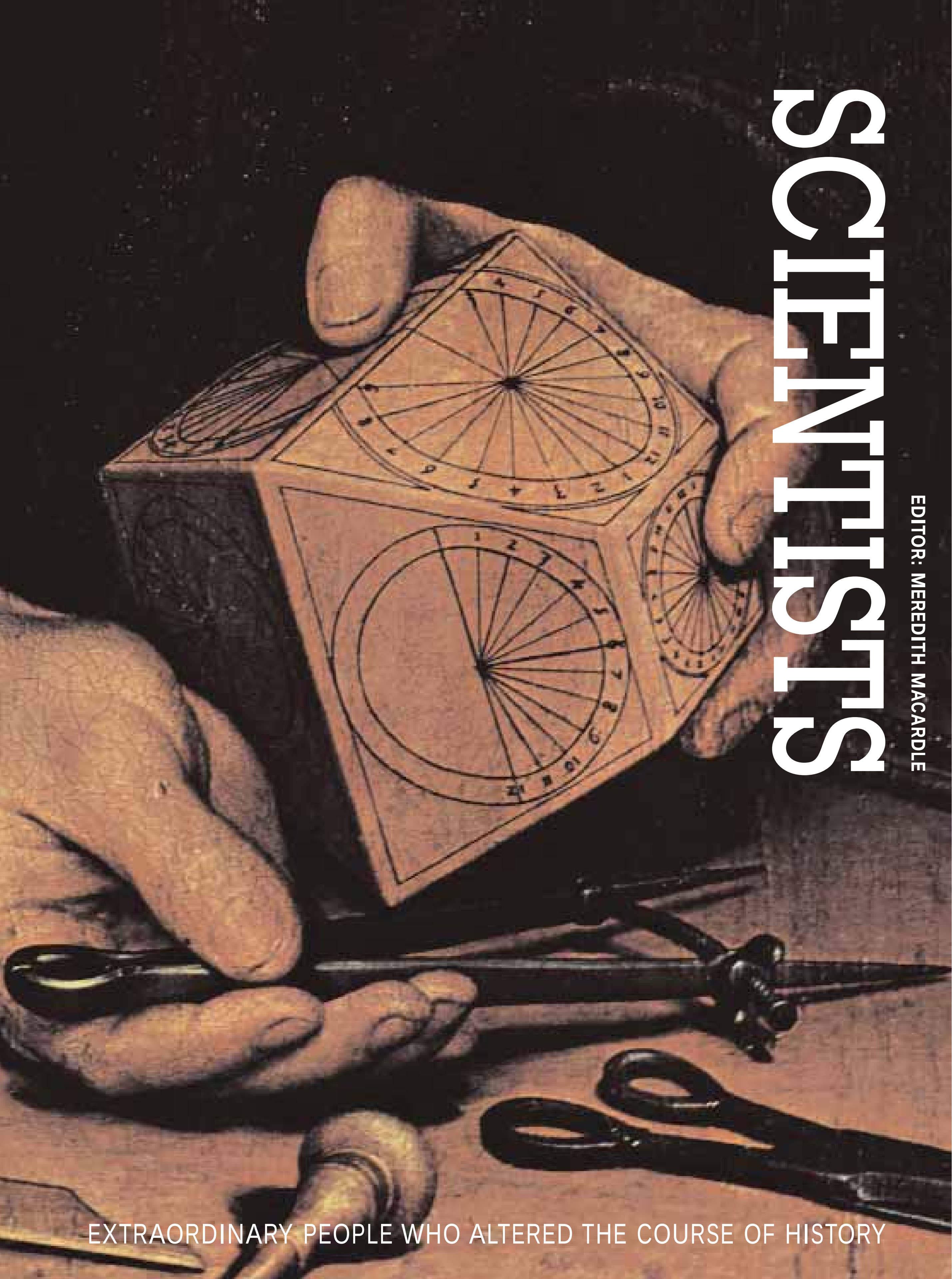

SCIENTISTS

EDITOR: MEREDITH MACARDLE

EXTRAORDINARY PEOPLE WHO ALTERED THE COURSE OF HISTORY

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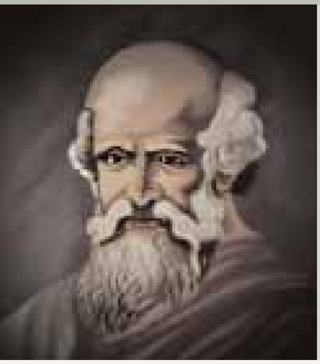
BASEMENT PRESS

c.287–212 BCE

Archimedes



Considered to be one of the greatest mathematicians of all times, Archimedes of Syracuse stood out as an intellectual figure even among the other great minds of ancient Greece. Although he is now appreciated for his original mathematical insights, during his lifetime he became famous mainly as an inventor of impressive mechanical devices. In popular culture he is also legendary for jumping out of the bath naked.

Archimedes was born in the independent Greek city-state of Syracuse on the island of Sicily. During his lifetime Syracuse became one of the battlegrounds in the Second Punic War (218–201 BCE) between Rome and Carthage and its allies (including Syracuse) – the same war in which Hannibal of Carthage crossed the Alps with the help of elephants to invade Rome.

The young Archimedes was probably exposed to mathematics early on, because in his treatise *The Sand Reckoner* he mentions that his father, Phidias, was an **astronomer**. As a young man he might have studied in Alexandria in Egypt, home of the ancient world's great library, because he later corresponded with several scholars who lived there. He was on good terms with King Hieron II of Syracuse and his son Gelon, and one historian claimed they were related. This is about the sum of our knowledge of Archimedes the man, but although a biography of him by a contemporary is lost, he gained such a powerful reputation in his own lifetime that other scientists and historians relayed stories about him.

Ironically, his reputation grew not because of his original advanced mathematics – which he considered to be the only worthy study and which he described clearly and eloquently – but because of the war-machines and other mechanical devices he invented. Although he helped keep the invading Romans at bay

Essential science

Archimedes' principle

Archimedes' most famous theorem, which he supposedly discovered while in the bath, works out the weight or volume of a body immersed in a liquid. According to tradition, King Hieron suspected that the goldsmith who had made him a new crown was dishonest and had adulterated the gold with silver. He asked Archimedes to investigate without destroying the crown, and after puzzling over the problem for some time, the answer came to Archimedes while he was in the public baths. (His servants had to regularly drag him away from his work to make sure he washed.) Archimedes was so excited by his insight that he jumped out of the baths and, forgetting to get dressed, ran home naked through the streets shouting *"Eureka!"* (*"I have found it!"*)

If he had been able to melt the crown down into a cube he could have easily measured its density, which would have been lower than expected if cheap and less dense metals than gold had been used. But instead he realized when he got in the bath that he had displaced a certain amount of water, and since water cannot be compressed, the volume that he displaced would be the same volume as the body put in it. So he immersed the crown in water, measured the amount of water it displaced, divided that by the weight of the crown, and arrived at the crown's density.

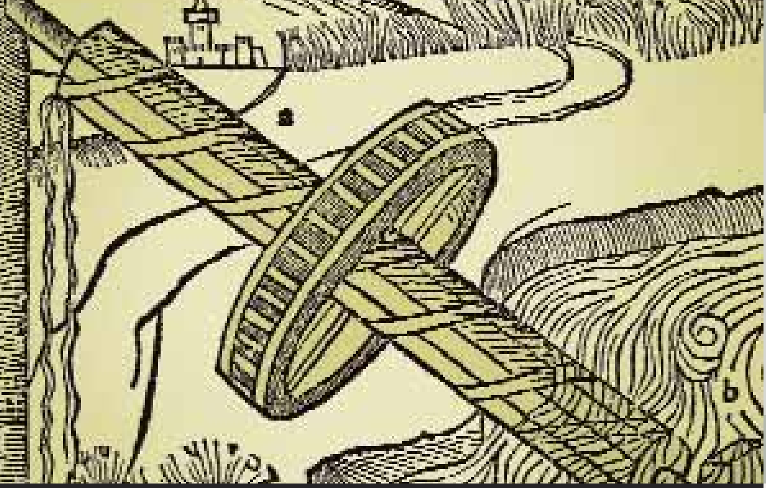
In his treatise *On Floating Bodies* Archimedes does not relate the story of the crown, but it is there that he states his principle that a body immersed in a fluid experiences a buoyant force equal to the weight of the displaced fluid, thereby giving rise to the science of **hydrostatics**, or the study of the mechanical properties of liquids at rest.

Method of exhaustion and pi (π)

Archimedes used a technique called the **method of exhaustion** to calculate the areas, volumes, and other properties of circles. This involves drawing a straight-sided polygon around the outside of the circle and another inside the circle, then adding sides to the polygons until they approximated the area of the circle. Since the area and other properties can be more easily worked out for a polygon than for a circle, this method allowed him to find the properties of all circular bodies, as well as to discover a near approximation of the value of pi, which he estimated as between 3.1429 and 3.1408. Considered to be an early form of **integral calculus**, this method also helped him prove that the area of a circle is pi multiplied by the square of the circle's radius.

Spheres and cylinders

Archimedes considered that his discoveries concerning the relationships between a sphere and a cylinder circumscribing the sphere to be his most important – and most beautiful – achievements.



Archimedes' screw as pictured in a fourteenth-century woodcut

for a while, eventually they did overrun Syracuse, and Archimedes was killed in the conquest despite orders from the Roman general Marcellus that the great scientist was to be left unharmed. Centuries later, the Greek historian Plutarch (46–120 CE) reported different versions of the murder. In one story, Archimedes was carrying scientific instruments to Marcellus' headquarters when Roman soldiers, thinking he had valuables, killed him for the loot. In another version, Archimedes had drawn a geometrical diagram in the sand, and was so involved in his puzzle that he ignored a Roman soldier's orders to come to Marcellus, crying out "*Do not step on my circles!*" Impatiently, the soldier simply stabbed the old man.

He proved that the sphere has two-thirds of the volume and surface area of the cylinder, including its bases.

Law of the lever

Although he did not invent levers, Archimedes supplied the first rigorous explanation for how they work in his two-volume *On the Equilibrium of Planes*, stating "*Equal weights at equal distances are in equilibrium, and equal weights at unequal distances are not in equilibrium but incline towards the weight which is at the greater distance.*"

Other mathematics

Among the many topics he explored were the values of **square roots**; calculating the arc of a **parabola** or the areas of sections of geometrical shapes; and the properties of "Archimedean solids" (symmetric, semi-regular **polyhedron** forms).

Archimedes' screw

Archimedes may have invented the water pump known as the "Archimedes' screw", which consists of a long screw enclosed in a cylinder, tilted so that its bottom is placed in a water source. When the handle is turned the screw draws water up the cylinder. Archimedes supposedly built it to empty bilge water from the huge ship he designed, the *Syracusia*. Archimedes' screws are still widely used in countries such as Egypt for irrigation.

Key dates

c.287 BCE	Born in Syracuse, Sicily.
c.260 BCE	By now is writing his treatises on mathematics and science.
213 BCE	Archimedes' war machines beat off a Roman invasion. The Roman siege and blockade begins.
212 BCE	Killed in the Roman conquest of Syracuse.

Legacy, truth, consequence

- Originally more famous for his machines than for his mathematics, his theorems and equations were forgotten for centuries until they were rediscovered in the sixth century CE and recognized for great, original works.
- He is held to be the "father" of disciplines as varied as hydrostatics and integral calculus.
- Modern experiments have shown that the claw could be a functioning defense, but a mirror weapon would work only in very narrow weather conditions.

> ***... certain things first became clear to me by a mechanical method, although they had to be proved by geometry afterwards because their investigation ... did not furnish an actual proof. But it is of course easier, when we have previously acquired, by the method, some knowledge of the questions, to supply the proof than it is to find it without any previous knowledge.***
>
> *The Method* (c.250 BCE)

Other machines

Many of his machines were built to help defend Syracuse from the Roman assault, but Archimedes also developed them as a pleasing scientific exercise. He designed a compound pulley, giant catapults, and the "claw of Archimedes" or the "ship shaker". This was a crane with a large metal grappling hook or claw that could either smash on to invading ships in an attempt to sink them, or could snatch them and lift them out of the water. He is also supposed to have created a mirror weapon that would focus sunlight to burn up a wooden ship.

c.83–c.161

Ptolemy

The last of the great ancient Greek astronomers, Ptolemy created the first mathematical model of the universe that explained the movements of the sun and planets. Based on the theory that the earth is the center of the cosmos, his model provided Europe's view of astronomy for around 1,500 years.

We know nothing about Ptolemy's personal life apart from the fact that he lived in Egypt when it was a province of the Roman Empire. Although his first name, Claudius, is Roman, his proper surname, Ptolemaeus, suggests Greek heritage, and he used Greek for his writings. Modern astronomers have confirmed that he made his observations of the heavens from the town of Alexandria, whose magnificent library was a magnet for ancient scholars of all disciplines.

Until Ptolemy began writing, there had been a gap in Greek **astronomy** since the days of **Hipparchus** (c.190–c.120 BCE), and it is only thanks to Ptolemy that we know about Hipparchus' work, such as his systematic observations of celestial bodies which Ptolemy combined with his own data. Ptolemy was a great synthesizer, and acknowledged using earlier theories in his explanation for how the universe moved.

Ptolemy's incredible influence is obvious by the fact that his **geocentric** model was followed for around 1,500 years, first in the Middle East and then in Western Europe. It aligned with religious belief, and scholars who dared dispute it faced a death sentence from the rigid and repressive Catholic Church. However, in the light of today's emphasis on scientific honesty, he is a controversial figure. By 1008, Arab astronomers were questioning his data and his ideas, and centuries later it was clear that at least some of his recorded observations were falsified to match his theories.

Essential science

The *Almagest*

Ptolemy's masterpiece was his thirteen-volume *Almagest*, named from the Arab translation (*al-Majisti* or *Great Work*) of his title *Mathematike Syntaxis* or *Mathematical Composition*. In this he laid out his understanding of the structure of the cosmos and his new mathematical systems that explained and predicted the movements of the planets. From earlier Greek natural philosophers/scientists, such as **Aristotle**, he had inherited the firm beliefs that the earth was a perfect sphere at the center of the universe, with the other known heavenly bodies orbiting around the earth, and that the movement of the sun and planets was at a uniform speed and in a perfect circle. Some of his own basic theories were that the moon was the closest heavenly body to the earth, followed by the planets, and then the stars, which were fixed points of light in a rotating sphere.

