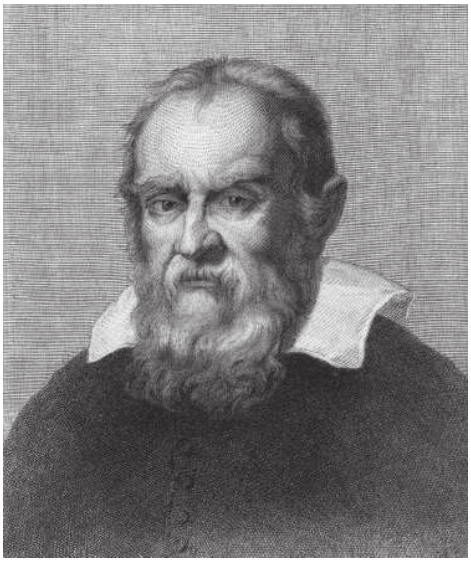
1 From Galileo to Daniel Bernoulli

Our first five remarkable physicists were born in the 137 years from 1564 to 1700. They came from Italy, Germany, the Netherlands, England and Switzerland.

Galileo Galilei (1564–1642)

The great scientist we know as Galileo was born in Pisa on February 15, 1564. He was the eldest son of the notable composer, lutenist and musical theorist Vincenzio Galilei, of a long-established Florentine family, and his wife Giulia (née Ammananti), a native of Pisa who considered herself socially superior to her husband. They had five or six other children. Like Dante, Leonardo, Michelangelo and other great Italians of that period he is universally known by his first name rather than by his family name. In 1574 the family moved to Florence. After four years of education in the Camaldolese abbey of Vallombrosa on the upper Arno, Galileo was expecting to make his career in the church. However, his father decided otherwise and arranged for his son to live in Pisa with a cousin, who would train him as a wool merchant. Before long it became clear that the young man was unusually able and so, at the age of seventeen, he entered the University of Pisa, training to become a doctor in accordance with his father's wishes. However, he was dissatisfied with the lectures provided, left after four years without taking a degree, and when he returned home it was to work on mathematics. Apparently he was introduced to the subject by Ostilio Ricci, said to have been a student of Tartaglia's, who was mathematician at the court of the Grand Duke of Tuscany. Galileo took pupils and gave some public lectures on mathematics in Siena and Florence. In 1587 he visited the leading Jesuit astronomer and mathematician Father Christopher Clavius at the Gregorian University in Rome, who was interested in his first research papers, one on the determination of centres of gravity of parabolic conoids and another on an ingenious balance (*La bilancetta*) he had designed for determining specific weights with precision.

In 1589 Galileo was appointed to a teaching post in mathematics at the priest-dominated University of Pisa, at that time something of an intellectual backwater. During his time there he wrote, but did not publish, a



paper called *De motu*, about the flight of projectiles and other dynamical problems. Three years later he moved to a professorship in Padua, one of the leading universities of Europe, where Copernicus had taught and Dante had studied. Padua, in the Venetian Republic, offered a far more congenial atmosphere than Pisa. Professors were not well-paid; they were expected to supplement their modest salaries by private tuition. Galileo was an excellent teacher, whose students were devoted to him. He presided over a lively household of young men to whom he taught practical subjects such as military architecture, elementary astronomy and perspective. He also ran a small workshop to manufacture scientific instruments, and, as a result of his entrepreneurship, he became a man of means. Even so, after the death of his father in 1591, he found it difficult to meet his responsibilities towards his improvident brother, who frequently came to him for money, also his sisters needed dowries if they were to marry, so that at times he ran the risk of being arrested for debt.

In the nearby city of Venice Galileo found friends in the nobility. The most important of these was Gianfrancesco Sagredo, a confirmed bachelor, who seemed to have been exhausted by dissipation in his youth. However, as he grew older he turned to tamer pursuits, including wild parties at his country estate on the River Brenta. Sagredo was interested in science and he formed a lasting friendship with Galileo, which they continued by correspondence when the Doge sent Sagredo to Aleppo for three years in a

diplomatic capacity in 1608. Galileo never married but he formed a lasting relationship with a twenty-one-year-old Venetian serving-woman named Marina Gamba, said to be beautiful, hot-tempered, lusty and probably illiterate. Galileo's shrewish mother thoroughly disapproved of her and caused trouble. Marina had three children by Galileo: Vincenzo, Virginia and Livia. Galileo took an interest in their son's education; once they were old enough he placed their daughters in the convent of San Matteo in Arcetri, on the outskirts of Florence.

