medicine, and about the way to make the woman enjoy sex; these are an important part of reproductive physiology.
> —*Canon*

Avicenna (av-i-**sen**-a), whose works span the entire spectrum of arts and sciences, is one of the most famous figures of Persian culture. Born in Bokhara (now in Uzbekistan), he was a child prodigy, learning and practicing medicine in his teens and gaining the position of court physician to Prince Nuh ibn Mansur when still only 18. This gave Avicenna access to the library of the Samanid court, of which he took full advantage. However, the Samanid rulers were overthrown by Turkish forces and Avicenna was forced to flee. After a period spent traveling and in several short-lived posts, he became physician to Prince Shams ad-Dawlah in Hamadan. Here he started on a massive medical textbook, the *Canon* (*Al Qanun*). In this, Avicenna collated virtually all preceding medical knowledge and set down his own ideas. Comprising five books, the *Canon* deals with anatomy, physiology, etiology, diagnosis, obstetrics, drugs, and so on, and runs to over one million words. It subsequently became a standard text throughout Europe and the Middle East until the 17th century, being translated into Hebrew and Latin. During this period, he also wrote his *Book of Healing*, a comprehensive encyclopedia covering mathematics, logic, natural sciences, and metaphysics and based largely on the ideas of ARISTOTLE and other Greek philosophers.

In 1022, the death of prince ad-Dawlah led Avicenna to leave Hamadan. He found refuge at the court of Prince 'Ala ad-Dawlah, where his immense output of writings continued. This included his account of the paths to spiritual enlightenment, the *Book of Directives and Remarks*. He also composed some notable works of poetry and wrote on many other topics, including astronomy, physics, and chemistry.

Avicenna was frequently involved in the political turmoil of warring Persian states and on several occasions had to escape possible capture and imprisonment. He was fond of wine, women, and, doubtless, song too and prescribed himself a glass of wine to combat fatigue. He died while accompanying the prince on a campaign, evidently of colic and exhaustion.

Avogadro, Amedeo (1776–1856) *Italian physicist and chemist*

Avogadro (av-oh-**gah**-droh) was born in Turin in northern Italy and came from a long line of lawyers. He too was trained in law and practiced for some years before taking up the study of mathematics and physics in 1800. His early work was carried out in the field of electricity, and in 1809 he became professor of physics at the Royal College at Vercelli. He was professor of mathematical physics at Turin from 1820 until 1822 and from 1834 to 1850.

His fame rests on his paper *Essai d'une manière de determiner les masses relatives des molecules des corps et les proportions selon lesquelles entrent dans cet combinaisons* (1811; On a Way of Finding the Relative Masses of Molecules and the Proportions in Which They Combine), published in the *Journal de Physique*. This states the famous hypothesis that equal volumes of gases at the same temperature and pressure contain equal numbers of molecules. It follows from the hypothesis that relative molecular weights can be obtained from vapor densities and that the proportion by volume in which gases combine reflects the combining ratio of the molecules. Using this theory, Avogadro showed that simple gases such as hydrogen and oxygen are diatomic (H_2, O_2) and assigned the formula H_2O to water, whereas John DALTON had arbitrarily assumed that the simplest compound of two elements would have the formula HO.

Avogadro's work provided the essential link between Gay Lussac's law of combining volumes and Dalton's atomic theory. This was not, however, realized at the time and, as a consequence, the determination of a self-consistent set of atomic weights was delayed for 50 years. The French physicist André AMPERE was one of the few who accepted the theory and for many years it was taken to be Ampère's own.

Avogadro's contribution to chemisty was not appreciated in his own lifetime. The importance and truth of the theory was unrecognized until 1860 when his fellow Italian, Stanislao CANNIZZARO, forcefully restated it at the Karlsruhe Conference and demonstrated that it was the key needed to unlock the problem of atomic and molecular weights. The number of particles in one mole of a substance was named *Avogadro's constant* in his honor. It is equal to $6.022\ 52 \times 10^{23}$.

Axel, Richard (1946–) *American neuroscientist*

Born in New York, Axel attended Columbia University, graduating AB in 1967, and then studied medicine at Johns Hopkins University School of Medicine, obtaining his MD in 1970. He returned to Columbia University to study pathology, and in 1978 was appointed professor in the pathology and biochemistry department. He became investigator in the Howard Hughes Medical Institute in 1984, and university professor in 1999. He was professor at Harvard Medical School (2001–02) and in 2003 he became affiliate professor in the Department of Physiology and Biophysics at the University of Washington, Seattle.

Axel is best known for his work on the sense of smell, or olfaction. In 1991 he published, jointly with Linda BUCK, a landmark paper that described a large family of genes for receptors of odor molecules. The scientists discovered about a thousand such genes in the mouse, each encoding a receptor protein with unique binding properties, and thus capable of responding to just one or a few odorant molecules. The receptors are anchored in the cell membrane of olfactory receptor cells within the nose. Axel and Buck showed that binding of an odor molecule to its corresponding receptor causes the receptor to activate a G protein inside the cell, which in turn stimulates the formation of cyclic AMP (cAMP). This acts as a second messenger, causing the opening of ion channels in the cell membrane and triggering electrical signals from the cell to the brain via long slender cellular processes. Hence, this work established that odor receptors belong to the class known as G protein-coupled receptors.

Axel and Buck subsequently pursued independent but often complementary lines of enquiry into olfactory reception. They showed that each olfactory receptor cell bears only one type of odor receptor molecule on its surface. However, odor molecules typically can bind to several different receptor types. Thus a single odor will elicit a characteristic pattern of signals from the olfactory receptor cells. This is why an animal such as the mouse can discriminate between as many as 10,000 different smells, even with only 1,000 or so types of receptor cells.

Subsequently, Axel's team at Columbia used genetically engineered mice to reveal that the processes of all olfactory sensory cells carrying the same receptor type converge on the same relay station, or glomerulus, in the olfactory bulb in the brain. Hence, any given odor will trigger signals to a particular set of glomeruli, creating a corresponding spatial "map" in the brain; different odors trigger overlapping but nonidentical combinations of glomeruli. Signals from the glomeruli are transmitted to higher regions of the brain, where the information is processed to produce a conscious experience, and memories of smells are stored.

Axel's attention then turned to the fruit fly *Drosophila* as a simple experimental model. The team confirmed that the fly brain follows the same principles of spatial patterning in olfaction as seen in mice, and that this has both functional and behavioral significance. For example, Axel's team could abolish the normal aversive response to an alarm substance (CO_2) by engineering flies in which the specific glomerulus for CO_2 was inhibited.

For his work on "odorant receptors and the organization of the olfactory system," Axel was awarded the 2004 Nobel Prize for physiology or medicine, jointly with his erstwhile colleague, Linda Buck.

Axelrod, Julius (1912–2005) *American neuropharmacologist*

Axelrod was born in New York City, becoming a student at New York University in 1929, and, after a year, transferring to the City College, where he took a degree in chemistry and biology. He wanted to study medicine but was turned down by several medical schools, despite his qualifications. Axelrod felt that his rejection was influenced by anti-Semitism. From 1933 to 1935 he was a laboratory assistant at the Department of Bacteriology, New York University Medical School. From 1935 to 1945 he had a job as a technician in a laboratory of industrial hygiene that had just been set up in New York. But still with an ambition for a career in scientific research, and after some years at the Goldwater Memorial Hospital and the National Heart Institute, he took a year off in 1955, obtained a PhD from George Washington University, and moved to the National Institute of Mental Health (NIMH) as chief of the pharmacology section. He held this post until his retirement in 1984, while also continuing to work in the cell biology laboratory at the NIMH.

Axelrod's research involved the mechanisms underlying the transmission between nerve cells, in particular, the action of the catecholamines, the neurotransmitters of the sympathetic nervous system. The most important of these is norepinephrine, first identified as a neurotransmitter by Ulf VON EULER in 1946. Axelrod realized that once the molecule had interacted with its target cell some mechanism must come into action to switch it off. Later he was able to describe the role of two enzymes, catechol-o-methyltransferase (COMT) and monoamine oxidase (MAO), which degrade the catecholamines.

However, studies with radioactive norepinephrine showed its persistence in the sympathetic nerves for some hours. This led Axelrod to propose that norepinephrine is taken up into, as well as released from, sympathetic nerves. This recapture inactivates the neurotransmitter. In general, Axelrod's research led to the development of drugs designed to affect neurotransmitters, in particular antidepressants that inhibit the uptake of serotonin. Axelrod also worked on a number of other topics, including the metabolism of the hallucinogenic drug LSD and the working of the pineal gland.

For work on the catecholamines Axelrod shared the 1970 Nobel Prize for physiology or medicine with von Euler and Bernard KATZ.

Ayala, Francisco José (1934–) *Spanish–American biologist*

Ayala (ah-**yah**-la), who was born in Madrid, Spain, began his higher education there at the University of Madrid, moved to America in 1961, and obtained his PhD from Columbia in 1964. He worked initially at Rockefeller before joining the Davis campus of the University of California in 1971, where he was later appointed professor of genetics in 1974. He was professor of biology at the University of California, Irving, from 1987 to 1989, when he became Donald Bren Professor of Biological Sciences.

Ayala has worked extensively in the field of molecular evolution. He has also sought to measure genetic variation in natural populations, rates of evolution, and the amount of genetic change needed to produce new species. Many of his results were published in his *Molecular Evolution* (1976) and in a work he coauthored in 1977 entitled *Evolution*. He has written a number of other books including *Molecular Genetics* (1984). Ayala has campaigned against government restrictions on stem-cell research.

Ayrton, William Edward (1847–1908) *British physicist*

Ayrton was born in London, where his father was a lawyer. After attending University College, London, and Glasgow University, he worked for the Indian Telegraph Company, and in 1873 was appointed to teach natural philosophy and telegraphy at the Imperial Engineering College, Tokyo, Japan. He returned to London in 1879 and became a professor at the City and Guilds College and later at Finsbury Technical College (1881). In 1884 he became a professor at the Central College.

B

Baade, Wilhelm Heinrich Walter (1893–1960) *German–American astronomer*

> Almost every one of Baade's papers turned out to have far-reaching consequences.
> —Sir Fred Hoyle

Baade (**bah**-de), born the son of a schoolteacher in Schröttinghausen, Germany, was educated at the universities of Münster and Göttingen, where he obtained his PhD in 1919. He worked at the University of Hamburg's Bergedorf Observatory from 1919 to 1931, when he moved to America. He spent the rest of his career at the Mount Wilson and Palomar Observatories, retiring in 1958.

In 1920 Baade discovered the minor planet Hidalgo, whose immense orbit extends to that of Saturn. He was also, in 1949, to detect the minor planet Icarus, whose orbit, which lies within that of Mercury, can bring it very close to Earth. In the 1930s he did important work with Fritz ZWICKY on supernovae, with Edwin HUBBLE on galactic distances, and with his old Hamburg colleague, Rudolph MINKOWSKI, on the optical identification of radio sources.

Baade's most significant work however began in 1942. As he was of German origin he was precluded from the general induction of scientists into military research, being allowed to spend the war observing the heavens. In early 1943 he was blessed with ideal viewing conditions. Los Angeles was blacked out because of wartime restrictions and, for a short while, the air was calm and the temperature constant. Under these near-perfect conditions Baade took some famous photographs with the 100-inch (2.5-m) reflecting telescope of the central region of the Andromeda galaxy. To his great excitement he was able to resolve stars in the inner region where Hubble before him had found only a blur of light.

These observations allowed Baade to introduce a fundamental distinction between types of stars. The first type, Population I stars, he found in the spiral arms of the Andromeda galaxy. They were young hot blue stars as opposed to the Population II stars of the central part of the galaxy, which were older and redder with a lower metal content. This distinction, now much expanded, has played a crucial role in theories of galactic evolution.

Some of the stars that Baade observed in the Andromeda galaxy were Cepheid variables, stars that vary regularly in brightness. His realization that there were two kinds of Cepheids had an immediate impact. The relationship between period and luminosity of Cepheids had been discovered by Henrietta LEAVITT in 1912 and put into a quantified form by Harlow SHAPLEY so that it could be used in the determination of stellar distances of great magnitude. In the 1920s Hubble had found Cepheids in the outer part of the Andromeda galaxy, and, using the period–luminosity rule, had calculated its distance as 800,000 light-years. Since then the relationship had been used by many astronomers.

Baade, by 1952, was able to show that the original period–luminosity relationship was valid only for Population II Cepheids whereas Hubble's calculation involved Population I Cepheids. Baade worked out a new period-luminosity relationship for these Cepheids and found that the Andromeda galaxy was two million light-years distant.

The distance to the Andromeda galaxy had been used by Hubble to estimate the age of the universe as two billion years. Baade's revised figure gave the age as five billion years. This result was greeted with considerable relief by astronomers as Hubble's figure conflicted with the three to four billion years that the geologists were demanding for the age of the Earth. Further, with Baade's revision of the distance of the Andromeda galaxy without any change in its luminosity, it was now clear that its size must also be increased together with the size of all the other galaxies for which it had been a yardstick. Baade was thus able to establish that while our galaxy was somewhat bigger than normal it was not the largest, as Hubble's work had implied.

Babbage, Charles (1792–1871) *British mathematician*

> The whole of the development and operations of analysis are now capable of being executed by machinery…. As soon as an Analytical Engine exists, it will necessarily guide the future course of science.
> —*Passages from the Life of a Philosopher* (1864)

> From church we went, by his special invitation, to see Babbage's calculating

> machine; and I must say, that during an explanation which lasted between two and three hours, given by himself with great spirit, the wonder at its incomprehensible powers grew upon us every moment.
>
> —George Ticknor, *Life, Letters, and Journals of George Ticknor* (1876)

Babbage, whose father was a banker, was born in Teignmouth in southwest England and studied at Cambridge. He played a major role in ending the isolationist attitudes prevalent in British mathematical circles in the early 19th century. In 1815 he helped to found the Analytical Society, which aimed to make the work of Continental mathematicians better known in Britain. Babbage's interest in stimulating British scientific activity was by no means confined to mathematics. In 1820 he was a founder of the Royal Astronomical Society and in 1834 of the Statistical Society, and he continued to attack the British public for their lack of interest in science. Among his inventions were a speedometer and the locomotive "cowcatcher." Babbage also did mathematical work that contributed to the setting up of the British postal system in 1840. From 1828 to 1839 he was Lucasian Professor of Mathematics at Cambridge University.

Babbage is best known for his work in designing and attempting to build three mechanical computers. He had been struck by the discrepancies found in mathematical tables and the persistence of error. "I wish to God these calculations had been executed by steam," he lamented in 1821. Mechanical execution, he argued, would eliminate error. Consequently he began work in 1823 on the machine later known as his Difference Engine No. 1. It operated by the method of finite differences and thus allowed values of functions to be obtained by addition rather than by multiplication. The engine was an analog decimal machine in which numbers were represented by the rotation of various wheels. After a decade of work the project was abandoned when Babbage's credit ran out. It had cost the equivalent of about $85,000, was 8-feet high, and was made from 25,000 parts.

He later designed a simpler version, Difference Engine No. 2, with only a third of the number of parts. Plans were drawn up in 1847 and offered to an uninterested government in 1852. Without financial support Babbage never saw the project develop beyond the design stage.

The more ambitious analytical engine, first described in 1834, was similarly unsuccessful. Unlike the Difference Engine, this was to be a general computing machine in the manner of a modern computer, and was intended to be programmed with punched cards. One of Babbage's more enthusiastic supporters in this work was Ada, Countess of Lovelace.

In 1985, Doron Swade and his colleagues at the Science Museum in London set out to build a full-size Babbage computer based upon his original designs. They chose to work on No. 2 and hoped to have it ready for Babbage's bicentenary in 1992. The construction was carried out in full public view on the floor of the museum. It was completed in May 1991, cost $500,000 to build, and has worked satisfactorily ever since.

Babbage was influential in a number of other areas. His *Reflections on the Decline of Science in England* (1830) began the move to the professionalization of British science. In his *On the Economy of Machinery and Manufactures* (1832), a work closely studied by Marx, Babbage argued that industry could only flourish by adopting a scientific approach to both technical and commercial matters. He also campaigned against street noises and was largely responsible for "Babbage's Bill" of 1864, restricting the rights of street musicians. The subject was sufficiently important to him to form a chapter in his revealing *Passages from the Life of a Philosopher* (1864).

Babcock, Harold Delos (1882–1968)
American astronomer

Babcock, who was born in Edgerton, Wisconsin, was educated at the University of California, Berkeley, where he graduated in 1907. In 1908 he joined the staff of the Mount Wilson Observatory where he remained until his retirement in 1948. After his formal retirement he continued to work for many years with his son Horace Babcock.

When he first joined the observatory George HALE had just discovered the presence of strong magnetic fields in sunspots by noting the splitting of their spectral lines, the so-called "Zeeman effect" first described by Pieter ZEEMAN in 1896. Babcock's first task was to supply the basic laboratory data on the effects of strong magnetic fields on various chemical elements.

Many years later, in collaboration with his son, he used their joint invention, the magnetograph, to detect the presence of weak and more generalized magnetic fields on the Sun. They also, in 1948, revealed the existence of strong magnetic fields in certain stars.

Babcock, Horace Welcome (1912–2003)
American astronomer

Babcock was born in Pasadena, California, the son of Harold Delos Babcock, a distinguished American astronomer who spent a lifetime observing at the Mount Wilson Observatory. Horace Babcock graduated in 1934 from the California Institute of Technology (Cal Tech) and obtained his PhD in 1938 from the University of California. He worked initially at Lick Observatory from 1938 to 1939 and at the Yerkes and McDonald observatories from 1939 to 1941. He then engaged in war work at the radiation laboratory at the Massachusetts Institute of Technology (1941–42) and at Cal Tech (1942–45). In 1946 Babcock returned to astronomy and joined his father at Mount Wilson where they began an enormously profitable collaboration. Babcock later served from 1964 until his retirement in 1978 as director of the Mount Wilson and Palomar Observatories, which became known in 1969 as the Hale Observatories.

In 1908 George Hale had detected splitting of the spectral lines in the light from sunspots. Such an effect results from the presence of a magnetic field, an effect first described by Pieter ZEEMAN in 1896. The fields observed by Hale were of considerable strength, ranging up to some 4,000 gauss. The field of the Earth by contrast is less than one gauss. The question then arose as to whether the Sun itself possessed a general magnetic field distinct from fields associated with sunspots. The problem facing early investigators was how to detect weak fields and this was not overcome until 1948 when the Babcocks successfully developed their magnetograph, permitting them to measure and record the Zeeman effect continuously and automatically. By the late 1940s they were able to report the presence of weak magnetic fields on the Sun, about one gauss in strength and restricted to latitudes greater than 55°. Further unexpected features were changes in polarity discovered in the 1950s: when examined in 1955 the north solar pole possessed positive polarity, the south negative polarity; by 1958 the situation was completely reversed.

In 1948 the Babcocks announced the further major discovery of stellar magnetic fields. By 1958 they had established the presence of magnetic fields in some 89 stars. The fields tended to be strong, of the order of several thousand gauss, and seemed to belong mainly to stars of spectral types O and B. Attempts to explain the presence of such fields were made considerably more difficult by the realization that some stars were "magnetic variables": the field of the brighter component of the binary star Alpha Canes Venatici was found to vary, with reversing polarity, from +5,000 to –4,000 gauss in 5.5 days. Such studies have done much to stimulate work on magnetohydrodynamics.

Babcock, Stephen Moulton (1843–1931) *American agricultural chemist*

A farmer's son from New York State, Babcock gained his BA degree from Tufts College, Massachusetts, in 1866 and after a period of farming became a chemistry assistant and (from 1875) instructor at Cornell University. In 1879 he gained his doctorate under Hans Hübner at Göttingen, Germany. After a further spell at Cornell on his return, he became chemist at the New York Agricultural Station in 1882, where he worked on the analysis of milk.

In 1888 Babcock became professor of agricultural chemistry at the University of Wisconsin. Here, in 1890, he devised an efficient test (the *Babcock test*), which quickly became standard, for measuring the butterfat content of milk. Studies followed on rennet, fermentation, metabolic water, and animal nutrition. In 1907 Babcock's associates began studies in which cattle were fed balanced diets derived from a single source – corn, wheat, or oats. The results obtained provided further evidence for the existence of accessory food factors and Babcock's school played an important part in the vitamin studies that followed.

Babinet, Jacques (1794–1872) *French physicist*

Babinet (ba-bee-**nay**), who was born in Lusignan, France, studied in Paris at the Ecole Polytechnique and from 1820 he was a professor at the Collège Louis le Grand. He was elected to the Académie des Sciences in 1840.

His major work was devoted to the diffraction of light; he used diffraction to measure wavelengths more accurately than before, and did theoretical work on general diffraction systems. The *Babinet theorem* states that there is an approximate equivalence between the diffraction pattern of a large system and that of the complementary system, which is opaque where the original system is transparent and vice versa.

Furthermore he showed an interest in the optical properties of minerals, developing new instruments for the measurement of angles and polarizations. He also studied meteorological phenomena, especially those of an optical nature, investigating rainbows and the polarization of skylight. Babinet was the first to suggest (1829) that the wavelength of a given spectral line could be used as a fundamental standard of length. The idea was adopted in 1960, when the meter was defined as 1,650,763.73 wavelengths of the radiation emitted by an atom of krypton–86 in a specified transition. (This definition was changed in 1983 to the distance traveled by light in a certain fraction of a second.)

Babo, Lambert Heinrich Clemens von (1818–1899) *German chemist*

Babo (**bah**-boh) was born in Ladenberg, Germany, and studied at Giessen under Justus von LIEBIG. He was appointed as an assistant professor at Freiburg University in 1845, later being appointed professor of chemistry in 1859.

In 1847 he showed that the vapor pressure of a liquid can be lowered by dissolving substances in it. He also succeeded in demonstrating that the degree of depression of the vapor pressure is, in general, proportional to the concentration of the solution (known as *Babo's* *law*). François RAOULT was able to use Babo's discovery in 1886 to establish some general rules and to determine molecular weights.

Bache, Alexander Dallas (1806–1867) *American geophysicist*

Bache (baych), the great-grandson of Benjamin FRANKLIN, was born in Philadelphia and graduated from West Point in 1825. After two years in the army he became professor of natural science and chemistry (1828–41) at the University of Pennsylvania. He spent the period 1836–38 studying the European educational system, publishing his findings in *Education in Europe* (1839).

In 1840 Bache founded the first American magnetic observatory at Girard College. He became, in 1843, superintendent of the U.S. Coast Survey, which he built up into a major institution. He had the entire coastline surveyed during his lifetime, his own particular research being into the Gulf Stream, an area also studied by his great-grandfather.

Dissatisfied with the American Association for the Advancement of Science he gathered around himself a group of scientists known as the "Lazzorconi," or beggars. He was successful in persuading Congress to create, in 1863, the National Academy of Sciences "to investigate, examine, experiment, and report upon any question of science and art." Bache was made its first president.

Backus, John (1924–2007) *American computer scientist*

Backus was born in Philadelphia. After graduating from Columbia University, New York, he joined the staff of IBM in 1952 and remained with them until his retirement in 1991. From 1959 until 1963 he worked at the IBM Research Center, Yorktown Heights, New York, and thereafter as an IBM Fellow at the IBM Research Laboratory, San Jose, California.

Backus has reported on the state of programming when he joined IBM. It was, he noted, "a black art, a private arcane matter." All programming was done using machine or assembly language. There were no compilers, no index registers, and the programmer spent most of his time debugging the program and feeding it into the computer. The programmers actually cost more than the computer. Backus commented, "They dismissed as foolish plans to make programming accessible to a larger population"; it was inconceivable "that any mechanical process could possibly perform the mysterious feats of invention required to write an efficient program."

In 1954 Backus led an IBM team determined to free computer programming from the professional élite. As the speed of computers increased it made no sense to have them standing idle while a programmer struggled to operate them. The problem was made more pressing by the development of the new and more powerful IBM 704. By late 1954 some of the main details of the high-level language Fortran (from *For*mula *Tran*slation) had been established. Backus defined his aim as "to design a language which would make it possible for engineers and scientists to write programs for the 704." The language itself was available in 1957 and soon became the most widely used programming language of the time.

Bacon, Francis (1561–1626) *British philosopher*

> They are ill discoverers that think there is no land, when they can see nothing but sea.
> —*The Advancement of Learning* (1605)

> I have taken all knowledge to be my province.
> —Letter to Lord Burleigh, 1592

Francis Bacon, Baron Verulam and Viscount St. Albans, was born in London into the Elizabethan ruling class; his father was Sir Nicholas Bacon, lord keeper of the Seal, and his uncle was Lord Burleigh. He entered Cambridge University in 1573 to study law, qualified in 1582, and entered parliament in 1584. His political career was noted for his ability both to attach himself to the side of royal favorites (and thereby rise) and to make sure that he was on the opposing side when they fell from favor (and thereby rise further). He held many state offices including those of attorney general (1613) and lord chancellor (1618).

