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European mathematics: A history in stamps

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Abstract. It is surprising how many hundreds of postage stamps from around the world have featured mathematics and its history. For the 8ECM meeting in Portorož I was invited to present a public lecture on those stamps that are related to European mathematics, and I illustrated it with more than 200 examples. I also designed a stamp exhibition for the Congress, also including over 200 mathematical stamps with historical commentary. In this article I present a selection of the stamps that I selected for this lecture and exhibition. The treatment is historical and is presented chronologically.

1. Greek mathematics

European mathematics is often taken to begin with Ancient Greece, although its origins can be traced back further. From around 600 BC, the subject flourished throughout the eastern Mediterranean where the Greeks developed deductive logical reasoning and proof – the hallmark of their work, especially in geometry.

An early Greek mathematician, around 600 BC, was *Thales of Miletus* (Figure 1(a)), who predicted a solar eclipse and showed how to cause electricity in feathers by rubbing them with a stone. In geometry he reportedly proved that a circle is bisected by any diameter and that the base angles of an isosceles triangle are equal.

Another semi-legendary figure is *Pythagoras of Samos* (Figure 1(b)), who formed a School in Crotona to further the study of mathematics and science. Supposedly believing that "All is number", the Pythagoreans emphasised the "mathematical arts" of arithmetic, geometry, astronomy, and music, later known as the "quadrivium". Several stamps feature the well-known *Pythagorean theorem* for a right-angled triangle (Figure 1(c)), that the areas of the squares on its two smallest sides add up to the area of the square on its largest side – or in algebraic form (which the Greeks did not use), $a^2 + b^2 = c^2$. We do not know who first proved this, but its connection with right-angled triangles had already been known many years earlier, in Mesopotamia and elsewhere.

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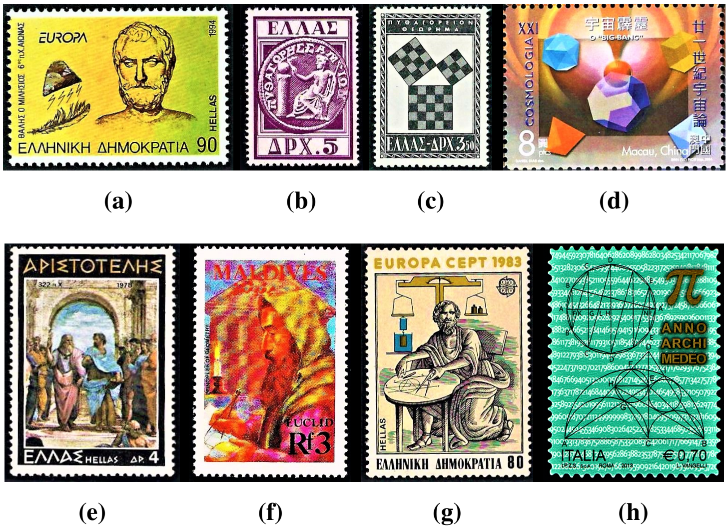


Figure 1. *Greek mathematics*
(a) Thales, (b) Pythagoras, (c) Pythagorean theorem, (d) Platonic solids, (e) Plato's Academy, (f) Euclid, (g) Archimedes, (h) Archimedes' geometry

The scene then moved to Athens, which became the most important intellectual centre in Greece. In 387 BC, the philosopher Plato founded a school in the suburb of Athens named "Academy", and Plato's Academy became the focal point for mathematical study. Convinced that mathematical training was essential for his ideal citizens, Plato emphasised the quadrivium subjects of the Pythagoreans and discussed the five regular (or "Platonic") solids (Figure 1(d)), while his pupil Aristotle formalised deductive reasoning. In Raphael's fresco *The School of Athens*, Plato and Aristotle are shown on the steps of the Academy (Figure 1(e)).

Around 300 BC, following the military successes of Alexander the Great, mathematical activity moved to Alexandria in the Egyptian part of the Greek world. The first important mathematician there was *Euclid* (Figure 1(f)) who is mainly remembered for his *Elements*, the most widely read and influential mathematical work of all time. A model of deductive reasoning, it presented plane and solid geometry, arithmetic, and number theory, by building them up from a small number of axioms to a great hierarchy of results that he derived in a logical and systematic order.