Despite these fundamental beliefs, in order to mathematically explain the movements of heavenly bodies Ptolemy had to violate his own rules by assuming that the earth is actually *not* the exact center of the planetary orbits. Pragmatically, he and his followers accepted this displacement, known as the "eccentric", as just a minor blip in the essential geocentric theory.

Ptolemy used a combination of three geometric constructs. The first, the eccentric, was not new, nor was his second construct, the **epicycle**. This proposes that planets do not actually move in large circles, but instead move around small circles or epicycles which in turn revolve around the circumference of a larger sphere focused (eccentrically) on the earth. Progress along the epicycle explains why planets sometimes appear to move backwards, or "retrograde".

His third construction – the equant – was revolutionary, and Ptolemy invented it to explain why the planets sometimes seem to move faster or slower, rather than uniformly. He suggested that the epicycle's center of motion on the circumference of its larger circle is not aligned with either the earth or the actual eccentric center of the larger circle, but with a third point, the equant, which is situated opposite the earth and at the same distance from the true center of the sphere as is the earth. It is only from the point of view of the equant that the planet would appear to be in uniform motion.

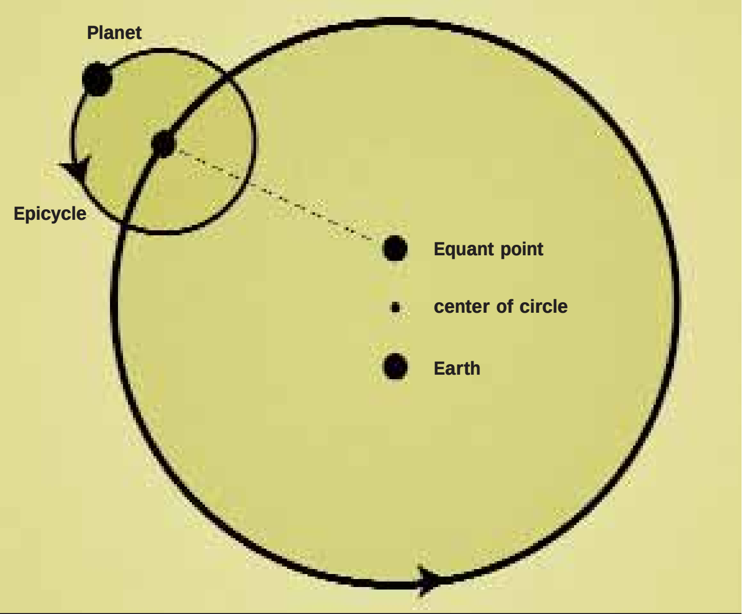
These three mathematical constructions, epicycle, eccentric, and equant, were complex and unsatisfactory to purists, but they worked. They explained some puzzling aspects of astronomy, such as why planets sometimes appear to move backwards in the night sky and why they appear brighter, and therefore closer, at different times. Together they actually approximated the modern view of the universe, in which the planets orbit the sun in elliptical paths. So Ptolemy's work allowed for reasonably accurate predictions of planetary positions for many years.

Legacy, truth, consequence

- The *Almagest* defined astronomy up till the sixteenth century, when **Copernicus** presented his model of a **heliocentric** universe. While Ptolemy's geocentric model is wrong, it was in keeping with religious belief, so it became a paradigm. And, although his framework was incorrect, his mathematical models actually worked, and could be used to gain sufficiently accurate predictions and explanations of the behavior of the sun, moon, and planets.
- Many of our modern constellations derive from Ptolemy's classifications.
- Ptolemy treated **astrology** as a serious science and generations of "natural philosophers" followed in his footsteps. His *Tetrabiblos* was the standard astrological textbook for centuries.
- His *Geographia* had a huge impact when it was reintroduced to Europe centuries later, galvanizing interest in the rest of the world. Unfortunately, for the far-flung areas he relied on hearsay, and since he also underestimated the earth's circumference, parts of his maps were wildly wrong. In particular, he greatly exaggerated the width of the European-Asian continent, helping to convince the explorer Christopher Columbus (1451–1506) that a westwards route to Asia across the Atlantic would be shorter. On this quest he found America, instead of Asia.

Key dates

c.83	Born, possibly in the town of Ptolemais in Egypt.
c.127–c.150	Makes astronomical observations from Alexandria.
c.161	Dies, probably in Alexandria.



Ptolemy's geocentric model placed the earth not at the exact center of the planetary orbits.

> ***[After the mathematical concepts] we have to go through the motions of the sun and of the moon, and the phenomena accompanying these motions; for it would be impossible to examine the theory of the stars thoroughly without first having a grasp of these matters.***
>
> *The Almagest* (second century CE)

The *Almagest* also contained a star catalog of more than 1,000 stars and 48 constellations, listing the stars' longitude, latitude, and magnitude (brightness). He included tables of observations of the sun, moon, and the five known lesser planets, Venus, Mercury, Mars, Jupiter, and Saturn, together with instructions for using the tables to predict celestial movements.

Geography

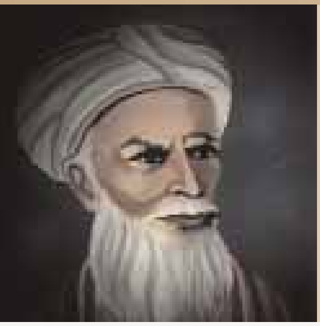
Ptolemy's other major work was his eight-volume *Geographia*, the oldest surviving atlas or collection of maps, in which he provided a compilation of geographical knowledge of the known world. It included an improved method of projecting maps, discussed **latitude** and **longitude**, and gave coordinates for some 8,000 places. From north to south, his maps covered from the Shetland Islands (northern Scotland) to anti-Meroe in the upper Nile valley, Africa, and from west to east he covered from the Cape Verde islands in the Atlantic Ocean to the middle of China.

Other publications

Ptolemy summed up his astronomical tables in a separate *Handy Tables*, which became the model for later quick reference tables. This supplied known positions of the sun, moon, and planets, and gave instructions on how to use these to make predictions or for navigation. He also wrote the textbook on **astrology**, *Tetrabiblos* (*Four Books*), and a book on **optics**. In this he foreshadowed the modern scientific method by combining experiments, observations, and reason to correctly conclude that rays of light are emitted from objects, not from the eyes. He therefore disproved various optical theories of such giants as **Euclid** and Aristotle.

860–c.925

Rhazes



An Iranian Muslim philosopher and doctor, Rhazes is considered to be the father of pediatrics for writing the first book on childhood illnesses as a separate field of medicine. He wrote several other influential medical texts, including the first distinction between smallpox and measles, and was one of the Islamic doctors who helped forge modern medicine by beginning to identify the organic causes of diseases.

Rhazes' Persian and Arab contemporaries would have known at once that he came from Rayy (Rai), an ancient town near modern Tehran in Iran, for the ar-Razi at the end of his full name, Abu Bakr Muhammad ibn Zakariya ar-Razi, simply means "from Rayy".

The few records of his early life suggest Rhazes started out as either a jeweler or a money-changer. He was also a musician and an **alchemist**, and he only became interested in medicine when an alchemical experiment blew up in his face and damaged his eyesight. He was at least 30 when he began medical and philosophical studies in Baghdad, then a center of Islamic science, but he soon became a famous doctor, writing more than 100 medical texts as well as at least that many on general science and philosophy. His continuing interest in alchemy, which in those days was considered to be just another natural science, contributed to his skill as a doctor, since it was from that practice that he first learnt the **empiricism** he brought to medicine.

He was a popular teacher, drawing crowds to his lectures, and filling his hospitals with students. Patients – or enquirers with a scientific question – were first seen by the newer students, or first circle, and then were passed on to the next circle if necessary, until, if no one else could help, they reached Rhazes himself.

Rhazes lived a simple life, and although he earned a good living he also treated the poor for free, and gave so much to charity that in the end he died poor himself. According to legend he suffered from an eye cataract towards the end of his life, but he refused to have any treatment for it, saying that he had seen so much of the world he was tired of it.

Essential science

Rhazes had a very modern steady, methodical way of researching cures and a clinical approach to studying illnesses. He considered himself to be the Islamic equivalent of **Hippocrates**, the great ancient Greek physician, and he suggested that medicine should be seen as a philosophical discipline, since it required independent thinking.

The Comprehensive Book

Among Rhazes' most significant books were two medical encyclopedias. The largest, the *Kitab al-Hawi* (*The Virtuous Life*), which was translated into Latin after his death, in 1279, as *The Comprehensive Book*, was a nine-volume compilation of his notebooks. It included knowledge from Greek, Syrian, and Arabic sources, some Indian ideas, and Rhazes' own many discoveries and commentaries.

Treatise on the Small Pox and Measles

Razes was the first known doctor to discover that smallpox and measles are different diseases, and to identify the differences between them. In his treatise on them he wrote:

"*The eruption of smallpox is preceded by a continued fever, pain in the back, itching in the nose and nightmares during sleep … A swelling of the face appears, which comes and goes, and one notices an overall inflammatory color noticeable as a strong redness on both cheeks and around both eyes … There is a pain in the throat and chest and one finds it difficult to breath and cough. Additional symptoms are: dryness of breath, thick spittle, hoarseness of the voice, pain and heaviness of the head, restlessness, nausea and anxiety. (Note the difference: restlessness, nausea and anxiety occur more frequently with 'measles' than with smallpox. On the other hand, pain in the back is more apparent with smallpox than with measles.)*"

Other works

Among his many "firsts" were his study of childhood illnesses, *The Diseases of Children*, and papers on allergies and hay fever (his splendidly titled *Article on the Reason why Abou Zayd Balkhi Suffers from Rhinitis when Smelling Roses in Spring*). He had the insight that some fevers are the body's defense mechanism to fight infection, recorded the first known use of animal gut for sutures, and was the first to use Plaster of Paris for casts. He was also one of the first practicing doctors to discuss **medical ethics** and the reasons why people choose to put their trust in a particular doctor.

In addition to his writings, Rhazes used several medical instruments that later became standard, and in the course of his alchemical work he discovered the medicinal value of ethanol. He did not hesitate to challenge wrong ideas; in his paper titled

A 1667 copy of the chapter on anatomy from Rhazes' *Book on Medicine*.

"Doubts about **Galen**" he showed how his clinical experiences sometimes clashed with the statements of the great Greek authority, and he wrote several attacks on medical charlatans or quacks. One of his particularly popular works was a sort of first-aid book, a general medical manual for use at home or while traveling, which he dedicated to the poor or to anyone who was not able to find a doctor.

Humors

Although Rhazes discovered many cures through observation and experiment, he lived at a time in history when the explanations for disease were still uncertain. According to one story, he was called to treat an emir who was so crippled by arthritis that he could not walk. Rhazes ordered the man's best horse to be brought to the door, before treating the patient with hot showers and a potion. Then he pulled out a knife, swore at the man, and threatened to kill him. The emir jumped to his feet and charged at the doctor, who fled for his life to the waiting horse. When he was sure he was safe he wrote to the emir, explaining that his treatment had softened the humors (elemental liquids thought to govern the body) and he had left it to the patient's own temper to finish dissolving them.

Legacy, truth, consequence

- A freethinker who was convinced of the value of experiment, Rhazes tried to show that the authority of the ancients could be challenged. He encouraged research in several fields – science and technology as well as medicine.
- From the twelfth century onwards, his books were translated from Arabic to Latin, particularly by Gerard of Cremona (c.1114–87). Arabs, Jews, and Christians considered him to be one of the greatest medical authorities ever known, and *The Comprehensive Book* became a standard text for Islamic and European medical students for centuries.
- His rational philosophy and outright attacks on religion did not win much support in Islamic countries, and many of his philosophical works are now known only through fragments.
- Rhazes' work contributed to the slow understanding that diseases have organic causes and are not due to magic, fate, or supernatural powers.

The doctor's aim is to do good, even to our enemies, so much more to our friends, and my profession forbids us to do harm to our kindred, as it is instituted for the benefit and welfare of the human race, and God imposed on physicians the oath not to compose dangerous remedies.

Quoted in FSTC Ltd article "Islamic Science, the Scholar and Ethics" (2006)

Key dates

860	Born in Rayy, Iran.
c.890	Studies medicine in Baghdad before returning to Rayy to run a hospital.
c.901	Moves to Baghdad and directs a large hospital there. Also becomes court physician.
902–8	Writes his general textbook of medicine while in Baghdad.
c.907	Returns to Rayy and teaches.
c.925	Dies in Rayy.

1170–1250

Leonardo Fibonacci

A sophisticated mathematician who found practical applications for abstract theorems, Fibonacci helped revive the science of mathematics in late medieval Europe by introducing the decimal system he learnt from the Arabs. He also made many of his own original contributions to mathematical theory, and he has been called the first great mathematician of Christian Europe.

During his lifetime Leonardo Pisano (Leonardo of Pisa) used several names, including Bigollo (the Traveler or possibly the Vagrant), but he is now most commonly known by a nickname meaning son of Bonacci, Fibonacci.

Although born in Italy, when he was a child he moved to North Africa to join his father, Guilielmo Bonacci, who worked as a representative for merchants of the Republic of Pisa in modern Bejaia, northeastern Algeria. Fibonacci accompanied his father on his business trips around the Mediterranean, visiting Egypt, Syria, and Sicily, among other countries.

Guilielmo recognized that the Arabs had preserved the classical Greek and Roman knowledge and had also received newer ideas from India and China, so their mathematics was way in advance of Europe. In the hope that Leonardo would be able to help with business accounts, he had the boy tutored by Arab scholars. With a natural mathematical mind – he considered mathematics to be an "art" – Fibonacci soaked up learning in all the countries they visited.

In about 1200 Fibonacci returned to Pisa and began to write books (some of which are lost to us) introducing to Europe several important concepts in **algebra** and arithmetic. In particular, he was responsible for Europe adopting our present-day numbering system, the Hindu-Arabic system with ten digits, including zero (0), and the decimal point. A number sequence he used in his work is now named after him, the Fibonacci sequence. He also made many personal contributions, especially offering practical applications of mathematics for business, accounting, and surveying.

Fibonacci was particularly drawn to practical matters, but at the same time he explored theoretical algebra and **geometry**. Although at the time his work on **number theory** was not recognized for the great achievement it is, he still gained a reputation for wisdom. He was rewarded with a salary by the City of Pisa for his advice and teachings, and successfully solving mathematical problems set for him as a challenge by scholars at the court of the Holy Roman Empire.

Essential science

Arab numerals

When Fibonacci was born, Christian Europe was still using Roman numerals – I, II, III, IV, V, VI, VII, VIII, IX, X, D, C, M, and so on. In his book *Liber Abaci*, published in 1202, Fibonacci argued persuasively for the adoption of the Hindu-Arabic decimal system including 0, a decimal point, and place-values (the position indicating whether a number is a tenth, hundredth, etc).

