Istituto e Museo
di Storia della Scienza

Court Scientists

The Art of Experimentation
in the Galilean Accademia del Cimento
(1657-1667)

INDEX

1. THE HISTORY

"Most Serene Lord,

The printing of the first samples of the experiments in natural philosophy that have been made for many years in our Academy with the assistance and under the continued protection of the Most Serene Prince Leopoldo Your Highness' brother, will itself carry to those regions of the world in which virtue shines most brightly, new evidence of the great munificence of Your Highness and call back towards you with a new sense of gratitude the true lovers of the fine arts and the most noble sciences."

(*Saggi di naturali esperienze*, Florence)

1.1. THE ORIGINS

Founded in 1657 by Prince Leopoldo and the Grand Duke of Tuscany Ferdinando II de' Medici, the Accademia del Cimento [Academy of Experiment] was the first scientific society in Europe, preceding the Royal Society of London and the Académie des Sciences of Paris by a few years. The foundation of the Accademia del Cimento institutionalized an informal tradition of experimentation started in the Court of Ferdinando II in the mid 1640s. The declared purpose of the Academy was the development and diffusion of Galilean experimental methodology. The academicians dedicated themselves to the systematic experimental verification of interpretations of natural phenomena that had, until then, been upheld purely on the authority of Aristotle. Those who regularly participated in the work included Lorenzo Magalotti, Vincenzo Vivinai, Giovanni Alfonso Borelli, Carlo Renaldini and Francesco Redi, while amongst the most illustrious correspondents Christaan Huygens, Robert Hooke, Gian Domenico Cassini, Athanasius Kircher and Henry Oldenburg deserve to be mentioned. The Accademia did not have rules; nor did it feel a need for them, since every issue depended on the supreme authority of the Prince: they lacked any form of autonomy. Their experimentation concentrated on the barometer and on the thermometer, new fields of research stimulated by the experiment by which, in the spring of 1644, Evangelista Torricelli demonstrated the existence of atmospheric pressure and the possibility of the void. The Accademia's activities concluded in 1667 with the publication of the *Saggi di naturali esperienze* [Examples of Natural Experiments], written up by its Secretary, Lorenzo Magalotti.

1.2. THE ACCADEMIA AND MEDICI PATRONAGE

Since the time of Cosimo I (1519-1574), the Medici carried out a sophisticated patronage of science, attaining international success with the protection granted to Galileo (1564-1642) and his dedication to the Medici dynasty of the satellites of Jupiter. The project of the Accademia del Cimento was directly promoted and personally controlled by Grand Duke **Ferdinando II** and by Prince **Leopoldo de' Medici**, and represents their greatest success in a long process of defining the Medicean strategy for promoting the sciences. Leopoldo was the Academy's patron and he diligently supervised its scientific work, even assuming the duty of resolving its frequent 'philosophical controversies'. He also assumed the enormous costs of supplying experimental equipment, since the Academy had neither its own budget nor financial account. The princes entrusted the Academy with the task of relaunching Galileo's image as a Medicean hero, an image s overshadowed by the Church's condemnation of his Copernicanism in 1633. Their constant presence imposed cast-iron rules of caution on the Academy, a rigid etiquette and the adoption of the style of conduct and communication typical of the court in the Baroque period.

1.3. THE ACCADEMIA'S SETTINGS

Florence, Pitti Palace

The Accademia del Cimento met in the Pitti Palace, the Medici's royal palace since 1553. The sessions were usually held in some rooms adjacent to the apartment of Prince Leopoldo's(1617-1675). Some experiments were also conducted in the adjoining Boboli Gardens.

Florence, Palazzo Vecchio

In September 1657, a barometric experiment was carried out in the Palazzo Vecchio to check the variation in atmospheric pressure at differing altitudes. This was done by comparing the degrees marked on the same barometer at the level of the Piazza della Signoria and at the top of the tower of the Palazzo Vecchio. Notable variations were observed in the height of the column of mercury, confirming the findings of Blaise Pascal (1623-1662) in his experiment on the summit of the Puy de Dôme in 1648.

Florence, Giotto's bell tower

On the evening of July 24, 1663, the Academy checked "the experiment of the movement of light: whether at a distance of twenty miles, (from Florence to Pistoia) the light of a fire uncovered at night goes instantaneously, or if it happens in time". In Pistoia was Vincenzo Viviani (1622-1703), while Lorenzo Magalotti (1637-1712) and Francesco Landini were in Giotto's bell tower in Florence.

Florence, San Miniato al Monte

From some rooms in the ancient fortress of San Miniato al Monte, Giovanni Alfonso Borelli (1608-1679), one of the most prominent personalities of the Accademia del Cimento, observed the passing of a comet in 1665.

Artimino

In the Medicean Villa of Artimino and the surrounding countryside, barometric experiments were carried out to examine the variation of atmospheric pressure at various altitudes. Numerous measurements of the atmospheric humidity using a condensation hygrometer in diverse meteorological conditions were taken (September 1657).