One of the greatest of mathematicians, around 250 BC, was *Archimedes* of Syracuse, now in Sicily (Figure 1(g)). In geometry he investigated spheres and cylinders and compared the surface areas and volumes of sections of these; he also listed the thirteen "Archimedean" (or semi-regular) solids, and found estimates for π by considering polygons that approximate a circle (Figure 1(h)). In mechanics he found the law of moments for a balance and invented the Archimedean screw for raising water. In statics he stated Archimedes' principle on the weight of an object immersed in water, but no contemporary evidence exists for the well-known story that he used his principle to test the purity of a gold crown or that he jumped out of his bath and ran naked through the streets celebrating his discovery.

2. Early European mathematics

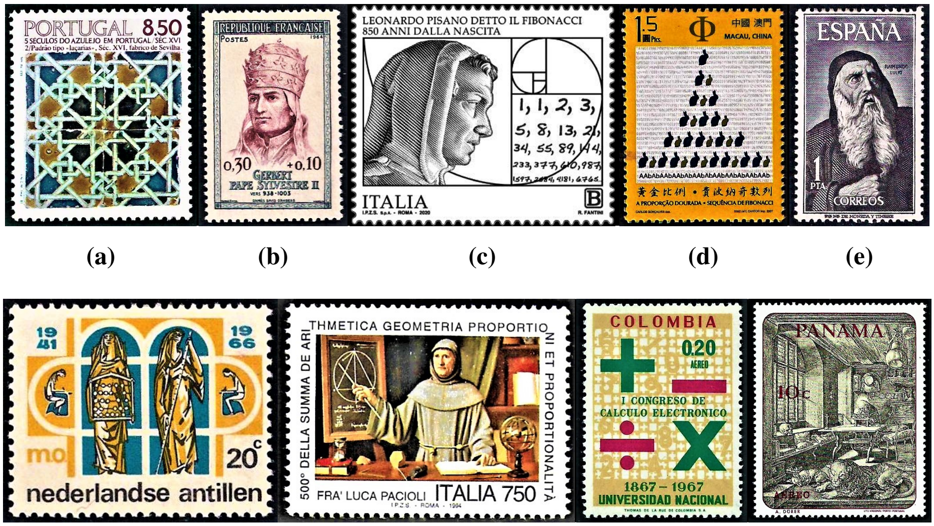
We now turn briefly to the Islamic world from AD 750 onwards. United by their new religion, and with Baghdad lying on the east-west trade routes, their scholars developed Greek writings from the west and Hindu writings from India. Some of our present terminology dates from this period: the word "algorithm" (a step-by-step procedure for solving a problem) comes from al-Khwārizmī, a Persian mathematician whose influential book on arithmetic introduced the Indian decimal place-value system to the Islamic world. He also wrote a book on solving equations, *Kitāb al-jabr wal-muqābala* (Calculation by Completion and Balancing), whose title gives us the word "algebra".

The Islamic world developed in all directions, and by the year 1000 it had spread across the top of Africa and up into southern Europe through Spain and Italy. Córdoba became the scientific capital of Europe, while Islamic decorative art and architecture spread through southern Spain and Portugal (Figure 2(a)) and included the magnificent geometrical arches in the mosque at Córdoba, and the tilings in Granada's Alhambra.

Meanwhile, in Europe, the period from 500 to 1000 had become known as the "Dark Ages". Much of the legacy from the ancient world was forgotten, and the general level of culture was low. Revival of interest began with the French scholar *Gerbert of Aurillac* (Figure 2(b)) who trained in Catalonia and introduced the Hindu–Arabic numerals to Christian Europe, using an abacus that he designed for the purpose. A major figure in the Church, he was crowned Pope in 999.