Liber Abaci contained several basic examples of adding, subtracting, multiplying, and dividing using the Hindu-Arab system: examples of standard introductory arithmetic similar to those any young child would be taught at school today. The book also studied problems involving **simultaneous linear equations**.

Practical applications

One of the skills Fibonacci learnt on his travels around North Africa was how to quickly convert between different currencies in order to calculate prices, profits, and losses. In *Liber Abaci* he provided basic lessons and examples for merchants covering a range of arithmetic problems including the price of goods, how to calculate profit on transactions, how to convert between the various currencies in use in Mediterranean countries, and theoretical problems to do with remainders which had originated in China.

In his book *Practica Geometriae*, written in 1220, Fibonacci explored problems of geometry, and included valuable advice on calculations for surveyors.

The Fibonacci sequence

A mathematical problem Fibonacci posed in the third section of *Liber Abaci* is solved by the sequence of numbers now known as the Fibonacci sequence, for which he is best remembered today:

> "*A certain man put a pair of rabbits in a place surrounded on all sides by a wall. How many pairs of rabbits can be produced from that pair in a year if it is supposed that every month each pair begets a new pair which from the second month on becomes productive?*"

The resulting sequence, which can be applied to many situations, starts as 1, 1, 2, 3, 5, 8, 13, 21, 34, 55 ... (Fibonacci omitted the first

■ **Hindu-Arabic numerals:** Fibonacci was responsible for convincing Christian Europe to adopt Arabic numerals, the mathematical concept of zero (0), and the decimal place system that is used today. In his books and teachings, he argued vehemently that these are much simpler than Roman numerals and provide a straightforward way to perform calculations. Although cumbersome, Roman numerals do allow simple addition and subtraction, but are very complex for multiplication and division, and at the time most accountants would have used an abacus instead. Fibonacci was not the first mathematician to propose Arabic numerals, but earlier texts, such as works by the Arab mathematician Al-Khwarizmi (c.780–c.850), were too academic to be widely read. With its everyday examples, Fibonacci's book was soon circulating among professional men as well as scholars. Europeans quickly realized that this proposed system allowed basic arithmetic to be performed swiftly and simply, and was not only more efficient and effective, but was also far more elegant for written calculations. Fibonacci's ideas were soon adopted and had a profound impact on European systems and thought.

■ **The Fibonacci sequence:** Fibonacci lived at a time when there was little interest in scholarship for its own sake, so the significance of the Fibonacci sequence was not recognized during his lifetime. But in recent times it has been accepted as a major contribution to number theory, with applications in many varied areas of science and mathematics, ranging from botany to psychology, music, and astronomy. For example, Fibonacci numbers apply to the distances between the sun and its planets in our solar system, and to the conversion of miles to kilometers. The Fibonacci sequence has even made its mark on popular culture.

These are the nine figures of the Indians: 9 8 7 6 5 4 3 2 1. With these nine figures, and with this sign 0 which in Arabic is called zephirum, any number can be written, as will be demonstrated.

Liber Abaci (1202)

Key dates

1170 Born, probably in Pisa, Italy.
1202 Writes *Liber Abaci* (*The Book of the Abacus* or *The Book of Calculating*), a groundbreaking mathematical text for Europe.
1220 Writes *Practica Geometriae* (*The Practice of Geometry*).
1225 Writes *Flos* (*The Flower*), a collection of solutions to problems set for him as a challenge by scholars at the court of Frederick II, the Holy Roman Emperor.
1225 Writes *Liber Quadratorum* (*The Book of Squares*), containing many impressive calculations mainly on quadratic equations.
1250 Dies, possibly in Pisa.

term in *Liber abaci*) with each number the sum of the two preceding numbers.

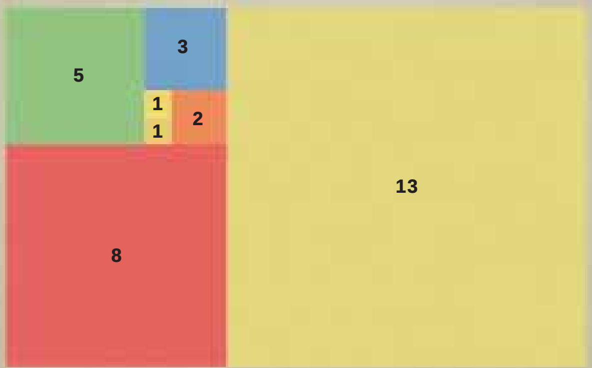
Number theory

Apart from the Fibonacci sequence, he made several other significant contributions to number theory, particularly in his 1225 book *Liber Quadratorum* (*The Book of Squares*). Not until the seventeenth century did any other Christian European offer so many original mathematical ideas.

One of the ideas he first presented is that square numbers can be constructed as sums of odd numbers:

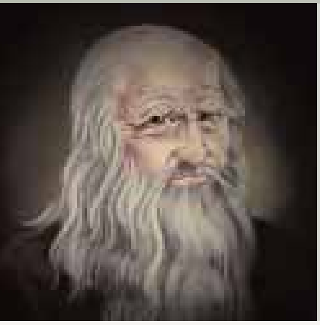
> *"I thought about the origin of all square numbers and discovered that they arose from the regular ascent of odd numbers. For unity is a square and from it is produced the first square, namely 1; adding 3 to this makes the second square, namely 4, whose root is 2; if to this sum is added a third odd number, namely 5, the third square will be produced, namely 9 …"*
>
> *Liber Quadratorum* (1225)

A tiling of squares showing the Fibonacci number sequence.



1452–1519

Leonardo da Vinci



Scientist, engineer, painter, architect, anatomist, mathematician, and much more, Leonardo da Vinci was a visionary genius like no other. He enlightened a superstitious world with his dedication to reason, truth, and learning. His contributions to the fields of anatomy, optics, hydrodynamics, and civil engineering were unconstrained by the technology and the perceived thinking of his world. Many of his ideas were not improved upon, or even understood, for several hundred years.

Leonardo di Ser Piero was born illegitimately near Vinci, Italy, to a young notary and a peasant girl. While growing up he had access to scholarly texts in his father's house, which helped to satisfy his great curiosity. Vinci, and the nearby city of Florence, were steeped in painting tradition and it was in that discipline that Leonardo first excelled. As a teenager he was apprenticed to the renowned Florentine workshop of Andrea del Verrochio. He was fascinated by drawing real things and representing them as accurately as possible on paper, with all their movement, light, and shade. He also wanted to know how these things worked – what, for example, made up the human eye? How did birds fly?

In 1482 he moved to Milan to enter into service for the Duke of the city. Over the next 17 years Leonardo reached new heights of scientific and artistic achievement alongside his professional work. He subsequently traveled throughout Italy working as a military architect and engineer for the Pope's son, Cesare Borgia. Leonardo was a peaceful man at heart, but he had to earn a living and the work enabled him not only to satisfy his appetite for knowledge and invention, but also to put some of his ideas into practice. It also made this charming, erudite, and handsome man a much sought-after presence in both the military arena and the royal court.

As he grew older, Leonardo became jaded by his lifelong association with unfinished projects (due to himself and to others). He moved to France to spend his last few years working as "first painter, architect and engineer" for King Francis I, though he was in effect an honored guest whom the young king was thrilled to have in his extended household.

Essential science

Mechanics

Leonardo's lifelong fascination with **mechanics** led to the invention or initial development of a vast number of machines and devices. Integral to his work was his dedication to precision – his drawings are laced with a myriad of levers, various types of gears, hydraulic jacks, screws, and swiveling appliances that between them accounted for every single tiny part of the potential working machine.

His studies in the world of nature led him to conclude that the universe was beholden to a basic mechanical energy that determined its structure and function. His study of bird flight, for example, led to his most famous visionary idea of developing a flying machine. Furthermore, he believed that the physical appearance of all organic and inorganic forms in the natural world was caused by the motion and the force within each one.

Painting as a science

At the core of Leonardo's belief that painting was a scientific art was his assertion that "*the eye deludes itself less than any other senses*". It followed, then, that the importance of the eye in painting gave the art form a genuine, scientific quality, based on a definite visual experience, rather than, for example, poetry, which was more open to the boundless, creative muses of the writer. He argued that painting gives, "*immediate satisfaction to human beings in no other way than the things produced by nature itself*".

He further linked science and painting by explaining that the ten optical functions of the eye, "*darkness, light, body and color, shape and location, distance and closeness, motion and rest*" were all vital constituents of painting.

Human anatomy

Leonardo originally studied human anatomy as part of his artistic training. Ultimately his unique skill was to represent the three-dimensional mechanics of the human body in a clear and complete two-dimensional way on paper. He drew the body in see-through layers, employing innovative devices such as using dotted lines to show hidden parts and drawing muscles as an elongated cluster of strings.

Astronomical theories

During the **Renaissance**, scientific thinkers such as Leonardo da Vinci, **Nicolaus Copernicus**, **Galileo Galilei**, and **Johannes Kepler** attempted to refine earlier thought on astronomy. Although Leonardo is less well known for his astronomy studies,

Legacy, truth, consequence

- Although Leonardo did not publish his anatomical findings, because it was not a field of his work in which he was professional, the techniques discovered in the drawings published after his death shaped the foundation of contemporary scientific illustration.
- In all Leonardo left 13,000 pages of drawings and technical notes, illustrating and describing a truly visionary range of creations and conceptions such as parachutes, swimming fins, machine guns, water turbines, submarines, apparatuses for breathing underwater, giant crossbows, cranes, pulley systems, compasses, armored cars, street lighting, and contact lenses.
- In 1502 he proposed a bridge across the Gulf of Istanbul. It was deemed to be an unfeasible project and was never built. In 2001 a smaller version of his bridge opened to foot and bicycle traffic in Norway, and a full-scale Leonardo bridge is currently being planned in Turkey.
- Leonardo's writing, which read from right to left and with the aid of a mirror, has for many years been a source of discussion. One practical reason for it could be that, being left-handed, and thus having an advantage in mastering the style, his writing hand stayed ahead of the words and did not smudge the ink.

Many will think they may reasonably blame me by alleging that my proofs are opposed to the authority of certain men held in the highest reverence by their inexperienced judgments; not considering that my works are the issue of pure and simple experience, who is the one true mistress. These rules are sufficient to enable you to know the true from the false ...

Quoted from *The Notebooks of Leonardo da Vinci*
(collected and translated by Jean-Paul Richter, 1888)

and his thoughts in this area are often contradictory, he did propose the hitherto unlikely theory that the earth rotated around the sun, which Copernicus would later develop:

> "*The earth is not in the center of the Sun's orbit nor at the center of the universe, but in the center of its companion elements, and united with them. And any one standing on the moon, when it and the sun are both beneath us, would see this our earth and the element of water upon it just as we see the moon, and the earth would light it as it lights us.*"
>
> *The Notebooks of Leonardo da Vinci*

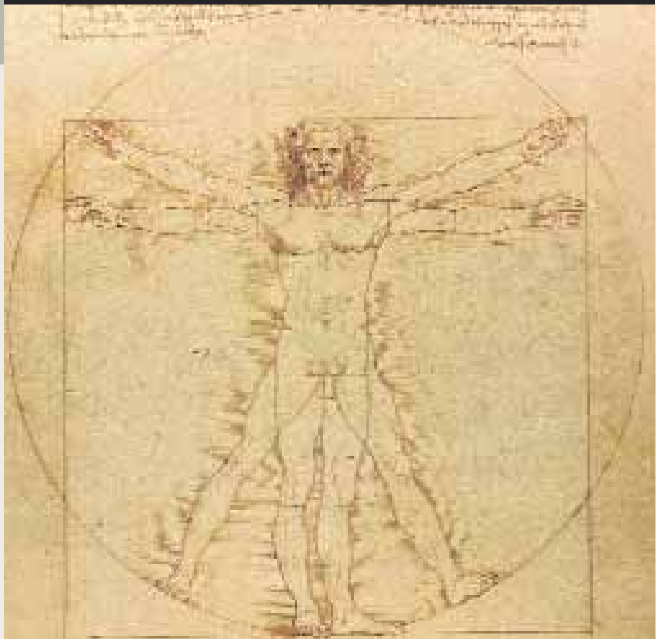
The moon itself, he proposed, was lit by reflected sunlight:

> "*The moon has no light of itself but so much of it as the sun sees, it illuminates. Of this illuminated part we see as much as faces us.*"
>
> *The Notebooks of Leonardo da Vinci*

Key dates

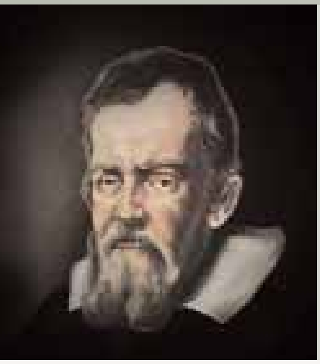
1452	Born in Anchiano, near Vinci (in present-day Italy), from where he takes his name.
1460	Moves with his father and stepmother to nearby Florence.
c.1466–69	Works at Verrocchio's workshop.
1472	He is registered as a painter working on his own for the first time.
1482	Moves to Milan where he offers the court of Ludovico il Moro a wide range of services, including architect, engineer, and organizer of court feasts.
1490	He works on projects to irrigate the countryside.
1495	Begins work on the painting, *The Last Supper*.
1499	Leaves Milan after it falls to the French.
1500	Returns to Florence.
1502	Begins work as a military engineer.
1503	Works on a way of connecting Florence by water to the sea. A canal along his route is built several centuries later.
c.1503–6	Paints the *Mona Lisa*.
c.1509	Engineers a project to channel the course of the Adda river.
1513	Moves to Rome and spends more time working on hydraulic engineering and geometry.
1516	Moves to the Castle of Cloux (in present-day France). Designs the royal residence at Romarantin.
1519	Dies at Cloux and is buried in nearby Amboise, Indre-et-Loire, in present-day France. He bequeaths his artistic and scientific drawings, manuscripts, and instruments to his pupil, the painter Francesco Melzi.

The Vetruvian Man, the drawing by Leonardo da Vinci, illustrates the mathematical proportions found in human anatomy as described in the Golden Section – a proportion used by many artists and architects since the Renaissance.



1564–1642

Galileo Galilei



A mathematician, physicist, and astronomer, Galileo was one of the pioneers who transformed physics into a mathematically-based discipline using experiments to establish facts. He built the first telescope powerful enough to observe the solar system in some detail, thereby revolutionizing astronomy. His support for Copernicus' heliocentric model led to a trial by the Inquisition for heresy, at which he was forced to recant his views, becoming a symbol of the scientific struggle to find the truth at all costs.