Galileo was already coming round to the view that the heliocentric system of Copernicus was much more plausible than the geocentric system of Aristotle and Ptolemy. In this he was influenced by the German astronomer Johannes Kepler, whose profile comes next. Among other things, Galileo invented a machine for raising large amounts of water from aquifers, an air thermoscope and a computing device for geometrical and ballistic purposes described in his first printed work *Le operazioni del compasso geometrico e militare* (Padua, 1606), which described the operation of a lightweight military compass he had designed in collaboration with a Venetian toolmaker. In pure science his research led him about 1602 to the discovery of the isochronicity of the pendulum and to the preliminary but wrong discussion of the law of falling bodies. In 1609 he was the first to apply the newly invented telescope to astronomical observations, revealing the mountains on the moon, numerous stars invisible to the naked eye, the nature of the Milky Way and four of Jupiter's satellites (named the Medicean stars). These sensational discoveries were described in his *Sidereus nuncius* (*The Sidereal Messenger*) (Venice, 1610), one of the most important scientific books of the seventeenth century, which at once made Galileo famous all over Europe. The popular excitement was overwhelming.

The Pope had declared the first year of the new century to be a Jubilee year. It was to be a year of celebration but also of renewed determination to stem the tide of reform. The greatest intellectual of the church of Rome, Cardinal Robert Bellamine, led the drive to stamp out heresy. One of the first victims was the Dominican friar Giordano Bruno, who was imprisoned, tortured and burnt at the stake for his beliefs. He conjectured that 'There are countless constellations, suns and planets; we see only the suns because they give light; the planets remain invisible, for they are small and dark. There are also numberless earths, circling round their suns.'

Students came from many parts of Europe to sit at Galileo's feet, including French, English, German and Polish nobility, also the Swedish King Gustavus Adolphus. The new Grand Duke of Tuscany, young Cosimo

de Medici, was one of his former pupils. In 1610, feeling he was not sufficiently appreciated in the Venetian Republic, Galileo relinquished his chair at the University of Padua after eighteen years of great creative activity and accepted an appointment as chief mathematician and philosopher at the court of the Medicis. Back in Florence, he devoted his entire energy to scientific research under the benevolent protection of the Grand Duke. In his social circle, the place of Sagredo was taken by a wealthy and accomplished young patrician named Filippo Salviati. His country retreat Le Selve in the hills above the lower Arno became a centre for philosophical discussions, in which Galileo was surrounded by young disciples.

Galileo decided it was time for another visit to Rome, this time as a kind of scientific ambassador, sponsored by the Grand Duke. Galileo was received by Pope Paul V, the successor of Clement VIII, and generally lionized. He set about promoting the new cosmology by demonstrating the latest discoveries. These included the phases of the planet Venus, the composite structure of Saturn and the existence of sun-spots, all described in his *Istoria e dimostrazioni intorno alle macchie solari* (Treatise on Sunspots) (Rome, 1613). However, the Jesuits at the Gregorian University continued to cling to the old cosmology. One of them was Father Clavius, on whom he had called twenty-four years earlier; the German mathematician took note of Galileo's discoveries, but refused to embrace Copernicanism.

Galileo found an important new patron in Federico Cesi, an influential young nobleman who possessed an enormous curiosity and the courage to break the confines of his aristocratic upbringing. When he was only eighteen Cesi had established the Accademia dei Lincei, arguably the first successful scientific society to be founded in the seventeenth century. The stated aim of the Lincei was to bring together 'philosophers who are eager for real knowledge, and who will give themselves to the study of nature, and especially to mathematics. At the same time, it will not neglect the ornaments of elegant literature and philology, which like graceful garments, adorn the whole body of science.' Initially the society had only four members, all non-scientists and all under thirty years of age; there hung about the Lincei a certain air of the occult and of pseudo-science, even the taint of scandal. The society held its meetings in Cesi's palace, which contained a splendid library, including many proscribed books, and a collection of scientific instruments, specimens and curiosities. Its early fame rested mainly on Galileo's participation; later it gave him much-needed support, stimulus and encouragement. Cesi was too powerful to have to worry about what the Jesuits at the Gregorian University thought.