The Hindu-Arabic numbers were also popularised by Leonardo of Pisa, or *Fibonacci* (Figure 2(c)) in his *Liber Abbaci* (Book of Calculation) of 1202. This famous work contains many problems from arithmetic and algebra, such as his *rabbits problem* (Figure 2(d)) that leads to the *Fibonacci sequence* of numbers, $1, 2, 3, 5, 8, 13, \ldots,$ where each successive number is the sum of the previous two. These numbers also arise in the arrangements of seeds in sunflowers and pine cones.

Another notable figure was the Catalan mystic *Ramon Lhull* (Figure 2(e)), who believed that *all* knowledge could be obtained by combining God's "divine attributes", such as power, wisdom, and goodness. His combinatorial ideas spread through Europe, later influencing such figures as Mersenne and Leibniz.



(a) (b) (c) (d) (e)

(f) (g) (h) (i)

Figure 2. *Early European mathematics*
(a) Tiling pattern, (b) Gerbert, (c) Fibonacci, (d) rabbits problem, (e) Llull,
(f) arithmetic and geometry, (g) Pacioli, (h) arithmetic symbols, (i) Dürer engraving

The Middle Ages renaissance in learning was largely due to three developments: the establishment of universities, the translation of Arabic texts into Latin, and the invention of printing. The first European university was in Bologna, founded in 1088, with Paris and Oxford following soon after. For hundreds of years, the curriculum was based on the Greek *quadrivium* (Figure 2(f)).

The invention of printing around 1440 enabled mathematical works to become widely available for the first time. At first, these were in Latin for the scholar, but gradually vernacular works appeared at prices accessible to all. These included texts in arithmetic, algebra, and geometry, and practical works on the mathematics of commerce. Important among these vernacular works was *Luca Pacioli*'s *Summa* in Italian (Figure 2(g)), a 600-page compilation of contemporary mathematics that included the first account of double-entry bookkeeping. Printing also led to a standardisation of *mathematical notation*: the symbols $+$ and $-$ first appeared in a German arithmetic text of 1489, but $\times$ and $\div$ were not used until much later (Figure 2(h)).

It was around this time that painters learnt how to give visual depth through geometrical perspective. Two of these were Brunelleschi who designed the dome of Florence Cathedral, and his friend Alberti who presented mathematical rules for perspective and insisted that "the first duty of a painter is to know geometry". Piero della Francesca wrote books on perspective that included polyhedron woodcuts by

Leonardo da Vinci who warned: "Let no one who is not a mathematician read my work". Another famous artist was Albrecht Dürer, who learnt perspective in Italy and introduced it into Germany. His engraving *St Jerome in His Study* shows his use of perspective (Figure 2(i)).

3. The age of exploration

The Renaissance period also coincided with many great sea voyages and explorations. In Portugal, Prince Henry the Navigator devoted his wealth and energies to maritime exploration, while Vasco da Gama became the first European to reach the west coast of India. Other well-known explorers included the Italian Christopher Columbus and Ferdinand Magellan of Portugal.

Such explorers needed accurate maps, and attempts to represent the spherical earth on a flat surface led to various types of map projection for use by navigators. Most notable was that of *Gerard Mercator* (Figure 3(a)) who projected the globe onto a vertical cylinder and adjusted the scale so that the lines of latitude and longitude appeared straight, as did fixed compass directions. Another early European to apply mathematical techniques to cartography was *Pedro Nunes* (Figure 3(b)), royal cosmographer and the leading figure in Portuguese nautical science.

For navigating at sea, *astrolabes* were used to determine latitude by measurements of the altitudes of heavenly bodies such as the sun or pole star (Figure 3(c)); other instruments included quadrants (in the shape of a quarter-circle, or 90°) and *sextants* (a sixth of a circle, or 60°) (Figure 3(d)). To measure an object's altitude, you viewed it along the top edge of the instrument, and the position of a movable rod on the rim gave the reading.

The 16th century was also important for astronomy, which was completely transformed when *Nicolaus Copernicus* replaced the Greek earth-centred planetary system by one with the sun at the centre and the earth as just one of the planets in circular orbits around it; his book *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Heavenly Spheres) was published in 1543 (Figure 3(e)). The Copernican system aroused much controversy, bringing its supporters into conflict with the church which placed the earth at the centre of creation.