Galileo was born in Pisa, Italy, to a noble but impoverished family. His father hoped he would become a well-paid doctor, and sent him to university. But, bored with everything except mathematical problems and **natural philosophy**, Galileo left university without a degree.

Although he gained a reputation as a mathematician, as his father had feared, he became desperately poor. He turned to inventing and created a thermometer, a pump, a hydrostatic balance, and, in 1597, a compass which finally brought him success and some money.

Galileo's fortunes improved dramatically with his creation of a telescope in 1609, modeled on a Dutch invention he had never seen. He refined the instrument, eventually producing one which enabled him to make amazing astronomical discoveries, including evidence that the earth and planets revolve around the sun. His new fame also brought him a lucrative role as court mathematician to Cosimo de Medici, the Grand Duke of Tuscany.

As well as **astronomy**, Galileo was fascinated by the study of motion and other fields of physics. He produced a mathematical paradox and designed technical instruments such as a microscope. He was an excellent self-publicist, and did not hesitate to insult his colleagues in his writings. His support for **Copernicus**' **heliocentric** system, that put the sun at the center of the cosmos, clashed with Church doctrine. In 1600 the Papal Inquisition had burnt the philosopher and cosmologist Giordano Bruno at the stake, so perhaps with this example in mind, Galileo recanted.

Galileo did not marry, but he did have three children with his mistress Marina Gamba, who later married another man.

> ***With regard to … the movement of the sun and earth, the inspired Scriptures must obviously adapt themselves to the understanding of the people.***
>
> Letter to the Grand Duchess Christina (1615)

Essential science

Empirical methods

Galileo championed the use of systematic experiments and the application of mathematics to scientific problems. In particular, he initiated a new approach by using logic and experience to break a problem down to simple terms to make it easier to analyze.

Astronomical discoveries

Galileo's improvements to the design of the telescope meant that he was the first person to turn an effective magnifying instrument upon the heavens, and was the first person to report seeing the craters and mountains of the moon. This particular observation disproved **Aristotle**'s theory that the heavenly bodies would be perfectly smooth spheres.

He made other original observations: of the four largest moons orbiting Jupiter, showing that at least some heavenly bodies did not go around the earth; the phases of Venus, suggesting that it orbited the sun; a vast number of stars indicating that the universe was far larger than previously believed; and – contemporaneous with other astronomers – the dark blotches known as sunspots, which he correctly concluded were part of the sun's surface, although contemporaries argued they were satellites passing around the sun. All in all, Galileo concluded that the Church was wrong to hold that the sun and other planets orbited around the earth.

Study of motion

When only 20 and watching a chandelier swinging in Pisa Cathedral, Galileo made an observation no one had previously recorded. Using his pulse to time it, he realized that a pendulum's swing always takes the same amount of time, regardless of the size of the arc of the swing. In actual fact, modern instruments can detect a tiny difference, but his discovery was an adequate basis for his later work on pendulum clocks.

Law of falling bodies

In a famous experiment (possibly legendary), Galileo dropped balls of different masses from the top of the Leaning Tower of

Legacy, truth, consequence

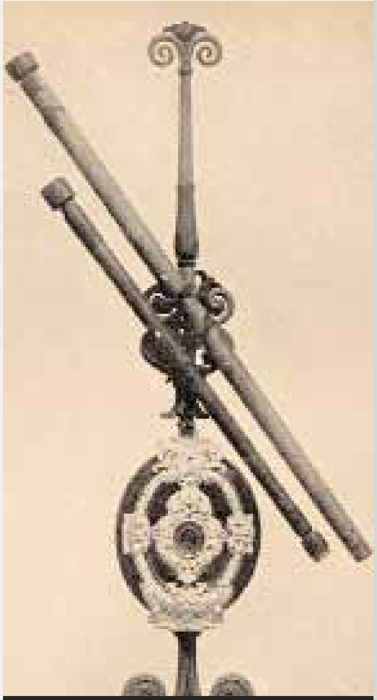
■ Galileo has been called by some the "father of modern science" and the "father of modern physics". Certainly he had a major impact on the development of science in general, and the quantitative experimental method he pioneered has become the standard scientific approach.

■ As the scientist who backed down before the Inquisition, he symbolized the tension between religion and scientific knowledge, but his work helped eventually to separate science from religion and philosophy.

■ His astronomical observations, made possible by his own ground-breaking work on telescopes, provided new knowledge of the solar system that astounded scientists and lay-people alike.

■ His law of uniformly accelerated motion has stood the test of time, and his systematic, mathematical approach to the study of motion was the foundation for modern **mechanics**.

■ Galileo had so many ideas that some were bound to be wrong. His explanation of tides, when he completely discounted the effect of the moon, was one.



Galileo's telescopes, c.1610.

Pisa, and observed that they all hit the ground at the same time. He certainly carried out several other experiments by rolling balls down a slope. He therefore disproved Aristotle's argument that in free fall objects with a greater weight have a greater velocity, but he was unable to produce a theory to explain his discovery. He did, however, later describe a law to cover the phenomenon of uniform velocity: in free fall an object will travel a distance proportional to the square of the elapsed time.

Galileo's law led him to an understanding of projectile motion and the conclusion that the path of a projectile must be a parabola.

Theory of tides

Galileo rejected the proposal of several contemporary scientists that the moon affects tides, instead attributing them to the earth's own motion. He argued that as the earth spins on its axis and revolves around the sun it effectively "swishes" the seas around.

Key dates

1564 Born near Pisa, Italy.
1581 Enters the University of Pisa to study medicine, but changes to mathematics and philosophy.
1589 Appointed professor of mathematics at the University of Pisa.
1592 Appointed professor of mathematics at the University of Padua.
1597 Invents a compass.
1609 Hearing that the Dutch have invented a "spyglass", he experiments and builds his own first telescope, applying it immediately to astronomy.
1610 Publishes *The Starry Messenger*, outlining his astronomical observations. Becomes court mathematician for the Medici family in Florence. He is now fully converted to **Copernicanism**.
1614 Accused of heresy for his support of heliocentrism.
1616 Warned by the Catholic Church that he can use Copernicanism as a tool for making calculations, but may not "hold or defend" it as a description of the universe.
1623 Publishes *The Assayer*, a treatise on the comets.
1632 Publishes *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican*. The book mainly concerns his theories about tides, but includes obvious support for Copernicanism.
1633 Called before the Inquisition, he is condemned for heresy. Galileo recants his views. The Inquisition bans the *Dialogue* and any further works by him, and sentences Galileo to life imprisonment, commuted to house arrest.
1638 Now blind, Galileo produces a final, significant work, *Discourses about Two New Sciences*, refining his theories of the laws of motion and describing his work on materials. It is smuggled out of Italy and published in the Netherlands.
1642 Dies in Arcetri, near Florence, Italy.
1992 A papal commission acknowledges that the Church had been wrong to suppress Galileo.

One cannot understand it [the universe] unless one first learns to understand the language and recognize the characters in which it is written. It is written in mathematical language …

The Assayer (1623)

1632–1723

Antony van Leeuwenhoek

Considered to be the first microbiologist, the Dutch lens-maker Antony van Leeuwenhoek opened up the microscopic world to eighteenth-century scientists. Making his own accurate microscopes, he discovered bacteria, single-celled organisms, spermatozoa, blood cells, the banded structure of muscle tissue, and microscopic creatures such as nematodes, as well as many other features of nature.

Christened Thonis Leeuwenhoek, he signed his name Antonij – Antony in English – and added the "van" to his name in 1686. In the seventeenth century most scientists (or natural philosophers) were gentlemen who had enjoyed a good university education, including classical and modern languages, but Leeuwenhoek came from a very different background. His family were tradesmen (his father was a basket-maker and his mother's relatives were brewers) and they were not particularly well-off; as a youngster he had only elementary schooling, and he never learnt any language other than Dutch.

When he was 16, Leeuwenhoek was apprenticed to a textile merchant in Amsterdam, where he spent six years learning the trade before returning to Delft to set up business for himself as a linen-draper. At that time magnifying glasses were used in the textile trade to examine the quality of cloth by counting the density of threads in material. The glasses, usually fixed on a stand, could magnify up to the power of three. Thus Leeuwenhoek would have early on encountered the principle of magnification, but it is thought that his interest in exploring the microscopic natural world was sparked off by the popular book *Micrographia*, written by the English scientist Robert Hooke (1635–1703) in 1665, which contained reports and vivid pictures of his observations of tiny objects and creatures such as fleas and lice.

Within three years Leeuwenhoek was grinding lenses to make his own microscopes and telling scientists in Delft about his discoveries. In 1673 a doctor, Regnier de Graaf, described Leeuwenhoek's reports to the secretary of the **Royal Society of London**, the world's oldest surviving society for the advancement of science, which had only recently been founded in 1660. The letter was published in the Society's *Philosophical Transactions*, and the secretary requested an introduction to Leeuwenhoek, beginning a correspondence that was to last until Leeuwenhoek's death at the age of 90. Written in Dutch and translated by the Society into Latin or English for its *Transactions*, he sent hundreds of illustrated letters and several of his specimens to the Society, and others to the Paris Academy of Science and to private individuals. In 1680 he was elected a full member of the Royal Society, although he never attended their meetings.

Leeuwenhoek must have had very good eyesight to be able to distinguish the details that he did. But he could not draw, so he hired an illustrator to provide the drawings that went with his written descriptions. His letters to the Royal Society were rambling and conversational, nothing at all like scientific papers, except that he described the meat of his studies factually, clearly, and accurately.

Essential science

Microscopes

Leeuwenhoek made more than 500 microscopes, although technically they were simply powerful magnifying glasses, not modern microscopes that have compound or multiple lenses. Early compound microscopes had been known since about 1595, but they could not magnify beyond 30 times natural size, whereas Leeuwenhoek achieved up to 300 times magnification. He inserted a single lens between two metal plates – brass, copper, or silver – that were then riveted together and fixed three or four inches above the base of the instrument. This usually had a spike for holding the specimen, and had screws to allow the focus to be adjusted by raising, lowering, or rotating the specimen. Some of his lenses were as small as a pin head.

Not only did he achieve greater magnification than other instrument makers, but his lenses were also notably clear and bright. He kept some of his techniques secret, and we still do not know exactly how he achieved his results. Perhaps he discovered a way of obliquely illuminating the specimens in order to enhance the lens, or, as other researchers think, perhaps he used the properties of spheres to improve his images, either encasing his specimens in spherical drops of fluid or using balls of glass for lenses instead of ground lenses.

Discoveries

Curious about everything that could be placed under a microscope, Leeuwenhoek examined plants and animal tissues, insects, fossils, and crystals. As a result he was the first person to describe many microscopic aspects of life such as living spermatozoa, from which he correctly concluded that an egg is

Leeuwenhoek is thought to be pictured in this painting by Johannes Vermeer, *The Astronomer*, c.1668.

… my work … was not pursued in order to gain the praise I now enjoy, but chiefly from a craving after knowledge … I have thought it my duty to put down my discovery on paper, so that all ingenious people might be informed thereof.

Letter (June 1716)

Many of his reports were published separately and widely circulated, making him famous as a man who had discovered the secrets of nature. Kings and queens were among the many curious people who visited him to look through his microscopes.

Since Leeuwenhoek was executor for the estate of the artist Johannes Vermeer, some art historians think that Leeuwenhoek is pictured in two Vermeer paintings: *The Astronomer* and *The Geographer*.

Legacy, truth, consequence

- Leeuwenhoek is held to be the "father of **microbiology**" not just because he identified so many microscopic creatures, but also because of the way he confined himself to the pure facts in his descriptions.
- His discoveries disproved the commonly held belief that lower forms of life could be spontaneously generated or born out of the corruption of natural material. For example, fleas were thought to be produced from sand or dust, and flour mites were thought to spring from rotten wheat. Leeuwenhoek showed that these tiny creatures actually had the same life-cycles as larger insects.

Key dates

1632	Born in Delft, the Netherlands.
1648	Begins apprenticeship to a textile merchant.
1654	Returns to Delft; sets up as a draper.
1660–99	Serves as chamberlain to the city sheriffs.
c.1665	Reads Robert Hooke's *Micrographia* and is inspired to use microscopes to look at the natural world.
1668	By now has learnt to grind lenses, make microscopes, and observe microscopic life.
1673	Begins correspondence with the Royal Society of London.
1676	Reports the discovery of single-celled organisms.
1676	Serves as executor of the estate of the artist Jan Vermeer.
1680	Elected a full member of the Royal Society.
1698	Demonstrates microscopes to Russian Tsar Peter the Great.
1723	Dies in Delft.

fertilized when the sperm penetrates it. However, perhaps because he lacked a scientific education and background, he seldom theorized about what he described. Among his most important discoveries are:

1. Unicellular organisms: On September 7, 1674, Leeuwenhoek wrote about pond water:

   "I found floating therein divers earthy particles, and some green streaks, spirally wound … The whole circumference of each of these streaks was about the thickness of a hair of one's head … all consisted of very small green globules joined together: and there were very many small green globules as well."

   He had here discovered the single-cell structure of spirogyra algae. Until Leeuwenhoek reported his observations of pond life, single-celled or unicellular organisms were unheard of. The Royal Society thought this report was so unlikely that it sent a special mission comprising a vicar, medical doctors, and lawyers to examine his studies, and, in 1680, Leeuwenhoek's observations were fully confirmed.

2. Bacteria: Among some of the earliest accounts of bacteria are his studies of plaque on teeth, such as this letter of September 17, 1683: *"a little white matter, which is as thick as if 'twere batter."* He coined the world animalcule (little animal) for many of the tiny creatures he saw, as described in this extract:

   "… there were many very little living animalcules, very prettily a-moving. The biggest sort … had a very strong and swift motion, and shot through the water (or spittle) like a pike does through the water. The second sort … oft-times spun round like a top … and these were far more in number."

1642–1727

Isaac Newton

A mathematician and physicist, Isaac Newton is considered to be one of the greatest scientific intellects of all time and the major figure of the seventeenth-century Scientific Revolution, which laid the foundations for modern experimental and investigative science. He is best known for his laws of motion and theory of gravity, which provided the first scientific explanation of how the universe was physically held together, but he made other significant discoveries in physics and mathematics.

Isaac Newton was born on 25 December 1642. Britain was still using the old Julian calendar rather than the Gregorian calendar which moved dates ten days ahead, but historians adopting retrospective Gregorian dates record his birth as 1643, not 1642.