Galileo was becoming more and more audacious in pointing to the incompatibility of the new celestial phenomena with traditional astronomy. He openly confessed his Copernican conviction, already stated in a letter to Kepler, at the same time as he successfully attacked current views on hydrostatics in his *Discorso intorno alle cose che stanno in su l'acqua* (*Bodies in Water*). Increasingly Galileo had to defend his discoveries and opinions against numerous attacks from scientific opponents and jealous academic enemies. A conspiracy among the latter aiming at Galileo's downfall led first to an abusive sermon against him in Florence in 1614. There were signs of paranoia in his reaction, although the enemies were real enough. The most powerful of these was Cardinal Bellarmine, the persecutor of Giordano Bruno, who warned him not to defend the Copernican system in public. As a result, he wrote a letter to Christina, the mother of the Grand Duke, giving his carefully considered opinions about the proper relation between science and religion; this *Letter to the Grand Duchess Christina* was not published until 1636.

Galileo was already fifty years of age. He was suffering from arthritis, a condition of long standing, and from pains in the chest and kidneys. On his return from Rome he first took advantage of Salviati's villa Le Selve to recuperate before settling down in a modest villa of his own, at Bellosguardo, overlooking Florence and not too far from Arcetri where his daughters lived inside their convent. However, it is hardly surprising that the following years saw some decline in his scientific activity. He mainly occupied himself with computing tables of the motion and eclipses of the moons of Jupiter, which could be used to determine longitude at sea. He tried in vain to sell this idea to the Spanish and Dutch governments. In 1618 he was involved in a bitter argument over the nature of comets, which lost him the sympathy of his former supporters among the Roman Jesuits. A result of this controversy was the polemical work *Il saggiatore* (*The Assayer*) (Rome, 1623) in which Galileo expressed his thoughts on epistemological and methodological questions, stressing the necessity of quantitative experiments and observations and the strength of hypothetical–deductive reasoning.

In 1623 one of his former supporters, Cardinal Maffeo Barberini, became Pope Urban VII, and, after a fourth visit to Rome, Galileo felt himself encouraged to begin with the composition of a major work on astronomy, planned many years before and finally published under the title *Dialogo sopra i due massimi sistemi del mondo* (*Dialogue Concerning the Two Chief World Systems*). This was a technical account in the form of a dialogue among a supporter of the Aristotelian–Ptolemaic tradition named

Simplicio, a youthful enquiring mind named Sagredo and an advocate of the new astronomy named Salviato. Galileo had tried to safeguard himself by letting Simplicio prevail, and the book was published with the imprimatur of the ecclesiastical authorities. Nevertheless the strength of Salviato's arguments was evident.

The initial reception of the book was generally favourable, but it gave Galileo's enemies the opportunity they had been waiting for. The Pope thought the imprimatur should never have been granted and tried to have the book suppressed, but it was too late. He decided that Galileo must stand trial and summoned him to Rome. The Grand Duke was powerless to shield Galileo from the wrath of the Pope. For reasons of health Galileo asked for the proceedings to be held in Florence. This was refused but, as a concession, when he arrived in Rome, instead of being committed to prison while awaiting trial, he was allowed to live in the Tuscan embassy. Formally the charge against him was one of disobedience. His accusers maintained that Bellamine in 1616 had formally admonished Galileo not to promote Copernicanism in public; Galileo denied this, documentation was lacking and Bellamine was no longer alive to give evidence. During the trial the ailing Galileo was imprisoned in the Vatican, until eventually, more dead than alive and under threat of torture, he was forced solemnly to abjure his Copernican convictions before the Congregation of the Holy Office, before being sentenced to life imprisonment and punished in other ways.