Before the invention of the telescope, the greatest observer of the heavens was the Danish astronomer Tycho Brahe, who designed instruments of unequalled accuracy and measured over 700 stars. His assistant *Johannes Kepler* (Figure 3(f)) is remembered for his laws of planetary motion. From Tycho's extensive observations, he proposed *elliptical* orbits for the planets, with the sun at one focus, and introduced the word "focus" into mathematics. Kepler also rotated curves around an axis and found the volumes of many solids of revolution by summing thin discs, foreshadowing the integral calculus of some years later.

Figure 3. *The age of exploration*
(a) Mercator, (b) Nunes, (c) mariner's astrolabe, (d) sextant,
(e) Copernicus, (f) Kepler, (g) Galileo

Another Copernican supporter was *Galileo Galilei* (Figure 3(g)), who made extensive use of the telescope, drawing our moon's surface and discovering the moons of Jupiter and Saturn. His mechanics book *Discorsi e Dimostrazioni Matematiche Intorno a Due Nuove Scienze* (Discourses and Mathematical Demonstrations Relating to Two New Sciences) investigated uniform and accelerated motion and explained why the path of a projectile must be a parabola.

4. The 17th century

A major difficulty of the time, particularly for navigators and astronomers, was numerical calculation. In 1614 John Napier of Scotland introduced his "logarithms", designed to replace lengthy multiplications and divisions by easier additions and subtractions. These soon led to practical instruments based on a logarithmic scale, such as the *slide rule* (Figure 4(a)); dating from around 1630, they were used for over 300 years until pocket calculators appeared in the 1970s. The Slovenian mathematician *Jurij Vega* also published a celebrated compendium of logarithms, as well as 7-figure and 10-figure tables that ran to many editions (Figure 4(b)), and calculated π to 140 decimal places.

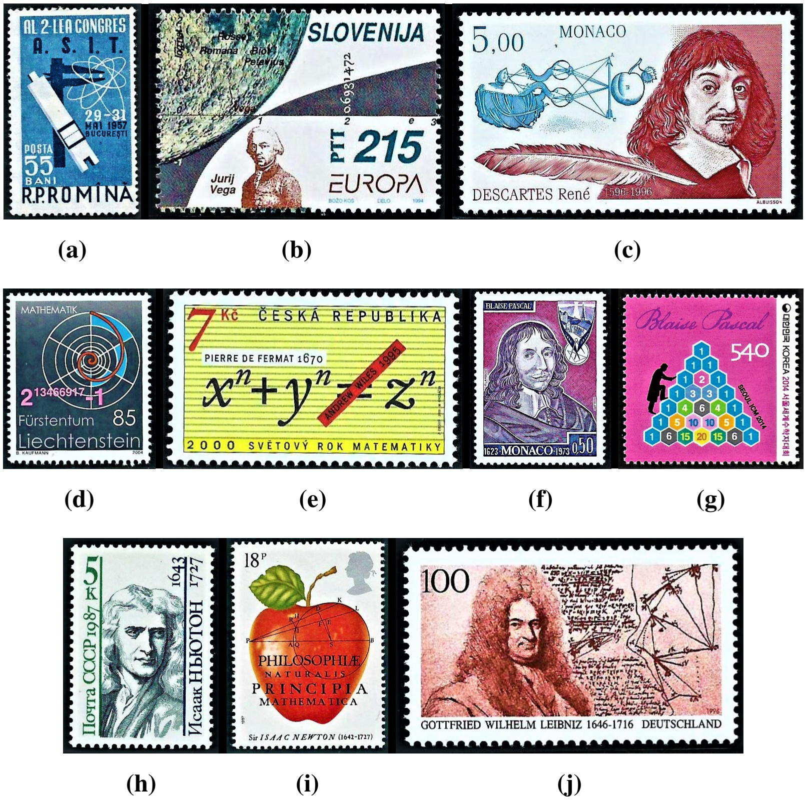


Figure 4. *The 17th century*
(a) Slide rule, (b) Vega's logarithms, (c) Descartes,
(d) Mersenne prime, (e) Fermat's last theorem, (f) Pascal, (g) Pascal's triangle,
(h) Newton, (i) Newton's *Principia*, (j) Leibniz

Meanwhile, in France, *René Descartes* (Figure 4(c)) solved an ancient problem of Pappus who had asked for the locus of a point that moved in a specified way relative to certain fixed lines. To solve this, Descartes named two lengths x and y and calculated every other length in terms of them, obtaining a quadratic expression (a conic) as the required path. In this way he introduced algebraic methods into geometry (a development that would continue over the next 100 years), but not the "Cartesian coordinates" that are named after him.