His family were gentlemen farmers, but early on he realized that the farming life was not for him. He went to Cambridge University, but formulated many of his greatest ideas while the university was closed because of plague. During the two years of 1665–6, while working at home, he made the most intense scientific advances ever known in such a short period, although he did not publish his ideas for some years. He experimented in **optics** and **mechanics**, and observed (or was hit on the head by) a falling apple, leading him to conclude that it was the same force – **gravity** – which acted on the apple and on the moon's orbit.

If I have seen a little further it is by standing on ye shoulders of giants.

Letter to Robert Hooke (1676)

He was morbidly sensitive to criticism, and after an initial set-back did not offer his great ideas for debate. As a result, his theories were finally published almost by chance. In 1684 the astronomer Sir Edmund Halley (1656–1742) consulted Newton about planetary orbits. He was astounded to find that Newton had a complete scientific theory: gravity as a universal force holding together the structure of the universe. Halley persuaded Newton to publish, and arranged and paid for the work.

The result was *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*), commonly known as *Principia*, published in 1687. This is considered to be the cornerstone of modern science, and has been described as the greatest single work in the history of science. Covering gravity and the laws of motion, the treatise became the accepted scientific view of the universe.

Newton wrote extensively on alchemy, ancient history, and Bible studies. He also held unorthodox Christian views, rejecting the Trinity. Partly because of these interests, he is associated with the organization known as the Priory of Sion, which, as popularized in Dan Brown's *The Da Vinci Code*, is supposed to hold secret religious knowledge.

Essential science

Scientific approach

He considered himself to be a natural philosopher, speculating on the nature of reality. This speculation led him to the possibility of universal forces underlying the mechanistic nature of the universe. He held that understanding can be reached by experiment, and that mathematical reasoning is the best way to describe the physical world.

Theory of universal gravitation

Newton showed that the same force – gravity – acts both at close quarters and at vast distances: pulling an apple to earth and holding the planets in orbit around the sun. An object with more matter, or mass, exerts the greater force of attraction. His Inverse Square Law of Attraction explains the force of gravity as related to the inverse square of the distance between the two objects: $F = Gm_1m_2/r^2$ where F is the gravitational force, G is the universal gravitational constant, r is the separation between the objects, and m_1 and m_2 are the two objects.

Calculus

An essential tool for advanced mathematical analysis, this enables calculation of the area bounded by a curve and the slope of a point along a curve, among many other applications. Newton discovered these problems are inversely related, and resolved them by using "fluxions", algebraic expressions to calculate the magnitude of "flow" of the curve. Although his theorem is valid, **Gottfried Leibniz**'s terms of differentiation and integration are now used instead of "fluxions".

Optics

Before Newton's experiments, it was thought that white light was homogeneous, and that color belonged to the colored object, not to a property of light. He was not the first to observe that light passed through a prism separates into the full **spectrum** of colors,

I wish we could derive the rest of the phenomena of nature by the same kind of reasoning from mechanical principles: for I am induced by many reasons to suspect that they may all depend upon certain forces ...

Principia (1687)

Legacy, truth, consequence

- Newton's explanation in mathematical terms for how a large part of the physical universe works – both on earth and in the skies – was a revolution: before him scientists had only observed, not explained, planetary orbits and other mechanical phenomena.
- His work inspired a new generation of experimental scientists using his investigative and analytical methods to explain other aspects of the natural world.
- Newton's theories of universal gravitation and motion underpin modern disciplines such as rocket science, and remain valid except for within the comparatively new fields to do with near-light speed relativity and **quantum mechanics** (see **Max Planck**, pages 132–3).
- His theory of the mathematical properties of light and color established the modern discipline of optics.

Plato is my friend, Aristotle is my friend, but my best friend is truth.

Certain Philosophical Questions (c.1664)

Key dates

1642	Born in Lincolnshire, England.
1661	Enters Cambridge University.
1665–6	Returns to Lincolnshire because of plague in Cambridge; conducts increasingly complex experiments and formulates his theories on optics, calculus, mechanics, and a universal force of gravitation.
1667	Becomes a Fellow of Trinity College, Cambridge, teaching mathematics.
1668	Builds the first reflecting telescope using mirrors rather than lenses.
1669	Is appointed Lucasian Professor of Mathematics at Cambridge University.
1669	Writes an early exploration of **calculus**. Begins alchemical investigations.
1671	Elected a Fellow of the **Royal Society of London**. Although his telescope is well received, his early theories on principles of light and color are criticized, and he withdraws into private alchemical study.
1684	Gottfried Leibniz (1646–1716) publishes his own calculus, sparking a lasting argument with Newton about precedence and plagiarism. It is now accepted they made independent discoveries.
1687	Publishes his most famous work, *Principia*, containing his work on mechanics, his three Laws of Motion, and his universal theory of gravitation. Becomes famous.
1689–90	Elected Member of Parliament for the University of Cambridge.
1696–1727	Administers the Royal Mint in London. Cuts down on counterfeiting and corruption.
1701–2	Re-elected Member of Parliament.
1703	Elected President of the Royal Society, and is re-elected annually for the remainder of his life.
1704	Publishes *Opticks*, reporting his experiments and refined theories of color and light.
1705	He is knighted by Queen Anne, gaining the title Sir Isaac Newton.
1727	Dies in London.

but he continuously refined his experiments until he could prove that white light is composed of colors, each with different properties.

First law of motion, or law of inertia

An object at rest will stay at rest and an object in motion will remain in motion until acted upon by an external force.

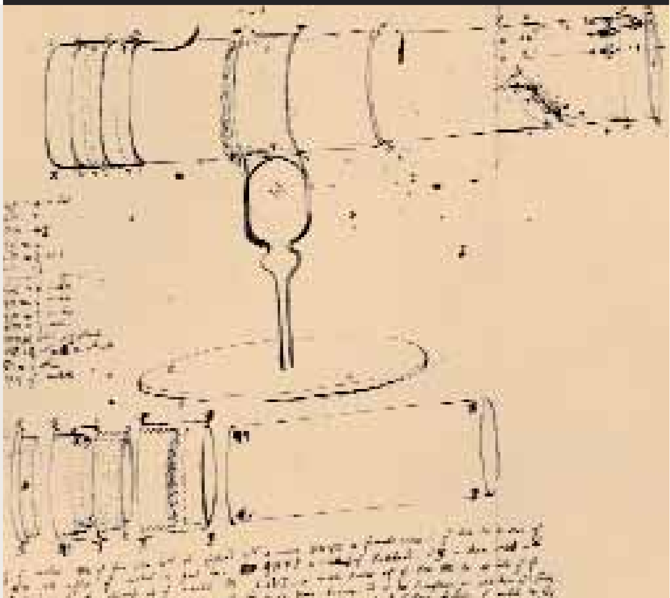
Second law of motion, or law of acceleration

A force acting upon an object will change the object's velocity in the direction of the force, directly proportional to the force applied and inversely proportional to the mass of the object, as often reduced to the equation $F = ma$ (force = mass x acceleration).

Third law of motion

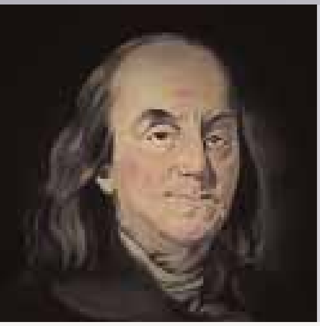
For every action there is an equal and opposite reaction.

Newton's drawing of a telescope and its parts.



1706–90

Benjamin Franklin



Printer, inventor, scientist, statesman, revolutionary, philanthropist, and much more, Benjamin Franklin was a omnipresent figure throughout the development of eighteenth-century America. Such was his importance that had he been only a scientist, or only a philanthropist, or only a politician, he would still have achieved enough in any one of those careers to be considered a major luminary.

Benjamin Franklin is recognized as a great American, but he was born to English parents, the fifteenth of seventeen children, in Boston, Massachusetts. He was only schooled for two years, and after a stint learning the trade of his chandler father he became an apprentice printer for his brother James, who had just set up Boston's first original newspaper, *The New England Courant*. One of the most successful articles was a series of recurring advisory letters written by a mysterious woman called Silence Dogood. It turned out that they'd been penned by Benjamin, and the subsequent fallout led to his search for further employment.

Printing was a progressive and increasingly significant trade in eighteenth-century America and Franklin decided to stick with it. He settled in Philadelphia where, interrupted by an ill-starred couple of years in London, he set up his own printing business, took over the running of a newspaper and published annually his *Poor Richard's Almamac*. His reputation was such that, still only in his twenties, he began to receive contracts for government work.

So busy did Franklin become in so many aspects of professional life that his interest in science almost seems like something he did to pass the time. In the mid-1800s, with some successful inventions, such as the Franklin stove, already to his name, he begun studies on electricity. His famous, and rather dangerous, experiment of flying a kite in a thunderstorm proved the connection between lightning and electricity and led to his invention of the lightning conductor.

Franklin's later years were spent in politics. He regularly worked with the English. His diplomatic trips backwards and forwards between the two countries culminated in his conclusion that American independence was the way forward. He was consequently a significant contributor to the resultant Declaration of Independence.

His son, William, became the Royal governor of New Jersey. William remained loyal to England, a decision that caused a permanent rift between him and his father.

Essential science

Electricity

In the Europe of the 1740s, the idea that electricity could have more application than just being a novel form of entertainment was beginning to take hold. An electrical machine was dispatched from England to Franklin's Library Company and he began experimenting in 1746. The fact that he had little idea of what the Europeans had discovered possibly helped him maintain a open mind in his observations.

One of his initial conclusions was that electricity was a form of energy that could spread through many substances and that, once touched by an electric current, the natural order always reverted to the norm. It was traditionally thought that electricity was made up of two kinds of fluid. Franklin showed there was only one fluid that had a positive charge and a negative charge occurring in equal amounts. This is called the law of conservation. He also experimented with a capacitor – a simple box made of charged glass plates that could store electrical charges – which he called a battery. The word is derived from its alternative definition of a physical attack, supposedly because that is what the effect of an electric shock from the device felt like.

Lightning rods

The eighteenth century's many wooden buildings were always susceptible to fire by lightning strikes. Franklin's discovery that lightning and electricity are identical prompted him to develop the lightning rod. In his experiment he ran a length of cable down the side of the house. The bottom end was buried several feet into the ground. A long rod pointing up to the sky was attached to the top end. Lightning struck the rod and ran its charge down the cable into the ground, bypassing the house altogether and significantly cutting down the risk of a fire.

Bifocal glasses

This was an invention borne out of personal necessity. As he grew older, Franklin found it hard to see both close-up and far away, and had to constantly swap between two pairs of glasses. It was a tiresome task so he put his mind to developing a lens with two focal points. The final product actually entailed fitting two lenses into the frame of the spectacles, one for distance at the top and one for seeing close-up at the bottom, where it would be better suited to aid reading.

Legacy, truth, consequence

- A look at the long list of institutions Franklin helped to found, many of which still thrive today, gives an idea of the range of his influence – The Philadelphia Union Fire Company, the American Philosophical Society, and the Pennsylvania Hospital to name but three. Franklin himself considered his work in public service more consequential than his scientific contributions.
- His will stipulated that a significant amount of money be used to support future enterprises. Many social and technical advances that benefit his country today, especially around Pennsylvania, are a legacy of his foresight.
- Franklin was the first to use electrical science words such as battery, electrify, charge, conductor.
- He was a passionate advocate for the abolition of slavery. The year before he died he wrote an anti-slavery treatise, and after his death, his will decreed that his son-in-law should "*set free his negro man Bob*".

Our new Constitution is now established, and has an appearance that promises permanency; but in this world nothing can be said to be certain, except death and taxes.

Letter to Jean-Baptiste Leroy (1789)

Heat-efficient stove

Franklin redesigned the inefficient household fireplace of the day. By adding a canopy-like structure on the front of the stove, a ventilator at the back and a new arrangement of flues within, he created a fire that produced twice as much heat and burned one quarter the amount of fuel – an eight-fold improvement in performance.

He declined to take out a patent, because the stove's purpose was for the benefit of society.

Does thou love life? Then do not squander time, for that's the stuff life is made off.

Poor Richard's Almanack (1741)

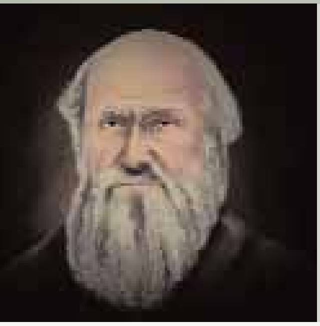
Key dates

1706 Born in Boston, Massachusetts, US.
1718 Becomes an apprentice printer to his brother, James.
1724 Moves to London for two years.
1729 Takes over publication of the *Pennsylvania Gazette*.
1730 Marries Deborah Read.
1731 Founds the first public library.
1732 Prints the first *Poor Richard's Almanack*. Continues publication until 1758.
1740 Invents the Franklin stove.
1748 Retires from printing.
1751 *Experiments and Observations on Electricity* is published in London.
1752 Flies a kite in a thunderstorm.
1753 Becomes postmaster general of the British Colonies in America.
1757 Travels to England as colonial representative.
1771 Begins his autobiography.
1776 Helps to draw up the Declaration of Independence.
1778 Negotiates the Treaty of Alliance with France. The two countries agree to help each other in the event that either is attacked by the British.
1783 Signs the Treaty of Paris with Britain.
1784 Invents bifocal glasses.
1790 Dies in Philadelphia; 20,000 people attend his funeral.

Franklin's reception at the court of France, 1778, where he negotiated the Treaty of Alliance with France.

1809–82

Charles Darwin



Charles Darwin was an English naturalist and is the most famous exponent of the theory of evolution. His doctrine of natural selection revolutionized biology and forever altered our idea of life on earth.

Born in Shrewsbury, England, in 1809, into an upper-middle class family, Darwin was a late developer academically, although he was always very interested in natural history. After attending Christ's College, Cambridge, he gained an opportunity that would prove to be one of the defining moments of his life. In 1831 Captain Robert Fitzroy required a naturalist for his scientific expedition aboard his ship HMS *Beagle*, which provided Darwin with the opportunity to sail around the world. He later described this voyage as "*by far the most important event in my life*", one that "*determined my whole career*". On board, Darwin studied *The Principles of Geology* by Charles Lyell (1797–1875) and was deeply influenced by Lyell's discussion of **James Hutton**'s view that the earth is much older than biblical scholars had claimed. Throughout the many excursions on the trip, Darwin was fascinated by the earth's varied species of animals and plants.