Gorgona Island (Tuscan Archipelago)

On June 16, 1666, from the highest point on the mountain of the island of Gorgona, Donato Rossetti (1633-1686), a clergyman from Livorno and student of Giovanni Alfonso Borelli (1608-1679) and of Lorenzo Bellini (1643-1704), used a telescope to observe and draw, on behalf of the Accademia del Cimento, a 'horizontal' eclipse of the Moon, a rare phenomenon in which the setting Sun and the eclipsed Moon appeared simultaneously above the horizon.

Livorno

Experiments on the phenomena of freezing were carried out between the end of 1657 and the beginning of 1658. On April 2, 1662 the tower of the Fortezza Vecchia was the setting for observations on projectile motion.

Pisa

During the years of the Accademia del Cimento, a kind of branch office for the Accademia operated at the University of Pisa. Here Giovanni Alfonso Borelli (1608-

1679) and his young talented assistants, Carlo Fracassati (1630-1672), Marcello Malpighi (1628-1694) and Lorenzo Bellini (1643-1704), revealed the structure and function of the fundamental organs of the living machine, such as the tongue, kidneys, testicles and lungs. In addition, Carlo Renaldini (1615-1679) attempted on several occasions to examine the altitudinal variations in the level of mercury "at the foot and the summit of the bell tower of Pisa", but without managing to "produce anything of worth".

Pistoia

On the evening of July 24, 1663, the Academy checked "the experiment of the movement of light: whether at a distance of twenty miles, (from Florence to Pistoia) the light of a fire uncovered at night goes instantaneously, or if it happens in time". In Pistoia was Vincenzo Viviani (1622-1703), while Lorenzo Magalotti (1637-1712) and Francesco Landini were in Giotto's bell tower in Florence.

Poggio a Caiano

Acquired by Lorenzo Il Magnifico (1449-1492) in 1479, this Medicean villa boasts rich interior decorations commissioned by Giovanni de'Medici, with frescos by Andrea del Sarto (1486-1530), Pontormo (1494-1556) and Alessandro Allori (1535-1607). In the latter's paintings and frescos, glass objects are often depicted that appear similar to the scientific instruments belonging to the Accademia del Cimento.

Vallombrosa

Between the 17th and 18th centuries, the monastery of Vallombrosa was an important point of reference for Tuscan scientific culture. The Vallombrosans conducted surveys for the Medicean meteorological network as well as botanical research.

1.4. OTHER SCIENTIFIC ACADEMIES

Accademia dei Lincei (the Lynxes)

The Accademia dei Lincei was founded in 1603 on the initiative of the young Prince Federico Cesi (1585-1630) who was joined by Anastasio De Filiis (1577-1608), Johannes Van Heeck (1574-after 1616) and Francesco Stelluti (1577-1646). The Academy set as its goal the radical renewal of knowledge, carrying out a spirited attack against the dominant Aristotelian philosophy. It adopted the emblem of the lynx, symbol of sharp and penetrating vision. The Academy immediately grasped the revolutionary potential of

Galileo's (1564-1642) astronomical discoveries and urged him to join, which he did on 25th December 1611. They supported his war waged against the bastions of traditional culture, and later against the hostility of the ecclesiastical authorities. The Academy promoted and published Galileo's *Istoria e dimostrazioni intorno alle macchie solari* [*History and Demonstrations concerning Sunspots*] in 1613 and the *Saggiatore* [Assayer] in 1623. The Accademia broke up in 1630, following the death of Federico Cesi.

Royal Society

This London-based scientific society was founded in 1660 by a group of natural philosophers inspired by Robert Boyle's (1627-1691)They met at Gresham College in London with the intention of promoting mathematical-experimental science, following the teachings of Francis Bacon (1561-1626). The period of foundation continued from 1660 to July 15, 1662, when the Society obtained Charles II's (1630-1685) royal recognition. In return, the Crown was entitled to appoint the Society's President, but the Society maintained full autonomy. They received no financial backing from the Monarchy. From 1665 on, the Royal Society published the "Philosophical Transactions", the first European scientific journal, which quickly became a medium for the diffusion of new scientific ideas. Amongst its members were the greatest scientists of Britain and Europe. Robert Hooke (1635-1702) long served as Secretary, charged with planning and preparing the experimental sessions. The Royal Society was for a long time chaired by Isaac Newton (1642-1727) who published his famous articles on light and color in the "Philosophical Transactions" in 1672. The Royal Society's prestige was preserved unchanged through the succeeding centuries. The institution is still active and preserves one of the most important archives in the world in its London base.