Bacon's first work of philosophy was *The Advancement of Learning* (1605), a review of the current state of knowledge. He planned an encyclopedia of all knowledge, the *Instauratio Magna* (Great Renewal), but this was never completed, the most substantial fragment being the *Novum organum* (1620; New Organum alluding to the *Organum* of ARISTOTLE concerning logic). Bacon rejected completely deference to the authority of the ancients, in particular the deductive logic of Aristotle, in dealing with science and the investigation of the world. He asserted that nature could be understood and even controlled by man. Bacon's method to accomplish this was induction, by which he understood a method of proceeding from the particular to the general by a process of exclusions, generalizing from particular experiments and investigations. Bacon had a great influence on the first generation of British experimental scientists. Despite his urge toward completeness, Bacon's knowledge of the science of his day was inadequate. In one field, however, he was highly prescient: by induction he concluded that heat was a form of motion.

In 1621 Bacon was accused of bribery, imprisoned for a few days, fined, and banished from parliament and the Court. He retired to his estate in Hertfordshire and in this last period of his life he wrote a revision of *The Advancement of Learning* known by its Latin title *De augmentis scientiarum* (1623). He also produced some fragments of the *Instauratio* and *The New Atlantis*, a utopia that foreshadowed the scientific societies founded later in the century.

Bacon's death was brought on by his last scientific experiment. He had the idea that snow might preserve flesh and to test this he stuffed a chicken with snow, which he himself collected. It is said that as a result he caught a chill and died soon after.

Bacon, Roger (1220–1292) *English philosopher and alchemist*

> All science requires mathematics.
> —*Opus majus* (1733; Major Work)

> Without experience nothing can be known sufficiently.
> —As above

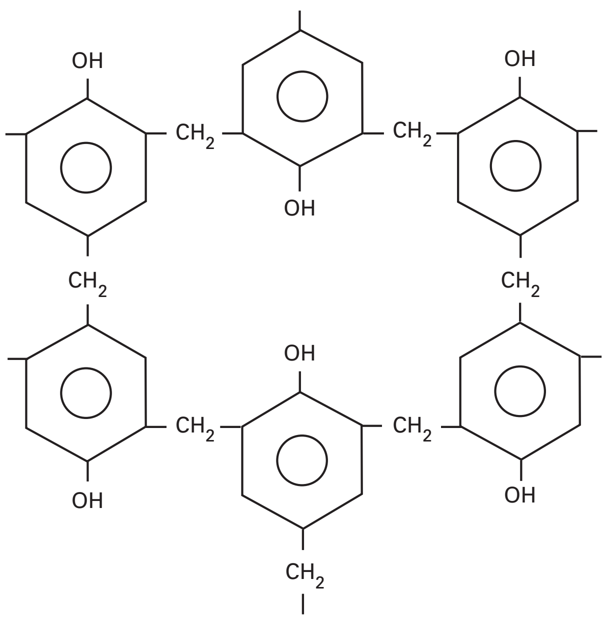
Bacon, who was born in Ilchester, southwest England, studied at Oxford and then at Paris (1234–50) under Petrus Peregrinus. In about 1257 he joined the Franciscan Order and from about 1250 until 1277 he was at Oxford, where he studied under Grosseteste. He is supposed to have been confined in Paris from 1277.

Bacon was often in disgrace with the authorities but he had a considerable reputation as a philosopher and alchemist, being called *Doctor Mirabilis* (Miraculous Teacher). From about 1247 until 1257 he concentrated on research in mathematics, optics, alchemy, and astronomy and during this developed a magnifying glass, defined reflection and refraction, and also mentioned gunpowder in his writings. Bacon distinguished two kinds of alchemy, speculative and operative, and he believed firmly in the practical benefits of science. His writings, the *Opus majus* (Major Work, published in 1733), *Opus secundus* (Second Work), and *Opus tertius* (Third Work), include a number of predictions, of powered cars, aircraft, and ships, and of machines for extending the powers of man. He was committed to the belief that the Earth was round, and suggested that it could be circumnavigated. He stressed that experimentation was essential to the progress of science.

Baekeland, Leo Hendrik (1863–1944) *Belgian–American industrial chemist*

Baekeland (**bayk**-land) was born in Ghent and educated at the university there, graduating in 1884. He was professor of physics and chemistry at Bruges in 1887 and returned to Ghent the next year as assistant professor of chemistry. But Baekeland grew impatient with academic life and in 1889 a honeymoon tour took him to America where he settled.

Baekeland worked at first as a photographic chemist and in 1891 he opened his own consulting laboratory. In 1893 he began to manufacture a photographic paper, which he called Velox, and six years later his company was bought out by the Kodak Corporation for one



BAKELITE *The polymeric structure of bakelite.*

million dollars. Now financially independent, Baekeland returned to Europe to study at the Technical Institute at Charlottenburg.

On his return to America, Baekeland began to investigate, as a synthetic substitute for shellac, the phenol–formaldehyde resins discovered by BAEYER in 1871. Since nothing remotely like shellac emerged, he began to look for other uses for this material. By choosing suitable reaction conditions he produced a hard amberlike resin, which could be cast and machined and which had excellent durability and electrical properties. Bakelite was finally unveiled in 1909, when Baekeland set up the General Bakelite Corporation.

In 1922 Baekeland's company merged with two rivals and in 1939 it became a subsidiary of the Union Carbide and Carbon Corporation. Baekeland continued to produce scientific papers throughout this period. He received many honors and held many professional posts, including that of president of the American Chemical Society.

Baer, Karl Ernst von (1792–1876) *German–Estonian biologist, comparative anatomist, and embryologist*

Baer (bair) is generally considered the father of modern embryology. He was born on his family's estate in Piep, Estonia, and received private tutoring and schooling before entering Dorpat University to study medicine. He graduated in 1814 and then studied comparative anatomy at the University of Würzburg, where he was introduced to embryology by Ignaz DÖLLINGER. In 1817 Baer became professor of zoology at Königsberg and in 1834 was appointed academician and librarian of the Academy of Sciences at St. Petersburg.

It was prior to his move to St. Petersburg that Baer did most of his pioneering work in laying the foundation of comparative embryology as a separate discipline. In distinguishing the mammalian ovum within the Graafian follicle he established that all mammals, including man, develop from eggs. He also traced the development of the fertilized egg and the order in which the organs of the body appear and develop, showing that similar (homologous) organs arise from the same germ layers in different animals, thus extending the work of Kaspar WOLFF and the German anatomist Christian Pander. His expounding of the "biogenetic law," demonstrating the increasing similarity and lack of specialization in the embryos of different animals as one investigates younger and younger embryos, provided DARWIN with basic arguments for his evolutionary theory. Baer was, however, opposed to the idea of there being a common ancestor for all animal life, although he conceded that some animals and some races of man might have had common ancestry. His other notable discoveries included the mammalian notochord and the neural folds as the precursors of the nervous system. Baer intended his embryological work to be, at least partly, a means of improving animal classification by demonstrating vertebrate affinities. Indeed modern zoological classification is now based partly on biogenetic principles. His great work on the mammalian egg, *De ovi mammalium et hominis genesi* (1827; On the Origin of the Mammalian and Human Ovum) was followed (1828–37) by *Über Entwickelungsgeschichte der Tiere* (On the Development of Animals), in which he surveyed all existing knowledge of vertebrate development.

A man of wide interests, Baer did much work in other scientific disciplines. He was instrumental in founding the German Anthropological Society and helped to found the Russian Geographical and Entomological Societies.

Baeyer, Johann Friedrich Adolph von (1835–1917) *German organic chemist*

Baeyer (**bay**-er) was the son of a member of the Prussian General Staff and his mother was the daughter of a celebrated jurist and literary historian. Born in Berlin, Baeyer went to Heidelberg in 1856 to study chemistry with Robert BUNSEN. Here he met August KEKULE, who had a profound influence on his development as a chemist and gave him the theoretical foundation for his work. After obtaining his PhD (1858) Baeyer took up a teaching position in 1860 at a small technical school, the Gewerbe-Institut, in Berlin. In 1872 he was appointed professor of chemistry at Strasbourg and in 1875 succeeded LIEBIG as professor of chemistry at Munich, where he remained for the rest of his life.

In 1864, continuing the work of WÖHLER, Liebig, and Schlieper on uric acid, Baeyer characterized a related series of derivatives including alloxan, parabanic acid, hydantoin, and barbituric acid. In 1871 he discovered the phthalein dyes, phenolphthalein and fluorescein, by heating phenols with phthalic anhydride. In the course of this work he discovered the phenol–formaldehyde resins, which were later developed commercially by BAEKELAND. The centerpiece of Baeyer's prolific researches, however, was his work on indigo, which started in 1865 and lasted for 20 years.

The first step consisted of the reduction of indigo to its parent substance, indole, which Baeyer accomplished by the new method of heating with zinc dust. The first synthesis was a lengthy one, starting from phenylacetic acid. This was soon followed by shorter methods starting from *o*-nitrocinnamic acid and *o*-nitrophenylpropionic acid. In 1883 he gave a structure of indigo that was correct except for the stereochemical arrangement of the double bond, which was later shown to be *trans* by x-ray crystallography (1928). Baeyer's syntheses proved too costly for commercial manufacture and he took no part in the industrial development of indigo, terminating his work in 1885. Commercial synthetic indigo was eventually produced in 1890. Baeyer's work also led to the production of many other new dyes.

From indigo Baeyer turned to the polyacetylenes, compounds whose explosive properties led him to consider the stability of carbon–carbon bonds in unsaturated and ring compounds. He formulated the *Baeyer strain theory*, stating that compounds are less stable the more their bond angles depart from the ideal tetrahedral arrangement. Baeyer's other researches included work on oxonium compounds; on the reduction of aromatic compounds, in which he observed a loss of aromaticity on reduction; and on terpenes, including the first synthesis of a terpene in 1888.

The strain theory was one of Baeyer's few theoretical contributions; he was a virtuoso of test-tube chemistry at a time when this could produce extraordinary results. In 1905 he received the Nobel Prize for chemistry for his work on indigo and aromatic compounds.

Bahcall, John Noris (1934–2005) *American physicist*

Bahcall was born in Shreveport, Louisiana, and educated at the universities of California, Chicago, and Harvard, where he obtained his PhD in 1961. He immediately moved to the faculty of the California Institute of Technology, and remained there until 1971 when he was appointed to the Institute of Advanced Studies, Princeton.

In the 1960s Bahcall began to consider the emission of neutrinos from the Sun. One of the apparent early triumphs of nuclear physics was the light it threw on the internal workings of the Sun. Theorists such as Hans BETHE had proposed the existence of a number of cyclic fusion reactions producing vast amounts of energy, heavier elements, and a certain number of neutrinos. As neutrinos have a low probability of interacting with other particles, some solar neutrinos should be received at the Earth's surface. Bahcall calculated that there occurs one event per second for every 10^{36} target atoms, for which one solar neutrino unit (SNU) should be detectable. The matter was put to the test by Raymond DAVIS, who used a detector consisting of a tank of 100,000 gallons of cleaning fluid in a one-mile-deep mine.

Bahcall predicted that Davis would observe a flux of about 8 SNU. In fact, from 1967 onwards, Davis recorded a flux of about 2 SNU. The burden was placed upon the theorists to account for the anomalous results, or to revise the theory in ways that would make the results acceptable. This is the *solar neutrino problem*.

A number of options were considered by Bahcall. Perhaps, the Sun was passing through a quiet phase and over long periods of time neutrino output would agree with theory. It was also thought that the issue would eventually be resolved when the abundance of radioactive technetium, produced by interactions deep in the Earth between neutrinos and molybdenum, has been accurately measured.

Or, perhaps, our solar model is wrong. This, Bahcall pointed out, leads nowhere. Alternative solar models agree with the standard model in the rate of neutrino production. Other theorists have challenged generally accepted physical principles. Bahcall considered the possibility that *neutrino oscillations* occurred, i.e., the transition from one type of neutrino to another type. This process is only possible if neutrinos have nonzero masses. This is necessarily the case in most grand unified theories. Since there is evidence from other sources that neutrinos do have nonzero masses, the current consensus is that these neutrino oscillations explain the solar neutrino problem, although this has not been conclusively demonstrated.

As a number of new and more sensitive detectors are being built, theorists seem inclined to await fresh data before judging between competing theories. Until then, as Bahcall noted, physicists will dismiss the problem as a matter of astronomy while astronomers will attribute the anomaly to the failings of physics.

Baillie, Matthew (1761–1823) *British physician*

Baillie, who was born in Scotland, studied classics, mathematics, and philosophy at Glasgow University and then arts and medicine at Oxford University. He graduated MD in 1787 and was appointed physician to St. George's Hospital, London. A nephew of William and John HUNTER, he inherited William Hunter's house and medical school at Windmill Street in 1783. Baillie's major work was the *Morbid Anatomy of Some of the Most Important Parts of the Human Body* (1793). This was a pioneering work, illustrated by a series of engravings, that helped establish pathology as a separate subject. From 1810 onward he was a physician to the royal family, attending George III during his final illness.

His sister was the poet and dramatist, Joanna Baillie.

Baily, Francis (1774–1844) *British astronomer*

Born in Newbury in southern England, Baily was a prosperous stockbroker who, on retirement, devoted himself to astronomy. During the total eclipse of the Sun in 1836 he noted that immediately before and after totality a number of bright points of light appear around the edge of the Moon. This effect, known as

Baily's beads, is caused by light from the Sun shining through the lunar valleys.

Baird, John Logie (1888–1946) *British inventor*

Baird, who was born in Helensburgh, Scotland, studied electrical engineering at the Royal Technical College in Glasgow and then went to Glasgow University. His poor health prevented him from active service during World War I and from completing various business enterprises in the years following the war.

After a breakdown in 1922 he retired to Hastings and engaged in amateur experiments on the transmission of pictures. Using primitive equipment he succeeded in transmitting an image over a distance of a couple of feet, and in 1926 he demonstrated his apparatus before a group of scientists. Recognition followed, and the next year he transmitted pictures by telephone wire between London and Glasgow. In the same year he set up the Baird Television Development Company. He continued to work on improvements and on 30 September 1929 gave the first experimental BBC broadcast. Synchronization of sound and vision was achieved a few months later. In 1937, however, the Baird system of mechanical scanning was ousted by the all-electronic system put forward by Marconi–EMI. Baird was at the forefront of virtually all developments in television and continued research into color, stereoscopic, and big-screen television until his death.

Baird, Spencer Fullerton (1823–1887) *American biologist*

Baird was born in Reading, Pennsylvania, and educated at Dickinson College. From 1845 to 1850 he was professor of natural sciences at the college, making immense collections of North American fauna from several expeditions. In 1874 he was appointed United States Commissioner of Fish and Fisheries. He was assistant secretary and then full secretary (1878–87) of the Smithsonian Institution and in 1857 was one of the founders of the Institution's National Museum. Baird was also one of the principal founders of the Woods Hole Marine Laboratory. A colleague of Louis AGASSIZ and John J. Audubon, Baird did much to introduce field study in botany and zoology in the United States, in ornithology in particular, stressing the importance of extreme accuracy in descriptions. From 1853 to 1884 he published several accounts of North American reptiles, birds, and mammals.

Bakewell, Robert (1725–1795) *British stock breeder*

Little is known about Bakewell's early life except that he helped his father on their 440-acre rented farm at Dishley in Leicestershire in central England, which he took over in 1760 on the death of his father. Bakewell's aim was to "get beasts to weigh where you want them to weigh." His most impressive achievement was the production of his Leicester breed of sheep. Within 50 years the breed had spread throughout the world and Bakewell apparently succeeded in producing two pounds of mutton where there had only been one before. He also introduced the custom of letting out his rams for breeding. He was, however, less successful with his Leicester long horn cattle, which, though good meat-producers, did not yield much milk.

Bakker, Robert (1945–) *American paleontologist*

> Let dinosaurs be dinosaurs. Let the Dinosauria stand proudly alone, a class by itself. They merit it. And let us squarely face the dinosaurness of birds and the birdness of the Dinosauria.
> —*The Dinosaur Heresies* (1986)

The son of an electrical engineer, Bakker was born in Ridgewood, New Jersey, and educated at Yale and at Harvard, where he completed his PhD in 1976. After teaching for eight years at Johns Hopkins University, Baltimore, he moved to Boulder, Colorado, in 1984 to work as an independent paleontologist.

In the early 1970s, while still a graduate student, Bakker argued that traditional views on the nature of dinosaurs were misguided. Dinosaurs, he claimed, were warm-blooded, like mammals, and not cold-blooded like reptiles. In support Bakker offered three main arguments derived from comparative anatomy, latitudinal zonation, and ecology.

Anatomically the bones of endotherms (warm-blooded creatures) are rich in blood vessels and show no growth rings. Precisely these features are found in mammals, birds, and, Bakker noted, dinosaurs as well. They are lacking in cold-blooded reptiles (ectotherms).

Further, endotherms can cope with most temperature variations and can be found in temperate, arctic, and equatorial zones. Large reptiles, however, cannot survive cool winters. Yet, during the Cretaceous, dinosaurs could have been found in the far north of Canada, well within the Arctic Circle.

Finally Bakker points to predator–prey ratios. The Komodo dragon, the largest living lizard, consumes its own weight every 60 days, a lion in only eight days. Such are the demands of endothermy. As a consequence a community can support fewer warm-blooded predators than cold-blooded predators. The predator–prey ratio, Bakker argued, is a constant characteristic of the predator's metabolism. Calculations revealed that a given biomass can support a warm-blooded predator biomass of 1–3% and a cold-blooded predator biomass of up to 40%. Given that some fossil deposits yield thousands of individuals, their predator– prey ratio should be measurable. And Bakker did find that among the reptiles of the Permian (285–225 million years ago) the ratio was very high (35–60%), while the dinosaurs of the Triassic (225–195 million years) had a ratio of only 1–3%.

Bakker's work called for a revision of vertebrate systematics. In traditional classifications birds and dinosaurs are seen as collateral descendants of thecodonts, that is, animals with teeth set in sockets. Bakker, however, has proposed that birds are descended from dinosaurs. Such views, vigorously and frequently expressed, have made Bakker a controversial and well-known figure. It is often said that Bakker was the inspiration for the main character in the popular film *Jurassic Park*.

Bakker has sought to reach an even wider public with his *Raptor Red* (1995), a popular novel dealing with a year in the life of a large predatory dinosaur. He now lives in Wyoming, where he conducts guided digs.

Balard, Antoine-Jérôme (1802–1876) *French chemist*

Balard (ba-**lar**) was born in Montpellier in southern France, and studied there at the School of Pharmacy. After graduating in 1826, he remained at Montpellier as a demonstrator in chemistry. In 1825, while investigating the salts contained in seawater, he discovered a dark red liquid, which he proved was an element with properties similar to chlorine and iodine. Balard proposed the name "muride" but the editors of the journal *Annales de chimie* (Annals of Chemistry) preferred "brome" (because of the element's strong odor, from the Greek for "stink") and the element came to be called bromine. Balard also (1834) discovered dichlorine oxide (Cl_2O) and chloric(I) acid ($HClO$).

In 1833 he became professor at Montpellier and in 1843 succeeded Louis Thenard at the Sorbonne as professor of chemistry. In 1854 he was appointed professor of general chemistry at the Collège de France, where he remained until his death.

Balfour, Francis Maitland (1851–1882) *British zoologist*

The younger brother of the British statesman Earl Balfour, Francis Balfour's career was cut short when, while convalescing from typhoid fever in Switzerland, he died attempting an ascent of the Aiguille Blanche, Mont Blanc. Balfour, who was born in Edinburgh, Scotland, held the position of animal morphologist at the Naples Zoological Station and in 1882 was appointed to the specially created post of professor of animal morphology at Cambridge University. Much influenced by the work of Michael FOSTER, with whom he wrote *Elements of Embryology* (1883), Balfour showed the evolutionary connection between vertebrates and certain invertebrates, both of which have a notochord (a flexible rod of cells extending the length of the body) in their embryonic stages. Similar research was being conducted at that time by Aleksandr KOVALEVSKI. Balfour proposed the term Chordata for all animals possessing a notochord at some stage in their development, the Vertebrata (backboned animals) being a subphylum of the Chordata. He was an early exponent of recapitulation – the theory that ancestral forms are repeated in successive embryonic stages undergone by modern species. Balfour also did pioneer work on the development of the kidneys and related organs, as well as the spinal nervous system. His other important publications include *On the Development of Elasmobranch Fishes* (1878) and *Comparative Embryology* (1880–81) published in two volumes (invertebrates and vertebrates), the latter forming the basis of modern embryological study.

Balmer, Johann Jakob (1825–1898) *Swiss mathematician*

Born in Lausanne, Switzerland, Balmer (**bahl**-mer) was not a professional scientist but worked as a school teacher in Basel from 1859. In 1885 he discovered that there was a simple mathematical formula that gave the wavelengths of the spectral lines of hydrogen – the *Balmer series*. This formula proved to be of great importance in atomic spectroscopy and in developing the atomic theory. Balmer arrived at his result purely from empirical evidence and was unable to explain why it yielded correct answers. Not until the further development of the atomic theory by Niels BOHR and others was this possible.

Baltimore, David (1938–) *American molecular biologist*

Baltimore was born in New York City and studied chemistry at Swarthmore College. He continued with postgraduate work at the Massachusetts Institute of Technology, and at Rockefeller University, where he obtained his PhD in 1964. After three years at the Salk Institute in California, he returned to MIT in 1968 where, in 1972, he became professor of biology.

Francis CRICK had formulated what came to be known as the Central Dogma of molecular biology, namely, that information could flow from DNA to RNA to protein but could not flow backward from protein to either DNA or RNA. Although he had not actually excluded the passage of information from RNA to DNA it became widely assumed that such a flow was equally forbidden. In June 1970 Baltimore and, quite independently, Howard TEMIN announced the discovery of an enzyme later to be known as reverse transcriptase, which is capable of transcribing RNA into DNA. Apparently certain viruses, like the RNA tumor viruses used by Baltimore, could produce DNA from an RNA template. For this work Baltimore shared the 1975 Nobel Prize for physiology or medicine with Temin and Renato DULBECCO. A few years later their work took on an added significance when GALLO and MONTAGNIER identified a retrovirus as the cause of AIDS.

Earlier (1968) Baltimore had done important work on the replication of the polio virus. He revealed that the RNA of the virus first constructed a "polyprotein" (or giant protein molecule), which then split into a number of smaller protein molecules. Two of these polymerized further RNA while the remainder formed the protein coat of the new viral particles.

In 1982 Baltimore became founding director of the Whitehead Institute, Cambridge, Massachusetts, a research biomedical foundation backed by the industrialist E. C. Whitehead. While at Whitehead, in collaboration with D. Schatz, he identified two antibody genes, RAG-1 and RAG-2. In 1990 Baltimore was appointed president of Rockefeller University; it was not to prove a fruitful or happy time. Many staff opposed the appointment and Baltimore became involved in a bitter controversy. It had been claimed that a paper coauthored by Baltimore and published in 1986 in the journal *Cell* was based on falsified data. Although Baltimore withdrew his name from the paper, the public controversy persisted in Congressional hearings and the correspondence columns of the British scientific journal *Nature*. Baltimore resigned the presidency in 1992 and returned to MIT in 1994 as professor of molecular biology. He was appointed president of the California Institute of Technology in 1997, resigning in 2006. Baltimore is currently president of the American Association for the Advancement of Science.

Bamberger, Eugen (1857–1932) *German chemist*

Bamberger (**bahm**-ber-ger) studied at Breslau, Heidelberg, and in his native city of Berlin, where he graduated. After working as an assistant, first to Karl Rammelsberg in Berlin (1882) and then to Adolf von BAEYER in Munich (1883), he became professor of chemistry at the Federal Institute of Technology in Zurich in 1893.

Bamberger worked on a number of topics in organic chemistry, including the synthesis of nitroso compounds and quinols, the conversion of sulfonic acids into sulfanilic acids, and the production of diazonium anhydrides. He also extended Baeyer's ideas on benzene structure to naphthalene and first proposed the term "alicyclic" to describe unsaturated organic ring compounds.