He conceived his theory of natural selection in 1838 and devoted the next 20 years to exploring this new idea of evolution. Published in 1859, *On the Origin of Species by means of Natural Selection*, usually shortened to *The Origin of Species* was the result. His theory of **evolution** through the process of natural selection attempted to show that the evolution of life could be explained without postulating a supernatural being such as God. Predictably this drew an angry reponse from members of the Christian Church. On one occasion, Samuel Wilberforce, Bishop of Oxford, subjected *The Origin of Species* to a range of objections at the British Association, a learned society formed to promote science, although supporters of Darwin were present to defend the Darwinian view.

In 1839 Darwin married his cousin Emma Wedgwood. Together they had ten children and lived in Down, Kent. As the author of many books on the natural world, he became very famous and in later life was regarded as something of an elder statesman of the scientific community. After several years troubled by illness, he died at home in 1882, aged 73. He is buried in Westminster Abbey, London.

Essential science

Theory of evolution

While on his voyage with the HMS *Beagle*, Darwin visited the Galápagos Islands, an archipelago in the Pacific Ocean inhabited by numerous endemic species. He discovered that the tortoises exhibited slight physical differences on each island. It occurred to Darwin that the tortoises had not in fact been created differently but were developing differences – or evolving – as they responded to the differing environmental conditions of each island. While this seemed to be true for one species, Darwin came away believing that the theory of evolution as a general thesis warranted scientific study. Darwin's research on other species proved that the process of evolution had in fact occurred: that rather than life on earth being the product of a creator, it developed from simple to more complex organisms in accordance with their reaction to their surrounding environment.

Natural selection

In 1838, after his return from his trip on HMS *Beagle*, Darwin discovered "natural selection", the mechanism with which to explain the theory of evolution. While evolution was conceived of as a *process*, natural selection was identified as its *cause*. Darwin described *natural* selection by analogy with *artificial* selection: the idea that a breeder can play a modifying role in breeding domestic plants and animals by artificially selecting mates. With natural selection, however, there is no breeder. Instead environmental conditions, such as reproductive competition and an aptitude for survival, serve to shape the futures of individual species by the natural process of selecting the fittest organisms and eliminating the unfit ones. The general idea of competition was also employed in Darwin's overall theory in order to explain phenomena such as extinction and diversification through time.

Alfred Russel Wallace

Darwin hurried to complete *The Origin of Species* in 1859 because he was aware that other scientists were developing similar theories. In particular, Alfred Russel Wallace (1823–1913) developed a theory of evolution independently of Darwin, starting it as early as 1855. The two men became friends and corresponded regularly from 1858. Many contemporary scholars credit Wallace as the co-discoverer of evolution.

Legacy, truth, consequence

- Darwin's *Origin of Species* was an immediate bestseller, appearing in six editions in Darwin's lifetime. Evoking a storm of controversy on its initial publication, particularly in relation to the prevalent **creationism** of the time, it continues to stimulate thought to the present day. It is undoubtedly one of the most important scientific books in history.
- Darwin's theory was a direct challenge to orthodox religion. For many, it constitutes a challenge to the existence of God, in particular with its connection to the **argument from design**. Darwin's theory continues to be frequently cited by proponents of atheism, such as **Richard Dawkins**. Equally, Darwinism has proven controversial in recent years, particularly in the US, where Christian groups have questioned its cogency as a theory and argued that **intelligent design** should be taught in schools as a genuine alternative.
- Some ideas only loosely related to Darwin's theory developed that Darwin would not have endorsed himself, for example, eugenics, which applied the concepts of Darwinism to human society, in particular the inheritance of certain characteristics. Eugenics in the twentieth century became stigmatized after it was taken up in the rhetoric of the Nazi Germans in their drive for genetic "purity". Social Darwinists also attempted to apply concepts of "survival of the fittest" and evolution to society and economic systems in the late nineteenth and early twentieth centuries. Darwin himself dismissed the idea of policies for social change being instigated by governments based on the theory of evolution and natural selection.

The old argument of design in nature … fails, now that the law of natural selection has been discovered. We can no longer argue that, for instance, the beautiful hinge of a bivalve shell must have been made by an intelligent being, like the hinge of a door by man. There seems to be no more design in the variability of organic beings and in the action of natural selection, than in the course which the wind blows. Everything in nature is the result of fixed laws.

Autobiographies (1887 & 1958)

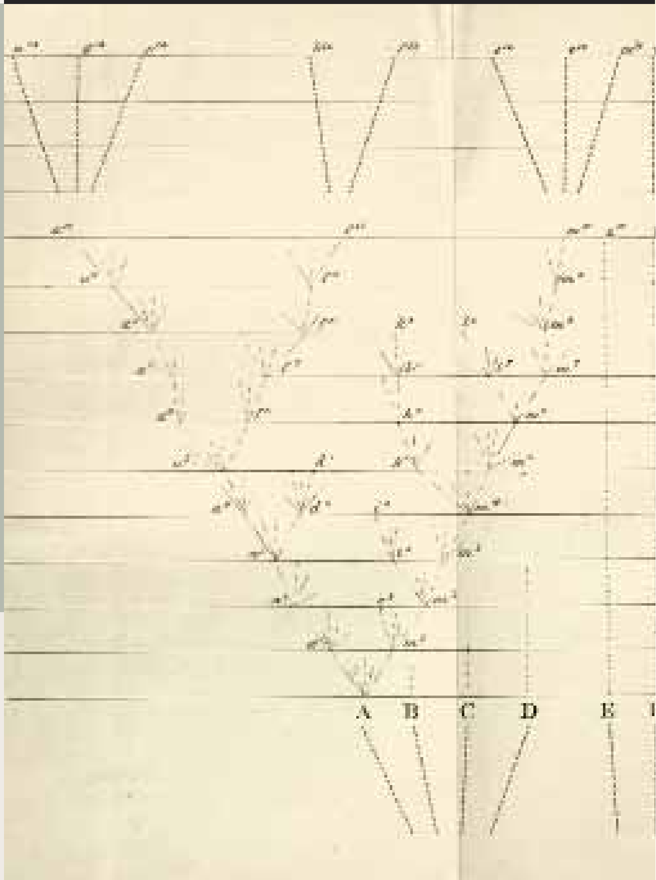
Other work

In addition to his work on evolution, Darwin published technical books on **geology**, a treatise on barnacles, and a widely celebrated account of his voyage on the HMS *Beagle*.

Key dates

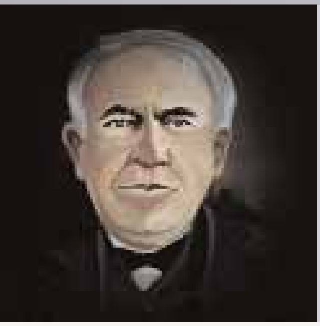
1809	Born in Shrewsbury in the West Midlands of England.
1818	Boards at Shrewsbury School.
1825–7	Attends Edinburgh University to study medicine but leaves without completing his degree.
1828	Attends Christ's College, Cambridge.
1831	Gains BA (without honors).
1831–6	Sails the world on HMS *Beagle*.
1839	Marries Emma Wedgwood. Publishes *The Voyage of the Beagle*.
1842	Moves to Down, Kent, with his wife and family.
1859	Publishes *On the Origin of Species By Means of Natural Selection*.
1860	Samuel Wilberforce, Bishop of Oxford, criticizes *The Origin of Species* at the British Association for the Advancement of Science at Oxford.
1871	Publishes *The Descent of Man and Selection in Relation to Sex*.
1872	Publishes *The Expression of the Emotions in Man and Animals*.
1881	Publishes *The Formation of Vegetable Mold through the Action of Worms*.
1882	Dies at home.

Detail of the Tree of Life, used by Darwin as a model for the theory of evolution, from the 1859 edition of *The Origin of Species*.



1847–1931

Thomas Edison



A prolific inventor of unsurpassed productivity, Thomas Edison is responsible for many of the commodities that the modern world takes for granted, from the electric light bulb to the film industry. He worked in self-financed laboratories with a small team of co-workers, often discovering momentous principles by chance as a consequence of his haphazard, but unflinchingly positive approach to experimentation. He never invented anything unless it was necessary.

Edison was born in Milan, in the American state of Ohio. Like many great scientists before him, he had a strong sense of curiosity from a young age. He devoured books on chemistry and gave an indication of his practical and hard-working approach to life when, aged only ten, he grew and sold vegetables in order to finance chemical experiments in his cellar. By the age of 15 he was printing his own newspaper on a printing press located in the luggage wagon of a train.

In a developing country as vast as America the telegraph, as well as the train, played a hugely important role in the growth of the country's economy. To learn about telegraphy, Edison worked for a number of telegraph offices, finally settling in a job in New York. Within a year he had set up his first workshop.

Edison was a fervent experimenter. He fed this passion by establishing two laboratories – firstly for eight highly successful years at Menlo Park in New Jersey and then at the grander, but less productive, Edison laboratory in New Jersey.

One invention would lead to another. His phonograph (a device for recording messages), for example, needed a power source to operate, yet most homes didn't have electricity, so he began developing the alkaline storage battery. When he subsequently became an automobile enthusiast, he saw this kind of battery as the most likely to power cars. By the time it was developed, gasoline had superseded it, so the battery was used for other things such as train signaling and for lighting miners' lamps and submarines.

Edison's lack of good managerial or organizational skills actually instigated a fearless and open-minded approach to work that insulated him from the disenchantment of failure. He didn't believe that he was particularly clever – he was an advocate of hard graft. He begrudged wasteful tasks such as eating and resting that would impinge on his work time and was known to sleep fully dressed on his workshop tables.

He was married twice and had six children. The first two were nicknamed "Dot" and "Dash" after the telegraph code terms.

Essential science

Telegraphy

Telegraphy, the communication system involving the transmission of electric signals through wires that translated into a message, was developed in the nineteenth century, most successfully by Samuel Morse (1791–1872). Morse's system sent pulses of current through a wire, which deflected an **electromagnet**, which in turn embossed a strip of paper with dots and dashes – known as Morse code. Edison's contribution was to develop a printer that turned the electric signals into printed letters. He also patented a duplex telegraph (allowing communication in both directions), which was able to send up to two messages together over the same wire without getting them mixed up. Later he put two of these machines together to create the appropriately named quadruplex telegraph.

Carbon-button transmitter

Between 1877 and 1878 Edison invented a carbon-button transmitter or microphone that would prove to be a crucial component in the next development of telegraphy – the "speaking telegraph" or telephone – along with Alexander Graham Bell's receiver. Edison's device used a diaphragm to convert sound to electrical signals and consisted of two metal plates connected by an electric current and separated by granules of carbon. One plate acting as a diaphragm would vibrate in response to a speaker's voice, which would change the pressure on the granules, and this in turn changed the electrical resistance between the plates (a higher pressure would push the granules closer together and lower the resistance). The changing resistance resulted in a changing electrical current between the plates, which could then be fed into a telephone system as an electrical signal.

The phonograph

Edison saw that the new invention of the telephone had a major drawback: the transmission of messages was too rapid for people to write down what was being said. His answer was the invention of the phonograph: a device that could record and play back a vocal message. He came to this idea after playing the tape of a telegraph transmitter at high speed and hearing a sound similar to a human voice. The idea that the paper tape moving through the machine could produce a

Legacy, truth, consequence

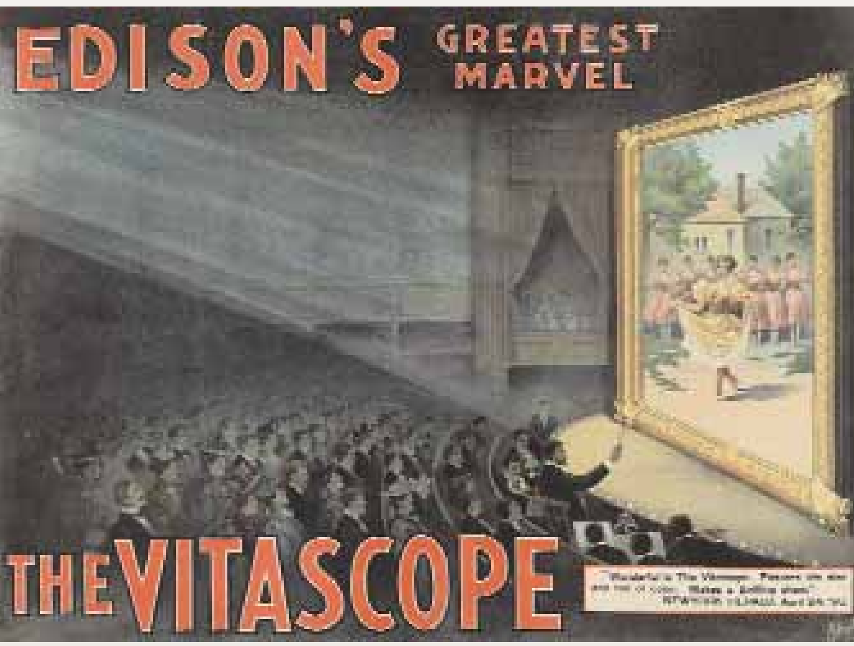
- Principles discovered by the "Edison effect" led to the development of the **electron tube** and form the bedrock on which the electronics industry is laid.
- Edison's carbon-button transmitters used in telephones until recently have only become less common since the growth of cordless phones.
- He set up the first industrial research laboratory, in Menlo Park, New Jersey, US, employing a team of researchers under his direction with the purpose of developing new and improved technology.
- 1,093 patents are recorded in his name. As a compulsive experimentalist, not everything that Edison touched was liable to turn into gold. One of his ideas was to make things out of cement – from cupboards and pianos to houses. It didn't catch on quite as he had hoped, but he did receive a contract to build the New York Yankees' stadium with cement.

Key dates

1847 Born in Milan, Ohio, US.
1869 Moves to New York. Receives first patent.
1870 Opens first workshop in Newark, New Jersey.
1876 Moves to his Menlo Park laboratory.
1877 Invents the phonograph.
1882 Opens a commercial electric station in New York.
1883 The electric light bulb is patented.
1888 Meets Eadweard Muybridge (1830–1904), an expert in photographic motion analysis. Develops an interest in the moving picture, which culminates in the founding of the motion picture industry.
1889 Edison General Electric Company is formed. Develops talking dolls.
1893 Completes construction of his first film studio, called the Kinetographic Theater.
1896 Forms National Phonograph Company.
1913 Launches the Kinetophone which attempts to synchronize phonographic cylinder records with moving pictures.
1928 Awarded the Congressional Gold Medal.
1931 Dies in West Orange, New Jersey, US. During his funeral the American public dim their lights for one minute.

What man's mind can create, man's character can control.