Académie Royale des Sciences

The Académie Royale des Sciences was founded in 1666 during the reign of Louis XIV, on the initiative of Jean Baptiste Colbert (1619-1683), to develop theoretical research as well as the advancement of arts and trades. In contrast to the Royal Society of London, the Parisian Academy depended upon the Crown for its finances and organization. The number of members was fixed. It established a hierarchical structure, divided according to its diverse disciplines. During its initial phase, the Académie was remarkably active and secured the collaboration of the major representatives of French scientific culture and important foreign scholars. The Dutch scientist Christiaan Huygens (1629-1695), for example, was one of the principal protagonists of the Academy's activities for twenty years. The Academy declined after the Revocation of the Edict of Nantes (1685), when many scientists abandoned France. Completely restructured in 1699, it became one of the most authoritative scientific institutions of the seventeenth century. It was finally abolished in 1792.

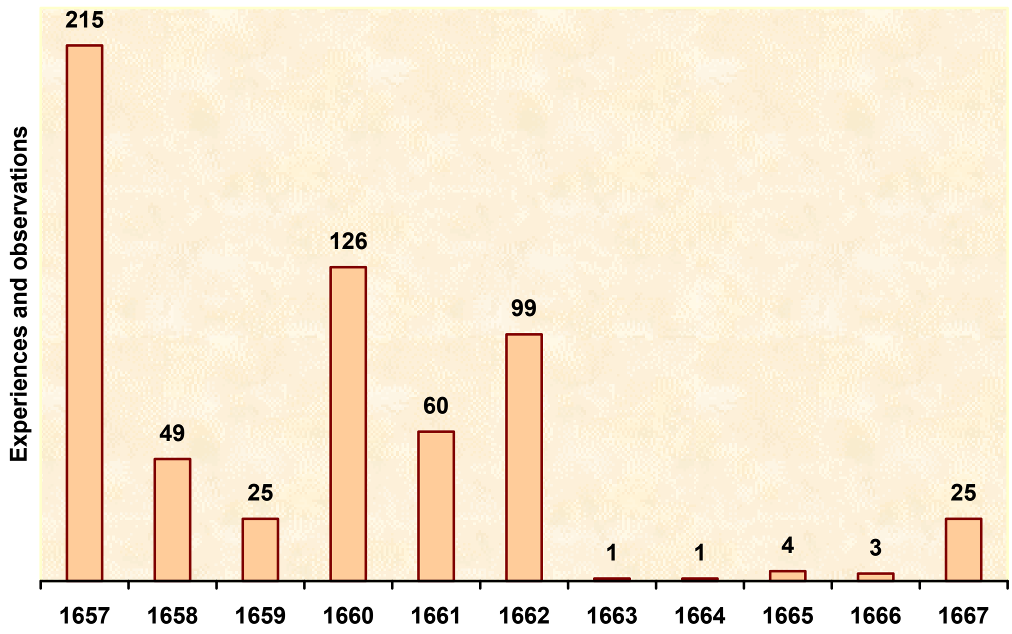
Berlin Society of Sciences

The Berlin Society of Sciences was born from a project by the great German philosopher and mathematician Gottfried Wilhelm Leibniz (1646-1716), who wanted to establish an academy inspired by the French model, but free from any government control, and therefore with a great deal of autonomy. With such an institution, Leibniz proposed a diffusion of the German language, a deepening of the sciences, the expansion of industry and commerce and the propagation of universal Christianity by means of science. On the basis of this plan, the *Societas Regia Scientiarum* was established on 11th July 1700 and was upheld by the Elector (later King) of Brandenburg-Prussia, Frederick I. The Society was finally recognised on January 19, 1711. In 1746, Frederick II, who reorganised its structure, made Pierre-Louis Moreau de Maupertuis (1698-1759) its head, on the suggestion of Voltaire. The Society assumed the name of *Konigliche Preussiche Akademie der Wissenschaften* [Royal Prussian Academy of Sciences]. Maupertuis brought a notable French influence to German culture. French was the official language of the Academy. The Society of Sciences had at its disposal its own anatomical theatre, a botanical garden, collections for the study of natural history and scientific instruments.

1.5. CHRONOLOGY

The documents presented are testimony to ten years of experimental activity by the Cimento. The chronological sequence of the experiments, calculated mostly on the basis of the documentation offered by Targioni Tozzetti in his *Notizie degli aggrandimenti* (Florence, 1780), permits us to emphasise at least three characteristic elements: the discontinuity of the sessions; the insistence on precise related disciplines; and the repeated validation of some experiments. The discontinuity of the sessions [see diagram] was above all due to the political and diplomatic duties of Prince Leopoldo and the Grand Duke Ferdinando II, who enjoyed participating personally in the meetings. On some occasions the academicians followed the movements of the Court, conducting experiments in locations other the Pitti Palace, where meetings were usually held. After

1662, the number of group experimental meetings diminished dramatically. This was probably due to the decision to prepare for publication a synthesis of the work thus far carried out. This work was later realized as the *Saggi di naturali esperienze* [Examples of natural experiments]. The chronology also includes 221 transcripts with passages from the Academy's 'Diaries' and a subdivision of disciplines.