Initially he was confined to the palace of the Archbishop Ascanio Piccolomini of Siena, a man of broad cultural interests, where he was treated as an honoured guest. Before long, however, the Pope's agents reported that the episcopal palace did not keep him sufficiently isolated and he was allowed to move to his villa in Bellosguardo. In 1631, finding the journey from there to see his daughters too much, Galileo proposed to move to a house in Arcetri itself. The Pope agreed that he could do so, although still effectively under house arrest, since he was not even allowed to go to nearby Florence without permission, which was sometimes withheld. His younger daughter Livia suffered from depression but Galileo was to find great comfort in the company of his elder daughter Virginia in his declining years. In the simple beauty of the weekly letters she sent him, as 'Suor Maria Celeste', we can follow her efforts to comfort him and lift his spirits; unfortunately his side of the correspondence has not survived. Sadly, she died from dysentery not long after he had arrived in Arcetri, at the age of thirty-three.

Galileo's own health was seriously threatened; there was a troublesome hernia and palpitations of the heart, and he also suffered from insomnia and melancholia. He continually heard his beloved daughter calling him. The Florentine Inquisitor was right to believe that the aged Galileo would never again attempt to promote Copernicanism. In fact, Galileo went further by stating that the falsity of Copernicanism must not on any account be called into doubt, especially by Catholics. All Copernican conjectures, he wrote, are removed by the most solid arguments from God's omnipotence. He had resigned himself to the fact that his own part in the campaign to establish Copernicanism was over, although his personal convictions remained the same and many were protesting against the injustice of his condemnation and sentence.

Galileo engaged in new research, although hampered both by cataracts and by glaucoma, ending in complete blindness, and by the constant supervision of the Inquisition. He succeeded in finishing his final and most important work, the *Discorsi e dimostrazioni matematiche intorno a due nuove scienze* (*Discourses on Two New Sciences*) (Leyden, 1638), which was, significantly, published beyond the reach of the Inquisition. This work, containing among other things the proof of the laws governing the fall of a body in a vacuum, the principle of the independence of forces and the complete theory of parabolic ballistics, was destined to become one of the cornerstones upon which Huygens and Newton one generation later built classical mechanics. The laws of fall made it possible to study accelerated motion. Simplicio, Sagredo and Salviati reappear to debate the arguments in another dialogue like the one he had used in 1632; Galileo's fondness for this manner of presentation may have come from his father, who in 1581 had published a *Dialogo della musica antica e moderna*. Galileo died at Arcetri during the night of January 8, 1642. He was buried privately in Santa Croce, the great church where so many famous Tuscans lie, but not in the Galilei family tomb, for fear of Papal disapproval. No monument to his memory was erected until 1737, when he was re-interred and the skeleton of a young woman was found beneath his in the original grave; it is thought that this could have been his beloved daughter.

Galileo had a versatile mind. He was an accomplished amateur musician and a master of the vernacular language; his polemical work *Il saggiatore* is one of the Italian classics. He occupied himself with almost every branch of physics, but is chiefly remembered for the example he gave of the efficacy of the hypotheco-deductive method combined with quantitative experiments. In general history too he occupies an important place because

of his personal fate, which was an important factor in the widening fissure between natural science and the spirituality of the counter-Reformation. The last traces of official anti-Copernicanism were not removed until 1822. While geocentrism was the official doctrine, there was some latitude for teaching heliocentrism as a working hypothesis in schools and universities where Jesuits were in control.

Johannes Kepler (1571–1630)

Kepler was a near-contemporary of Galileo but his life-story was very different, as was his family background. He was born in the small Lutheran town of Weil der Stadt, near Stuttgart, on December 27, 1571. Judging by the account Kepler wrote of his early life, he seems to have had a most miserable childhood. He described his father Heinrich as 'criminally inclined, quarrelsome, liable to a bad end' and his mother Catharina (née Guldenmann), as 'small, thin, swarthy, gossiping and quarrelsome', adding that 'treated shabbily, she could not overcome the brutality of her husband'. When he was three years old, his father joined a group of mercenary soldiers to fight the Protestant uprising in Holland. His mother followed her husband to Flanders. The children were abandoned to the care of grandparents who treated them roughly. When their parents returned in 1576 the family, in disgrace because of Heinrich's part in the persecution of Protestants, had

to leave Weil for nearby Leonberg, in the Grand Duchy of Württemberg. Heinrich rejoined the infamous Duke of Alba's military service for a few more years; by 1588 he had abandoned his family forever.