Newspaper interview (1921)



An advertisement for one of Edison's inventions, c.1896.

noise resembling spoken words made him think that by combining the technologies of the telephone and the telegraph he might succeed in both recording and playing back a spoken message. First he attached a stylus taken from a telegraph machine to the diaphragm in a telephone receiver (the mouthpiece), with the loose end of the stylus placed so that it would indent a sheet of paper as the diaphragm vibrated. These indentations could then be played back by another stylus and diaphragm unit, reproducing the original recorded vibrations, or sound. He soon replaced the paper with tinfoil wrapped around a rotating cylinder, and achieved a clear result: after speaking into the machine he could rotate the cyclinder to play back his recorded message. Thus it was that, with some astonishment, he heard his own voice reciting, "*Mary had a little lamb*".

Electric light bulb

A problem for previous experimenters had been the overheating and disintegration of the bulb itself. Edison intended not only to sort that out, but ultimately to produce an incandescent light that was safe, practical, and cheap – something that could be used in the home. A year and a half of experimentation, characterized by Edison's trial and error approach, produced a bulb in which a reduced current of electricity, operating in a more efficient vacuum, flowed from a fine, carbonized wire filament to a plate fixed inside, and which, crucially, burned for over 13 hours.

By the time the bulb was patented, in 1883, it was noted that in a vacuum bulb the wire and the bulb itself blackened at the negative pole, but at the positive pole a blue glow was observed. This became known as the "Edison effect".

Electric light distribution

The invention of the light bulb necessitated further electrical development, the most significant being Edison's seven-point program for electricity distribution, the components of which are the parallel circuit, a durable light bulb, an improved dynamo, the underground conductor network, devices for maintaining constant voltage, safety fuses and insulating materials, and light sockets with on-off switches. Each of these components had to be separately invented and developed into producible units.

1856–1939

Sigmund Freud

The Austrian doctor and philosopher Sigmund Freud created the modern discipline of psychoanalysis as both a theory of the mind and a form of therapy. Introducing concepts such as the power of the unconscious mind and the sexual origin of psychological problems, he revolutionized our idea of the mind and its neuroses.

Aged 41 when Sigmund was born, and 20 years older than his wife, Freud's father was a remote, authoritarian figure, while Sigmund's mother was caring and nurturing. The oldest child of seven, Freud was favored because of his intellectual brilliance. His early family circumstances played a major part in the theories of the mind that he later formulated.

Unable to make a decent living as wool merchants, the family moved to Vienna. Freud studied medicine and in 1885 won a scholarship to study in France under the renowned **neurologist** Jean Martin Charcot (1825–93), who used hypnotism to treat hysterical disorders.

> ***The ego is not master in its own house.***
>
> *A Difficulty in the Path of Psycho-Analysis* (1917)

Back in Vienna, Freud specialized in neurology, using the then standard treatments of electrotherapy or hypnotism. He soon realized that these were ineffective, and instead experimented with what was called the "talking cure", encouraging patients to talk about and release their problems. Freud used cocaine to expand his mind, and at some points in his life he was clearly addicted to the drug.

In his forties Freud spent a period of time intensively exploring his own psychology. He reached several universal conclusions from this, particularly that the sexual impulse is the source of many neuroses. The wider scientific community reviled his explorations of sexuality, especially his belief that even infants are driven by it, and for a time Freud had to work in isolation. But by 1906 he had gathered a group of followers, including Carl Jung (1875–1961) and Alfred Adler (1870–1937), and in 1908 the first psychoanalytic conference took place in Salzburg, shortly followed by the establishment of the International Association of Psychoanalysts in 1910.

When Hitler's Nazis took power in Germany in 1933, Freud's books were among the first to be thrown on the public bonfires. Five years later the Nazis took over Austria and began to harass everyone with Jewish ancestry, such as Freud, even though he himself was an atheist. Freud decided he would prefer to "die in

Essential science

Psychoanalysis

Freud's psychoanalysis covered three different areas: a therapeutic technique; a theory of the mind and its related human behavior; and a philosophy.

Psychoanalytical method

Freud developed the technique of analytical discussion between patient and psychotherapist, through which patients will eventually bring their problems into the open, be able to confront them rationally, and thus make any necessary changes in their behavior. He asked patients to lie on a couch, which he thought would make them relaxed and open-minded, and approached their neuroses through free association of ideas and the interpretation of dreams, which he thought offered an insight into the unconscious – "the royal road to the unconscious". He also introduced the idea of transference in a psychotherapeutic relationship, whereby the patient projects feelings and ideas onto the analyst.

The unconscious

Freud's fundamental theory was that the mind has several layers and levels of functioning. Most of the time these layers are unaware of each other, and may in fact act in opposition to each other. They are:

• The id – the primitive, selfish, infantile, demanding lower level. Sometimes it can sabotage the other layers by its impulses, or reveal itself through "Freudian" slips.

• The super-ego – the superior moral psychological code.

• The ego – the part of the psyche supposedly in control of everyday matters, balancing the other two parts. This ego may try to repress the id and any painful memories of the past.

Freud concluded that the adult personality was largely created by childhood experiences, even though many formative experiences might have been forgotten by the conscious mind.

Sexuality

Freud speculated that much of our unconscious motivation is driven by our sexual drives, and that neuroses often originate from

The unconscious is the larger circle which includes within itself the smaller circle of the conscious, everything conscious has its preliminary step in the unconscious …

Psychoanalysis for Beginners (1920)

Freud's sofa, forever associated with the discipline of psychoanalysis.

freedom", even if it meant he had to leave Vienna, so he and his family left for London in 1938.

Freud endured many unsuccessful operations for throat cancer, but eventually he could take no more suffering. In September 1939 he persuaded his friend the doctor Max Schur to help him die – "*You promised me then not to forsake me when my time comes. Now it is nothing but torture …*" Schur gave him three doses of morphine, and Freud died peacefully in his home in north London.

an abused, frustrated, or complicated sexuality. Probably his most famous example is the Oedipus Complex, when he argued that the attraction that young boys feel towards their mother is partly sexual, and subconsciously they hate their father out of jealousy because he can have sexual relations with her. He named this theory after the ancient Greek prince Oedipus who was given away as a baby, and as a grown man unknowingly killed his real father and married his real mother. He wrote: "*I found in myself a constant love for my mother, and jealousy of my father. I now consider this to be a universal event in childhood.*"

Freud developed a similar theory for girls, and is also famous for suggesting that objects that pop up in the subconscious or in dreams have sexual meaning. For example, linear shapes such as swords and pens are supposed to be phallic symbols, but he also pointed out, "*Sometimes a cigar is just a cigar!*"

Sexual instincts are part of what Freud called life instincts, the drive to sustain life and reproduce. He contrasted this with death instincts, the unconscious self-destructive or aggressive impulse.

Legacy, truth, consequence

■ Freud initiated the whole field of psychoanalysis. Other giants of psychotherapy such as Carl Jung owed their inspiration to Freud. Jung launched a new approach involving concepts such as mythological archetypes, the collective unconscious, extroversion, and introversion, but was set on his path by Freud's original work.

■ A controversial figure from start to finish, Freud has always had critics. Many psychologists think that his theories are unproven speculation, and some think that his ideas of infantile erotic instincts are obscene and shocking. On the other hand, there have always been enthusiastic supporters of his ideas, particularly of the fact that the unconscious can drive us in unsuspected ways.

■ Regardless of whether we agree or disagree with him, he changed the way people think about themselves and about their behavior.

■ Many terms and concepts he introduced such as id, ego, Oedipus Complex, libido, repression, the death drive, defense mechanism, penis envy, and Freudian slip are now not only accepted in mainstream psychology, but are also commonplace ideas and parts of everyday conversation.

Key dates

1856	Born in Freiberg, Moravia, Austro-Hungary (now Pribor in the Czech Republic).
1885	Studies under famous neurologist Jean Martin Charcot in Paris.
1886	Opens a medical practice in Vienna specializing in "brain disorders".
1895	Publishes his first work on psychoanalysis, *Studies in Hysteria*, with Joseph Breur.
1895	Embarks on a four-year period of self-analysis.
1896	Introduces the term "psychoanalysis".
1900	Publishes *The Interpretation of Dreams*, outlining the first approach to psychoanalysis.
1901	Publishes *The Psychopathology of Everyday Life*, suggesting that slips of the tongue ("Freudian slips") are the unconscious at work.
1902	Appointed a professor at the University of Vienna, teaches, and founds a psychoanalytical society.
1905	Publishes *Three Essays on the Theory of Sexuality*.
1923	Publishes *The Ego and the Id*.
1923	Diagnosed with cancer of the jaw, possibly due to cigar-smoking.
1930	Receives prestigious German award, the Goethe Prize, for contributions to literature and culture.
1938	Flees the new Nazi regime for London, UK.
1939	Dies from assisted suicide in London.

1867–1934

Marie Curie

Physicist, chemist, and the recipient of two Nobel prizes, Marie Curie was one of the most renowned scientists of her time. The first female professor of the University of Paris, she and her husband Pierre were pioneers in the field of radioactivity, discovering not only the concept of radioactive material, but also being the first to identify new radioactive elements.

Marie Sklodowska-Curie was born in Warsaw in 1867, and was one of four children. She attended local schools and was taught advanced science by her father, a high school teacher. Because of a turbulent Polish uprising against the Russian Empire, Marie was prevented from attending university in Warsaw and was forced to work as a governess. Involved in a student revolutionary organization, Marie left Warsaw for the relative safety of Cracow, then a part of Austria.

In early childhood, Marie and her sister Bronislawa had formed an agreement under which Marie would help fund her sister's education in exchange for the same favor; as a result, in 1891, Marie was able to join Bronislawa in Paris to pursue her own studies at the Sorbonne, the University of Paris. Curie obtained degrees in physics and mathematics. She also met her future husband and colleague, Pierre Curie, then the Head of the Physics Laboratory at the Sorbonne and renowned for his work in **crystallography** and **magnetism**.

Together with Pierre, Marie Curie pioneered the field of **radioactivity**. Fascinated by the recent observations of **Henri Becquerel** on the unique properties of uranium, the Curies investigated similar properties in other elements. They studied large amounts of pitchblende (uranium ore) and found that the unique activity observed by Becquerel was maintained even when the uranium had been extracted. Further research resulted in the discovery of polonium and radium and, subsequently, to a purified form of metallic radium. Combined, these findings comprised the discovery of the phenomenon known today as "radioactivity", earning the Curies and Henri Becquerel the Nobel Prize for Physics in 1903.

Marie and Pierre Curie had two children together, before Pierre's tragic death in 1906, struck by a vehicle in the street. Although crushed by her loss, Marie was appointed to Pierre's professorship, making her the first female to become a lecturer at the Sorbonne. In recognition of her isolation of radium in its pure metallic form, Marie Curie received the Nobel Prize for Chemistry in 1911, making her the first woman to ever receive two Nobel Prizes and the first person to win two Nobel Prizes in two different fields of science. Despite these accomplishments and multiple accolades from other countries, Marie Curie faced opposition and prejudice against female scientists in her adopted France, and failed to be elected to the French Academy of Sciences by one vote.

Sadly, as a pioneer of the field of radioactivity, neither Marie nor her contemporaries were aware of the risks of radioactive exposure. She died in 1934 of a form of leukemia, presumed to be a result of her increased exposure to radioactive material. Studies of the notebooks and laboratory tools she left behind show her notebooks are radioactive to this day.

Essential science

Radioactivity and the new elements: polonium and radium

Henri Becquerel was the first to observe the "unique activities" of uranium (see pages 120–1). Trying to identify a focus for her postgraduate study, Marie Curie decided to investigate this "unique activity" in other elements. She and Pierre Curie studied waste obtained from uranium plants, and found that this activity was still present in the uranium-free material. They concluded that there must be some other elements responsible for the observed activity, and then the subsequent isolation and identification of polonium, named after Marie's native Poland, and, later on, radium, named after their newly coined term for the unique activity – radioactivity – because of its intensely radioactive properties.

Radioactivity in medicine

In their early research days, Pierre had been the first to observe that the "unique activity" of radium, later identified by the pair as radioactivity, was a chemical property directly affecting organic tissue. It was this fundamental discovery that led Marie Curie to research the application of radioactivity in medicine, and in 1915 she began to train doctors in the use of radium to treat scar tissue, arthritis, and some types of cancers. Later on she initiated research into radioactive therapeutics and their medical application. During World War I, she worked with X-ray scientists to bring mobile radiography units (popularly known as *petites Curies* or "Little Curies") to the field, to help remove shrapnel from the wounds of soldiers.

Legacy, truth, consequence

- The curie (Ci), the unit used to measure radioactivity, and the element curium are so named in honor of Marie and Pierre Curie as pioneers in the field of radioactivity.
- Marie Curie pioneered the use of the radioactive properties of radium in medicine. Her research into the therapeutic potential of radioactive material was crucial for the development of X-rays in surgery.
- Radium was used in luminous paints for watch dials, and even as a food additive, until the discovery of the associated serious adverse health effects in the 1930s.
- Marie Curie is a female icon in the scientific world and has been a major influence on subsequent generations of nuclear physicists and chemists.

An experimental X-ray apparatus from the late 1800s. Later on, Marie Curie's research would be crucial for the development of X-rays in surgery.

Key dates

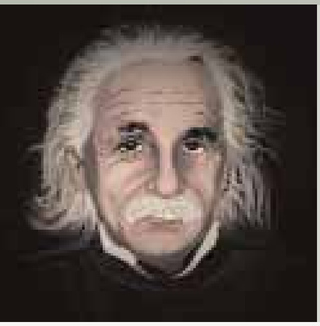
1867 Born in Warsaw, then part of the Russian Empire.
1891 Studies mathematics, physics, and chemistry at the University of Paris.
1893 Graduates first in her class from the University of Paris.
1892 Obtains a masters degree in mathematics from the University of Paris.
1895 Marries Pierre Curie.
1898 With Pierre Curie publishes an article describing their discovery of a new chemical element, polonium, and names it in honor of her native Poland. Later that year, the Curies publish their discovery of a second new element, named radium.
1902 Refines radium chloride.
1903 Along with Pierre Curie and Henri Becquerel, Marie Curie is awarded the Nobel Prize in Physics for their research on **radiation**, making her the first female Nobel laureate.
1903 Under the supervision of Becquerel, becomes the first female in France to receive a doctorate degree from the University of Paris.
1906 Pierre Curie is killed in a street accident.
1909 Appointed the first female professor at the University of Paris.
1911 Awarded the Nobel Prize in Chemistry for her discovery of radium and polonium and the isolation of radium.
1921 Receives a gift of a single gram of pure radium to use in her research from the United States President W. G. Harding.
1925 Founds the Warsaw Radium Institute and appoints her sister Bronislawa as Director.
1932 Founds the Radium Institute, now the Maria Sklodowska-Curie Institute of Oncology, in Warsaw, Poland.
1934 Dies in Sallanches, Savoy, of aplastic anemia most likely caused from her increased exposure to radiation.
1935 Curie's eldest daughter, Irene Joliot-Curie, wins the Nobel Prize in Chemistry for her discovery that aluminium can be radioactive and emit neutrons when treated with alpha rays.
1955 In honor of Marie's and Pierre's lifetime achievements, the remains of the couple are moved to the Pantheon in Paris.