2. THE EXPERIMENTAL METHOD

> *"The first seeds of false opinions arose from human rashness. [...] Now here, where we are no longer permitted to step forward, there is nothing better to turn to than our faith in experiment. As one may take a heap of loose and unset jewels and seek to put them back one after another into their setting, so experiment, fitting effects to causes and causes to effects – though it may not succeed at the first throw, like geometry – performs enough so that by testing and re-testing it sometimes succeeds in hitting the target."*
>
> (*Saggi di naturali esperienze*, Florence 1667)

2.1. CRITICISING ARISTOTLE

Aristotle's (384-322 BC) encyclopedic thought organised almost all the domains of knowledge in a systematic and coherent way, beginning with some fundamental philosophical principles such as the doctrine of the four causes, the dialectic between Potentiality and Actuality, and the distinction between matter and form. Particularly in the "Physics", Aristotle called upon a qualitative analysis of natural phenomena without resorting to a mathematical method. In Aristotelian cosmology, the Earth – the realm of corruption – was in the centre of the Universe and was composed of the four elements: earth, water, air and fire, which naturally moved straight up and down. By contrast, the movements of celestial bodies (the Sun, planets and the stars, composed of perfect and incorruptible material) were uniform and circular. To explain the independent movement of the planets, Aristotle thought that they rotated on concentric spheres. During the thirteenth and fourteenth centuries, this system was cleansed of all ideas incompatible with the Christian faith (the eternity of the world, the materiality of the soul, etc). This was due particularly to the writings of Aquinas (1225-1274). Aristotelian physics became the basis for university education, remaining substantially unopposed until the claims of the new mathematical and experimental science.

The Accademia del Cimento carried out a comprehensive and anti-traditional strategy and offensive in science, emphasising those works and contributions of Galileo that were more properly "physics" and more directly founded on the values of experience and experiment, assigning a very formal role for mathematical reason. In fact, the Accademia was prevalently made up of from personalities who, in their speculations, occupied a critical spectrum including the still dominant Aristotelianism. Peripatetics such as Alessandro Marsili and Carlo Renaldini were also present. Between the two camps – as can be seen from the academicians' correspondence – there was sharp confrontation, often resorting to insults, that nevertheless, due to the constant intervention of Prince Leopoldo, was not seen publicly.

2.2. MATHEMATICAL REASON

The Accademia del Cimento was assigned the task of relaunching Galileo Galilei's (1564-1642) scientific heritage, which had become embarrassing for the Medici after his condemnation by the Church in 1633. The Accademia's experimental program was presented as the logical development of Galileo's lessons, which, thanks to the constant recourse to "sense experiences", had reformed vast areas of natural philosophy. In reality, Galileo's heritage in the Cimento was losing its discursive character, a comprehensive coverage of nature that had constituted its fundamental novelty, and was being reduced to pure experimental activity. But the academicians did not develop the method of a systematic mathematical treatment of natural phenomena followed with revolutionary results by Galileo. Apart from the geometrical-mathematical analysis of physical phenomena, they also excluded discussion based on principles. Nothing remained but to have faith in recourse to experiment.

2.3. THE RECOURSE TO EXPERIMENT

In the introductory pages of the *Saggi* the need to rely on "faith in experiment" is stressed. It is also recognisable in the Accademia's name: *Cimento* is a goldsmith's term meaning the mixture used to purify or *assay* precious metals. This is how the Florentine academicians arrived at the meaning of *cimento* as *test, experiment*. The Accademia's emblem (or what we would now call *logo*) emphasises the duplicity of the meaning of *Cimento* (chemical operation / experiment) by means of the image of the crucible exposed to the flames from a furnace, in which the metal becomes subjected to tests. In reality the Accademia's name was decided only for the publication of the *Saggi di naturali esperienze* [Examples of Natural Experiments]. Until 1666, when the text was in the process of being printed, the institution was prevalently known as "Leopoldo's Academy" or "Academy of the Experiments", but never by the name by which we recognise it today. In anticipation of the publication it was decided to attribute a title and a public face to the institution which would only approximately correspond with the reality of ten years of experimental work. During this time there was never a critical investigation into the foundations of the "experimental method". Besides this, there is no trace of the influence of the thought of Francis Bacon (1561-1626) on the Cimento's experimentalism, which is visible, by contrast, in the English and French institutions. The necessity of a rigorous and repetitive checking of experiments by the academicians – summarised in their motto *provando e riprovando* [*testing and retesting*] – served simply to overcome the dogmatic and naïve traditional experimentalism of the Aristotelian system.

2.4. TESTING AND RETESTING

The academicians' motto is a literal citation from the third Canto of Paradise (lines 1-3) in Dante Alighieri's *Divine Comedy*:

> Quel sol che pria d'amor mi scaldò il petto
> Di bella verità m'avea scoperto,
> PROVANDO E RIPROVANDO, il dolce aspetto.
>
> [that sun which first had warmed my heart with love
> Had now, by argument and refutation

Revealed to me the lovely face of truth.]