Banach, Stefan (1892–1945) *Polish mathematician*

Banach (**bah**-nak) was born into a poor family in Krakow, Poland, and was largely self-educated. Although he attended the Lwow Institute of Technology he did not graduate. He taught mathematics privately for some years before being appointed in 1922 to the University of Lwow, where he was elected professor of mathematics in 1927. Lwow was occupied by the Germans in 1941 and although Banach managed to survive the war years he died from lung cancer in 1945.

Banach is one of the few mathematicians, along with EUCLID and HILBERT, who have given their name to a space. A *Banach space* is a type of vector space more general than a Hilbert space.

In 1924, Banach, with A. TARSKI, proved an apparently nonsensical theorem. The *Banach–Tarski paradox* claims that it is possible to dissect a sphere into a finite number of pieces which can be reassembled to form two spheres the same size as the original. It was later shown that the sphere must be dissected into at least five pieces.

Banks, Sir Joseph (1743–1820) *British botanist*

> He [Banks] stopped and, looking round, involuntarily exclaimed, "How beautiful!" After some reflection he said to himself, "It is surely more natural that I should be taught to know all these productions of Nature, in preference to Greek and Latin; but the latter is my father's command and it is my duty to obey him; I will however make myself acquainted with all these different plants for my own pleasure and gratification."
> —Sir Everard Home, *Hunterian Oration* (1822)

The son of William Banks of Revesby Abbey, Lincolnshire, Joseph Banks inherited a large fortune when he came of age, and later used this money to finance his scientific expeditions. Born in London, he studied botany at Oxford, graduating in 1763, and three years later traveled abroad for the first time as naturalist on a fishery-protection vessel heading for Labrador and Newfoundland. On the voyage he was able to collect many new species of plants and insects and, on his return, was elected a fellow of the Royal Society.

In London Banks learned that the Royal Society was organizing a voyage to the South Pacific to observe the transit of Venus across the Sun. In 1768 James COOK set sail in the *Endeavour* and Banks, together with a team of artists and the botanist Daniel Solander, accompanied him. Cook landed in Australia, a continent with a flora and fauna different from any found elsewhere. Banks found that most of the Australian mammals were marsupials, which are more primitive, in evolutionary terms, than the placental mammals of other continents.

After three years with the *Endeavour* Banks returned, with a large collection of unique specimens, to find himself famous. George III, interested in hearing a first-hand account of Banks's travels, invited him to Windsor. This visit was the start of a long friendship with the king, which helped Banks establish many influential contacts – possibly a factor in his election as president of the Royal Society in 1778, a post that he held until his death.

Throughout his life Banks retained his interest in natural history and in the specimens collected on the many expeditions mounted during that period. As honorary director of Kew Gardens he played a major part in establishing living representatives of as many species as possible at Kew and in providing a center for advice on the practical use of plants. He initiated many successful projects, including the introduction of the tea plant to India from its native China and the transport of the breadfruit from Tahiti to the West Indies. By George III's request, he also played an active role in importing merino sheep into Britain from Spain.

The British Museum (Natural History) now houses Banks's library and herbarium, both regarded as major collections.

Banting, Sir Frederick Grant (1891–1941) *Canadian physiologist*

Banting, a farmer's son from Alliston, Ontario, began studying to be a medical missionary at Victoria College, Toronto, in 1910. During his studies he concentrated increasingly on medicine and graduated MD in 1916, whereupon he immediately joined the Canadian Army Medical Corps. In 1918 he was awarded the Military Cross for gallantry in action and was invalided out of the army.

Banting then returned to Toronto and worked for a time studying children's diseases before setting up practice in London, Ontario, in 1920. He also began work at the London Medical School, specializing in studies on the pancreas, particularly the small patches of pancreatic cells known as the islets of Langerhans. Earlier work had shown a connection between the pancreas and diabetes and Banting wondered if a hormone was produced in the islets of Langerhans that regulated glucose metabolism. In 1921 he approached John Macleod, professor of physiology at Toronto University, who was initially skeptical. Feeling that Banting needed help in physiological and biochemical methods, Macleod suggested the assistance of a young research student, Charles BEST, and eventually merely granted Banting and Best some laboratory space during the vacation, while he went abroad.

Over the next six months Banting and Best devised a series of elegant experiments. They tied off the pancreatic ducts of dogs and made extracts of the islets of Langerhans free from other pancreatic substances. These extracts, called "isletin," were found to have some effect against diabetes in dogs. Prior to trials on humans, Macleod asked a biochemist, James Collip, to purify the extracts and the purification method for what was now known as insulin was patented by Banting, Best, and Collip in 1923. They allowed manufacturers freedom to produce the hormone but required a small royalty to be paid to finance future medical research.

The pharmaceutical firm Eli Lilly began industrial production of insulin in 1923 and in the same year Banting was awarded the chair of medical research at Toronto University and a government annuity of $7,000. The Nobel Prize for physiology or medicine was awarded jointly to Banting and Macleod in 1923; Banting was furious that Best had not been included in the award and shared his part of the prize money with him. Macleod shared his portion with Collip. In 1930 the Banting and Best Department was opened at the University of Toronto and Banting became its director. Under Best's guidance, it became the center of medical research in Canada. His own later researches were into cancer and also the function of the adrenal cortex.

Banting was knighted in 1934. When war broke out in 1939 he joined an army medical unit and worked on many committees linking Canadian and British wartime medical research. His bravery was much in evidence at this time, particularly his personal involvement in research into mustard gas and blackout problems experienced by airmen. In 1941 on a flight from Gander, Newfoundland, to Britain his plane crashed and he died in the snow.

Bárány, Robert (1876–1936) *Austro-Hungarian physician*

Bárány (**bah**-rah-nee) was born in Vienna and educated at the university there, graduating in medicine in 1900. After studying at various German clinics, he returned to Vienna to become an assistant at the university's ear clinic. In 1909 he was appointed lecturer in otology. Through his work at the clinic he devised a test, now called the *Bárány test*, for diagnosing disease of the semicircular canals of the inner ear by syringing the ear with either hot or cold water. For this he was awarded the 1914 Nobel Prize in physiology or medicine. At this time he was being held as a prisoner of war in Siberia, but through the offices of the Swedish Red Cross he was released for the presentation.

In 1917 Bárány was appointed professor at

Uppsala University, where he continued his investigations on the inner ear and the role of the cerebellum in the brain in controlling body movement. *Bárány's pointing test* is used to test for brain lesions.

Barcroft, Sir Joseph (1872–1947) *Irish physiologist*

Barcroft was born in Glen Newry in Northern Ireland. As professor of physiology at Cambridge University (1926–37) and director of animal physiology for the Agricultural Research Council (1941–47), he carried out extensive research into human embryology, physiology, and histology. He investigated the oxygen-carrying role of hemoglobin, and devised (1908) an apparatus for the analysis of blood gases.

Barcroft led three high-altitude expeditions – to Tenerife (1910); Monte Rosa, Italy (1911); and the Peruvian Andes (1922) – in order to study acclimatization and the effects of rarefied atmospheres on respiration. He found that, at low oxygen pressures, the human lung is not able to secrete oxygen into the blood at a higher pressure than the pressure of the inhaled air.

During World War I, Barcroft was chief physiologist at the Experimental Station at Porton, Wiltshire, where he studied the effects of poisonous gases. Elected a fellow of the Royal Society in 1910 and knighted in 1935, Barcroft wrote the famous text *Respiratory Function of the Blood* (1914), as well as publications on the brain and its environment and on prenatal conditions.

Bardeen, John (1908–1991) *American physicist*

Bardeen, the son of a professor of anatomy, was born in Madison, Wisconsin, and studied electrical engineering at the University of Wisconsin. He obtained his PhD in mathematical physics at Princeton in 1936. Bardeen began work as a geophysicist with Gulf Research and Development Corporation, Pittsburgh, in 1931 but in 1935 entered academic life as a junior fellow at Harvard, moving to the University of Minnesota in 1938. He spent the war years at the Naval Ordnance Laboratory, followed by six creative years from 1945 until 1951 at the Bell Telephone Laboratory, after which he was appointed professor of physics and electrical engineering at the University of Illinois, a post he held until 1975.

Bardeen is remarkable as a recipient of two Nobel Prizes for physics. The first, awarded in 1956, he shared with Walter BRATTAIN and William SHOCKLEY for their development of the point-contact transistor (1947), thus preparing the way for the development of the more efficient junction transistor by Shockley.

Bardeen's second prize was awarded in 1972 for his formulation, in collaboration with Leon COOPER and John SCHRIEFFER, of the first satisfactory theory of superconductivity – the so-called BCS theory. In 1911 Heike KAMERLINGH-ONNES had discovered that mercury lost all electrical resistance when its temperature was lowered to 4.2 kelvins. Superconductivity was also shown to be a property of many other metals, yet despite much effort to understand the phenomenon, a full explanation was not given until 1957. The basic innovation of the BCS theory was that the current in a superconductor is carried not by individual electrons but by bound pairs of them, later known as *Cooper pairs*. The pairs form as a result of interactions between the electrons and vibrations of the atoms in the crystal. The scattering of one electron by a lattice atom does not change the total momentum of the pair, and the flow of electrons continues indefinitely.

The success of the BCS theory led to an enormous revival of interest in both the theory of superconductors and their practical application. Beginning in the 1970s, there began to emerge a new industry capable of exploiting superconducting materials, especially in devices based on the effects discovered by Brian JOSEPHSON.

Barger, George (1878–1939) *British organic chemist*

Barger, of Anglo-Dutch parentage, was born in Manchester, England, attended school in Holland, and studied natural sciences at Cambridge University, where he graduated with equal distinction in chemistry and botany.

While a demonstrator in botany at the University of Brussels (1901–03) Barger discovered a method of determining the molecular weight of small samples by vapor-pressure measurements. From 1903 to 1909 he was a researcher at the Wellcome Physiological Research Laboratories, where he worked mainly on ergot, isolating ergotoxine in collaboration with Francis Carr (1906).

In the course of the work on ergot Barger and Henry DALE isolated a series of related amines, derived from tyramine, which had sympathomimetic activity. This work led to a better understanding of the nervous system and to the development of new drugs. The work on active amines was collected in *The Simpler Natural Bases* (1914) and the work on ergot culminated in the definitive monograph on every facet of the subject, *Ergot and Ergotism* (1931).

From 1909 to 1919 Barger worked in London, as head of chemistry at Goldsmiths' College, professor of chemistry at Royal Holloway College, and from 1914 as chemist with the National Institute of Medical Research. In 1919 he was elected a fellow of the Royal Society and appointed to the new chair of chemistry in relation to medicine at Edinburgh. The most notable researches of this period were Charles Harington's structural elucidation and synthesis of thyroxine, in which Barger collaborated, and Barger's synthesis of methionine. His school did important work on physostigmine, cholinesterase, and vitamin B_1. In 1938 Barger became professor of chemistry at the University of Glasgow. He was a pioneer of medicinal chemistry, an excellent linguist, and a tireless ambassador for science.

Barkhausen, Heinrich Georg (1881–1956) *German physicist*

After attending the gymnasium and engineering college in his native city of Bremen, Barkhausen (**bark**-how-zen) gained his PhD in Göttingen and in 1911 became professor of electrical engineering in Dresden. Here he formulated the basic equations governing the coefficients of the amplifier valve.

In 1919 he discovered the *Barkhausen effect*, observing that a slow continuous increase in the magnetic field applied to a ferromagnetic material gave rise to discontinuous leaps in magnetization, which could be heard as distinct clicking sounds through a loudspeaker. This effect is caused by domains of elementary magnets changing direction or size as the field increases.

In 1920, with K. Kurz he developed an ultrahighfrequency oscillator, which became the forerunner of microwave-technology developments. After World War II he returned to Dresden to aid the reconstruction of his Institute of High-Frequency Electron-Tube Technology, which had been destroyed by bombing, and remained there until his death.

Barkla, Charles Glover (1877–1944) *British x-ray physicist*

Barkla was born in Widnes in the northwest of England. After taking his master's degree in 1899 at Liverpool, Barkla went to Trinity College, Cambridge but, because of his passion for singing, he transferred to King's College to sing in the choir. At King's College he started his important research on x-rays. In 1902 he returned to Liverpool as Oliver Lodge Fellow and in 1909 became Wheatstone Professor at King's College, London. From 1913 onward he was professor of natural philosophy at Edinburgh University.

His scientific work, for which he received the 1917 Nobel Prize for physics, concerned the properties of x-rays – in particular, the way in which they are scattered by various materials. He showed in 1903 that the scattering of x-rays by gases depends on the molecular weight of the gas. In 1904 he observed the polarization of x-rays – a result that indicated that x-rays are a form of electromagnetic radiation like light. Further confirmation of this was obtained in 1907 when he performed certain experiments on the direction of scattering of a beam of x-rays as evidence to resolve a controversy with William Henry BRAGG who argued, at the time, that x-rays were particles.

Barkla also demonstrated x-ray fluorescence, in which primary x-rays are absorbed and the excited atoms then emit characteristic secondary x-rays. The frequencies of the characteristic x-rays depend on the atomic number of the element, as shown by Henry Mosely, who could well have shared Barkla's Nobel Prize but for his untimely death.

From about 1916, Barkla became isolated from modern physics with an increasingly dogmatic attitude, a tendency to cite only his own papers, and a concentration on untenable theories.

Barnard, Christiaan Neethling (1922–2001) *South African surgeon*

> The prime goal is to alleviate suffering and not to prolong life. And if your treatment does not alleviate suffering but only prolongs life, that treatment should be stopped.

Barnard, who was born in Beaufort West, South Africa, was awarded his MD from the University of Cape Town in 1953 and joined the Medical Faculty as a research fellow in surgery. After three years at the University of Minnesota (1955–58), where he studied heart surgery, he returned to Cape Town as director of surgical research. He concentrated on improving techniques for artificially sustaining bodily functions during surgery and for keeping organs alive outside the body. On 2 December 1967 Barnard performed the first heart-transplant operation on a human patient, a 54-year-old grocer named Louis Washkansky. He received the heart of Denise Duvall, a traffic accident victim. The heart functioned but the recipient died of pneumonia 18 days after the operation. The body's immune system had broken down following the administration of drugs to suppress rejection of the new heart as foreign tissue.

Barnard subsequently performed further similar operations with improved postoperative treatment giving much greater success. In 1974 he performed the first successful double heart-transplant operation. His pioneering work generated worldwide publicity for heart-transplant surgery and it is now widely practiced. In 1984 he became professor emeritus at the University of Cape Town. He wrote a number of books, including his interesting autobiography *One Life* (1970).

Barnard, Edward Emerson (1857–1923) *American astronomer*

Although Barnard was born into a poor family in Nashville, Tennessee, and received little formal education, he developed a great interest in astronomy and also became familiar with photographic techniques from his work in a portrait studio. He managed both to study and instruct at Vanderbilt University from 1883 to 1887. From 1888 he worked at the Lick Observatory until in 1895 he became professor of astronomy at Chicago and was thus able to work at the newly established Yerkes Observatory.

Barnard was a keen observer and had detected more than ten comets by 1887 and several more in subsequent years. In 1892 he became the first astronomer after GALILEO to discover a new satellite of Jupiter, subsequently named Amalthea, which lay inside the orbits of the four Galilean satellites and was much smaller and fainter. In 1916 he discovered a nearby red star with a very pronounced proper motion of 10.3 seconds of arc per year: in 180 years it will appear to us to have moved a very considerable distance, equal to the diameter of the Moon. The star is now called *Barnard's star*.

Barnard's other discoveries included various novae, variable stars, and binary stars. He was also one of the first to appreciate that dark nebulae were not areas of the sky containing no stars at all (as William HERSCHEL had thought) but, as Barnard and Max WOLF demonstrated, were enormous clouds of dust and gas that shielded the stars behind them from our view. By 1919 he had discovered nearly 200 such nebulae.

Barnard, Joseph Edwin (1870–1949)
British physicist

While working in his father's business, Barnard used his spare time to study at the Lister Institute, King's College, London, where he developed an interest in microscopy, especially photomicrography, which led to his receiving a chair at the Charing Cross Medical School. He was a fellow and three times president of the Royal Microscopical Society and in 1920 became honorary director of the applied-optics department at the National Institute for Medical Research.

His research and experience in photomicrography led him to write *Practical Photomicrography* (1911), which became a standard work. Later he developed a technique for using ultraviolet radiation, which is of shorter wavelength than visible light, and therefore gives greater resolution. With W. E. Gye he used this method to identify several ultramicroscopic organisms connected with malignant growths that were too small to see using standard microscopy.

Barr, Murray Llewellyn (1908–1995)
Canadian geneticist and anatomist

Barr was born in Belmont, Ontario, and was educated at the University of Western Ontario, gaining his BA in 1930, MD in 1933, and MSc in 1938. His association with Western Ontario was continued with his appointment as an instructor in 1936. He subsequently became professor of microscopical anatomy (1952), professor of anatomy and head of the anatomy department (1964), and emeritus professor (1979).

Barr is best known for his discovery, made in 1949 in conjunction with Ewart Bertram, of the densely staining nuclear bodies present in the somatic cells of female humans and other female mammals. These are called sex chromatin or *Barr bodies*. Later studies by Barr and others revealed that the single Barr body in normal cells is one of the two X-chromosomes in a highly condensed and genetically inactive state. The other X-chromosome is in the diffuse state and is genetically active.

Their discovery enabled Barr and his coworkers to devise a relatively simple diagnostic test for certain genetic abnormalities, in which cells rubbed from the lining of the mouth cavity (a buccal smear) were stained and examined microscopically. For instance, individuals suffering from Turner's syndrome, which usually affects females, have only one X-chromosome and lack Barr bodies. In contrast, males affected by Klinefelter's syndrome possess an extra X-chromosome and exhibit Barr bodies in their cells.

Besides his work in cytogenetics and inherited human disorders, Barr is also noted for his descriptions of nervous-system anatomy. His publications included *The Human Nervous System: an Anatomical Viewpoint* (1972; 5th edition, with J. A. Kiernan, 1988).

Barringer, Daniel Moreau (1860–1929)
American mining engineer and geologist

Barringer, who was born in Raleigh, North Carolina, graduated from Princeton in 1879 and then studied law at Pennsylvania, geology at Harvard, and chemistry and mineralogy at the University of Virginia. In 1890 he established himself as a consulting mining engineer and geologist; he was the author of the standard work *Law of Mines and Mining in the U.S.* (1907).

Barringer is remembered for his investigation of the massive Diabolo Crater in Arizona, which is nearly 600 feet (200 m) deep and over 4,000 feet (1,200 m) in diameter. The cause of such a gigantic hole was a matter of speculation, most considering it to be of volcanic origin. Barringer, finding numerous nickel–iron rocks in the area, became convinced that the remains of an enormous meteorite lay buried at the center of the crater. He began drilling in 1902 but failed to find anything of significance. He later concluded that a meteorite would have been unlikely to enter vertically; after experimenting with projectiles he established that it probably entered at an angle of 45° and would therefore be embedded to one side. In 1922 drilling began again but rapid flooding of the shafts caused Barringer to abandon the search. After his death the crater became known as the *Barringer Meteor Crater*.

Barrow, Isaac (1630–1677) *British mathematician*

Born the son of a prosperous London linen draper, Barrow was educated at Cambridge University. Because of his royalist sympathies he was rejected, on Cromwell's instructions, as a candidate for the professorship of Greek. Consequently he began in 1655 an extensive tour of Europe. With the restoration of Charles II, he returned to Britain in 1660 and was finally elected professor of Greek at Cambridge. In 1663 he accepted the newly created Lucasian Professorship of Mathematics, a post he resigned from in 1669.

The claim has often been made that Barrow resigned his chair in favor of his pupil, Isaac NEWTON. In reality Newton was not the pupil of Barrow and, while he appreciated Newton's mathematical genius and saw to it that Newton succeeded him, Barrow was more interested in advancing his own career. He was appointed chaplain to Charles II in 1669 and in 1673 returned to Cambridge as Master of Trinity College, an office in the gift of the king. He died soon after in 1677 from, according to John Aubrey, an overdose of opium, an addiction that he had acquired in Turkey.

Barrow is best known for his *Lectiones opticae* (1669; Lectures on Optics) and *Lectiones geometricae* (1670; Lectures on Geometry), both edited by Newton, and the posthumously published *Lectiones mathematicae* (1683; Lectures on Mathematics). Unfortunately for Barrow's reputation, his work in both optics and mathematics was soon overshadowed by Newton's own publications.

Bartholin, Erasmus (1625–1698) *Danish mathematician*

Bartholin (bar-**too**-lin), the son of Caspar and brother of Thomas Bartholin, who were both distinguished anatomists, was born in Roskilde, Denmark, and educated in Leiden and Padua, where he obtained his MD in 1654. After further travel in France and England he returned to Denmark in 1656 and held chairs in mathematics and medicine at the University of Copenhagen from 1657 until his death.

Bartholin worked on the theory of equations and with Ole RØMER made an unsuccessful attempt to calculate the orbits of the comets prominent in the late 1660s. He is however best remembered for his discovery of double refraction announced in his *Experimenta crystalli Islandici disdiaclastici* (1669; Experiments on Icelandic Double–Refracting Crystal). In it he described how Icelandic feldspar (calcite) produces a double image of objects observed through it. This discovery greatly puzzled scientists and was much discussed by NEWTON and Christiaan HUYGENS, who tried unsuccessfully to incorporate the strange phenomenon into their respective theories of light.

Double refraction proved remarkably recalcitrant to all proposed explanations for well over a century and it was only with the work of Etienne MALUS on polarized light in 1808, and that of Augustin FRESNEL in 1817, that Bartholin's observations could at last be understood.

Bartlett, Neil (1932–) *British–American chemist*

Bartlett was born in Newcastle upon Tyne in northeast England and educated at the University of Durham, where he obtained his PhD in 1957. He taught at the University of British Columbia, Canada, and at Princeton before being appointed to a chemistry professorship in 1969 at the University of California, Berkeley. Bartlett retired in 1993. He became a naturalized American citizen in 2000.

Bartlett was studying metal fluorides and found that the compound platinum hexafluoride (PtF_6) is extremely active. In fact it reacted with molecular oxygen to form the novel compound $O_2^+PtF_6^-$. This was the first example of a compound containing the oxygen cation. At the time it was an unquestioned assumption of chemistry that the noble gases – helium, neon, argon, krypton, and xenon – were completely inert, incapable of forming any compounds whatsoever. Further, there was a solid body of valence theory that provided good reasons why this should be so. So struck was Bartlett with the ability of PtF_6 to react with other substances that he tried, in 1962, to form a compound between it and xenon. He knew that the ionization potential of xenon was not too much greater than the ionization potential of the oxygen molecule. To his and other chemists' surprise xenon fluoroplatinate ($XePtF_6$) was produced – the first compound of a noble gas. Once the first compound had been detected xenon was soon shown to form other compounds, such as xenon fluoride (XeF_4) and oxyfluoride ($XeOF_4$). Krypton and radon were also found to form compounds although the lighter inert gases have so far remained inactive.

Bartlett, Paul Doughty (1907–1998) *American chemist*

Bartlett was born in Ann Arbor, Michigan, and educated at Amherst College and Harvard, where he obtained his PhD in 1931. After teaching briefly at the Rockefeller Institute and the University of Minnesota he returned to Harvard in 1934 and served there as professor of chemistry from 1948 until his retirement in 1975.

Bartlett worked mainly on the mechanisms involved in organic reactions; for example, the behavior of free radicals and the kinetics of polymerization reactions. He also investigated the chemistry of elemental sulfur and the terpenes (a family of hydrocarbons found in the essential oils of plants).

Barton, Sir Derek Harold Richard (1918–1998) *British chemist*

Barton was born in the port of Gravesend in southeast England, and was educated at Imperial College, London, where he obtained his PhD in 1942. After doing some industrial research he spent a year as visiting lecturer at Harvard before being appointed reader (1950) and then professor (1953) in organic chemistry at Birkbeck College, London. Barton moved to a similar chair at Glasgow University in 1955 but returned to Imperial College in 1957 and held the chair of chemistry until 1978, when he became director of the Institute for the Chemistry of Natural Substances at Gif-sur-Yvette in France. In 1986 he became a distinguished professor at Texas Agricultural and Mechanical University.

In 1950 Barton published a fundamental paper on conformational analysis in which he proposed that the orientations in space of functional groups affect the rates of reaction in isomers. Barton discussed six-membered organic rings, particularly, following the earlier work of Odd HASSELL, the “chair” conformation of cyclohexane, and explained its distinctive stability.

This was done in terms of the distinction between equatorial conformations, in which the hydrogen atoms lie in the same plane as the carbon ring, and axial conformations, where they are perpendicular to the ring. He confirmed these notions with further work on the stability and reactivity of steroids and terpenes.