Marin Mersenne was a minimite friar living just outside Paris, who made great advances in the mathematical theory of sound and who is mainly remembered for listing prime numbers of the form $2^n - 1$, such as 3, 7, and 31. Fifty-one of these *Mersenne primes* are now known, and Figure 4(d) exhibits the largest Mersenne prime that had been discovered up to 2004.

Pierre de Fermat is mainly remembered for analytic geometry and number theory. In particular, he famously claimed to have proved *Fermat's last theorem*, that the equation $x^n + y^n = z^n$ has no non-zero integer solutions when $n > 2$ (Figure 4(e)). This was eventually proved by *Andrew Wiles* in 1995, as indicated on the stamp by the bar across the equals sign.

Blaise Pascal (Figure 4(f)) showed an early interest in mathematics – when only 16 he discovered his "hexagon theorem" about six points on a conic. One of the earliest to explore the theory of probability, he is also remembered for "Pascal's principle" in hydrodynamics, *Pascal's triangle* of binomial coefficients (Figure 4(g)), and for an early calculating machine, operated by cogged wheels, that could add and subtract.

In England, *Isaac Newton* (Figure 4(h)) was born in 1642, and at Cambridge University he was appointed Lucasian Professor of Mathematics, a post later held by Stephen Hawking. Together with Leibniz (but independently) he recognised the inverse relationship between differentiation and integration, the two branches of the calculus.

The story of Newton and the apple is well known. Seeing it fall, he realised that the gravitational force that pulled it to earth was the same as the force that keeps the moon orbiting the earth and the earth orbiting the sun – and claimed that this motion was governed by a "universal law of gravitation", where the force of attraction between two objects varies inversely as the square of the distance between them. In his *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy) of 1687, Newton used this law to explain Kepler's laws of elliptical planetary motion, and to account for cometary orbits, the variation of tides, and much else besides (Figure 4(i)).

Newton justly claimed priority for the calculus, but it was *Gottfried Leibniz* who was the first to publish it (Figure 4(j)). But his calculus was different from Newton's, being based on geometry rather than on velocity and motion. Also, his notation was more versatile than Newton's: his "D" for differentiation and his integral sign, which are still used today, were introduced within just three weeks of each other in the autumn of 1675.

5. The 18th century

The Bernoulli family included several distinguished Swiss mathematicians. In his book of 1713 on the "Art of Conjecturing", *Jakob Bernoulli* presented his *law of large numbers* (Figure 5(a)). With his brother Johann, he was the first to develop Leibniz's calculus, introducing the word "integral" and applying calculus to such curves as cycloids and spirals.

(a) **(b)** **(c)**

(d) **(e)** **(f)**

Figure 5. *The 18th century*
(a) Bernoulli, (b) Euler, (c) Königsberg bridges problem,
(d) geodetic missions, (e) d'Alembert, (f) Monge

Leonhard Euler also grew up in Switzerland, but spent his working life at the scientific academies of St. Petersburg and Berlin. The most prolific mathematician of all time, he contributed to almost every branch of mathematics and physics, from number theory and the calculus to mechanics, astronomy, and optics. Euler introduced the notations e for exponential, f for a function, i for $\sqrt{-1}$, and Σ for summation, and linked the exponential and trigonometric functions via his equation $e^{i\varphi} = \cos\varphi + i\sin\varphi$ as shown on the stamp (Figure 5(b)). In 1735 he solved the *Königsberg bridges problem* of deciding whether one can cross the seven bridges of the city visiting no bridge twice, but he never drew the associated graph that is often attributed to him (Figure 5(c)).