It is evident that this is only a simple literary reminiscence. Yet with such a motto the academicians intended to continually call attention to the experimental verification of natural phenomena. This seems clear in the *Saggi di naturali esperienze* [Examples of Natural Experiments] when the phrase is recalled in three passages other than in the Accademia's logo:

> […] there is nothing better to turn to than our faith in experience . As one may take a heap of loose and unset jewels and seek to put them back one after another into their setting, so experiment, fitting effects to causes and causes to effects – though it may not succeed at the first throw, like geometry – performs enough so that by **testing and re-testing** it sometimes succeeds in hitting the target. (Proem)
>
> The third [thermometer] is also a copy of the first, but made larger. On that account it becomes a good four times faster and more sensitive, although divided into 300 degrees. Its construction is the same as that of the other two; but as has been noted, the craft of making it cannot be taught by rote, needing long practical experience, reducing and increasing by **testing and retesting** either the volume of the bulb, the bore of the tube, or the quantity of spirit, until it is just right. (p. VII)
>
> By testing and retesting the same experiment, we were finally assured that this was the way the thing went, and that we had not made any mistake; so we were curious to see the process of congelation in various liquids. For greater brevity, these freezings were recorded in the tables that follow (p.CLIII)

3. THE PROTAGONISTS

"June 21, 1657. It was decided that Drs. Rinaldini, Borelli, and Uliva should meet at the Palace at 6 p.m. every day to discuss the experiments to be made the following day, and to give the necessary orders."

(Diary manuscript)

3.1. THE PRINCES

3.1.1. Ferdinando II de'Medici (1610-1670)

Ferdinando II succeeded his father Cosimo II (1590-1621) in 1620 as Grand Duke of Tuscany, under the regency of his grandmother, Cristina di Lorena (1565-1636), and his mother, Maria Maddalena of Austria. He fostered maritime trading, boosting the port city of Livorno and drawing up commercial contracts. He supported Galileo (1564-1642) and encouraged his research. During the trial of 1633, he energetically strove to have Galileo's innocence acknowledged and to let him carry on with his studies. After Galileo's condemnation, Ferdinando cautiously pursued the goal of annulling or attenuating the decision against Galileo. He always strongly encouraged his experimental work. In fact, in the mid 1640s, the Grand Duke introduced informal experimental activities inside the Court. Experiments were carried out with the first ever thermometers , the humidity of the air was measured with the condensation hygrometer, and "the heaviness and the lightness of any liquid" with the hydrometer. In 1644, in the citrus greenhouses of the Boboli Gardens, a type of artificial incubator was tested to hatch chicks. It was based on the temperature indicated on a 60-degree thermometer placed under a brooding hen. These experimental activities constituted the premise on which the Accademia del Cimento, founded in 1657 by Ferdinando's brother, Leopoldo, was based.

3.1.2. Leopoldo de'Medici (1617-1675)

As protector of scientists, enthusiast of scientific studies, and promoter of Galileo's heritage, Leopoldo, along with his brother Ferdinando II, inspired and directed the experimental work of the Accademia del Cimento. He also used the Accademia as an efficient "public relations" instrument, calling upon it for Court entertainment to "delight" illustrious guests, as well as an efficient medium for establishing authoritative contacts, such as in relations with the Parisian and London institutions. From a scientific point of view, the Prince showed particular interest in astronomy and had a regular correspondence with Europe's greatest thinkers. In 1667, the year of the Accademia del Cimento's closure, he was appointed Cardinal. His personal patrimony included, amongst other treasures, a Galileo lens, his telescopes, the Giovilabe, and the glassware of the Cimento. Upon Leopoldo's death in 1675, these objects became part of the Medici collection.

3.2. THE SECRETARIES

3.2.1. Alessandro Segni (1633-1697)

Initiated into geometry by Evangelista Torricelli (1608-1647), Segni became Prince Leopoldo de' Medici's secretary, for whom he undertook various diplomatic trips in Europe. He also held the post of Secretary for the Accademia della Crusca. Moreover, he was the Accademia del Cimento's first secretary until May 20, 1660, when he was replaced by Lorenzo Magalotti.