It was for this work that he shared the 1969 Nobel Prize for chemistry with Hassell. Barton’s later work on oxyradicals and his predictions about their behavior in reactions helped in the development of a simple method for synthesizing the hormone aldosterone.

Basov, Nikolai Gennediyevich (1922–1998) *Russian physicist*

Basov (**bah**-sof), who was born in Voronezh in western Russia, served in the Soviet army in World War II, following which he graduated from the Moscow Institute of Engineering Physics (1950). He studied at the Lebedev Institute of Physics of the Soviet Academy of Sciences in Moscow, gaining his doctoral degree in 1956 and going on to become deputy director (1958) and later director (1973). In 1989 he became director of the quantum radiophysics division.

Basov’s major contribution was in the development of the maser (*m*icrowave *a*mplification by *s*timulated *e*mission of *r*adiation), the forerunner of the laser. From 1952 he had been researching the possibility of amplifying electromagnetic radiation using excited atoms or molecules. His colleague at the Lebedev Institute, Aleksandr PROKHOROV, was involved in the microwave spectroscopy of gases, with the aim of creating a precise frequency standard, for use in very accurate clocks and navigational systems. Their work led to theories and experiments designed to produce a state of “population inversion” in molecular beams, through which amplification of radiofrequency radiation became possible.

Together Basov and Prokhorov in 1955 developed a generator using a beam of excited ammonia molecules. This was the maser, developed simultaneously but independently in America by Charles TOWNES. Basov, Prokhorov, and Townes received the 1964 Nobel Prize for physics for this work.

The first masers used a method of selecting the more excited molecules from a beam, but a more efficient method was proposed by Basov and Prokhorov in 1955, the so-called “three-level” method of producing population inversion by “pumping” with a powerful auxiliary source of radiation. The next year the method was applied by Nicolaas BLOEMBERGEN in America in a quantum amplifier.

Basov went on to develop the laser principle, and in 1958 introduced the idea of using semiconductors to achieve laser action. In the years 1960–65 he realized many of his ideas in practical systems. He subsequently did considerable theoretical work on pulsed ruby and neodymium-glass lasers, which are now in common use, and on the interaction of radiation with matter. In particular, he worked on the production of short powerful pulses of coherent light.

Bassi, Agostino (1773–1856) *Italian microbiologist*

Bassi (**bah**-see), who was born in the northern Italian town of Lodi and educated at the University of Pavia, conducted valuable research into animal diseases. Anticipating PASTEUR, he suggested that certain diseases are caused by minute animal or plant parasites. Some of his most important studies were concerned with cholera and with pellagra, a deficiency disease of the skin. In 1835 he was able to show that the disease of silkworms known as muscardine was caused by a fungus, subsequently named *Botrytis bassiana* in his honor. He demonstrated that muscardine is contagious and formulated methods to prevent and eliminate the disease. Bassi also published accounts of work on potato cultivation, cheese-making, and vinification.

Bates, Henry Walter (1825–1892) *British naturalist and explorer*

The son of a stocking-factory owner in the central English town of Leicester, Bates left school at 13 and was apprenticed to a hosiery manufacturer, but still found time for indulging his hobby of beetle collecting. In 1844 he met Alfred WALLACE and stimulated the latter's interest in entomology. This led, three years later, to Wallace suggesting they should travel together to the tropics to collect specimens and data that might throw light on the evolution of species.

In May 1848 they arrived at Pará, Brazil, near the mouth of the Amazon. After two years collecting together they split up, and Bates spent a further nine years in the Amazon basin. By the time he returned to England in 1859, he estimated he had collected 14,712 species, 8,000 of which were new to science.

While collecting Bates had noted startling similarities between certain butterfly species – a phenomenon later to be termed *Batesian mimicry*. He attributed this to natural selection, since palatable butterflies that closely resembled noxious species would be left alone by predators and thus tend to increase. His paper on this, *Contributions to an Insect Fauna of the Amazon Valley, Lepidoptera: Heliconidae* (1861) provided strong supportive evidence for the Darwin–Wallace evolutionary theory published three years earlier.

DARWIN persuaded Bates to write a book on his travels, which resulted in the appearance of *The Naturalist on the River Amazon* (1863), an objective account of the animals, humans, and natural phenomena Bates encountered. Although one of the best and most popular books of its kind, Bates was to comment that he would rather spend a further 11 years on the Amazon than write another book. He became assistant secretary of the Royal Geographic Society in 1864.

Bates, Leslie Fleetwood (1897–1978) *British physicist*

Bates was educated at the university in his native city of Bristol and at Cambridge University, where he obtained his PhD in 1922. After teaching first at University College, London, he moved to Nottingham, where he served as professor of physics from 1936, apart from wartime duties on the degaussing of ships, until his retirement in 1964.

Most of Bates's work was on the magnetic properties of materials. He was the author of a widely used textbook, which went through many editions, *Modern Magnetism* (1938).

Bateson, William (1861–1926) *British geneticist*

Born in the coastal town of Whitby in northeast England, Bateson graduated in natural sciences from Cambridge University in 1883, having specialized in zoology. He then traveled to America, where he studied the embryology of the wormlike marine creature *Balanoglossus*. He discovered that, although its larval stage resembles that of the echinoderms (e.g., starfish), it also has gill slits, the beginnings of a notochord, and a dorsal nerve cord, proving it to be a primitive chordate. This was the first evidence that the chordates have affinities with the echinoderms.

Back at Cambridge Bateson began studying variation within populations and soon found instances of discontinuous variation that could not simply be related to environmental conditions. He believed this to be of evolutionary importance, and began breeding experiments to investigate the phenomenon more fully. These prepared him to accept MENDEL's work when it was rediscovered in 1900, although other British scientists were largely skeptical of the work. Bateson translated Mendel's paper into English and set up a research group at Grantchester to investigate heredity in plants and animals.

Through his study of the inheritance of comb shape in poultry, Bateson demonstrated that Mendelian ratios are found in animal crosses (as well as plants). He turned up various deviations from the normal dihybrid ratio (9:3:3:1), which he rightly attributed to gene interaction. He also found that certain traits are governed by two or more genes, and in his sweet-pea crosses showed that some characters are not inherited independently. This was the first hint that genes are linked on chromosomes, but Bateson never accepted T. H. MORGAN's explanation of linkage or the chromosome theory of inheritance.

In 1908 Bateson became the first professor of the subject he himself named – genetics. However, he left Cambridge only a year later and in 1910 became director of the newly formed John Innes Horticultural Institution at Merton, Surrey, where he remained until his death. He was the leading proponent of Mendelian genetics in Britain and became involved in a heated controversy with supporters of biometrical genetics such as Karl PEARSON. The views of both sides were later reconciled by the work of Ronald FISHER. Bateson wrote a number of books, including the controversial *Materials for the Study of Variation* (1894) and *Mendelian Heredity – A Defence* (1902); he also founded, with R. C. Punnett, the *Journal of Genetics* in 1910.

Bauer, Georg *See* AGRICOLA, GEORGIUS.

Bawden, Sir Frederick Charles (1908–1972) *British plant pathologist*

Bawden was born in North Tawton, England, and was educated at Cambridge University, receiving his MA in 1933. From 1936 to 1940 he worked in the virus physiology department at Rothamsted Experimental Station, becoming the head of the plant pathology department in 1940. He was director of the station from 1958 until his death.

In 1937 Bawden discovered that the tobacco mosaic virus (TMV) contains ribonucleic acid, this being the first demonstration that nucleic acids occur in viruses. With Norman PIRIE, Bawden isolated TMV in crystalline form and made important contributions to elucidating the structure of viruses and the ways in which they multiply. Bawden's work also helped in revealing the mechanisms of protein formation.

Bayer, Johann (1572–1625) *German astronomer*

Born in Rhain in Germany, Bayer (**bI**-er) was an advocate (lawyer) by profession. In 1603 he published *Uranometria* (Measurement of the Heavens), the most complete catalog of pretelescopic astronomy. To Tycho BRAHE's catalog of 1602, he added nearly a thousand new stars and twelve new southern constellations. The catalog's main importance, however, rests on Bayer's innovation of naming stars by letters of the Greek alphabet. Before Bayer, prominent stars were given proper names, mainly Arabic ones such as Altair and Rigel. If not individually named, they would be referred to by their position in the constellation. Bayer introduced the scheme, which is still used, of referring to the brightest star of a constellation by "alpha," the second brightest by "beta," and so on. Thus Altair, which is the brightest star in the constellation Aquila, is systematically named Alpha Aquilae. If there were more stars than letters of the Greek alphabet, the dimmer ones could be denoted by letters of the Roman alphabet and, if necessary, numbers.

Bayer's other proposed innovation – to name constellations after characters in the Bible – was less successful.

Bayliss, Sir William Maddock (1860–1924) *British physiologist*

Bayliss was the son of a wealthy iron manufacturer in the industrial town of Wolverhampton in central England. In 1881 he entered University College, London, as a medical student but when he failed his second MB exam in anatomy he gave up medicine to concentrate on physiology. He graduated from Oxford University in 1888, then returned to University College, London, where he worked for the rest of his life, holding the chair of general physiology from 1912. Bayliss was elected a fellow of the Royal Society in 1903 and was knighted in 1922.

He was chiefly interested in the physiology of the nervous, digestive, and vascular systems, on which he worked in association with his brother-in-law, Ernest STARLING. Their most important work, published in 1902, was the discovery of the action of a hormone (secretin) in controlling digestion. They showed that in normal digestion the acidic contents of the stomach stimulate production of the hormone secretin when they reach the duodenum. Secretin is transported in the bloodstream to initiate secretion of digestive juices by the pancreas. In 1915 Bayliss produced a standard textbook on physiology, *Principles of General Physiology*, which treated the subject from a physicochemical point of view.

Beadle, George Wells (1903–1989) *American geneticist*

Beadle was born in Wahoo, Nebraska, and graduated from the University of Nebraska in 1926; he gained his PhD from Cornell University in 1931. He then spent two years doing research in genetics under T. H. MORGAN at the California Institute of Technology. Beadle was a professor at the California Institute of Technology from 1946 until 1961 and was president of the University of Chicago from 1961 until 1968. In 1937 Beadle went to Stanford University, where in 1940 he began working with Edward TATUM on the mold *Neurospora*. They used nutritional mutants, which were unable to synthesize certain essential dietary compounds, to determine the sequence of various metabolic pathways. Substances similar to the missing compound were added to the mutant mold cultures to find whether or not they could substitute for the lacking chemical. If the culture survived then it could be assumed that the mold could convert the substance into the chemical it needed, showing that the nutrient was likely to be a precursor of the missing chemical.

From this and similar work Beadle and Tatum concluded that the function of a gene was to control the production of a particular enzyme and that a mutation in any one gene would cause the formation of an abnormal enzyme that would be unable to catalyze a certain step in a chain of reactions. This reasoning led to the formulation of the one gene–one enzyme hypothesis, for which Beadle and Tatum received the 1958 Nobel Prize for physiology or medicine, sharing the prize with Joshua LEDERBERG, who had worked with Tatum on bacterial genetics.

Beaufort, Sir Francis (1774–1857) *British hydrographer*

Beaufort was born in Navan in Ireland; his father was a cleric of Huguenot origin who took an active interest in geography and topography, publishing in 1792 one of the earliest detailed maps of Ireland. Beaufort joined the East India Company in 1789 and enlisted in the Royal Navy the following year, remaining on active service until 1812.

He proposed, in 1806, the wind scale named for him. This was an objective scale ranging from calm (0) up to storm (13) in which wind strength was correlated with the amount of sail a full-rigged ship would carry appropriate to the wind conditions. It was first used officially by Robert FITZROY in 1831 and adopted by the British Admiralty in 1838. When sail gave way to steam the scale was modified by defining levels on it in terms of the state of the sea or, following George SIMPSON, wind speed.

In 1812 Beaufort surveyed and charted the Turkish coast, later writing his account of the expedition, *Karamania* (1817). He was appointed hydrographer to the Royal Navy in 1829. In this office Beaufort commissioned voyages to survey and chart areas of the world, such as those of the *Beagle* with Charles DARWIN and the *Erebus* with Joseph HOOKER. The sea north of Alaska was named for him.

Beaumont, Elie de (1798–1874) *French geologist*

Beaumont (**boh**-mon), who was born and died in Canon, France, was educated at the Ecole Polytechnique and the School of Mines, Paris, and taught at the School of Mines from 1827, later becoming professor of geology there (1835). He is remembered chiefly for his theory on the origin of mountains. He published his views in 1830 in his *Revolutions de la surface du globe*, in which he argued that mountain ranges came into existence suddenly and were the result of distortions produced by the cooling crust of the Earth. Such a view fitted in well with the catastrophism of such zoologists as Georges CUVIER. Beaumont summarized his theories in his *Notice sur les systèmes des montagnes* (1852; On Mountain Systems).

Beaumont served as engineer-in-chief of mines for the period 1833–47. He also collaborated with Ours Pierre Dufrénoy in compiling the great geological map of France, published in 1840.

Beaumont, William (1785–1853) *American physician*

Born in Lebanon, Connecticut, Beaumont started out as a farmhand and then a schoolteacher before becoming a doctor's apprentice. He received his license to practice medicine in 1812 and joined the army as a surgeon's mate. While serving as post surgeon at Fort Mackinac, Michigan, he treated a Canadian trapper, Alexis St. Martin, for wounds caused by a close-range shotgun blast. His patient recovered but was left with an opening (fistula) in his stomach wall. Beaumont took this opportunity to conduct pioneering experiments on the process of digestion in the human stomach, sampling its contents through the fistula and studying the rates of digestion of various foods and the effects of emotional changes on digestion. His *Experiments and Observations on the Gastric Juice and the Physiology of Digestion* (1833) helped trigger further research in this field.

Beche, Sir Henry Thomas de la *See* DE LA BECHE, SIR HENRY THOMAS.

Becher, Johann Joachim (1635–1682) *German chemist and physician*

Becher (**bek**-er), a pastor's son from Speyer in southwest Germany, was largely self-taught. After traveling throughout Europe he gained his MD from the University of Mainz in 1661 and became professor of medicine there in 1663. Short spells as court physician in Mainz (1663–64) and physician to the elector of Bavaria (1664) were followed by a period in Vienna from 1665, where he attempted to realize several economic projects, including a Rhine–Danube canal. He fell from favor and was forced to flee via Holland to England, where he died.

Becher is a transitional figure between alchemy and modern chemistry. He claimed to have a process for producing gold from silver and sand and his chemical system was an extension of the Paracelsian *Tria prima* of sulfur, salt, and mercury. He stated that all inorganic bodies were a mixture of water and three earthy principles: vitreous earth (*terra fusilis*), combustible earth (*terra pinguis*), and mercurial earth (*terra fluida*). *Terra pinguis* was identified as the cause of combustion and this became the phlogiston of Georg STAHL's later theory. Becher's most influential work was *Physicae subterraneae* (1669; Subterranean Physics), which was republished by Stahl in 1703. This work contained his theories on the nature of minerals and experiments.

Beckmann, Ernst Otto (1853–1923) *German organic and physical chemist*

Beckmann (**bek**-man) was born in the German industrial city of Solingen in the Ruhr. His father was an industrial chemist who independently discovered the pigment Paris green. Ernst served an apprenticeship as a pharmacist before studying chemistry at the University of Leipzig, where he graduated in 1878. In 1886, while *Privatdozent* at Leipzig, he discovered the *Beckmann rearrangement* whereby ketoximes are converted into amides. This reaction was soon to be used by Arthur HANTZSCH to determine the stereochemistry of the oximes.

Needing an efficient method for finding molecular weights, Beckmann devised the *Beckmann thermometer*, suitable for measuring changes in temperature over a small range. It is used in finding the elevation in boiling point or depression of freezing point for a solution – which can then be used to calculate the molecular weight of the solute. His other research included work on terpenes and the chlorides of sulfur and selenium. Beckmann was professor at Giessen (1891), Erlangen (1892), and Leipzig (1897). In 1912 he became the first director of the Kaiser Wilhelm Institute at Dahlem, a post with opportunities that never materialized owing to the demands of World War I.

Becquerel, Antoine Henri (1852–1908) *French physicist*

Becquerel (bek-er-**el**) was born in Paris, France; his early scientific and engineering training was at the Ecole Polytechnique and the School of Bridges and Highways, and in 1876 he started teaching at the Polytechnique. From 1875 he researched into various aspects of optics and obtained his doctorate in 1888. In 1899 he was elected to the French Academy of Sciences, continuing the family tradition as his father and grandfather, both renowned physicists, had also been members. He held chairs at the Ecole Polytechnique, the Museum of Natural History, and the National Conservatory of Arts and Crafts, and became chief engineer in the department of bridges and highways.

Becquerel is remembered as the discoverer of radioactivity in 1896. Following Wilhelm RÖNTGEN's discovery of x-rays the previous year, Becquerel began to look for x-rays in the fluorescence observed when certain salts absorb ultraviolet radiation. His method was to take crystals of potassium uranyl sulfate and place them in sunlight next to a piece of photographic film wrapped in black paper. The reasoning was that the sunlight induced fluorescence in the crystals and any x-rays present would penetrate the black paper and darken the film.

The experiments appeared to work and his first conclusion was that x-rays were present in the fluorescence. The true explanation of the darkened plate was discovered by chance. He left a plate in black paper next to some crystals in a drawer and some time later developed the plate. He found that this too was fogged, even though the crystals were not fluorescing. Becquerel investigated further and discovered that the salt gave off a penetrating radiation independently, without ultraviolet radiation. He deduced that the radiation came from the uranium in the salt.

Becquerel went on to study the properties of this radiation; in 1899 he showed that part of it could be deflected by a magnetic field and thus consisted of charged particles. In 1903 he shared the Nobel Prize for physics with Pierre and Marie CURIE.

Beddoes, Thomas (1760–1808) *British chemist and physician*

Beddoes, who was born in Shifnal, England, studied classics at Oxford and medicine and chemistry at Edinburgh, where he was the pupil of Joseph BLACK. After obtaining his MD in 1787 he returned to Oxford as reader in chemistry.

When, in 1792, Beddoes lost his Oxford post because of his sympathy for the French Revolution, he approached the Lunar Society of Birmingham, which included Josiah Wedgwood, Joseph PRIESTLEY, Matthew BOULTON, and James WATT, with the idea of forming an institute to investigate the medicinal uses of the gases discovered in the previous 20 years. As a result one of the first specialized research institutes, the Pneumatic Medical Institute, was opened at Clifton, Bristol, in 1799 with Humphry DAVY, then 19 years old, as Beddoes's assistant. The work proved disappointing except in the case of dinitrogen oxide (nitrous oxide, N_2O), the euphoriant properties of which provided Davy with his first serious chemical paper.

Beddoes's work on gases was published as *Considerations on the Medicinal Use of Factitious Airs* (1794–96). Beddoes later moved to London where he built up a successful medical practice.

Bednorz, Johannes Georg (1950–) *German physicist*

Bednorz (**bed**-norts) was educated at the Federal Institute of Technology, Zurich, where he gained his PhD in 1982. He immediately joined the staff of the IBM Research Center in Zurich, where he now leads the high-temperature superconductivity research group.

Here he was invited by his senior colleague, Alex MULLER, to collaborate in a search for superconductors with higher critical temperatures. Little progress had been made in this area for a decade and, as a young unknown scientist, Bednorz's decision to work in such an unpromising field appeared to many to be somewhat rash. Success, however, came relatively quickly and in 1986 Bednorz and Muller found a mixed lanthanum, barium, and copper oxide that had a critical temperature of 35 K (–238°C), which was significantly higher than that of any other superconductor known at the time. Their work was quickly recognized and in 1987 Muller and Bednorz were awarded the Nobel Prize for physics.

Beebe, Charles William (1887–1962) *American naturalist*

Beebe (**bee**-bee) was born in New York City and graduated from Columbia University in 1898. The following year, he began organizing and building up the bird collection of the New

York Zoological Park. After serving as a fighter pilot in World War I he became, in 1919, director of the Department of Tropical Research of the New York Zoological Society.

Beebe is noted as one of the pioneers of deep-sea exploration. His first observation capsule was a cylinder; later collaboration with the geologist and engineer Otis Barton resulted in the design of a spherical capsule (the bathysphere). Various dives were made and in August 1934 Beebe and Barton were lowered to a (then) record depth of 3,028 feet (923 m) near Bermuda. Beebe made many interesting observations, such as the absence of light at 2,000 feet (610 m), phosphorescent organisms, and an apparently unknown animal estimated to be some 20 feet (6.1 m) long. He abandoned deep-sea exploration after making thirty dives. Descents to even greater depths were subsequently made by Auguste PICCARD and others.

Beer, Wilhelm (1797–1850) *German astronomer*

Beer (bayr) was born in Berlin, where he spent his whole adult life working as a banker. Like his friend Johann Heinrich von Mädler, Beer was a very competent amateur observer of Mars and the Moon. In 1830 they published the first reasonable map of Mars. It did not show the canals that Giovanni SCHIAPARELLI and others were later to "observe." In 1836 they published a large map of the Moon that was the most comprehensive of its time. Beer also measured the heights of the larger lunar mountains.

Béguyer de Chancourtois, Alexandre Emile (1820–1886) *French mineralogist*

The Parisian Béguyer de Chancourtois (bay-gee-**ay** de shahng-kor-**twah**), who was inspector-general of mines in France, is remembered for his work on the classification of the elements. In 1862 he proposed his system, known as the "telluric screw," in which the elements were arranged in order of atomic weight and then plotted on a line descending at an angle of 45° from the top of a cylinder. It was found that elements on the same vertical line resembled each other.

The proposal received little attention, largely because it was published without the explanatory diagram, which made the article virtually impossible to understand. As with John NEWLANDS's system of classifying the elements, Béguyer de Chancourtois's proposal was overshadowed by that of Dmitri MENDELÉEV, first published in 1869.

Behring, Emil Adolf von (1854–1917) *German immunologist*

> For hundreds of thousands of years, the wisest physicians and scientists have studied the properties of blood and its relation to health and illness, without ever suspecting the specific antibodies appearing in the blood as a result of an infectious disease, which are capable of rendering infectious toxins harmless.
> —Describing his work on immunization

Behring (**bay**-ring) was born in Hansdorf in Germany. He graduated in medicine at Berlin University and entered the Army Medical Corps before becoming (in 1888) a lecturer in the Army Medical College, Berlin. In 1889 he moved to Robert KOCH's Institute of Hygiene and transferred to the Institute of Infectious Diseases in 1891, when Koch was appointed its chief.

In 1890, working with Shibasaburo KITASATO, Behring showed that injections of blood serum from an animal suffering from tetanus could confer immunity to the disease in other animals. Behring found that the same was true for diphtheria and this led to the development of a diphtheria antitoxin for human patients, in collaboration with Paul EHRLICH. This treatment was first used in 1891 and subsequently caused a dramatic fall in mortality due to diphtheria.

Behring's success brought him many prizes, including the first Nobel Prize in physiology or medicine, awarded in 1901. He was appointed professor of hygiene at Halle University in 1894 and one year later moved to a similar post at Marburg. In 1913 he introduced toxin–antitoxin mixtures to immunize against diphtheria, a refinement of the immunization technique already in use. He also devised a vaccine for the immunization of calves against tuberculosis.

Beilby, Sir George Thomas (1850–1924) *British industrial chemist*

Beilby (**beel**-bee), the son of a clergyman, was born in the Scottish capital of Edinburgh and educated at the university there. He began work with an oil-shale company as a chemist in 1869 and increased the yield of paraffin and ammonia from oil shales by improving the process of their distillation. He also worked on cyanides, patenting, in 1890, a process for the synthesis of potassium cyanide in which ammonia was passed over a heated mixture of charcoal and potassium carbonate. This had wide use in the gold-extracting industry.

From 1907 to 1923 Beilby was chairman of the Royal Technical College, Glasgow, later the University of Strathclyde. He became interested in the economic use of fuel and smoke prevention, submitting evidence to the Royal Commission on Coal Supplies in 1902. In 1917 he was appointed as the first chairman of the Fuel Research Board. He was knighted in 1916.

Beilstein, Friedrich Konrad (1838–1906) *Russian organic chemist*

Born to German parents in the Russian city of

St. Petersburg, Beilstein (**bIl**-shtIn) studied chemistry in Germany under BUNSEN, LIEBIG, and WURTZ and gained his PhD under WÖHLER at Göttingen (1858). He was lecturer at Göttingen (1860–66) and from 1866 professor of chemistry at the Technological Institute at St. Petersburg.