Newton had predicted that the earth's rotation causes a flattening at the poles, whereas an alternative theory of Descartes claimed that it is elongated. In the 1730s *geodetic missions* went to Peru (led by Charles-Marie de la Condamine) and Lapland (led by Pierre Louis de Maupertuis) to measure the swing of a pendulum and ascertain who was correct (Figure 5(d)). These missions confirmed Newton's view: the earth is flattened at the poles.

In France a leading Enlightenment figure was Jean d'Alembert (Figure 5(e)), who attempted to put the calculus on a firm basis by formalising the idea of a limit. He also derived the wave equation that describes the motion of a vibrating string, and in later years wrote many mathematical and scientific articles for Denis Diderot's *Encyclopédie* (Encyclopedia).

Napoleon Bonaparte's rise to power in France led to important developments in mathematics. Napoleon himself was interested in the subject – there's even a "Napoleon's theorem" – and his close friend, the geometer *Gaspard Monge* (Figure 5(f)), while investigating fortress gun emplacements, developed improved methods for projecting 3-dimensional objects onto a plane; this became known as "descriptive geometry".

6. The 19th century

An important consequence of the French Revolution was the founding in Paris of the École Polytechnique, where the finest mathematicians of the day – Monge, Lagrange, Laplace and Cauchy – taught students who were destined to serve in both military and civilian capacities.

Joseph-Louis Lagrange (Figure 6(a)) wrote on mechanics, functions, and number theory; and proved that every positive integer can be written as the sum of four squares. *Pierre-Simon Laplace* (Figure 6(b)) is remembered for the Laplace transform of a function and Laplace's equation in physics and wrote a monumental five-volume treatise on celestial mechanics that earned him the title of "the Newton of France". Shortly after the French Revolution, a commission was set up to standardise weights and measures and introduce a metric system; led by Lagrange, its members included Laplace and Monge.

Work in analysis continued with *Augustin-Louis Cauchy* (Figure 6(c)). The calculus was still on shaky foundations, but Cauchy rescued it with formal treatments of limits and continuity, while also developing complex analysis. Meanwhile, in Prague, *Bernard Bolzano* (Figure 6(d)) had formalised the idea of continuity before Cauchy, proving the "intermediate value theorem" that a continuous function takes every value between its greatest and least values.

In algebra a major breakthrough in 1826 occurred when the Norwegian *Niels Abel* (Figure 6(e)) solved a long-standing problem. Although there were general formulas for solving polynomial equations of degrees 2, 3, and 4, none was known for those of higher degrees. Abel showed that no such formulas can exist. Abel's work was continued by *Évariste Galois* (Figure 6(f)), who explained in algebraic terms exactly *which* equations can be solved. Galois had a short and turbulent life, being sent to jail for political activities and dying tragically in a duel at the age of 20, having sat up the previous night summarising all his mathematical achievements for posterity.

The Irishman William Rowan Hamilton was a child prodigy who discovered an error in Laplace's writings while a teenager and was appointed Astronomer Royal of Ireland when he was still a student. He made important advances in mechanics and geometrical optics, and while attempting to generalise the complex numbers

(a) (b) (c) (d)

(e) (f) (g)

(h) (i) (j) (k)

(l) (m) (n) (o)

Figure 6. *The 19th century*
(a) Lagrange, (b) Laplace, (c) Cauchy, (d) Bolzano,
(e) Abel, (f) Galois, (g) Hamilton's quaternions,
(h) Gauss and polygon, (i) Bolyai's geometry, (j) Lobachevsky, (k) Chebyshev,
(l) Kovalevskaya, (m) Agnesi, (n) Germain, (o) Nightingale

discovered the *quaternions*, a non-commutative system that involves *three* interconnected square roots of -1 (i, j, and k), as shown in Figure 6(g).

Meanwhile, in Germany, *Carl Friedrich Gauss* worked in many areas, from complex numbers (the "Gaussian number plane") to statistics (the "Gaussian distribution"). One of the greatest mathematicians of all time, he also discovered which regular polygons can be drawn by straight-edge and compasses alone – these include triangles and pentagons, and also a regular polygon with 17 sides (Figure 6(h)).