3.2.2. Lorenzo Magalotti (1637-1712)

Born into a noble Florentine family, Magalotti studied at Pisa where he had well known teachers such as Marcello Malpighi (1628-1694) and Giovanni Alfonso Borelli. In Florence he gained the friendship and tutelage of Vincenzo Viviani. In 1660, still at a young age, he was appointed Secretary of the Accademia del Cimento. He drew up the *Saggi di naturali esperienze* (Florence, 1667), which contained the orderly account of the most relevant experiments carried out by the academicians. He undertook long trips, first under his own name, then as a diplomat for the Grand Duke Ferdinando II, and later for the Grand Duke Cosimo III (1642-1723). In 1678, a sudden break in his relations with Cosimo III interrupted his dazzling scholarly career and voyages. Magalotti retired for a decade from public life, dedicating himself to the writing of *Lettere familiari*, published posthumously in Venice in 1719. He returned to public life in 1689 (with the occupation of "third adviser to the State") and an intense writing schedule (during these years he began his *Lettere su le terre odorose d'Europa e d'America dette volgarmente buccheri*). First Galilean, then libertine and friend of Saint-Evremond, and finally follower of Pierre Gassendi's (1692-1655) corpuscularian philosophy, Magalotti lived the contrast between the new science and religious orthodoxy to the full, and went into an ascetic practice which for some time led him to take the habit of the congregation of S. Filippo Neri. The tension between new science and religious orthodoxy urged his anti-atheist *Lettere familiari*.

3.3. THE RESIDENT MEMBERS

3.3.1. Giovanni Alfonso Borelli (1608-1679)

Born in Messina, the first details regarding Borelli's life arise from around 1630, when we find him in Rome as a student of Benedetto Castelli (1578-1643). It was Castelli – it seems – who gave Borelli's name to the University of Messina for the vacant Chair of Mathematics. Between 1641 and 1642 the Senate of Messina, as a sign of particular appreciation for his increase in scientific activity, sent him on a voyage to the major Italian centres, with the aim of enlisting lecturers for the University. During the years immediately following, in addition to publishing the booklet *Delle cagioni de le febbri maligna*

(Rome, 1649), Borelli began to work on a compendium of Apollonius' four surviving books, which he was to publish many years later (Rome, 1679). He had already embarked on a revision of Euclid's *Elements* (which he published in 1658 with the title of *Euclides restitus*), when he received and immediately accepted the offer of the Chair of Mathematics at the University of Pisa. During the ten years that passed in Tuscany Borelli established a point of reference for all the scientific-experimental activities organised by Prince Leopoldo de' Medici. There were practically no experiments by the Accademia del Cimento that did not carry his contribution, often finding himself in opposition to Carlo Renaldini, who Borelli named as the "Simplicius" of the Cimento. But Borelli's most important contribution during his stay in Tuscany was without a doubt the work concluded on Jupiter's satellites, the *Theoricae Mediceorum Planetarum ex causis physicis deductae* (Florence, 1666), a text destined to enter effectively into European cosmological discussions. In a self-professed Copernican framework, Borelli managed to hypothesise about the curvilinear motion of planets pushed by two forces: a centrifugal force and an attraction towards the sun, which together would create equilibrium in the heavens. In 1667 Borelli left the Medici family and returned to Messina; in the same year he published *De vi percussionis* in Bologna, which collected and broadened the physical research undertaken by the Accademia del Cimento. Following the anti-Spanish rebellion which took place in Messina in 1670, Borelli, whose role in the event is still not clear, was forced to leave the island and transfer first to Calabria, and then to Rome, where he became one of the members of the Academy founded by Queen Christina of Sweden. His increasingly precarious financial situation constrained him in 1677 to accept the hospitality of the Clerks Regular of the Pious Schools (Piarists). He lived his last years giving mathematical lessons to some novices of the Order and completing that which is considered to be his masterpiece, *De motu animalium* (Rome, 1680-81). This work presents a mechanistic physiology based entirely on the corpuscularian composition of matter, representing an attempt to extend a rigorous style of geometrical analysis utilising Galileo in a mechanical context to the field of biology.

3.3.2. Carlo Roberto Dati (1619-1676)

As a Florentine disciple of Galileo (1564-1642) and friend of Lorenzo Magalotti and Francesco Redi, Dati was amongst the founders of the Accademia del Cimento. As Secretary for the Crusca, he promoted the third edition of the *Vocabolario* (which came out in 1691) and wrote the *Discorso dell'obbligo di ben parlare la propria lingua* (1657) in which he rigidly claimed the supremacy of the Florentine language. He left numerous scientific works -- including the *Lettera ai Filaleti della vera storia della cicloide e della famosissima esperienza dell'argento vivo* (Florence, 1663), written under the pseudonym of Timauro Antiate. In it he claimed the Tuscan – and thus Medicean – prominence in the correct interpretation of the Torricellian experiment of 1644, the implications of which ignited a lively discussion all over Europe. He also published many historical, political and literary works, including the fascinating *Vite de' pittori antichi* (1667) dedicated to Louis XIV.

3.3.3. Candido del Buono (1618-1676)

Candido del Buono was a Florentine priest, who, together with his brother Paolo, frequented lessons on mathematics given by Famiano Michelini (1604-1665). Del Buono was the Chamberlain of the Hospital of S. Maria Nuova in Florence and a member of the Accademia del Cimento, presenting several of his own invented instruments. From the documents there is no clear indication if the invention of the so-called "arcicanna," a complex system that resolves some typical problems with large telescopes from the second half of the seventeenth century, should be attributed to him or to his brother Anton Maria.