Beilstein's many researches in organic chemistry included work on isomeric benzene derivatives. He is better remembered, however, for his monumental *Handbuch der organischen Chemie* (1880–82; Handbook of Organic Chemistry), in which he set out to record systematically all that was known of every organic compound. He produced the second (1886) and third (1900) editions, after which the work was assigned to the Deutsch Chemische Gesellschaft, who have published it ever since.

Békésy, Georg von (1899–1972) *Hungarian–American physicist*

Békésy (**bay**-ke-shee), the son of a diplomat in the Hungarian capital, Budapest, studied chemistry at the University of Bern and physics at Budapest University, where he obtained his PhD in 1923. He immediately joined the research staff of the Hungarian Telephone Laboratory where he remained until 1946 while simultaneously holding the chair of experimental physics at Budapest University from 1939. He left Hungary in 1947, via the Swedish Karolinska Institute, for America, where he served first as a senior fellow in psychophysics at Harvard from 1949 to 1966 and finally as professor of sensory science at the University of Hawaii from 1966 until his death.

Békésy first worked on problems of long-distance telephone communication before moving to the study of the physical mechanisms of the cochlea within the inner ear. When he began this study it was generally thought, following the work of Hermann von HELMHOLTZ, that sound waves entering the ear selectively stimulated a particular fiber of the basilar membrane; this in turn stimulated hairs of the organ of Corti resting on it, which transferred the signal to the auditory nerve.

Using the techniques of microsurgery, Békésy was able to show that a different mechanism is involved. He found that when sound enters the cochlea, a traveling wave sweeps along the basilar membrane. The wave amplitude increases to a maximum, falling sharply thereafter; it is this maximum point to which the organ of Corti is sensitive. For this insight into the mechanism of hearing, Békésy was awarded the 1961 Nobel Prize for physiology or medicine.

Bell, Alexander Graham (1847–1922) *British inventor*

> Mr Watson come here; I want you.
> —Speaking to his assistant Thomas Watson in the world's first telephone conversation, 10 March 1876

Bell's family were practitioners in elocution and speech correction and he himself trained in this. Born in Edinburgh, as a child he was taught mainly at home. For a short time he attended Edinburgh University and University College, London, after which he taught music and elocution at a school in Elgin, Scotland. It was in Elgin that he carried out his first studies on sound.

From 1868 Bell worked in London as his father's assistant, but after the death of his two brothers from tuberculosis, the family moved to Canada, where Alexander, who had also become ill, recovered. In 1871 he went to Boston where he gave lectures on his father's method of "visible speech" – a system of phonetic symbols for teaching the deaf to speak. A year later he opened a school for teachers of the deaf. In 1873 he became professor of vocal physiology at Boston University.

With financial help from two of his deaf students, Bell experimented with the transmission of sound by electricity, aided by Thomas Watson, his technician. His multiple telegraph was patented in 1875 and, in 1876, the patent for the telephone was also granted. Bell's wife Mabel Hubbard, whom he married in 1877, was deaf. Later she founded the Aerial Experiment Association.

In 1880 he received the Volta Prize from France and the money was used to fund the laboratories in which an improved form of the gramophone was invented by Thomas EDISON. Although best known as the inventor of the telephone, Bell investigated a wide range of related technical subjects, including sonar and various equipment for the deaf. In 1885 he bought land and established laboratories and a summer home on Cape Breton Island.

Bell, Sir Charles (1774–1842) *British physician*

Bell, who was born in Edinburgh, Scotland, studied under his elder brother John, a surgeon, and attended lectures at Edinburgh University. In 1804, Charles moved to London, where he started his own surgical practice and began his investigations into the nervous system. In *A New Idea of the Anatomy of the Brain* (1811), Bell described how nerves are not single structures but bundles of many nerve fibers. He also showed that the anterior and posterior roots of each spinal nerve carry different types of nerve fibers, which he later clarified as being respectively excitatory (motor) and sensory in function. The French physiologist, François MAGENDIE, is also credited with this discovery and the functional differentiation of the spinal nerve roots is sometimes called the *Bell–Magendie law*. In *The Nervous System of the Human Body* (1830), Bell amplified his findings, establishing that a nerve fiber can carry impulses in one direction only and that each muscle must be supplied with both excitatory and sensory fibers.

Bell also contributed to knowledge of facial paralysis and to other surgical fields besides lecturing at the Great Windmill Street School of Anatomy and the Middlesex Hospital. In addition, he wrote *Essays on the Anatomy of Expression in Painting* (1806). He received the first medal awarded by the Royal Society in 1829 and was knighted two years later.

Bell, John Stuart (1928–1990) *British physicist*

> I think that when we have solved the problem of the interface between the classical and the quantum-mechanical worlds, there will be something different in the theory.
> —Quoted by J. Bernstein in *Quantum Profiles*

Born into a poor family in the Northern Irish capital of Belfast, Bell was encouraged by his mother to continue his education after leaving school at sixteen. Consequently, after working for a year as a laboratory assistant in the physics department of Queen's University, Belfast, he enrolled as a student and graduated in 1949. Rather than pursue a PhD and burden his family further, Bell began work immediately at the Atomic Energy Research Establishment at Harwell. He worked initially on the design of the first accelerator at CERN (Conseil Européen pour la Recherche Nucléaire; European Organization for Nuclear Research), the Proton Synchrotron. He was also given a year's leave of absence to work on a doctorate at Birmingham University. On his return to Harwell he turned to the theoretical study of elementary particles. Bell moved to CERN in Geneva in 1960 where he remained for the rest of his life. He was accompanied by his wife, Mary Bell, also a physicist, who worked at CERN on accelerator design.

In 1964 Bell published what for many has become the single most important theoretical paper in physics to appear since 1945; it was entitled *On the Einstein Podolsky Rosen Paradox*. The title referred to a thought experiment proposed by Einstein and others in 1935 sharply challenging the basis of quantum theory. He proposed a principle of reality stating that: "If, without in any way disturbing a system we can predict with certainty … the value of a physical quantity then there exists an element of physical reality corresponding to this physical quantity." For example, electrons have a spin that can take one of two values, conveniently classed as positive or negative. Spin, like angular momentum, is conserved. Consequently, if a particle with zero spin decays into an electron/positron (e^-/p^+) pair, the two particles must have equal and opposite spins. Knowing, for example, that the electron has a negative spin, it can be inferred that the positron must have a positive spin.

But this, according to Einstein, gives us a way to measure the spin of a particle without disturbance. If the p^+ spin is measured and found to be positive, the measurement may well disturb the p^+, but on this basis the spin of the e^- can be concluded to be negative without in any way disturbing the e^-. It follows from Einstein's reality principle that the negative spin of e^- is a real property of the electron. This view, however, conflicts with the usual interpretation of quantum mechanics, which sees the spin of the electron as a superposition of both spin states, a condition only resolved when the electron is observed and the wave function collapses. Nor can it be said that the state of the electron is in any way influenced by the outcome of the observation of the positron's spin for, as no signal can travel faster than the speed of light, instantaneous communication between separated particles is impossible.

The theoretical physicist is therefore presented with an uncomfortable choice. He or she can accept that electrons have intrinsic spin, in accordance with the reality principle and against quantum mechanics, or adopt what Einstein scornfully termed a "spooky action at distance." One weekend in 1964 Bell saw a way in which the matter could be resolved.

The spin of a particle is complicated in that it can be independently measured along three coordinates x, y, and z at right angles to each other. Further, a measurement of the electron's spin in the x direction will influence the spin of the positron in the x direction also; it will, however, have no effect on measurements along the y and z directions. Similar rules apply to measurements along the y and z axes. Bell argued that, if the reality principle is correct, then one would expect to find for a large number of observations:

$$x^+y^+ < (x^+z^+ + y^+z^+)$$

That is, the number of particles with a positive spin along the x and y axes is smaller than the number found on both the x^+z^+ and y^+z^+ axes. The result is known variously as *Bell's inequality* and *Bell's theorem*. Although it proved impossible to test Bell's inequality in terms of the reactions described in the 1964 paper, later workers have produced equivalent formulations that are testable. The most convincing of these, the *Aspect experiment* performed by Alain Aspect of the Institute of Optics at the University of Paris in 1982, using correlations between polarized photons, established that the inequality did not hold. The conclusion seemed to be that nature preferred to act "spookily" at a distance rather than using Einstein's reality principle.

At first Bell's five-page paper was ignored. Only when experimentalists such as John Clauser at Berkeley in 1969 took his work up did Bell's argument become widely known.

Bell's views on his own work, more tentative and less extreme than those of many of his followers and popularizers, were collected in his *Speakable and Unspeakable in Quantum Mechanics* (1987).

Bell Burnell, Dame Susan Jocelyn
(1943–) *British astronomer*

> A bit of scruff.
> —Referring to the pen-recorder trace of the first recorded pulsar

Born in Belfast, Northern Ireland, the daughter of the architect who designed the Armagh planetarium, Jocelyn Bell developed an early interest in radioastronomy. She was advised by Bernard LOVELL to study physics first and consequently found herself the only woman in a class of 50 physics students at Glasgow University. After graduating from Glasgow she moved to Cambridge, where she completed her PhD in 1969.

As part of her duties she visited the Mullard Radio Astronomy Laboratory each day, filled the inkwells and monitored the 100-foot length of paper chart produced daily by the 4.5-acre telescope. The sky was scanned every four days and, with little computer power available at that time, the data had to be analyzed by hand. One day she identified a strange signal. As it meant nothing to her, Bell simply put a question mark next to it. When she noticed it again she drew it to the attention of her supervisor, Antony HEWISH. But nothing more was seen for a month. Perhaps, Hewish suggested, it had been a one-time event, a flare that had been and gone.

But after a month it reappeared. On examination Bell found the signals were equally spaced out at intervals of about 1.3 seconds. It was soon established that the signal was genuine and not an instrumental malfunction; nor was it produced by satellites or any terrestrial interference. The source was shown to lie outside the solar system and to have a sidereal motion. A more detailed examination of the signals revealed a regular sequence of pulses at intervals of 1.33730113 seconds with an accuracy better than one part per hundred million. Bell discovered a second signal coming from a different part of the sky in December, and a third and fourth the following month.

Once it had been decided that no LGMs, or "Little Green Men," were involved in the signals, Hewish made the discovery public in 1968. The name "pulsar" was soon coined and soon after Thomas GOLD proposed that the signals were emitted by a small, rapidly rotating neutron star. In an earlier age the first pulsar would have been known as *Bell's Star*; today it carries number CP 1919. Bell's work helped Hewish to gain the 1974 Nobel Prize for physics.

Bell herself married and became Bell Burnell and was appointed in 1968 to a research fellowship at the University of Southampton, where she worked on gamma rays. In 1973 she moved to the Mullard Space Science Laboratory in London to work on x-ray astronomy. Bell moved again in 1982 to head the James Clerk Maxwell Telescope project at the Royal Observatory, Edinburgh. In 1991 she was appointed professor of physics at the Open University, Milton Keynes, a position she held for ten years. In 2001 she became Dean of Science at the University of Bath, retiring in 2004. At present she is Visiting Professor of Astrophysics at Oxford University. She became a Dame in 2001.

Belon, Pierre (1517–1564) *French naturalist*

Belon (be-**lon**) was born in Le Mans, France, and studied medicine in Paris. In 1540 he went to Germany to study botany, becoming a leading figure in the 16th-century revival of natural history that followed the great voyages, the invention of printing, and the new artistic realism of the Renaissance.

Between 1546 and 1549 Belon traveled in the eastern Mediterranean countries, comparing the animals and plants he observed with their descriptions by classical authors. The results were published as *Les Observations des plusieurs singularitez et choses mémorables trouvées en Grèce, Asie, Judée, Egypte, Arabie et autre pays éstranges* (1553; Observations of Many Singularities and Memorable Items in Greece, Asia, Judea, Egypt, Arabia, and Other Foreign Countries). On his travels, Belon was in the habit of investigating the birds and fishes that came to market, and in England he met the Venetian Daniel Barbaro, who had made many drawings of Adriatic fishes. From these sources Belon produced two books on fishes: *L'Histoire naturelle des éstranges poissons marins* (1551; The Natural History of Foreign Sea Fish) and *De aquatilibus* (1553; On Water Creatures). The first is notable for its dissertation on the dolphin, in which he identified the common Atlantic species with the dolphin of the ancients and distinguished it from the porpoise.

Belon's principal achievement is a history of birds, *L'Histoire de la nature des oyseaux* (1555; The Natural History of Birds). An illustrated book of the kind inspired by the drawings of Albrecht Dürer and Leonardo da Vinci, it describes about 200 birds, mostly of European origin. He drew attention to the correspondence between the skeletons of birds and man, an early hint of the discipline of comparative anatomy.

Belon was also interested in geology and botany and is reputed to have introduced the cedar of Lebanon into western Europe. He also established two botanical gardens in France and suggested that many exotic plants might be acclimatized and grown in temperate regions. In many ways a typical figure of the Renaissance, Belon's end was all too typical of that time, for he was murdered in the Bois de Boulogne in 1564.

Belousov, Vladimir Vladimirovich (1907–1990) *Russian geologist and geophysicist*

Belousov (byel-**oo**-sof), a Muscovite by birth, became head of the department of geodynamics at the Soviet Academy of Sciences, Moscow, in 1942 and was later (1953) made professor of geophysics at Moscow University. His main work concentrated on the structure and development of the Earth's crust. In 1942 he put forward his theory on Earth movements, in which he proposed that the Earth's material has gradually separated according to its density and this is responsible for movements in the crust. He at first rejected theories on continental drift.

Belousov became chairman of the Soviet Joint Geophysical Committee in 1961. His works include *Principles of Geotectonics* (1975).

Benacerraf, Baruj (1920–) *American immunologist*

Benacerraf (bay-nah-**se**-raf), who was born in the Venezuelan capital of Caracas, was brought up in France but moved to America in 1940, becoming naturalized in 1943. He studied at Columbia and the University of Virginia where he obtained his MD in 1945. He worked first at the Columbia Medical School before spending the period 1950–56 at the Hospital Broussais in Paris. He returned to America in 1956 to the New York Medical School where he served from 1960 to 1968 as professor of pathology. After a short period at the National Institute of Allergy and Infectious Diseases at Bethesda, Maryland, Benacerraf accepted the chair of comparative pathology at Harvard in 1970. From 1980 until 1992 he was president of the Dana-Farber Cancer Institute, Boston.

In the 1960s, working with guinea pigs, Benacerraf began to reveal some of the complex activity of the H-2 system, described by George SNELL. In particular he identified the Ir (immune response) genes of the H-2 segment as playing a crucial role in the immune system. This was achieved by injecting simple, synthetic, and controllable "antigens" into his experimental animals and noting that some strains responded immunologically while others were quite tolerant. Such differential responses have so far indicated there are over 30 Ir genes in the H-2 complex.

Later work began to show how virtually all responses of the immune system, whether to grafts, tumor cells, bacteria, or viruses, are under the control of the H-2 region. Benacerraf and his colleagues continued to explore its genetic and immunologic properties and also to extend their work to the analogous HLA system in humans. This work may well be important in the study of certain diseases, such as multiple sclerosis and ankylosing spondylitis, which have been shown to entail defective immune responses.

In 1980 Benacerraf was awarded for this work, together with George Snell and Jean DAUSSET, the Nobel Prize for physiology or medicine.

Beneden, Edouard van (1846–1910) *Belgian cytologist and embryologist*

Beneden (be-**nay**-den) was born in Louvain, Belgium, the son of the zoologist Pierre-Joseph van Beneden. Edouard followed his father's footsteps, taking charge of zoology teaching at Liège University in 1870. Here he extended Walther FLEMMING's work on cell division. Working with the horse intestinal worm, *Ascaris megalocephala*, Beneden had demonstrated by 1887 that the chromosome number in all the body cells is constant, but that this number is halved in the germ cells. This halving is achieved because the two successive divisions preceding ova and spermatozoa formation are accompanied by only one chromosome doubling. Such a reduction division (meiosis) is necessary to prevent chromosome numbers from doubling on fertilization.

Beneden also made important contributions to embryology from his studies on the cleavage and gastrulation of the fertilized egg.

Bennet, Abraham (1750–1799) *British physicist*

Bennet's scientific work was in electrostatics, the study of stationary electric charges and their effects, and he contributed many experiments and observations to the early development of this field. He was the inventor of the gold-leaf electrometer (an instrument for detecting and measuring electric charges) and did various experiments on electrostatic induction (the effect by which one body induces a charge on a nearby uncharged body). He also tried, though unsuccessfully, to demonstrate that light has momentum by focusing light rays on a sheet of paper hanging free in a vacuum.

Bentham, George (1800–1884) *British botanist*

Bentham, son of the naval architect Samuel Bentham, was born in the southwestern English county of Devon; he first became interested in botany at the age of 17, while living in France with his parents. There he read Augustin Pyrame de CANDOLLE's revision of J. B. LAMARCK's *Flore Française* (French Flora) and was much impressed with its analytical keys for plant identification. Thus began his consuming interest in plant taxonomy, on which he consistently worked during his leisure time.

From 1826 to 1832 he was secretary to his uncle, the famous jurist and philosopher, Jeremy Bentham, and studied for the bar at Lincoln's Inn. However, in 1833 he abandoned law for his growing botanical collection and library, which he generously presented to the Royal Botanic Gardens, Kew, in 1854. He then worked at Kew for the rest of his life.

His first botanical work, *Catalogue des plantes indigènes des Pyrénées et du bas Languedoc* (Catalog of the Indigenous Plants of the Pyrenees and Lower Languedoc), was published in Paris in November 1826. On his return to England he published *Outlines of a New System of Logic* (1827). Then in the early 1830s, Bentham turned his attention more to botany and his first important work in this field, *Labiatarum Genera et Species* (Genera and Species of the Labiatae), appeared between 1832 and 1836. While at Kew he published his popular *Handbook of the British Flora* (1858) and contributed to the Kew series of colonial floras with his *Flora Hongkongensis* (1861; Flora of Hong Kong) and the seven-volume *Flora Australiensis* (1863–78; Flora of Australia). In collaboration with Joseph HOOKER he produced his greatest work, the *Genera Plantarum* (1862–83; Plant Genera), which remains a standard in plant classification.

Benz, Karl Friedrich (1844–1929) *German engineer*

Benz was born in the city of Karlsruhe in southwest Germany, where his father was a railway engineer. After training in mechanical engineering (1853–64), he opened his own machine-tools works in Mannheim and in 1877 began experimenting with a two-cycle engine. In 1885 he ran his first Benz car, a three-wheeled vehicle now preserved in Munich, which was the first practical automobile powered by an internal-combustion engine. The vehicle was not patented until January 1886. The company founded by Benz to manufacture the vehicle, Benz & Cie., produced its first four-wheeled automobile in 1893 and its first series of racing cars in 1899. Benz left the company in about 1906; it later merged to form Daimler–Benz (1926), the makers of Mercedes-Benz automobiles.

Benzer, Seymour (1921–2007) *American geneticist*

Benzer was born in New York City, graduated from Brooklyn College in 1942, and gained his PhD in physics from Purdue University in 1947. He spent the years 1948–52 at various research institutes to familiarize himself with biological techniques, returning to Purdue as assistant professor in biophysics.

Benzer hoped to disprove the theory that the gene is an indivisible unit by demonstrating that recombination can occur within genes. However, such recombinations would be expected to occur so rarely that huge numbers of organisms would need to be studied to find one. In 1954 Benzer found a suitable organism to work on – the virus T4, a bacteriophage that infects the bacterium *Escherichia coli*. It multiplies approximately 100 fold in 20 minutes, giving millions of phage in a relatively short period.

Benzer found various mutants of T4, termed rII mutants, that had lost the ability to multiply on a specific strain of *E. coli*. He mixed together mutants that had mutated in different parts of the same gene and placed the mixture on a dish of *E. coli*. Any recombination within the gene that restored its function (and thus its ability to multiply in and destroy the bacteria) could be easily identified as clear areas in the *E. coli* dish. Such areas were indeed found, which proved that the gene can be split into recombining elements and verified James WATSON's and Francis CRICK's model of the gene as consisting of many nucleotide pairs.

Benzer went on to show that the number of distinguishable mutation sites corresponds with the estimated number of nucleotide pairs for that gene and that the sites are arranged linearly. He identified functionally independent units within the gene, naming these "cistrons."

Benzer also did important work on chemical mutagens and on the degeneracy of the genetic code. More recently he concentrated on the genetic control of behavior and the application of molecular biology to brain function. He moved from Purdue University to the California Institute of Technology in 1965, becoming professor of biology in 1967 and Boswell Professor of Neuroscience in 1975.

Berg, Paul (1926–) *American molecular biologist*

Berg was born in New York City and educated at Pennsylvania State University and Case Western Reserve University, where he obtained his PhD in 1952. He taught first at the School of Medicine at Washington University, St. Louis, moving to Stanford University in California in 1959, where he was professor of biochemistry from 1959 to 1970 and Willson Professor of Biochemistry from 1970. From 1985 until 2000 he was director of the Center for Molecular and Genetic Medicine. Berg is professor emeritus at Stanford. He ceased his research work in 2000.

In 1955 Francis CRICK proposed his adaptor hypothesis, in which he argued that amino acids did not interact directly with the RNA template but were brought together by an adaptor molecule. Crick offered little information on the nature of such molecules, merely arguing that they were unlikely to be large protein molecules and suggesting that there might well be a specific adaptor for each of the 20 amino acids. In 1956 Berg successfully identified such an adaptor, later known as transfer RNA, even though he was then unaware of Crick's hypothesis. He found a small RNA molecule that appeared to be quite specific to the amino acid methionine.

Berg's name later became known to a much wider public with the publication in *Science* (24 July 1974) of the "Berg letter," written with the backing of many leading molecular biologists, in which he gave clear warning of the dangers inherent in the uncontrolled practice of recombinant DNA experiments. It had become possible, Berg stated, to excise portions of DNA from one organism, using specialized enzymes, and to insert them into the DNA of another organism. For example, the harmless microorganism *Escherichia coli*, found in all laboratories, could be implanted with active DNA from the tumor-causing virus SV 40 and perhaps allowed to spread throughout a human population with quite unpredictable results. Berg consequently proposed an absolute voluntary moratorium on certain types of experiments and strict control on a large number of others. An international conference was held in Asilomar, California, followed by the publication of strict guidelines by the National Institutes of Health in 1976. That such agreement could be reached and maintained, it has been claimed, was largely a result of the integrity and authority of Berg. Ironically Berg was awarded the Nobel Prize for chemistry in 1980 for the large part he played in developing the splicing techniques that made recombinant DNA techniques possible in the first place.

Berger, Hans (1873–1941) *German psychiatrist*

Berger (**bair**-ger) was born in Neuses, Germany, and studied medicine at the University of Jena; having joined the university psychiatric clinic in 1897 as an assistant, he eventually served as its director and professor of psychiatry (1919–38). In his early work, he attempted to correlate physical factors in the brain, such as blood flow and temperature, with brain function. Disappointing results in this area made Berger turn to investigating the electrical activity of the brain. In 1924 he made the first human electroencephalogram by recording, as a trace, the minute changes in electrical potential measured between two electrodes placed on the surface of the head. Berger subsequently characterized the resultant wave patterns, including alpha and beta waves, and published his findings in 1929. The technique of electroencephalography is now used to diagnose such diseases as brain tumors and epilepsy. It is also used in psychiatric research and in diagnosing brain death.

Bergeron, Tor Harold Percival (1891–1977) *Swedish meteorologist*

Bergeron (**bair**-ger-on), who was born in Stockholm, studied at the universities of Stockholm and Leipzig. During the period 1925–28 he worked at the famous Geophysical Institute at Bergen before taking a teaching appointment at Oslo University (1929–35). He held various appointments in the Swedish Meteorological Institute and was elected to the chair of meteorology at Uppsala in 1947.

Bergeron is best known for his work on cloud formation and in 1935 published the fundamental paper *On the Physics of Clouds and Precipitation*. Clouds consist of minute drops of water, but these drops will only fall as rain when they coalesce to form sufficiently large drops. Bergeron considered various processes, such as electric attraction and collisions caused by turbulence, but dismissed these as being too slow and inefficient. He therefore proposed a mechanism in which both ice crystals and water droplets are present in clouds. The water droplets tend to evaporate and the vapor then condenses onto the crystals. These fall, melt, and produce rain. Thus all rain, according to Bergeron, begins as snow and without the presence of ice crystals in the upper reaches of clouds there can be no rain. This theory was supported by the experimental and observational work of Walter Findeisen in 1939 and became known as the *Bergeron–Findeisen theory*. It does not explain precipitation from tropical clouds where temperatures are above freezing point.