In the early 19th century, there were important developments in geometry. Euclid's *Elements* opens with five "postulates" – four are straightforward, but the fifth is more complicated and seemed to be provable from the others. One version of it was the "parallel postulate": "given a line *L* and any point *O* not on it, there is a *unique* line through *O*, parallel to *L*". For two millennia, mathematicians tried to deduce this from the other postulates, but they were unsuccessful because there are geometries that satisfy the first four postulates but not the fifth: these have *infinitely many* lines through *O* parallel to *L* (Figure 6(i)). Described around 1830 by *Nikolai Lobachevsky* of Russia (Figure 6(j)) and János Bolyai of Hungary, they forced mathematicians to ask: "Which geometry corresponds to the world we live in?" – our familiar Euclidean geometry or a non-Euclidean one? (The familiar spherical geometry of our globe is not a true geometry in the Euclidean sense, as two lines, or great circles, meet in more than one point.)

In Russia, *Pafnuty Chebyshev* (Figure 6(k)) investigated orthogonal functions ("Chebyshev polynomials"), probability ("Chebyshev's inequality"), and prime numbers. *Sofia Kovalevskaya* (Figure 6(l)) contributed to mathematical analysis and partial differential equations and won a coveted prize from the French Academy of Sciences for a memoir on the rotation of bodies; barred by her gender from studying in Russia, she later became the first female professor in Stockholm.

Other women mathematicians who have featured on stamps include *Maria Gaetana Agnesi* (Figure 6(m)), who published an early book on the calculus and after whom the cubic curve known as the "witch of Agnesi" is named, and *Sophie Germain* (Figure 6(n)), whose pioneering work on prime numbers and Fermat's last theorem greatly impressed Gauss; she also made important contributions to the theory of elasticity. *Florence Nightingale* saved many lives through her sanitary improvements in Crimean War hospitals; an accomplished statistician, she analysed Crimean mortality data and displayed them using her "polar diagrams", as depicted in Figure 6(o).

7. The 20th century

It was in the 20th century that mathematicians created the subject as we now know it. What follows is a brief selection.

Henri Poincaré (Figure 7(a)) worked on the still-unsolved "three-body problem" of determining the simultaneous motion of the sun, earth, and moon. A gifted populariser of mathematics, he also developed algebraic topology, differential equations, celestial mechanics, and much else. The range of *David Hilbert* was also immense – from number theory, "Hilbert space", and a space-filling curve (Figure 7(b)) to potential theory and the theory of gases. In 1900 he gave a celebrated lecture at the International Congress of Mathematicians in Paris, posing 23 mathematical problems that set the agenda for research over the coming century.