3.3.4. Paolo del Buono (1625-1656)

Paolo del Buono was a Florentine disciple of Famiano Michelini (1604-1665). He received his doctorate from Pisa in 1649. In 1655 he went to Germany to enter the service of the Emperor Ferdinando III and was appointed president of the Imperial Mint. During those years he and his student, Geminiano Montanari, visited the imperial mines in the Carpathian mountains, and invented a method of extracting water. He occupied himself with many physical problems and experiments and his name, along with that of his brother Candido, figures amongst the members of the Accademia del Cimento, with whom he corresponded from Germany.

3.3.5. Alessandro Marsili (1601-1670)

Marsili graduated in Law (1622) and in Philosophy (1623) from the University of Siena, his city of birth. In 1627 he was appointed lecturer of logic, and subsequently of philosophy, at the University of Siena. He met Galileo (1564-1642) after the trial, in the house of the Siena's archbishop, Ascanio Piccolomini. In 1638 he was accepted to the

Chair of Philosophy at the University of Pisa, where in 1622 he took on the job of Provost. He was a member of the Accademia del Cimento, but his declared Aristotelian convictions impeded him from adopting an innovative spirit. He proposed an experiment to understand whether the space left in the barometric tube during the Torricellian experiment contains mercury vapours.

3.3.6. Antonio Oliva (1624-1689)

At the age of nineteen Antonio Oliva was appointed theologian by Cardinal Francesco Barberini. During the years 1647-48 Oliva participated in the anti-Spanish rebellion and for this was arrested and incarcerated in the castle of Reggio Calabria, where he remained until 1652. From about 1657 he stayed in Tuscany, and during the years 1663-67 he held the Chair of Theoretical Medicine at the University of Pisa. Oliva participated in the activities of the Accademia del Cimento, showing a distinct tendency to occupy himself with hydraulics. With this in mind he wrote a treatise which has survived only in draft-form (*Tavola sinottica sopra l'acqua*, a manuscript preserved in the Galileian collection of Florence's Biblioteca Nazionale Centrale). During his stay in Tuscany he also produced commentary on the *Libro Quinto di Euclide* [Fifth Book of Euclid] (preserved, also in manuscript-form, in the Biblioteca Mediceo-Laurenziana in Florence). Oliva left Pisa in 1667 and returned to Rome. Accused of being part of the Accademia dei Bianchi, an unorthodox and libertine Francophile movement led by the prelate Pietro Gabrielli, he was arrested and tried by the Inquisition Tribunal. During the trial, to avoid a penal procedure, he threw himself out of a window of the Palace of the Holy Office.

3.3.7. Francesco Redi (1626-1698)

Born in Arezzo, Francesco Redi studied in the Jesuit school in Florence and graduated in medicine from Pisa in 1647. After some trips to Rome, Naples, Bologna, Padua and Venice, he began to work in medicine. In 1666 he was appointed Chief Physician by the Grand Duke Ferdinando II and was responsible for the granducal "spezieria" [pharmacy] and "fonderia" [foundry], a job which was also assigned to him by Cosimo III (1642-1723) and which he kept until his death, embodying the classic example of a scientist and courtier. He effectively applied himself to the natural sciences and the Accademia del Cimento's experimentalism. His first scientific work was *Osservazioni intorno alle vipere* [Observations concerning vipers] (Florence, 1664). Addressed to Lorenzo Magalotti, this was a memoir about how he found the location of the viper's poison, clarifying the way in which it wielded its toxins. Redi's true masterpiece, destined to signal a milestone in the history of modern science, was his *Esperienze intorno alla generazione degl'insetti* [Experiments concerning the generation of insects] (Florence, 1668). In this work, dedicated to Carlo Dati, he refuted the age-old theory of spontaneous generation of insects and parasites with a telling experiment, which introduced into the scientific method a serial procedure and a comparison between experimental research and controlled experiments. He prepared eight receptacles filled with various types of meat, four of which were left in open air while the others were carefully sealed. The result was unequivocal: only the first specimens, upon which flies stopped to lay their eggs on the flesh, provided a source for grubs that then developed into flies. Meanwhile, the meat in the sealed containers became putrid, but without generating any form of life. Furthermore, to avoid that the hermetic closure of the receptacles impeding the influx of air should alter the grub's life cycle, Redi produced a variation, utilising two other identical series of receptacles. He closed the control sample using a filter of thin fabric in a way that would permit only pure air to access the container, that is, without any contaminating element coming from flying insects. In the *Esperienze intorno a diverse cose naturali, e particolarmente a quelle che ci son portate dall'Indie* [Experiments concerning various natural things, particularly those that come to us from the Indies], published in 1671 and dedicated to Father Athanasius Kircher, who had been criticised in the preceding work for his defence of spontaneous generation, Redi intensified his attack on the unreliability of Jesuit experimental science. In 1684 Redi completed his biological tetralogy with the publication of the *Osservazioni intorno agli animali viventi che si trovano negli animali viventi* [Observations concerning live animals found in live animals], a treatise on the study of parasites and on comparative anatomy. This was completed with a second section fated never to see the light. In the field of medicine Redi made himself a representative of a reform of the therapy which recommended the prescription of simple remedies, which according to the rules of Hippocratic humourism, should serve to cleanse the organism of the superfluous impurities. Furthermore Redi played a decisive role in identifying the aetiology of scabies studied by Giovan Cosimo Bonomo (1666-1696) and Giacinto Cestoni (1637-1718), showing that infection depended on the attack of the microscopical mite that reproduced through eggs deposited under the skin. Redi was also a fine man of letters. As a member of the Accademia della Crusca, he was an active participant in the drafting of the third edition of the *Vocabolario* released in 1691. Amongst his literary works he had great success with the famous dithyramb *Bacco in Toscana* [Bacchus in