Bergeron also produced important work on weather fronts, methods of weather forecasting, and the growth of ice sheets.

Bergius, Friedrich Karl Rudolph (1884–1949) *German industrial chemist*

The son of a chemicals industrialist, Bergius (**bair**-gee-uus), who was born in Goldschmieden, Poland, obtained his doctorate at Leipzig (1907) and worked with Hermann NERNST at Berlin and Fritz HABER at Karlsruhe, where he became interested in high-pressure chemical reactions. He was a professor at the Technical University at Hannover (1909–14) and then worked for the Goldschmidt Organization until 1945.

He is noted for his development of the *Bergius process* – a method of treating coal or heavy oil with hydrogen in the presence of catalysts, so as to produce lower-molecular-weight hydrocarbons. The process was important as a German source of gasoline in World War II. After the war Bergius lived in Austria and Spain before settling in Argentina as a technical adviser to the government, working on the production of sugar, alcohol, and cattle feed from wood. He shared the Nobel Prize for chemistry with Carl BOSCH in 1931.

Bergman, Torbern Olaf (1735–1785) *Swedish chemist*

Bergman (**bairg**-man), who was born in Katrineberg, Sweden, studied at the University of Uppsala, at first reading law and theology before turning to science and mathematics. He was a prolific scientist, working in physics, mathematics, and physical geography as well as chemistry. After graduating with a master's degree in 1758, he became professor of mathematics at Uppsala in 1761 and later professor of chemistry and pharmacy in 1767.

Bergman carried out many quantitative analyses, especially of minerals, and he extended the chemical classification of minerals devised by Axel CRONSTEDT. He remained an adherent of the phlogiston theory and although he firmly supported the doctrine of constant composition his analyses were not as solidly based as those of his later compatriot Jöns BERZELIUS. His most influential work was probably *Disquisitio de Attractionibus Electivis* (1785; A Dissertation on Elective Attractions). He compiled extensive tables listing relative chemical affinities of acids and bases. Bergman gave early encouragement to Karl SCHEELE, some of whose work he published.

Bergmann, Max (1886–1944) *German organic chemist and biochemist*

Bergmann (**bairg**-mahn), who was born in Fuerth in Germany, studied in Munich and Berlin and gained his PhD under Emil FISCHER in 1911. He worked as Fischer's assistant in Berlin until the latter's death in 1919. From 1921 to 1934 he was director of the Kaiser Wilhelm Institute for Leather Research, Dresden, from which he resigned on Hitler's coming to power. He then emigrated to America where he worked as a member of the Rockefeller Institute for Medical Research.

Bergmann's research interests were those of his teacher, Fischer: carbohydrates and amino acids. In 1932 he discovered the carbobenzoxy method of peptide synthesis, the greatest advance in this field since Fischer's first peptide synthesis in 1901. In this method the amino group of amino acids is "protected" by the carbobenzoxy group during condensation to form the peptide linkage and later freed by hydrolysis. Following Bergmann's work, many other protective groups have been used in peptide syntheses.

In America Bergmann investigated the specificity of proteinase enzymes and discovered (1937) that enzymes like papain were capable of splitting quite small peptides at precise linkages. The last three years of his life were devoted mainly to problems connected with the war.

Bergström, Sune (1916–2004) *Swedish biochemist*

Bergström (**bairg**-stru(r)m) was born in Stockholm and educated at the Karolinska Institute there, where he obtained his MD in 1943. In 1947 he was appointed to the chair of biochemistry at Lund. In 1958 he moved to a comparable position at the Karolinska Institute, which he left in 1981.

In the 1930s Ulf VON EULER found an active substance in human semen capable of lowering blood pressure and causing muscle tissue to contract. He named it *prostaglandin* on the assumption that it came from the prostate gland. It soon became clear that there was not one such substance but a good many closely related ones with a variety of important physiological roles, but as they were produced in small quantities and rapidly broken down by enzymatic action, they proved to be very difficult to isolate and analyze. From 100 kilograms of rams' seminal vesicles, Bergström was able to extract a minute dose. To his surprise, however, he found the prostaglandin "extraordinarily active in virtually nonexistent doses."

In the 1950s Bergström succeeded in extracting the prostaglandins referred to as PGD_2, PGE_2, and PGF_2. He went on to demonstrate that they were derived from arachidonic acid ($C_{20}H_{36}O_2$), a fatty acid present in the adrenal gland, liver, and brain. Bergström's discovery opened up the study of prostaglandins by allowing them to be produced in the laboratory. For his pioneering work in this field he shared the 1982 Nobel Prize for physiology or medicine with John VANE and Bengt SAMUELSSON.

Beringer, Johann Bartholomaeus Adam (1667–1740) *German geologist*

Beringer (**bay**-ring-er) was a native of Würzburg, Germany, where his father was the dean of medicine at the university. He obtained his doctorate from Würzburg in 1693 and was appointed professor in 1694 – a position he held for the rest of his life.

He is largely remembered today for his extreme gullibility. Some colleagues, knowing him to be a keen fossil collector, decided to see if he could recognize artificial "fossils." They therefore prepared and scattered on the local hillside "fossils" of an increasingly unlikely nature. Nothing seemed to alert the suspicions of Beringer and indeed, the more bizarre the figure, the more excited he became. He published an account of them in 1726 with full illustrations despite warnings that he was dealing with fakes. Finally, the story goes although there is no documentary evidence for this, he found a stone with his own name on it and spent the rest of his life trying to buy up copies of his book.

Bernal, John Desmond (1901–1971) *British crystallographer*

> Life is a partial, continuous, progressive, multiform and conditionally interactive self-realization of the potentialities of atomic electron states.
> —*The Origin of Life* (1967)

> The full area of ignorance is not mapped: we are at present only exploring its fringes.
> —Quoted by Sagittarius and George in *The Perpetual Pessimist*

Bernal's family were farmers in Nenagh, now in the Republic of Ireland; his mother was an American journalist. He was educated at Cambridge University, where his first work on crystallography was done as an undergraduate on the mathematical theory of crystal symmetry. William BRAGG offered him a post at the Royal Institution, which he joined in 1922.

Bernal was one of the most influential scientists of his generation. He had decided early in his career that x-ray crystallography would turn out to be the most likely tool to reveal details of the structure of matter. In addition to his intellectual mastery of the subject, he also possessed the ability to transmit his own enthusiasm to others and to attract around him a large number of highly talented and ambitious colleagues. To this group he was always known as "Sage."

His first success came in 1924 when he worked out the structure of graphite. He also began to work on bronze. In 1927 Bernal moved to Cambridge to a newly created lectureship in structural crystallography. While at Cambridge he worked on the structure of vitamin B_1 (1933), pepsin (1934), vitamin D_2 (1935), the sterols (1936), and the tobacco mosaic virus (1937).

Much of this research came not from Bernal alone; in most of his Cambridge studies he collaborated closely with Dorothy HODGKIN and many others came to work with Bernal, including Max PERUTZ, Francis CRICK, and Rosalind FRANKLIN.

In 1937 he was appointed professor of physics at Birkbeck College, London. With the outbreak of war in 1939 he joined the Ministry of Home Security and carried out with Solly ZUCKERMAN an important analysis of the effects of enemy bombing. Later in the war he served as scientific adviser to Lord Mountbatten, the Chief of Combined Operations. Bernal's main duties were connected with the planned Normandy landings. He spent much time establishing the physical condition of the beaches the Allies would land on in 1944. Maps, he soon discovered, were inaccurate. "Do you realize," he would tell his staff, "no one knows where France is?" He was one of the first to land on the Normandy beaches on D-day.

Bernal's duties were performed despite the fact that he was one of Britain's best known communists, having joined the party in 1924. While many of his friends abandoned the party at some stage of their life, some because of the Stalinist purges, others because of the Molotov pact, and most of those remaining because of the Hungarian uprising, Bernal remained with the party throughout his life. He traveled frequently in Eastern Europe, Russia, and China, and he was probably the only significant Western scientist to give permanent support to the work of LYSENKO.

In 1963 Bernal suffered the first of several serious strokes. He became progressively less mobile and in the last two years of his life, unable to speak, he was confined to a wheelchair.

Bernard, Claude (1813–1878) *French physiologist*

> Science allows no exceptions; without this there would be no determinism in science, or rather, there would be no science at all.
> —*Leçons de la pathologie expérimentale* (1871; Lessons on Experimental Pathology)

Bernard (bair-**nar**), the son of a poor wine grower from St. Julien, began writing plays to earn money but turned to medicine on the advice of a literary critic. His first experiences of medicine were discouraging but, following his appointment as assistant to François MAGENDIE at the Collège de France, he began a period of extremely productive research. He drew attention to the importance of the pancreas in producing secretions for breaking down fat molecules into fatty acid and glycerine and showed that the main processes of digestion occur in the small intestine and not, as was previously thought, in the stomach. In 1856 he discovered glycogen, the starchlike substance in the liver, whose role is to build up a reserve of carbohydrate, which can be broken down to sugars as required; normally the sugar content of the blood remains steady as a result of this interaction. The digestive system, he found, is not just catabolic (breaking down complex molecules into simple ones), but anabolic, producing complex molecules (such as glycogen) from simple ones (such as sugars).

Bernard also did valuable work on the vasomotor system, demonstrating that certain nerves control the dilation and constriction of blood vessels; in hot weather blood vessels of the skin expand, releasing surplus heat, contracting during cold to conserve heat. The body is thus able to maintain a constant environment separate from outside influences. Apart from elucidating the role of the red blood corpuscles in transporting oxygen, Bernard's investigation of the action of carbon monoxide on the blood proved that the gas combines with hemoglobin, the effect being to cause oxygen starvation. He also carried out important work on the actions of drugs, such as the opium alkaloids and curare (curarine), on the sympathetic nerves.

Bernard's health deteriorated from 1860 and he spent less time in the laboratory. He thus turned to the philosophy of science and in 1865 published the famous *Introduction à la médecine expérimentale* (An Introduction to the Study of Experimental Medicine). The book discusses the importance of the constancy of the internal environment, refutes the notion of the "vital force" to explain life, and emphasizes the need in planning experiments for a clear hypothesis to be stated, which may then be either proved or disproved. On the strength of this work he was elected to the French Academy in 1869.

Berners-Lee, Sir Timothy John (1955–) *British computer scientist*

Berners-Lee was born in London and educated at Oxford University, graduating in 1976. When he was at Oxford, he built his first computer. After graduating, he worked for two years with Plessey Telecommunications and in 1978 he joined D. G. Nash, where he wrote software. During a spell of a year and a half that he spent as an independent consultant he was at CERN for six months as a consultant software engineer. Here he wrote a program called *Enquire*, which was never published, to store information. Between 1981 and 1984 he was at John Poole's Image Computer Systems Ltd., working on technical design.

In 1984 Berners-Lee started a fellowship at CERN, where he worked on systems for the acquisition of scientific data. In 1989 he built on his previous work on *Enquire* by proposing a system now known as the World Wide Web, which would enable people to combine information in a web of hypertext documents. This vision was realized with the release of the World Wide Web program, initially internally at CERN in 1990 and then on the Internet in 1991. Berners-Lee continued developing the Web between 1991 and 1993.

He joined the Laboratory for Computer Science at the Massachusetts Institute of Technology (MIT) in 1994 and was a founder of the World Wide Web Consortium, the organization that coordinates the development of the Web. In 2004 he was appointed to the chair of computer science at Southampton University. Berners-Lee is currently working on the Semantic Web – an extension of the World Wide Web in which information content is expressed in both natural language and in a form that can be understood by software. Berners-Lee was knighted in 2004.

Bernoulli, Daniel (1700–1782) *Swiss mathematician*

Daniel was a son of Johann I Bernoulli (ber-**noo**-lee). Of all the Bernoulli family he was probably the most outstanding mathematician and certainly the one with the widest scientific interests. Daniel, who was born in Groningen in the Netherlands, studied at the universities of Basel, Strasbourg, and Heidelberg. His studies, which reflected his already wide interests, included logic, philosophy, and medicine in addition to mathematics.

In 1724 Daniel produced his first important piece of mathematical research – a work on differential equations, which sufficiently impressed the European scientific community to earn him an invitation to the St. Petersburg Academy of Sciences as a professor of mathematics. Once installed in Russia he continued to pursue his varied interests and obtained a post at the academy for his friend Leonhard EULER. In 1733 he left Russia to return to Switzerland to take up a chair in mathematics at Basel. Bernoulli's wide interests continued to occupy him and during his time at Basel he also held posts in botany, anatomy, physiology, and physics.

In Switzerland Daniel did the work for which he is best known, namely his virtual founding of the modern science of hydrodynamics using Isaac NEWTON's laws of force. He published these ideas in his *Hydrodynamica* (1738; Hydrodynamics). Apart from his work in fluid dynamics Daniel made distinguished contributions to probability theory and differential equations in mathematics, and to electrostatics in physics.

He also laid the basis for the kinetic theory of gases. Like his uncle, Jakob I Bernoulli, Daniel corresponded voluminously with many scholars throughout Europe, thus extensively disseminating his new ideas.

Bernoulli, Jakob I (1654–1705) *Swiss mathematician*

Jakob I (or Jacques) was the first of the Bernoulli family of scientists to achieve fame as a mathematician. As with the two other particularly outstanding Bernoullis – his brother, Johann I, and nephew, Daniel – Jakob I played an important role in the development and popularization of the then recently invented integral and differential calculus of Isaac NEWTON and Gottfried LEIBNIZ. His particular contribution to the calculus consisted in showing how it could be applied to a wide variety of fields of applied mathematics.

Jakob I, who was born in Basel, Switzerland, began studying theology and in 1676 traveled through Europe where he met many of the important scientists of the day, such as Robert BOYLE in England. He returned to Basel in 1682 where he began lecturing on mechanics and held a chair in mathematics at Basel University from 1687 until his death. Apart from his mathematical work he was an influential figure in the European scientific community through his voluminous correspondence.

His most important contributions to mathematics were in the fields of probability and in the calculus of variations. His work on probability is contained in his treatise the *Ars conjectandi* (1713; The Art of Conjecturing) in which he made numerous important contributions to the subject, among which was his discovery of what is now known as the "law of large numbers." The law has a number of forms. In effect it says that for an event of probability P in a large number of trials n the number of actual events approaches $n P$ as n increases. *Ars conjectandi* also contains Bernoulli's work on permutations and combinations.

The Bernoulli family were always prone to rivalry and Jakob I and his younger brother, Johann I, became involved in a controversy over the problem of finding the shortest path between two points of a particle moving solely under the influence of gravity. The result of this vigorous dispute was the creation of the calculus of variations, a field that Leonhard EULER was later to develop. In addition to this Jakob I did important and useful work in the study of the catenary, which he applied to the design of bridges.

Bernoulli, Johann I (1667–1748) *Swiss mathematician*

Johann I (or Jean) was the brother of Jakob I Bernoulli and was born in Basel, Switzerland. As in the case of several of the Bernoulli family Johann I's father did not encourage him to make a career of mathematics and he graduated in medicine in 1694.

Once he had abandoned medicine for mathematics he became chiefly interested in applying the calculus to physical problems. He played an important role as a propagandist for the calculus in general and in particular as a champion of Gottfried LEIBNIZ's priority over Isaac NEWTON. Johann I held a chair in mathematics at Groningen, Holland, from 1695 and returned to Switzerland to take up a chair in mathematics at Basel on the death of his brother in 1705. Johann I's interests ranged over many fields outside mathematics including physics, chemistry, and astronomy. His mathematical work also included particularly important contributions to optics, to the theory of differential equations, and to the mathematics of ship sails.

Bert, Paul (1833–1886) *French physiologist and politician*

Bert (bair), who was born in Auxerre in eastern France, initially studied engineering and law but turned to medicine, becoming a pupil of the eminent physiologist, Claude Bernard, at the Sorbonne, Paris. From his studies of the effects of low and high pressures on the human body, Bert showed how deep-sea divers and others working at high external pressure could avoid the condition known as the bends by returning gradually to normal pressure conditions. In this way, the nitrogen gas that dissolves in blood at high pressure is removed slowly instead of forming bubbles in the blood and causing agonizing and possibly fatal cramps. Bert wrote *La Pression barométrique* (1878; Barometric Pressure), which was translated into English in 1943 for the benefit of aircrews flying at high altitudes during World War II.

Bert entered politics in 1876 as deputy for Yonne and served briefly as minister of education and welfare (1881–82). He was staunchly anticlerical and left-wing in his views. In 1886 he was appointed governor-general to the Annan and Tonkin provinces in Indochina but died of dysentery in the same year.

Berthelot, Pierre Eugène Marcellin (1827–1907) *French chemist*

The Parisian-born son of a doctor, Berthelot (bair-te-**loh**) studied medicine at the Collège de France but became interested in chemistry, becoming assistant to Antoine-Jérôme BALARD in 1851. He was professor of organic chemistry at the Ecole Supérieure de Pharmacie (1859–76) and professor of chemistry at the Collège de France (1864–1907).

Alcohols were Berthelot's early research interest and he introduced the terms mono-, di-, and polyatomic alcohols. He showed that glycerin was a triatomic alcohol and in 1854 he synthesized fats from glycerin and fatty acids. He carried out a great deal of work on sugars, which he recognized as being both polyhydric alcohols and aldehydes. Berthelot was one of the pioneers of organic synthesis. Before his time, organic chemists had mainly been concerned with degradations of natural products but Berthelot, in keeping with his logical systematic nature, began with the simplest molecules; his syntheses included methane, methanol, formic acid, ethanol, acetylene, benzene, naphthalene, and anthracene. His favored techniques were reduction using red-hot copper and the silent electric discharge. His methods were somewhat crude and the yields were low. Berthelot's work on organic synthesis was published as *Chimie organique fondée sur la synthèse* (1860; Organic Chemistry Based on Synthesis).

Arising from his interest in esterification, Berthelot studied the kinetics of reversible reactions. In 1862, working with Péan de Saint Gilles, he produced an equation for the reaction velocity. This was incorrect but it inspired Cato GULDBERG and Peter WAAGE to enunciate the law of mass action (1864).

In 1864 Berthelot turned to thermochemistry. In his book *Mecanique chimique* (1879; Chemical Mechanics) he introduced the terms "endothermic" and "exothermic" to describe reactions that respectively absorb and release heat. He also introduced the bomb calorimeter for the determination of heats of reaction and investigated the kinetics of explosions.

Berthelot's interest in agricultural chemistry was stimulated by his discovery of nitrogen uptake by plants in the presence of an electrical discharge. In 1883 he established an agricultural station at Meudon, where fundamental work on the nitrogen cycle was carried out. He looked forward to the day when poverty and squalor would be eradicated by the application of synthetic chemistry and new sources of energy.

Berthelot was a pioneer of historical studies in chemistry. In this he was influenced by his friend, the scholar Renan. In later life he became increasingly involved in affairs of state, mostly concerned with education, and in 1895–96 he served as foreign minister.

Berthollet, Comte Claude-Louis (1748–1822) *French chemist*

Born in Talloires, France, Berthollet (bair-to-**lay**) studied medicine at Turin and gained his MD in 1768. He went to Paris in 1772 where he began publishing chemical researches in 1776 and was elected a member of the Académie Française in 1780. His Italian medical degree was not recognized in France so he obtained a Parisian degree in 1778.

When Berthollet published his important paper on chlorine (which came from sea water), *Mémoire sur l'acide marin déphlogistique* (1785; Memoir on a Marine Dephlogistonated Acid), he was the first French chemist to accept Antoine LAVOISIER's new system. Unfortunately, he also accepted Lavoisier's erroneous idea that chlorine contains oxygen. In 1784 Berthollet became inspector of a dyeworks and he discovered and developed the use of chlorine as a bleach. He published a standard text on dyeing *Eléments de l'art de la teinture* (1791; Elements of the Art of Dyeing).

Berthollet was neither a great manipulator nor a persuasive lecturer, but he did original work in many fields. He analyzed ammonia (1785), prussic acid (hydrogen cyanide, 1787), hydrogen sulfide (1798), and discovered potassium chlorate (1787). Although a convert, he remained skeptical about Lavoisier's oxygen theory of acidity: his analyses showed no oxygen in prussic acid or hydrogen sulfide, despite their undoubted acidity. Berthollet attempted to use his newly discovered potassium chlorate in gunpowder but it proved too unstable, destroying a powder mill at Essones in 1788. More productive were his analyses of iron and steel, which resulted in better quality steel.

After the French Revolution of 1789 Berthollet was a member of various commissions and in 1795 he became a director of the national mint. In 1798 he was entrusted by Napoleon with the organization of scientific work on the expedition to Egypt and he established an Institute of Egypt. On his return to Paris in 1799 Berthollet bought a large house at Arcueil in the suburbs of Paris, where he set up a laboratory and subsequently founded the Société d'Arcueil, which included Pierre de LAPLACE, Alexander von HUMBOLDT, Jean BIOT, Louis Thenard, and Joseph GAY-LUSSAC. At Arcueil, Berthollet produced his magnum opus, the *Essai de statique chimique* (1803; Essay on Chemical Statics), in which he propounded a theory of indefinite proportions. By 1808, following the work of John DALTON, Jöns BERZELIUS, and Gay-Lussac, indefinite proportions was decisively rejected, but Berthollet's idea that mass influences the course of chemical reactions was eventually vindicated in the law of mass action of Cato GULDBERG and Peter WAAGE (1864).

Berthollet was made a senator in 1804 and in his later years was regarded as the elder statesman of French science.

Berzelius, Jöns Jacob (1779–1848) *Swedish chemist*

> I … have seldom experienced a moment of such pure and deep happiness as when the glowing stick which was thrust into it [oxygen] lighted up and illuminated with unaccustomed brilliancy my windowless laboratory.
> —*Autobiographical Notes*

Born in Väversunda, Sweden, Berzelius (ber-**zee**-lee-us) struggled to obtain a satisfactory education. In 1796 he entered the University of Uppsala but his studies were interrupted because of lack of funds. He began his chemical experiments without any official encouragement and from 1799 he worked during the summers as a physician at Medevi Springs where he analyzed the waters. He finally obtained his MD degree in 1802 with a dissertation on the medical uses of the voltaic pile.

After graduating Berzelius moved to Stockholm where he did research with Wilhelm HISINGER, a mining chemist. Their first success came in 1803 with the isolation of cerium but they were anticipated in this by Martin KLAPROTH. Berzelius later discovered selenium (1817), thorium (1828), and his coworkers discovered lithium (1818) and vanadium (1830). In 1807 Berzelius was appointed professor at the School of Surgery in Stockholm (later the Karolinska Institute), and he was soon able to abandon medicine and to concentrate on chemistry.

Berzelius was a meticulous experimenter and systemizer of chemistry. His early work was on electrochemistry and he formed a "dualistic" view of compounds, in which they were composed of positive and negative parts. He was an ardent supporter of John DALTON's atomic theory, but, like LAVOISIER, believed in the importance of oxygen – thus he argued for many years that chlorine contained oxygen.

In 1810 Berzelius began a long series of studies on combining proportions that established Dalton's atomic theory on a quantitative basis. This work led to tables of atomic weights that were generally very accurate, but he never accepted Amedeo AVOGADRO's hypothesis and this led to some confusion. He was a prolific author with about 250 papers to his credit. His *Lärbok i kemien* (1808–1818; Textbook of Chemistry) subsequently passed through many editions and was translated into most languages except English. Pupils who came to study with him included Friedrich WÖHLER, Leopold GMELIN, and Eilhardt MITSCHERLICH. His ideas on chemical proportions and electrochemistry are set out in *Essai sur la théorie des proportions chimiques et sur l'influence chimique de l'électricité* (1819; Essay on the Theory of Chemical Proportions and on the Chemical Effects of Electricity).

Berzelius's work in organic chemistry was less fruitful than the rest of his work but he improved organic analysis by introducing a tube of calcium chloride for the collection of water and the use of copper(II) oxide as an oxidizing agent. From 1835 Berzelius's rigid adherence to the dualistic theory proved obstructive to progress in organic chemistry, although it was given a certain plausibility by Wöhler and Justus von LIEBIG's discovery of the benzoyl radical (1832).

Berzelius introduced much of the familiar chemical apparatus, including rubber tubing and filter paper, and the modern chemical symbols, although these were little used in his lifetime. He had a knack of coining words for phenomena and substances – "catalysis," "protein," and "isomerism" were all introduced by him.