The future astronomer was a sickly child, with thin limbs and a large pasty face surrounded by dark curly hair. He was born with defective eyesight – short-sighted in one eye, multiple vision in the other. His stomach and gall bladder gave constant trouble; and he nearly died from smallpox. He began his education at the German Schreibschule in Leonberg but soon moved to the Latin school, there laying the foundation for the complex Latin style displayed in his later writings. After a period of 'hard work in the country', during which he did not attend school at all, he entered the Adelberg monastery school at thirteen; and two years later enrolled at the more senior Maulbronn, one of the preparatory schools for the Protestant University of Tübingen. In October 1587 Kepler formally matriculated at the university; but because no room was available at the Stift, the seminary where, as a student supported by the enlightened Duke of Württemberg, he was expected to lodge, he continued at Maulbronn for another two years. In September 1588 he passed the baccalaureate examination at the university, although he did not actually take up residence there until the following year. He was unpopular with his fellow-students, who gave him a hard time.

At Tübingen, Kepler's thought was profoundly influenced by Michael Maestlin, the professor of mathematics and astronomy. Although Maestlin was at best a very cautious Copernican, the 1543 *De revolutionibus* he owned is probably the most thoroughly annotated copy extant; he edited the 1571 edition of the *Prutenicae tabulae* and used them to compute his own *Ephemerides.* Kepler was an exemplary student; and, when he applied for a renewal of his scholarship, the university senate noted that he had 'such a superior and magnificent mind that something special may be expected of him'. Nevertheless, although Kepler himself wrote concerning his university education that 'nothing indicated to me a particular bent for astronomy', in student disputations he often defended Copernicanism.

In August 1591 the twenty-year-old Kepler received his master's degree from Tübingen and thereupon entered the theological course. Halfway through his third and last year, however, there occurred an event that completely altered the direction of his life. The teacher of mathematics and astronomy at the Lutheran school in the Styrian capital of Graz had died, and Tübingen was asked to nominate a replacement. Kepler was chosen, and, although he was reluctant to abandon his intent of becoming

a Lutheran pastor, at the age of twenty-two he embarked on the career destined to immortalize his name.

Kepler arrived in southern Austria in April 1594 to take up his duties as teacher and as provincial 'mathematicus'. In the first year he had few pupils in mathematical astronomy and in the second year none, so he was asked to teach Virgil and rhetoric as well as arithmetic. However, the young Kepler made his mark in another way; one of the duties of the mathematicus was to produce an annual calendar of astrological forecasts. His first calendar, for 1595, contained predictions of bitter cold, peasant uprisings and Turkish invasions. All were fulfilled, to the great enhancement of his local reputation. Five more calendars followed in annual succession, and later, when he had moved to Prague, he issued prognostications for the years 1602 to 1606. Later still Kepler produced a series of calendars from 1618 to 1624, excusing himself with the remark that, when his salary was in arrears, writing calendars was better than begging.

Kepler's attitude to astrology was mixed. He rejected most of the commonly accepted rules and repeatedly referred to astrology as the foolish stepdaughter of astronomy. However, casting horoscopes provided welcome supplementary income and later became a significant justification for his office as imperial mathematicus. Moreover, the profound feeling he developed for the harmony of the universe included a belief in a powerful accord between the cosmos and the individual. These views found their fullest development in the *Harmonicae mundi*, published towards the end of his life.

Meanwhile, just over a year after his arrival in Graz, Kepler's fertile imagination hit upon what he believed to be the secret key to the universe – the number, dimensions and motions of the planets. This theory, published in his decisively pro-Copernican treatise *Mysterium cosmographicum* of 1596, was based on the idea that the five regular solids space out the six known planets; each planetary orbit is circumscribed by a regular solid and has inscribed in it the solid of the next planet below. Although the principal idea was erroneous, Kepler established himself as the first (and, until Descartes, the only) scientist to demand physical explanations for celestial phenomena.

Kepler had submitted his manuscript to the scrutiny of the Tübingen senate because his publisher would not proceed without its approval. Although they raised no objection to the publication, he was requested to explain his discovery in a clearer and more popular style. When it appeared, the reasons for abandoning the Ptolemaic in favour of the Copernican