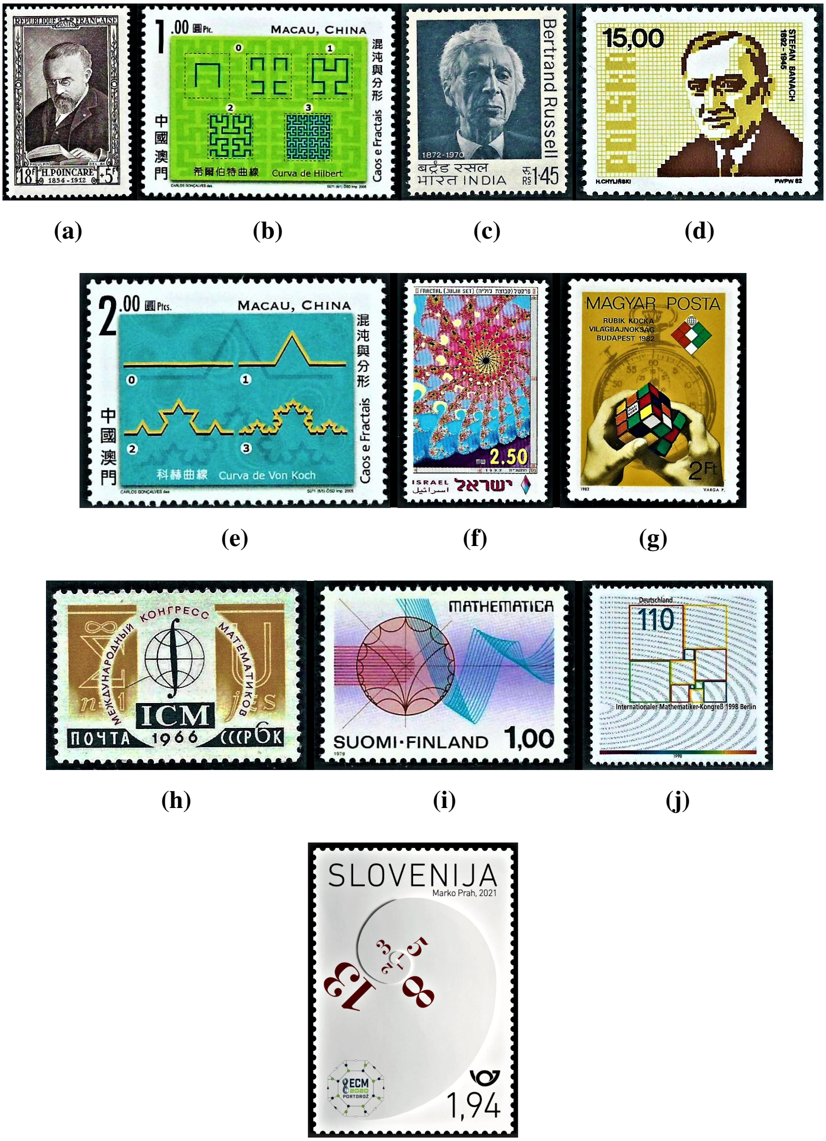
In England, *Bertrand Russell* (Figure 7(c)) made fundamental contributions to mathematical logic, such as "Russell's paradox", and with A. N. Whitehead wrote a three-volume *Principia Mathematica* on the foundations of mathematics, while in Poland *Stefan Banach* (Figure 7(d)) helped to create modern functional analysis and develop links between topology and algebra: the term *Banach space* is named after him.

Fractal patterns are "self-similar", in that they reproduce themselves for ever when magnified or reduced, such as von Koch's snowflake curve (Figure 7(e)), which has infinite length but encloses a finite area. Figure 7(f) features a *Julia set*, a fractal pattern that arises from iterating a quadratic formula.

For something more light-hearted, Figure 7(g) shows *Rubik's cube*, whose faces can be rotated to yield over 10^{19} different patterns; the object is to restore the original colours. In the early 1980s, when the craze was at its peak, over 100 million cubes were sold.

Mathematics continues to advance at an ever-increasing rate, and since 1897 the *International Congresses of Mathematicians* have been held regularly around the world, at which thousands of mathematicians gather to learn about the most recent developments in their subject. Several of these gatherings have been commemorated on stamps – those from Europe include *Moscow* in 1966 (Figure 7(h)), *Helsinki* in 1978 (Figure 7(i)), and *Berlin* in 1998 (Figure 7(j)). As for the European Congresses of Mathematics, only two stamps have been issued: in 1996 for the second congress in Hungary, and recently for the eighth one, 8ECM, at Portorož, showing the Fibonacci sequence (Figure 7(k)).

Postage stamps provide an attractive vehicle for presenting mathematics and its development. This brief account has shown how the subject has been shaped by factors ranging from scientific and geographical developments and trade to education. Crucial to this story have been the attempts to solve a wide range of theoretical and practical problems, as well as the subject's internal logic by which it has progressed to increasingly greater abstractness.



(a) (b) (c) (d)

(e) (f) (g)

(h) (i) (j)

(k)

Figure 7. *The 20th century*
(a) Poincaré, (b) Hilbert curve, (c) Russell, (d) Banach,
(e) von Koch curve, (f) Julia set, (g) Rubik's cube,
(h) 1966 ICM Moscow, (i) 1978 ICM Helsinki, (j) 2008 ICM Berlin,
(k) 2021 8ECM Portorož

See [5, 6] for further information about mathematical stamps, and [1–4] for accounts of the history of mathematics. Many mathematical stamps are featured on the website www.mathematicalstamps.eu

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