We must not forget that when radium was discovered no one knew that it would prove useful in hospitals. The work was one of pure science. And this is a proof that scientific work must not be considered from the point of view of the direct usefulness of it. It must be done for itself, for the beauty of science, and then there is always the chance that a scientific discovery may become like the radium a benefit for humanity.

Lecture at Vassar College, Poughkeepsie, New York (1921)

1879–1955

Albert Einstein



A theoretical physicist, Albert Einstein is considered one of the greatest scientists and intellects of all time. He answered fundamental scientific questions and revolutionized ideas on matter, energy, gravitation, light, space, and time. On completing his general theory of relativity, he advanced Newtonian physics, became world famous, and received a Nobel Prize that formally acknowledged his "*services to theoretical physics*".

Einstein's fascination for invisible forces began at an early age when he first saw the effects of a magnetic compass. A book on **Euclidean geometry**, read when he was 12 years old, also had a lasting impression. He was inspired by an uncle's interest in mathematics, and another uncle's interest in science, but was less impressed by his schooling. Strict classroom discipline and Einstein's own boredom led him to leave his secondary school in Munich at the age of 15, with poor grades. He joined his parents in Switzerland, finished his schooling, and then entered the highly acclaimed Swiss Federal Institute of Technology, Zürich. But he still preferred to read in the library than go to classes. After graduating and a short period as a mathematics teacher, he took a job at the Swiss Patent Office in Bern.

The new job allowed time for Einstein to pursue his own ideas and in 1905 he completed a dissertation for his doctorate. The same year he published four revolutionary papers. One was a **quantum theory** of light and an explanation of the **photoelectric effect** (see below); another was an analysis of **Brownian motion**; the third was his **special theory of relativity**, notes for which he had begun when only 16 years old; the fourth paper stated that energy and mass are interchangeable and provided the famous equation $E = mc^2$.

Einstein was soon admired by other physicists, and the doors to academia opened. In 1909 he took the post of associate professor at the University of Zurich, and in 1914 moved to Berlin to become the director of a new research center, the Kaiser Wilhelm Institute for Physics. World fame came in 1916 with the publication of his **general theory of relativity**. But Einstein, who was of Jewish descent, faced verbal attacks as anti-Semitism grew prevalent in Germany, and he preferred to travel abroad.

During the 1920s he worked on the theory of **quantum mechanics**, but began to doubt its truth by the middle of the decade. In his later years, Einstein focused on establishing a **unified field theory**, which would describe the universal properties of matter and energy in a single formula or sentence. It was never completed. With Hitler's rise to power in 1933 Einstein renounced his German citizenship and later joined the Institute for Advanced Study in Princeton, New Jersey, US, to continue his research. A lifelong pacifist, his concerns became focused on the atomic bomb, and how to control the spread of nuclear technology. Days before his death he signed the Russell–Einstein Manifesto, which highlighted the dangers of nuclear weapons and called on international leaders to use peaceful means to resolve conflicts.

Essential science

The photoelectric effect

Einstein's first important paper published in 1905 extended physicist **Max Planck**'s theory that energy is emitted in tiny packets, or units, each one called a **quantum** (plural quanta). Einstein explained that light is made up of quanta (now called **photons**), and that this explains the photoelectric effect – how **subatomic particles** (called **electrons**) are emitted from some solids (such as metals) when struck by light (photons).

Brownian motion

Brownian motion is the random movement of microscopic particles suspended in a fluid, or gas, caused by the random bombardment of molecules of the fluid, or gas. The movement was first noticed by botanist Robert Brown (1773–1858), in 1827. Working independently, Einstein in 1905, and Polish scientist Marian Smoluchowski (1872–1917) in 1906, were the first to explain it in terms that proved the existence of **atoms**.

Special theory of relativity

In his paper "On the Electrodynamics of Moving Bodies", Einstein presented his special theory of relativity. This states that all motion is relative and there is no stationary reference frame from which to take measurements (we stand on an earth which orbits around the sun, other planets move in relation to one another, and so on), effectively overthrowing **Isaac Newton**'s notions of absolute space and time.

His theory incorporates the principle that the speed of light is constant (which he called "c"). If two people, one sitting at the back of a train and one watching the train go by, were to measure the speed of a light shining along the train from its last carriage to its first, they would note exactly the same speed. The speed of light

Legacy, truth, consequence

- The year 1905 became known as Einstein's "miracle year" because of the publication of his four papers, each of which provided a major contribution towards an understanding of the universe. These theories and his general theory of relativity have become the foundations of modern physics.
- Ironically, proof of Einstein's equation $E = mc2$ came with the creation of atom bombs. It firmly linked him to the atomic age although he pleaded for the control of nuclear technology and worked to prevent the use of the bomb.
- After predictions in Einstein's general theory of relativity were verified in 1919, scientists around the world became profoundly impressed by his work. Though few fully understood his general relativity theory, it marked a step beyond Newton's view of the universe.
- Einstein's hope for a unified field theory was viewed by fellow scientists as impossible to achieve, largely because of quantum theory, which showed that there was an **uncertainty principle** in measurements of the motion of particles. Einstein continued to hope and became increasingly unsure about quantum theory.
- Elements of Einstein's theories were proven before and after his death. For example, **Edward Hubble**'s discovery in 1929 that the universe is expanding proved Einstein's equations that showed a dynamic universe; and overwhelming evidence that a star Cygnus X-1 is a black hole began to emerge in 1971.


EINSTEIN EXPOUNDS HIS NEW THEORY

It Discards Absolute Time and Space, Recognizing Them Only as Related to Moving Systems.

IMPROVES ON NEWTON

Whose Approximations Hold for Most Motions, but Not Those of the Highest Velocity.

***The New York Times*, 1919.**

Key dates

1879 Born in Ulm, Württemberg, Germany.
1896 Enters the Swiss Federal Polytechnic School, Zürich (renamed the Swiss Federal Institute of Technology in 1911).
1901 Granted Swiss citizenship and successfully applies for a post as technical assistant at the Swiss Patent Office.
1905 Publishes four ground-breaking papers, including his theory of special relativity.
1914 Appointed director of the Kaiser Wilhelm Institute for Physics, Berlin.
1916 Publication of his general theory of relativity.
1919 Observations taken during a solar eclipse prove Einstein's prediction of starlight bending near the sun.
1921 Begins first of many world tours. Awarded the Nobel Prize for Physics.
1932 Leaves Germany for the last time and joins the Institute of Advanced Studies in Princeton, US.
1936 Publishes, with other physicists, an article criticizing the quantum theory.
1939 Writes a letter to US President Roosevelt, warning him that Germany may be constructing atom bombs.
1940 Becomes a United States citizen.
1952 Offered and declines the post of president of Israel.
1955 Dies in Princeton, US.

The eternal mystery of the world is its comprehensibility … The fact that it is comprehensible is a miracle.

Einstein, "Physics and Reality",
Franklin Institute Journal (March 1936)

is the same for all observers, regardless of their motion relative to the source of the light, so long as the observers are still or in uniform motion and not accelerating.

This contradicts the fact that to the person watching the passing light, the light speed would seem to be faster than to the observer on the train. Einstein explained this in terms of time and space being relative to the observer: time and space are *perceived* differently by observers in different states of motion. For example, scientists have since shown that an atomic clock traveling at high speed in a jet plane ticks more slowly than if stationary on the ground.

$E = mc^2$

Einstein explained that his special theory of relativity led to the now famous equation $E = mc^2$, which states that a body's energy (E), equals the body's mass (m) multiplied by the speed of light (c) squared. Because the speed of light is extreme, the conversion of even a tiny amount of mass releases a vast amount of energy.

General theory of relativity

A main part of this theory explained that gravitation is not a force as Newton described, but is a curved field caused by the presence of mass. Einstein said that this could be proven through a study of the way the sun's gravitation bends light rays from stars. The astronomer Arthur Eddington (1882–1944) did just this during a total **solar eclipse** in 1919. His calculations showed how starlight was bending, as Einstein had predicted.

Einstein's explanation of gravitation was based on how time and space are not separate, and that the effects of gravity are equivalent to the effects of acceleration. The theory led to Einstein's prediction of the existence of **black holes**.

1907–64

Rachel Carson

A biologist, ecologist, and science writer, Rachel Carson almost single-handedly started the modern worldwide environmental movement with her powerful book *Silent Spring*, which eloquently showed the devastating effects of pesticide pollution on the natural world.

Growing up in the small riverside town of Springdale, Rachel Carson was encouraged by her mother to appreciate the natural world. Throughout her career, as a marine biologist and later as a general ecologist, her work was just as much her lifetime interest and hobby as a job. She was particularly absorbed by the seas, sea life, and the ecology of the seashore, a love she later expressed in her book *The Sea Around Us*.

After studying English then zoology, she spent several years working for the US Bureau of Fisheries, later the Fish and Wildlife Service, being only the second woman to secure a full-time professional job within the service. She eventually rose to become editor-in-chief of publications, with her enthusiasm for biology and nature shining through her writing.

After the success of *The Sea Around Us* she left her job to become a full-time writer on environmental issues, and began to research the material that would be *Silent Spring*, the book that woke the world to the dangers of industrial and agricultural pollution caused by indiscriminate crop-spraying. The title *Silent Spring* refers to an example she quoted of how all the wildlife in an area could be destroyed by widespread use of artificial chemical pesticides, resulting in an unnaturally silent region devoid of all nature whether animal or vegetable.

In 1957 she found herself in charge of an orphaned grandnephew as well as her aging mother, and had to rearrange her life in order to care for them.

Carson worked at a time when Americans believed that science could only be a force for good, and her proof that scientific progress was damaging the environment came as a double shock, particularly since she wrote in scientific terms and was already known as a science writer for her work on the seas and marine biology. Her books were recognized by other scientists for their scholarship, and were popular with ordinary people not just because of the topical subject matter, but also because of her eloquent and poetical language that brought science alive.

Silent Spring, however, was a call to arms, and was less lyrical and more angry and combative than her earlier books.

Essential science

Anti-pesticides

Carson was the first scientist to point out on a broad platform that pesticides created to kill just one weed or one insect or animal pest had a much wider impact by poisoning the food supply of other species, sometimes killing all insects, birds, fish, and wildlife in the area, and lingering on in the soil to have a lasting effect. She called these chemicals “biocides”, and identified more than 200 chemicals that had been developed since the 1940s to kill pests or weeds, and which then became widely available for public use in the US.

Pioneering later holistic concepts, she stressed that human beings are also part of nature, and our health is harmed by destructive environmental practices just as much as any other species. She showed that pesticides can go on to contaminate the human food chain.

Research

Carson was not automatically opposed to the use of chemicals in agriculture, but she argued that while the long-term effects of newly developed pesticides was not known, it was scientifically and morally wrong to use them indiscriminately and on a large scale. As with the dumping of nuclear waste at sea, she pointed out that there was a lack of research on the long-term effects.

Public awareness

Carson believed passionately that ordinary people should be informed of the environmental and health impacts of modern agricultural practices, feeling that only if people were informed could they make choices about their environment. She was also keen to warn people that humanity was recklessly squandering natural resources.

Scientific integrity

The big multi-national chemical companies were quick to attack or even deride her views, but Carson remained calm and dignified, and maintained confidence in her scientific integrity and impartiality in the face of vicious personal attacks. Although she was quiet and shy, she felt so strongly about the issues that she was prepared to fight back against attempts by industrial organizations to suppress her work.

Legacy, truth, consequence

- Carson's book *Silent Spring* was an environmental "wake-up" call that rocked not just the American public but also most of the world. It brought existing conservation and wildlife organizations together and inspired a new generation of environmental activists.
- Her work on pesticides sparked an immediate public debate that forced the government to examine the issue. As a result, a federal government advisory committee in 1963 called for research into the potential health hazards of indiscriminate pesticide use. Eventually several artificial pesticides, including DDT, were banned in the US because of her arguments, and many other countries also introduced restrictions on pesticide use.
- The chemical industry fought back, but it failed to disprove her science, and resorted to personal attacks – even calling her a "hysterical woman" – which swung public sympathy towards Carson's cause.
- She was the inspiration behind the establishment of the US's Environmental Protection Agency.
- She introduced into the public consciousness several concepts such as "**ecosystem**" that are now part of everyday language, and her ability to bring biology to life helped publicize and popularize science.
- Carson inspired scientific studies of the relationship between environmental pollution and human health; in a horrible irony, breast cancer, the disease she died from, has since been identified as a cancer which can sometimes be caused by environmental contamination.

I truly believe that we in this generation must come to terms with nature, and I think we're challenged as mankind has never been challenged before to prove our maturity and our mastery, not of nature, but of ourselves.

CBS television program, *The Silent Spring of Rachel Carson* (1963)

Key dates

1907	Born in Pennsylvania, US.
1936–52	Works for the federal government as a researcher and scientific editor.
1945	First notices the widespread effect of new chemical pesticides such as DDT.
1952	Publishes the award-winning book on the sea and marine life, *The Sea Around Us*, which becomes a bestseller and makes her a household name. Becomes a full-time author and begins to investigate effects of pesticides.
1962	Publishes *Silent Spring*, alerting the world to the environmental damage caused by pesticides and industrialized agriculture.
1963	Testifies before a Congressional enquiry into the labeling of pesticides.
1964	Dies in Maryland, US, of breast cancer.

Rachel Carson pointed out the danger of intensive crop-spraying of new chemical pesticides, sparking an important public debate.

To dispose first and investigate later is an invitation to disaster, for once radioactive elements have been deposited at sea they are irretrievable. The mistakes that are made now are made for all time.

Preface to the 1961 edition, *The Sea Around Us*

THEY CHANGED THE WORLD

All over the globe, in every field, scientists have used experimental methods to explore and verify theories ranging from evolution to general relativity. Beginning with the Ancients, through the pioneers of the Scientific Revolution, to the remarkable and increasingly specialized scientists of the modern era, they have inspired legions of followers, some have generated fear, and many have made such an impact as to alter the course of history.

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