Besicovitch, Abram Samoilovich (1891–1970) *Ukrainian–British mathematician*

Born in the Ukrainian town of Berdjansk, Besicovitch (be-**sik**-o-vich) graduated in 1912 from the University of St. Petersburg, having studied under A. A. MARKOV. In 1917 he became professor of mathematics at Perm (later Molotov University) and then taught at the Leningrad Pedagogical Institute and Leningrad University. He left the Soviet Union in 1924 to work briefly in Copenhagen before moving to England. G. H. HARDY was sufficiently impressed by Besicovitch's analytical powers to secure him a lectureship at Liverpool University. After a year he became a lecturer at Cambridge and in 1950 became Rouse Ball Professor of Mathematics, a post that he held for eight years.

Besicovitch was primarily an analyst. The subject with which he is most associated is that of almost periodic functions, an interest stemming from his collaboration with Bohr. 1932 saw the publication of his book *Almost Periodic Functions*. He also did important work on the "Karkeya problem," general real analysis, complex analysis, and various geometric problems. His other main work was on geometric measure theory.

Bessel, Friedrich Wilhelm (1784–1846) *German astronomer*

Bessel (**bes**-el) was born into a poor family in Minden, Germany, and started work as a clerk. His interest in and aptitude for astronomy brought him to the attention of Heinrich OLBERS, who obtained a position for him in the observatory at Lilienthal. Four years later he was entrusted with the construction of the observatory at Königsberg and appointed its director.

Bessel made many advances in astronomy. He cataloged the position of 50,000 stars down to the ninth magnitude between 15°S and 45°N and, using James BRADLEY's results, achieved new levels of accuracy. He also made careful observations of 61 Cygni and was able to detect a parallax of 30 arc seconds and to calculate the star's distance – the first such determination – as 10.3 light years. (The distance is now known to be 11.2 light-years.) Although Bessel was the first to announce the detection of parallax (1838), Thomas HENDERSON had in fact measured it in 1832 in his observations of Alpha Centauri.

Bessel's other great discovery came after observing a slight displacement in the proper motion of Sirius, which he explained as the effect of an orbit around an unseen star, and announced in 1844 that Sirius was a double star system having a dark companion. Sirius B was detected optically by Alvan CLARK in 1862. Bessel made a similar claim for Procyon whose companion was discovered optically in 1895. He also noted irregularities in the motion of Uranus and suggested that they were caused by an unknown planet, but died just before the discovery of Neptune.

In mathematics Bessel worked on the theory of the functions, named for him, that he introduced to determine motions of bodies under mutual gravitation and planetary perturbations. They still have a wide application in modern physics.

Bessemer, Sir Henry (1813–1898) *British inventor and engineer*

Bessemer was the son of a mechanical engineer who had fled from the French Revolution. After leaving the village school in Charlton, England, where he was born, he worked as a type-caster, until the family moved to London in 1830. At the age of 17 he set up his own business to produce metal alloys and bronze powder. In 1843 he had an idea that made his fortune. On purchasing some "gold" paint (made of brass) for his sister he was horrified at its high price. He designed an automatic plant to manufacture the paint and made sufficient money to pursue a career as a professional inventor.

During the Crimean War (1853–56) Bessemer invented a new type of gun with a rifled barrel. To manufacture the gun he needed a strong metal that could be run into a mold in a fluid state. At that time cast iron (pig iron) contained carbon and silicon impurities, which made it brittle. Wrought iron, which was relatively pure, was made by a laborious process of refining pig iron. The temperature of the furnace, while sufficient to melt the pig iron, was not sufficient to keep the purer iron molten. The refined metal was extracted in lumps after which it was "wrought." Bessemer proposed burning away the impurities by blowing air through the molten metal. The *Bessemer converter* that he invented is a cylindrical vessel mounted in such a way that it can be tilted to receive a charge of molten metal from the blast furnace. It is then brought upright for the "blow" to take place. Air is blown in through a series of nozzles at the base and the carbon impurities are oxidized and carried away by the stream of air.

Bessemer announced his discovery in 1856. At first his idea was accepted enthusiastically and within weeks he obtained the equivalent of about $135,000 in license fees. However, though the process had worked for him, elsewhere it failed dismally because of excess oxygen trapped in the metal, and because of the presence of phosphorus in the ores. (By chance Bessemer's ore had been phosphorus-free.) His invention was dropped and Bessemer found himself the subject of much ridicule and criticism. Bessemer established his own steelworks in Sheffield (1859) using imported phosphorus-free iron ore.

Robert Mushet (about 1856) solved the problem of the excess oxygen by the addition of an alloy of iron, manganese, and carbon to the melt. Bessemer's process then worked provided nonphosphoric ores were used, but it took much time and determination to convince ironworkers after the initial failure. The invention eventually reduced the price of steel to a fifth of its former cost, made it possible to produce it in large quantities, and made possible its use in a variety of new products. The problem of dealing with the phosphorus impurities was solved in 1878 by Sydney Gilchrist THOMAS and Percy Carlyle GILCHRIST. Bessemer retired a rich man in 1873.

Best, Charles Herbert (1899–1978) *American–Canadian physiologist*

Best, who was born in West Pembroke, Maine, graduated in physiology and biochemistry from the University of Toronto in 1921. In the summer of that year he gave up a lucrative holiday playing professional football and baseball to begin work with Frederick BANTING. Together they isolated the hormone insulin, and showed its use in the treatment of diabetes. Banting was furious when Best was not awarded a share in the 1923 Nobel Prize for physiology or medicine for the discovery of insulin.

Best remained at the University of Toronto and gained his MB in 1925. He was made head of the physiology department in 1929 and became director of the Banting and Best Department of Medical Research when Banting was killed in 1941. He continued the work on insulin throughout these years and in an important paper published in 1936 he suggested the administration of zinc along with insulin to reduce its rate of absorption and make it more effective over a longer time. He also studied cardiovascular disease and established the clinical use of heparin as an anticoagulant for blood in the treatment of thrombosis. He discovered the vitamin choline, which prevents liver damage, and the important enzyme histaminase, which takes part in local inflammation reactions, breaking down histamine.

Bethe, Hans Albrecht (1906–2005) *German–American physicist*

Bethe (**bay**-te), the son of an academic, was born in Strasbourg in France and educated at the universities of Frankfurt and Munich, where he obtained his doctorate in 1928. He taught in Germany until 1933 when he moved first to England and, in 1935, to America. In America he held the chair of physics at Cornell from 1937 until his retirement in 1975, serving in the war as director of theoretical physics at Los Alamos from 1943 to 1946.

Bethe soon established a reputation for his impressive knowledge of nuclear reactions. This was, in part, based on three review articles on nuclear physics he published in 1936 and 1937, which have been described as the first presentation of this field as a branch of science and which are sometimes known as "Bethe's Bible."

In 1938 Bethe was invited by Edward TELLER to contribute a paper on astrophysics for a conference he was organizing. Bethe at first pleaded ignorance of the subject but, under pressure from Teller, he finally agreed to search for a relevant topic. He noted that most astrophysicists seemed to be puzzling over the origin of the chemical elements. He therefore decided to consider another issue, namely, the sources of stellar energy. He managed to find, as he reported in his 1939 paper *Energy Production in Stars*, " … the only nuclear reaction which gives the correct rate of stellar energy production within the limits of the theory."

Bethe was referring to the carbon cycle (or CNO cycle). The cycle begins with a hydrogen nucleus or proton (^{1}H) and a carbon-12 atom; it has six stages:

$^{12}C + {}^{1}H \rightarrow {}^{13}N + \gamma$
$^{13}N \rightarrow {}^{13}C + e^{+} + \nu$
$^{13}C + {}^{1}H \rightarrow {}^{14}N + \gamma$
$^{14}N + {}^{1}H \rightarrow {}^{15}O + \gamma$
$^{15}O \rightarrow {}^{15}N + e^{+} + \nu$
$^{15}N + {}^{1}H \rightarrow {}^{12}C + {}^{4}He$

Here, γ is a gamma ray, e^+ a positron, and ν a neutrino. The net result of the cycle is to convert four protons (4^1H) into a helium nucleus (He^4), while the carbon-12-atom remains available after step 6 to repeat the cycle once more. In the process 27 MeV (million electron volts) are released.

Although the amount of energy produced per cycle is modest, the large amount of stellar matter involved is sufficient to generate the enormous energies met with inside stars. Bethe's CNO cycle, however, gives no indication of the origin of the carbon-12 that starts the cycle. It was left to Fred HOYLE and his colleagues to resolve this issue in the 1950s. Bethe did, however, contribute, with Ralph ALPHER, to George GAMOW's famous 1948 alpha-beta-gamma paper on the origin of the elements and the big bang. Unfortunately their paper advanced no further than the isotopes of hydrogen and helium.

Bethe also played a significant part in public affairs. He quarreled in the 1940s with Teller on the need to build the hydrogen bomb, and in the 1980s over the viability of the U.S. Strategic Defense Initiative (known as "Star Wars"). In 1958 he served as a delegate to the Geneva Conference that negotiated the first test-ban treaty. He also worked for the 1963 ban on atmospheric testing. More recently, in 1992, Bethe called upon the United States and Russia to reduce their nuclear arsenals to a thousand warheads each.

Bethe also worked in other branches of physics. In 1929 he published a classic paper initiating crystal-field theory, and in 1949 he made a pragmatic calculation of the LAMB shift. He also continued to work at physics in his retirement. He collaborated with John BAHCALL on several papers dealing with the solar-neutrino problem. He also began to tackle the problem of explaining how stars explode. Modern computer models, he complained, lead to moderate explosions when compared with the massive eruptions of a supernova.

For his earlier work on the theory of nuclear reactions, and for his contributions to astrophysics, Bethe was awarded the 1967 Nobel Prize for physics.

Bevan, Edward John (1856–1921) *British industrial chemist*

Bevan, who was born at Birkenhead in Lancashire, northwest England, was educated privately and in 1873 began employment with the Runcorn Soap and Alkali Company. From 1877 to 1879 he studied chemistry at Owens College, Manchester, where he met Charles CROSS with whom he went into partnership in 1885 as consulting chemists.

Their main interest was cellulose and in 1892 they patented the viscose process of rayon manufacture in which cellulose (woodpulp) is dissolved in carbon disulfide and alkali. The cellulose is regenerated by acid, either in the form of yarn (rayon) or film (cellophane). He wrote several books, including *Cellulose* (1895), which he coauthored with Cross.

Bichat, Marie François Xavier (1771–1802) *French pathologist*

> Life is the ensemble of functions that resist death.
> —*Recherches physiologiques sur la vie et la mort* (1800; Physiological Researches on Life and Death)

Bichat (bee-**sha**), the son of a physician, was born at Thoirette, France, and studied humanities at Montpellier and philosophy at Lyons. He switched to studies in surgery and anatomy and moved in 1793 to Paris, where he worked for some years under the patronage of Pierre Desault, the leading French surgeon. He was appointed physician at the Hôtel-Dieu in 1800 shortly before his death from tuberculous meningitis.

Despite his short life Bichat produced two highly influential works, *Traité des membranes* (1800; Treatise on Membranes) and *Anatomie générale* (1801; General Anatomy). He revealed the inadequacies of Giovanni MORGAGNI's claim that disease resided in the organs of the body, and instead stressed the role of the component tissues in determining health and disease. He consequently went on to make a detailed investigation of the tissues of the body, distinguishing 21 different types. He argued that in an organ made up of a number of tissues it is often found that while one tissue type is diseased the remainder are healthy.

This work was significant in bridging the gap between the organ pathology of Morgagni and the cell pathology of Rudolf VIRCHOW.

Biela, Wilhelm von (1784–1856) *Austrian astronomer*

Born in Rossia, Austria, Biela (**bee**-la) was an army officer and an amateur astronomer. In 1826 he observed a comet with a short period of 6.6 years. When *Biela's comet* reappeared in 1845 it had split into two parts. It was last seen in 1852 when it presumably broke up, for in November 1872 what was probably its remains was seen as a fantastic meteor shower, which caused a worldwide sensation. The shower can still be seen faintly in Andromeda in late November. The meteors are sometimes called the Bielids or, alternatively, the Andromedids.

Biffen, Sir Rowland Harry (1894–1949) *British geneticist and plant breeder*

Biffen was born in Cheltenham in Gloucestershire, England; after graduating in natural sciences from Cambridge in 1896, he joined a team investigating rubber production in Mexico, the West Indies, and Brazil. On his return he was appointed lecturer in botany at Cambridge and patented a method for handling rubber latex.

Biffen was inclined more toward applied than pure botany and joined the Cambridge School of Agriculture shortly after its foundation in 1899. He began conducting cereal trials in order to select improved types, and when Gregor MENDEL's laws of inheritance were rediscovered in 1900, he realized immediately that they could be applied to improving plant-breeding methods. Biffen speculated that physiological as well as morphological traits would prove to be inherited in Mendelian ratios, and in 1905 demonstrated that this was true for resistance to yellow rust, a fungal disease of wheat.

Little Joss and Yeoman, two wheat varieties bred by Biffen, were unequaled for many years. In 1912 Biffen became director of the Plant Breeding Institute at Trumpington, a newly formed research center established by the government to promote Biffen's work and the application of scientific principles to plant breeding. Biffen was also professor of agricultural botany at the university from 1908 to 1931 and was instrumental in setting up the National Institute of Agricultural Botany at Cambridge. He was knighted for his services to agriculture in 1925.

Billroth, Christian Albert Theodor (1829–1894) *Austrian surgeon*

Billroth (**bil**-roht), who was born in Bergen, Germany, first studied natural sciences and later medicine at the University of Göttingen and subsequently in Berlin, becoming qualified to practice in 1852. In the following year he was appointed to the surgical clinic at Berlin University and in 1860 became director of a similar clinic at the University of Zurich, where he wrote his *Allgemeine chirurgische Pathologie und Therapie* (1863; General Surgical Pathology and Therapy). However, it was as professor of surgery at the University of Vienna (1867–94) that Billroth made his greatest contributions to surgery. Here, he introduced the new antiseptic methods in abdominal surgery, thus enabling hitherto impossibly dangerous operations. Billroth was the first to perform the removal of a section of the esophagus (1872), to undertake a complete laryngectomy (1873), and to excise the lower half of the stomach, rejoining the upper half to the duodenum. This is sometimes called *Billroth's operation*.

Apart from being an eminent surgeon of international repute, Billroth was also a gifted musician and like Theodor ENGELMANN a friend of Johannes Brahms.

Bina, Eric (1964–) *American computer scientist*

Bina (**bee**-na) worked at the National Center for Supercomputer Applications (NCSA) at the University of Illinois at Urbana in the early 1990s. While there, he collaborated with Marc ANDREESSEN and some other colleagues in producing a prototype Internet browser called *Mosaic*.

After Andreessen founded Mosaic Corp. with Jim Clark in 1994, Bina joined the new company, subsequently named Netscape Communications, and helped to develop an improved version of *Mosaic*, which was called *Navigator*. This invention was a key development in the very rapid growth of the Internet.

Binnig, Gerd (1947–) *German physicist*

Binnig was born in Frankfurt, Germany, and educated at the Goethe University there, where he obtained his PhD in 1978. He immediately joined the staff of the IBM Research Laboratory at Roschliken, Zurich.

One limitation of the conventional electron microscope developed in the 1930s by E. RUSKA was its failure to reveal much information about the surface of a material. Overall surface structure can be distinguished by the techniques of low-energy electron diffraction (LEED) and some indication of the detailed structure can be gained from the field-emission and field-ion microscopes developed by Erwin MUELLER. Binnig, in collaboration with Heinrich ROHRER, began work on a high-resolution *scanning tunneling microscope* (STM) in 1978. By 1981 they were able to resolve details on the surface of some calcium–iridium–tin crystals.

The STM employs a small conducting probe which is held close to the surface and slowly scanned across it. Electrons tunnel between the surface and the probe, and the probe is raised or lowered so as to keep the signal constant. A computer-generated map of the surface is produced. Like the similar *atomic force microscope* (ATM), the device can, under suitable conditions, resolve individual atoms or molecules on the surface.

For their work in this field Binnig and Rohrer shared the 1986 Nobel Prize for physics.

OPTICAL ACTIVITY Biot showed that compounds such as tartaric acid could rotate polarized light in solution. The explanation was later given by Le Bel and van't Hoff, who suggested that carbon molecules have a three-dimensional tetrahedral structure. Tartaric acid (above) has two isomers that are mirror images of each other. One rotates the light to the left (levo); the other to the right (dextro).

Biot, Jean Baptiste (1774–1862) *French physicist*

Biot (**bI**-oh), a Parisian by birth, grew up during the French Revolution and at the age of 18 he joined the army as a gunner. He left a year later to study mathematics at the Ecole Polytechnique in Paris. On leaving he taught at a school in Beauvais but soon returned to Paris to become a professor of physics at the Collège de France.

In 1804 Biot made an ascent in a balloon with Joseph GAY-LUSSAC. They reached a height of three miles and made many observations, including the fact that the Earth's magnetism was not measurably weaker at that height.

For the next few years Biot collaborated with François ARAGO in many fields of research and they traveled to Spain together to measure the length of an arc of meridian, in order to calibrate a standard unit of length. Biot later went on a number of other important expeditions.

His most famous work was on optical activity, for which, in 1840, he was awarded the Rumford medal of the Royal Society. He was the first to show that certain liquids and solutions, as well as solids, can rotate the plane of polarized light passing through them. Biot suggested that this is due to asymmetry in the molecules. From this idea grew the technique of polarimetry as a method of measuring the concentration of solutions.

Birkeland, Kristian Olaf Bernhard (1867–1917) *Norwegian physicist and chemist*

Birkeland (**beer**-ke-lan) was born in the Norwegian capital, Christiania (now Oslo), and studied in Paris, Geneva, and Bonn where he was a pupil of Robert BUNSEN. In 1898 he was appointed to the chair of physics in Oslo University. He is remembered today for his discovery of a means for the fixation of nitrogen (the *Birkeland–Eyde process*).

Energy crises are not monopolies of the 1970s. In 1898 William CROOKES in his presidential address to the British Association had pointed out that, given the world demand for nitrogeneous fertilizers, the deposits of nitrates would rapidly be exhausted. As there is a virtually unlimited supply of nitrogen in the atmosphere the obvious solution was to find some way in which it could be used. Birkeland, in collaboration with Samuel EYDE, solved the problem in 1903 by passing air through an electric arc to form oxides of nitrogen, which could then be absorbed in water to give nitric acid. This was mixed with lime to give calcium nitrate. The process is particularly useful in regions (as in Scandinavia) where there is a plentiful supply of hydroelectric power, although the Haber process is now the main industrial method of fixing nitrogen.

Birkeland also spent much time studying the aurora borealis, making several expeditions and establishing a geophysical laboratory as far north as 70°. In 1896 he was the first to suggest the correct explanation that the aurora borealis could be the result of charged rays emitted by the Sun and trapped in the Earth's magnetic field near the poles. He derived this idea from the resemblance between the newly discovered cathode rays and the aurora.

Birkhoff, George David (1884–1944) *American mathematician*

Birkhoff, who was born in Overisel, Michigan, studied at the Lewis Institute (now the Illinois Institute of Technology) from 1896 to 1902, and subsequently at the University of Chicago and at Harvard. In 1907 he obtained his PhD from Chicago and took up a teaching post at the University of Wisconsin, moving to Princeton in 1909. In 1912 he became assistant professor at Harvard and, in 1919, professor there, a post he held until 1939.

Birkhoff's mathematical interests were wide, and among the many areas to which he made notable contributions were differential equations, celestial mechanics, difference equations, and the three-body problem. His main field of research was mathematical analysis, especially applied to dynamics. In the course of his work on dynamical systems Birkhoff obtained a famous proof of a conjecture made by Henri POINCARÉ in topology, usually known as Poincaré's last geometric theorem. In 1923 he proved a result, now known as *Birkhoff's theorem*, for spherically symmetric systems in General Relativity Theory. This has turned out to be important in the theory of black holes and cosmology. The ergodic theorem, a result concerned with the formal mathematics of probability theory that Birkhoff proved in 1931, is another of his outstanding achievements. Modern dynamics received an enormous impetus from Birkhoff's work, and he also worked on the foundations of relativity and quantum mechanics.

Bíró, Ladislao José (1899–1985) *Argentinian inventor*

Throughout the 1930s Bíró (**bI**-roh) worked as a journalist and artist in Budapest, the capital of his native Hungary. While thus engaged he noticed how quickly printer's ink dried and began to think of a new type of pen. Before Bíró the alternatives were expensive and unreliable fountain pens, or steel nibs with bottles of ink. To meet the demand Birmingham was producing nearly 200 million nibs each year. Bíró saw that a ball rotating in an ink supply would write when pushed along a sheet of paper. The ink bottle and leaking fountain pen could be dispensed with. In 1938, with his brother Georg, a chemist, Bíró applied for a patent.

Europe, however, was no place to develop a new product in 1938. Bíró had happened to meet president Justo of Argentina while on holiday in Yugoslavia. Intrigued by the new pen, the president invited Bíró to come and work in Argentina. Bíró accepted the invitation and soon found backers in return for a substantial share in any future profits. In 1944 the North American rights were sold for $2 million. But Bíró had little taste for business and resigned from the company in 1947 to devote more time to art. He also continued to invent and produced, among other items, a heat-proof tile and a pick-proof lock.

The durability of Bíró's work can be seen partly in the billions of ballpoint pens that are made and thrown away each year, and partly in the fact that in most of the world's languages a ballpoint pen is also known as a "biro."

Bishop, John Michael (1936–) *American immunologist and microbiologist*

Bishop attended Gettysburg College and studied medicine at Harvard University. In 1962 he secured an internship at Massachusetts General Hospital in Boston, and in 1964 he moved to the National Institutes of Health, Washington, DC, as research associate in virology, later becoming senior investigator (1966) and assistant professor (1968). He was appointed professor of microbiology and immunology at the University of California Medical Center, San Francisco, in 1972, and in 1981 he became director of the G. W. Hooper Research Foundation. He became chancellor of the University of California in 1998.

Bishop, working in collaboration with Harold VARMUS, demonstrated for the first time that cancer-causing genes (*oncogenes*) carried by certain viruses are derived from normal genes present in the cells of their host, known as *proto-oncogenes*. This work by the team at the University of California, published in 1976, led to the discovery of many more such cellular genes, and represented a major advance in cancer research. In recognition of this, Bishop and Varmus were jointly awarded the 1989 Nobel Prize for physiology or medicine.

Bittner, John Joseph (1904–1961) *American experimental biologist*

Bittner, who was born in Meadville, Pennsylvania, gained his doctorate at the University of Michigan and spent the greater part of his academic life involved in cancer research. He was George Chase Christian Professor of Cancer Research at the University of Michigan and director of cancer biology of the University of Minnesota's medical school (1942–57), and later professor of experimental biology.

While working at Ben Harbor Research Station, Maine (1936), Bittner found that some strains of mice were highly resistant to cancer, while others were very prone to it. If the young of cancer-resistant mice were transferred to cancer-prone mothers they became cancerous, apparently via the mothers' milk, whereas cancer-resistant parents induced resistance in cancer-prone young. Bittner's discovery of viruslike organisms in the milk of cancer-prone parents suggested that these organisms are the cause of the cancer. Bittner's findings followed, and may be linked with, those of Francis ROUS, who made the controversial finding that other viruslike organisms are, perhaps, the cause of sarcomas (tumors originating in connective tissue) in chickens. Such work does not, of course, suggest that all cancers are caused by viruses or viruslike organisms, merely that some forms may be.

Bjerknes, Jacob Aall Bonnevie (1897–1975) *Norwegian meteorologist*

Bjerknes (**byairk**-nays), the son of Vilhelm Bjerknes, followed the example of his father in studying meteorology. Born in the Swedish capital, Stockholm, he was educated at the University of Oslo, where he obtained his PhD in 1924, and worked at the Geophysical Institute at Bergen with his father from 1917, remaining there when Vilhelm moved to Oslo in 1926.

During World War I Bjerknes worked with his father in establishing a series of weather observation stations throughout Norway. From the data collected, and working with other notable meteorologists, including Tor BERGERON, they developed their theory of polar fronts, also known as the *Bergen theory* or the *frontal theory*. They had established that the atmosphere is composed of distinct air masses possessing different characteristics and applied the term "front" to the boundary between two air masses. The polar front theory showed how cyclones (low-pressure centers) originated from atmospheric fronts over the Atlantic Ocean where a warm air mass met a cold air mass.

In 1939 Bjerknes moved to America and, unable to return to occupied Norway, became professor of meteorology at the University of California where he continued to study atmospheric circulation. In 1952 he became one of the first to use space techniques for meteorological research when he used photographs of cloud cover taken by research rockets for weather analysis.

Bjerknes, Vilhelm Friman Koren (1862–1951) *Norwegian meteorologist*

Bjerknes was born in the Norwegian capital, Christiania (now Oslo), where his father, Carl, was professor of mathematics at the university. In 1890 Vilhelm traveled to Germany and became assistant to Heinrich HERTZ. He was made professor of applied mechanics and mathematical physics at the University of Stockholm in 1895. He returned to Norway in 1907 and in 1912 moved to the University of Leipzig to become professor of geophysics.

Bjerknes's important contributions to meteorology and weather forecasting include his mathematical models (1897) of atmospheric and oceanic motions, which later led to the theory of air masses. In 1904 he produced a program for weather prediction based on physical principles. He returned to Norway in 1907 and in 1912 moved to the University of Leipzig to become professor of geophysics.

During World War I he founded the famous Bergen Geophysical Institute, gathering there a group of notable meteorologists, including his son, Jacob Bjerknes, Tor BERGERON, and Carl-Gustaf ROSSBY. In 1921 he produced an important work, *On the Dynamics of the Circular Vortex with Applications to the Atmospheric Vortex and Wave Motion*.

Bjerrum, Niels (1879–1958) *Danish physical chemist*

The son of a professor of ophthalmology, Bjerrum (**byair**-um), who was born in the Danish capital, Copenhagen, received his master's degree in 1902 and doctorate in 1908, becoming professor at the Royal Veterinary and Agricultural College (1914–49).

His first notable work was an extensive study of chromium complexes by means of conductivity, equilibrium constant, and absorption spectrum measurements. In 1909 he proposed (contrary to Svante ARRHENIUS's original dissociation theory) that strong electrolytes are completely dissociated. In 1911, working with Hermann NERNST, he applied the quantum theory of a harmonic oscillator to the temperature dependence of the specific heats of gases. This led to work on molecular rotation and vibration and hence to pioneer work on the infrared spectra of polyatomic molecules.

Black, Sir James Whyte (1924–) *British pharmacologist*

Black graduated from St. Andrews University, Scotland, in 1946, and, after a number of academic posts, joined ICI as a pharmacologist (1958–64). After working for Smith, Kline, and French he became professor of pharmacology at University College, London (1973–77), before joining Wellcome as Director of Therapeutic Research (1978–84). From 1984 until 1992 he was professor of analytical pharmacology at King's College Hospital, London. From 1992 to 2006 he was chancellor of the University of Dundee. Black was knighted in 1991.

Black has been associated with two important advances in pharmacology. In the 1950s he isolated the first beta blockers. These are compounds that prevent the stimulation of certain nerve endings (beta receptors) in the sympathetic nervous system, thus reducing heart activity. Beta blockers are widely used to treat hypertension and angina. His subsequent work has been concerned with the control of gastric ulcers and his discovery of the drug cimetidine, which reduces acid secretion in the stomach and is used to treat ulcers in the stomach and duodenum. For this work and his work on beta blockers he was awarded the 1988 Nobel Prize for physiology or medicine.

Black, Joseph (1728–1799) *British physician and chemist*

> Upon the whole, Chymistry is as yet but an opening science, closely connected with the usefull and ornamental Arts, and worthy the attention of a liberal mind … While our knowledge is imperfect, it is apt to run into error: but Experiment is the thread that will lead us out of the labyrinth.

Black, the son of a wine merchant, was born in Bordeaux, France, and studied languages and natural philosophy, and later, medicine and chemistry at Glasgow University (1746–50). He moved to Edinburgh in 1751, where he presented his thesis in 1754. Black published very little and the thesis, expanded and published as

Experiments upon Magnesia Alba, Quicklime, and some other Alcaline Substances (1756), contained his most influential work. The paper in fact marked the beginning of modern chemistry. Black investigated quantitatively the cycle of reactions:

limestone→quicklime→slaked lime→ limestone

and showed that the gas evolved ("fixed air" or carbon dioxide) is distinct from and a constituent of atmospheric air, and is the cause of the effervescence of limestone with acids. He proved that mild alkalis will become more alkaline when they lose carbon dioxide and they are converted back to mild alkalis through reabsorption of the gas.

Black's other great discovery was that of latent heat (the heat required to produce a change of state). The concept of latent heat came to him in 1757 and the experimental determination of the latent heat of fusion of ice was made in 1761. The next year he determined the latent heat of formation of steam. Black also distinguished the difference between heat and temperature and conceived the idea of specific heat.

Black was professor of medicine and lecturer in chemistry at Glasgow (1756–66) and then professor of chemistry at Edinburgh for the rest of his life. Black's lectures, which he gave for over 30 years, were immensely popular and were published in 1803.

Blackett, Patrick Maynard Stuart (1897–1974) *British physicist*

Blackett, the son of a London stockbroker, attended the Royal Naval College at Dartmouth. After serving with the navy in World War I, during which he fought at the Battle of the Falklands and Jutland, he entered Cambridge University, resigned his commission, and decided to become a scientist. He worked in the 1920s with Ernest RUTHERFORD at the Cavendish Laboratory and, in 1933, was appointed professor of physics at London University. In 1937 he moved to Manchester, returning to London in 1953 to take the chair at Imperial College where he remained until his retirement in 1963. During World War II he worked on numerous advisory bodies and from 1942 to 1945 was director of operational research at the admiralty.

Just as Blackett was beginning his research career Rutherford had announced his discovery of the atomic transmutation of nitrogen into oxygen by bombardment with alpha particles. Blackett, using a cloud chamber, took some 23,000 photographs containing some 400,000 alpha particle tracks in nitrogen and found in 1925 just eight branched tracks in which the ejected proton was clearly separated from the newly formed oxygen isotope.

Blackett continued with the Wilson cloud chamber and began, in collaboration with Giuseppe OCCHIALINI, to use it to detect cosmic rays. As the appearance of cosmic rays is unpredictable it was standard practice to set up the chamber to take a photograph every 15 seconds, producing a vast amount of worthless material for analysis. To avoid this Blackett introduced in 1932 the counter-controlled chamber. Geiger counters were so arranged above and below the chamber that when a cosmic ray passed through both, it activated the expansion of the chamber and photographed the ion tracks produced by the ray. Using this device they confirmed in 1933 Carl ANDERSON's discovery of the positron. They also suggested that the positron was produced by the interaction of gamma rays with matter, such that a photon is converted into an electron–positron pair. The phenomenon is known as pair production.

After the war Blackett's research interests moved from cosmic rays to terrestrial magnetism. Using new sensitive magnetometers his group began a major survey of the magnetic history of the Earth. By 1960 they could report that there had been considerable change in the relative positions of the continents over the past 500 million years, thus providing further support for the doctrine of continental drift.

Blackett was also active in public affairs and a noted opponent of nuclear weapons. In 1948 he was awarded the Nobel Prize for physics for "his development of the Wilson cloud chamber and his discoveries therewith in the field of nuclear physics and cosmic radiation." He was raised to the British peerage as Baron Blackett in 1969.

Blackman, Frederick Frost (1866–1947) *British plant physiologist*

Blackman, born in London the son of a doctor, studied medicine at St. Bartholomew's Hospital there and natural sciences at Cambridge University. He remained in Cambridge for the whole of his career where he served as head of plant physiology until his retirement in 1936.

Blackman is mainly remembered for his classic 1905 paper, *Optima and Limiting Factors*, in which he demonstrated that where a process depends on a number of independent factors, the rate at which it can take place is limited by the rate of the slowest factor. This paper was stimulated by the research of one of his students, who showed that raising the temperature only increased the rate of photosynthesis if the level of illumination was high. Increased temperatures had no effect at low light intensities.

He had earlier, in 1895, provided convincing experimental support for the long held view that gaseous exchange between the leaves and the atmosphere takes place through the stomata, the pores on the leaf's surface.

Blackwell, Elizabeth (1821–1910)
British–American physician

Blackwell is best remembered for being the first woman to receive a medical degree in the United States, in 1849. However, she also did much in promoting women's health and training for women physicians. She was born in Bristol, England, and emigrated to America as a child. The early death of her father forced her into teaching to support the family, but she soon determined on a career in medicine. Yet formidable obstacles faced her; apart from lack of money to finance her preliminary studies, no woman had ever been admitted to a medical school. While continuing to teach she arranged to lodge in the house of a physician, Samuel Henry Dickson of Charleston, where she could acquire some basic medical knowledge. She was turned down by all the major medical colleges, and was accepted by just one of the minor medical schools, Geneva Medical College, New York State. She overcame the initial skepticism and embarrassment of staff at the college, and the hostility of the townspeople, to complete her course and graduate first in her class. To continue her medical training she then went to Europe, initially to La maternité lying-in hospital in Paris, where she contracted an eye disease that left her blind in one eye. Thereafter she studied at St. Bart's Hospital in London, where she was generally welcomed by the teaching staff, an exception being the professor of midwifery: according to Blackwell, "[he told me that] his neglecting to give me aid was owing to no disrespect for me as a lady, but to his condemnation of my object!" Blackwell returned to America in 1851 and settled in New York, where she opened a free part-time dispensary for poor women and children. In 1857 she founded the New York Infirmary for Indigent Women and Children. Apart from medical care, an important aspect was the training for women medical and nursing students. In 1859, while on a lecture tour of Britain, Blackwell become the first woman to be included in the United Kingdom's Medical Register. Back in America, in the face of continuing hostility to women from the established medical schools, Blackwell opened a Women's Medical College in 1868, with an initial intake of 15 students and nine faculty members. The following year she returned to live in England, leaving her sister Emily in charge of the College. Elizabeth went on to promote medical education in England, helping to set up the National Health Society and founding the London School of Medicine for Women. In 1875 she was appointed professor of gynecology at the London School of Medicine for Children.

Blaeu, Willem Janszoon (1521–1638)
Dutch cartographer

Blaeu (blow), who was born in Alkmaar, Holland, began work as a carpenter. In 1595 he spent a year with Tycho BRAHE at his observatory at Hven. He opened his cartographic shop in Amsterdam soon after his return to Holland and specialized in producing globes. He published his first world map in 1605 and his first atlas in 1633.

After his death the business was carried on by his sons, Jan and Cornelis. In 1648 they produced their world map, which contained much that was new including the coastline of north and west Australia and parts of New Zealand and the Antarctic. It also abandoned the great southern continent previously believed to exist.

Blagden, Sir Charles (1748–1820) *English physician and chemist*

Blagden, born in Wotton under Edge in England, studied medicine at Edinburgh, where one of his professors was Joseph BLACK, and graduated in 1768. He became a medical officer in the British army in the same year and theoretically remained in that post until 1814. From 1782 to 1789 Blagden was assistant to Henry CAVENDISH, a post that involved him in the so-called "water controversy," a dispute between James WATT, Cavendish, and Antoine LAVOISIER concerning the priority of the discovery of the synthesis of water from its elements. Blagden was friendly with the great French scientists of the day, especially Claude BERTHOLLET, and on a visit to Paris in 1783 he told Lavoisier of Cavendish's synthesis, an experiment that Lavoisier repeated in Blagden's presence. Blagden became secretary of the Royal Society soon afterward, in which capacity he published Watt's papers on the same subject. The dispute was largely artificial because the three men drew different conclusions from their work.

Blagden's own scientific work was concerned with the freezing of mercury, the supercooling of water, and the freezing of salt solutions. He discovered, in 1788, that the lowering of the freezing point of a solution is proportional to the concentration of the solute present. This became known as *Blagden's law*. Blagden was knighted in 1792.

Blakeslee, Albert Francis (1874–1954)
American botanist and geneticist

Blakeslee was born at Geneseo in New York State and educated at Wesleyan University, Connecticut, graduating in 1896. He taught science for four years before entering Harvard to do postgraduate research, gaining his PhD in 1904. In this year he discovered that the bread molds (*Mucorales*) exhibit heterothallism (self-sterility) and spent the next two years in Germany making further investigations on the fungi.

From 1907 to 1914 Blakeslee was professor of botany at Connecticut Agricultural College. In 1915 he moved to the department of genetics at the Carnegie Institution, where he remained until 1941. In 1924 he began work on the alkaloid colchicine, which is found in the autumn crocus, and 13 years later he discovered that plants soaked in this alkaloid had multiple sets of chromosomes in their cells. Such plants, termed polyploids, often exhibit gigantism and this discovery proved of immediate use in the horticultural industry in producing giant varieties of popular ornamentals. More importantly, however, colchicine often converts sterile hybrids into fertile polyploids and is therefore an invaluable tool in crop-breeding research.

Other contributions made by Blakeslee to plant genetics include his study of inheritance in the jimson weed and his research on embryo culture as a method of growing hybrid embryos that would abort if left on the parent plant.

Blane, Sir Gilbert (1749–1834) *British physician*

Blane was born in Blanefield, Scotland, and studied medicine at Edinburgh and Glasgow, receiving his MD in 1778. In the following year he sailed with the fleet as personal physician to Admiral Lord Rodney and later as physician to the fleet. While in the West Indies, he made intelligent use of James LIND's results and introduced the provision of lime juice and other citrus fruits to combat scurvy among the seamen. He also generally improved the standards of hygiene on board ship.

He returned to London in 1783 and became a physician at St. Thomas's Hospital, London, and later attended both George IV and William IV as physician-in-ordinary. He was instrumental in enforcing his health regulations throughout the Royal Navy and helped draft the Quarantine Act of 1799. He was made a baronet in 1812.

His rather grave manner earned him the nickname of "chilblaine" among his colleagues.

Blau, Marietta (1894–1970) *Austrian–American physicist*

Noted for her pioneering work in the photographic detection of subatomic particles, Blau was born in Vienna, Austria, and attended the university there, receiving a PhD in 1919. After working briefly in Berlin and at the University-Institute of Frankfurt-am-Main, she returned to Vienna to work unpaid at the Radiuminstitut and the Second Physical Institute, from 1923 until 1938. During this time she relied on the financial support of her family, apart from a grant (1933–34) from the Austrian Association of University Women, which permitted her brief spells working in Gottingen and at the Curie Institute, Paris. In the face of growing anti-Jewish feeling, Blau left Vienna just before the Nazis annexed Austria; initially she went to Oslo, then, on the recommendation of Albert EINSTEIN, to the Technical University, Mexico City (1939–44). She subsequently worked in the metallurgical industry (1944–48) in North America, and as a physicist at Columbia University (1948–50) and the Brookhaven National Laboratory (1950–55) before being appointed associate professor at the University of Miami (1955–60).

As early as 1925 in Vienna, Blau created photographic emulsions that could detect the tracks of high-energy protons, and in collaboration with Hertha WAMBACHER was the first (in 1932) to expose emulsions to neutron beams to determine the spectrum of neutrons arising from reactions in the emulsion. In 1937 the two women showed how cosmic rays cause the disintegration of heavy nuclei in photographic emulsions, producing so-called Blau–Wambacher stars. In North America, after World War II, Blau was involved in the early development of photomultiplier tubes, and continued her researches into elementary particles. In 1962 she was awarded the Erwin Schrödinger Prize, shared (posthumously) with Wambacher.

Bliss, Nathaniel (1700–1764) *British astronomer*

Bliss was born in Bisley, Gloucestershire, in western England and was educated at Oxford. In 1736 he was appointed rector of St. Ebbe's church, Oxford, and succeeded HALLEY in 1742 as Savillian Professor of Geometry, also in Oxford. He left Oxford in 1762 when he was appointed fourth Astronomer Royal in succession to James BRADLEY.

The tenure of his position at Greenwich was too short for Bliss to leave much of a mark on the Royal Observatory. He did, however, observe in 1761 that rare astronomical event, a transit of Venus, enabling him to calculate the horizontal parallax of the Sun as 10.3″ (compared with the modern figure of 8.8″).

Blobel, Günter (1936–) *German-born American cell biologist*

Blobel (**blo**-bel) was born in Waltersdorf, Silesia, Germany (now in Poland). He graduated in medicine from the University of Tübingen in 1960, and in 1962 secured a fellowship at the University of Wisconsin, Madison, to study oncology. After gaining his PhD in 1967, Blobel moved to the Cell Biology Laboratory at Rockefeller University, New York. He became assistant professor in 1969, associate professor in 1973, and professor in 1976.

Blobel's work has focused on how the many different proteins made by living cells are sorted and distributed to their correct destinations. He followed on from pioneering studies of cell structure and protein secretion undertaken by his Rockefeller colleague and mentor George PALADE, helping to unravel some of the fundamental mechanisms of cell biology.

In 1971, Blobel proposed the "signal hypothesis," which postulated that proteins destined for transport out of the cell are given a special tag, rather like a baggage label, that directs the protein to its destination. His subsequent work described how this tag consists of a short sequence of amino acids – the signal peptide – that transiently forms part of the protein.

Proteins are assembled from amino acids by particles called ribosomes, which are associated with an intracellular network of membranous chambers called the endoplasmic reticulum (ER). The signal peptide instructs the ribosome to attach to the ER membrane over a membrane channel. The signal peptide leads the growing chain of amino acids (polypeptide) through the channel, until eventually the signal peptide is removed and the complete polypeptide is released into the lumen of the ER. From here it is ultimately transported out of the cell.

Blobel's team, as well as other research groups, went on to show that similar signal peptides are employed in targeting proteins to organelles (miniorgans) within the cell, such as mitochondria and chloroplasts. In 1980 Blobel proposed the general principle that proteins contain specific amino acid sequences (topogenic sequences) that determine not only whether they are exported from the cell or retained, but also their position and orientation in a particular target membrane. Subsequent work by various groups has revealed a variety of topogenic sequences, and established their universal importance to protein targeting in all cell types.

Blobel's work has provided insights into how certain diseases are caused by proteins having faulty address tags, which means that they fail to reach their proper destinations. It also paves the way for the development of drugs that can be targeted more precisely to particular cell locations.

For his discovery that proteins have intrinsic signals that govern their transport and localization in the cell, Blobel was awarded the 1999 Nobel Prize for physiology or medicine.

Bloch, Felix (1905–1983) *Swiss–American physicist*

Bloch (blok) was born in Zürich, Switzerland, and educated at the Federal Institute of Technology there and at the University of Leipzig, where he obtained his PhD in 1928. He taught briefly in Germany and in 1933 moved to America, via various institutions in Italy, Denmark, and Holland. In 1934 he joined the Stanford staff, remaining there until his retirement in 1971 and serving from 1936 onward as professor of physics. He also served briefly as first director of the international laboratory for high-energy physics in Geneva, known as CERN (1954–55).

In 1946, Bloch and Edward PURCELL independently introduced the technique of nuclear magnetic resonance (NMR). This utilizes the magnetic property of a nucleus, which will interact with an applied magnetic field such that it takes certain orientations in the field (a quantum mechanical effect known as space quantization). The different orientations have slightly different energies and a nucleus can change from one state to another by absorbing a photon of electromagnetic radiation (in the radiofrequency region of the spectrum). The technique was used initially to determine the magnetic moment (i.e., the torque felt by a magnet in a magnetic field at right angles to it) of the proton and of the neutron. It has since, however, been developed into a powerful tool for the analysis of the more complex molecules of organic chemistry. The energy states of the nucleus are affected slightly by the surrounding electrons, and the precise frequency at which a nucleus absorbs depends on its position in the molecule. In 1952 Bloch shared the Nobel Prize for physics with Purcell for this work on NMR.

Bloch worked extensively in the field of solid-state physics developing a detailed theory of the behavior of electrons in crystals and revealing much about the properties of ferromagnetic domains.

Bloch, Konrad Emil (1912–2000) *German–American biochemist*

Born in Neisse (now Nysa in Poland), Bloch (blok) was educated at the Technical University, Munich, and – after his emigration to America in 1936 – at Columbia University, New York, where he obtained his PhD in 1938. He then taught at Columbia until 1946, when he moved to the University of Chicago, becoming professor of biochemistry there in 1950. In 1954 Bloch accepted the position of Higgins Professor of Chemistry at Harvard, a post he retained until his retirement in 1978.

In 1940 the important radioisotope carbon-14 was discovered by Martin KAMEN and Samuel Ruben. Bloch was quick to see that it could be used to determine the biosynthesis of such complex molecules as cholesterol, a basic constituent of animal tissues characterized by four rings of carbon atoms. Thus in 1942, in collaboration with David Rittenberg, Bloch was able to confirm the earlier supposition that cholesterol was partly derived from the two-carbon acetate molecule.

The many steps through which acetate develops into the 27-carbon cholesterol took years of analysis to establish. The breakthrough came in 1953, when Bloch and R. Langdon identified squalene as an intermediate in cholesterol synthesis. Squalene, a terpene with an open chain of 30 carbon atoms, initiates the folding necessary to produce the four rings of cholesterol. For this work Bloch shared the 1964 Nobel Prize for physiology or medicine with Feodor LYNEN.

Bloembergen, Nicolaas (1920–) *Dutch–American physicist*

Bloembergen (**bloom**-ber-gen) was born in Dordrecht in the Netherlands and was educated at the universities of Utrecht and Leiden, where he obtained his PhD in 1948. He moved to America soon afterward, joined the Harvard staff in 1949, and served from 1957 as Gordon McKay Professor of Applied Physics; from 1974 to 1980 he was also Rumford Professor of Physics. He became Gerhard Gade university professor in 1980, a post he held until his retirement in 1990.

In the mid 1950s Bloembergen introduced a simple yet effective modification to the design of the maser. First built by Charles TOWNES in 1953, the early maser could only work intermittently: once the electrons in the higher energy level had been stimulated they would fall down to the lower energy level and nothing further could happen until they had been raised to the higher level once more. Bloembergen developed the three-level and multilevel masers, which were also worked on by Nikolai BASOV and Aleksandr PROKHOROV in the Soviet Union. In the three-level maser, electrons are pumped to the highest level and stimulated. They consequently emit microwave radiation and fall down to the middle level where they can once more be stimulated and emit energy of a lower frequency. At the same time more electrons are being pumped from the lowest to the highest level making the process continuous. Bloembergen has worked extensively on nonlinear optics – i.e., on effects produced by high intensities of radiation. He has particularly investigated the use of lasers to excite or break particular bonds in a chemical reaction. For his work he shared the 1981 Nobel Prize for physics with Arthur SCHAWLOW (and Kai Siegbahn).

Bloembergen wrote *Nuclear Magnetic Relaxations* (1948) and *Nonlinear Optics* (1965).

Blumberg, Baruch Samuel (1925–) *American physician*

Blumberg was born in New York City and studied physics and mathematics at Union College, Schenectady, and at Columbia, where, after a year, he changed to medical studies. He received his MD from Columbia in 1951 and his PhD in biochemistry from Oxford University in 1957. After working at the National Institutes of Health in Bethesda from 1957 until 1964 Blumberg was appointed professor of medicine at the University of Pennsylvania, a position he held until his retirement in 1994.

In 1963, while examining literally thousands of blood samples in a study of the variation in serum proteins in different populations, Blumberg made the important discovery of what soon became known as the "Australian antigen." He found in the blood of an Australian aborigine an antigen that reacted with an antibody in the serum of an American thalassemia patient. It turned out that the antigen was found frequently in the serum of those suffering from viral hepatitis, hepatitis B, and was in fact a hepatitis B antigen.

It was hoped that from this discovery techniques for the control of the virus would develop. It certainly made it easier to screen blood for transfusion for the presence of the hepatitis virus; it also permitted the development of a vaccine from the serum of those with the Australian antigen. Blumberg has also suggested that the virus is involved in primary liver cancer.

For his work on the Australian antigen Blumberg shared the 1976 Nobel Prize for physiology or medicine with Carleton GAJDUSEK.

Blumenbach, Johann Friedrich (1752–1840) *German anthropologist*

Blumenbach (**bloo**-men-bahk), the son of an assistant headmaster of the local gymnasium, was born in Gotha, Germany, and educated at the universities of Jena and Göttingen, where he obtained his MD in 1775. He remained at Göttingen for the whole of his career, serving as professor of medicine from 1778 onward.

In his *De generis humani variatate nativa* (1776; Concerning the Natural Diversity of the Human Race) Blumenbach took up the problem posed by LINNAEUS in 1747, which challenged scientists to find a generic character that would distinguish between men and apes. Blumenbach's solution was to attribute two hands to humans and four hands to monkeys. This enabled him to form a separate order, Bimanus, for man alone while including apes, monkeys, and lemurs in the Quadrumana.

In Bimanus he included five races – Caucasian, Ethiopian, Mongolian, Malayan, and American Indian – insisting that they were "all related and only differing from each other in degree." Nonetheless he favored a monogenetic view of mankind, which led him to see the Caucasian race as primary, with the other four races existing as "degenerate" forms. Blumenbach's version of this common 18th-century view was relatively mild. He argued that the degeneration was an acquired trait, the result of climatic and dietary influences. The rampant racism found in some of his contemporaries is