Tuscany], published in 1685 with many erudite annotations. From 1670 onwards he also worked diligently on a *Vocabolario di alcune voci aretine* [Vocabulary of some words from Arezzo].

3.3.8. Carlo Renaldini (1615-1679)

Carlo Renaldini was a Noble from Ancona. In 1644 he was nominated first Lecturer of Philosophy at the University of Pisa. He was one of the most present and active members of the Accademia del Cimento, proposing numerous experiments. He was an ambiguous figure, enticed by Galilean philosophical-scientific novelties and yet still immersed in the mentality and prejudices of Aristotelianism. During the academicians' work he often found himself in clear opposition to Giovanni Alfonso Borelli. He carried out astronomical observations with Toscanelli's gnomon in the Basilica of Santa Maria del Fiore in Florence. Furthermore, he tutored Prince Cosimo III (1642-1723). In 1667 he obtained the Chair of Philosophy at the University of Padua. He published numerous works, among the most memorable are the *Ars analytica mathematicum* (Florence-Padua 1665-1669), the *De resolutione et compositione mathematica* (Padua, 1668) and *Philosophia rationalis, naturalis atque moralis* (Padua, 1681).

3.3.9. Vincenzo Viviani (1622-1603)

Vincenzo Viviani studied mathematics at the Piarists school, under the guidance of the Galilean Clemente Settimi (1612-?). He fondly assisted Galileo (1564-1642) from October, 1639 until the death of the Pisan scientist. Ferdinando II and then Cosimo III (1642-1723) granted him important public roles. He participated in the Accademia del Cimento's works, playing a primary role and proposing many experiments. Furthermore, for many decades he held the job of engineer for the Magistrature of the Guelph Party (a position responsible for the regulation of waterways and general care of the territory). During his long public life he published numerous mathematical works, nearly always conceived as a development of his Galilean heritage. He occupied himself with celebrating and keeping alive the memory of the Master. With that aim, he edited a large edition of Galileo's works, published in Bologna in 1656. In 1654 he composed the well-received *Racconto istorico della vita di Galileo*, written in the form of a letter to Prince Leopoldo de' Medici, which remained unpublished until 1717. He dedicated a great deal of time to the systematic collection of documents, testimonies and letters belonging to Galileo. He left a legacy in his will for the erection of a sepulchral monument to Galileo to be erected in the Basilica of S. Croce in Florence. Furthermore, on the façade of his house on the street now known as via S. Antonino, he put up a bust of Galileo flanked by two long commemorative inscriptions.

3.4. MEMBERS BY CORRESPONDENCE

3.4.1. Gian Domenico Cassini (1625-1712)

Gian Domenico Cassini dedicated himself to the study of astronomy and in 1650 obtained the Chair of Mathematics at the University of Bologna as successor to Bonaventura Cavalieri (1598-1647). His observations of the Sun led him to important discoveries that brought him much recognition. After a stay in Rome, in 1668 he published an almanac of Jupiter's satellites. The following year, after long negotiations and upon the invitation from Jean-Baptiste Colbert (1619-1683), minister of the King of France Loius XIV (1638-1715), Cassini moved to Paris, where he was received into the Académie des Sciences. Despite his wish to return to Italy, Cassini ended up establishing himself permanently in France. Between 1671 and 1684 he discovered four satellites of Saturn that were added to those discovered previously by Christiaan Huygens. After a brief re-entry into Bologna, Cassini returned to France where he died, then blind, in 1712. He was a friend and correspondent with important scientists of his time such as Edmund Halley (1656-1742) and Vincenzo Coronelli (1650-1718).

3.4.2. Honoré Fabri (1607-1688)

A French Jesuit, Honoré Fabri studied theology at Lyon from 1632 to 1636. He occupied himself mainly with mathematics, physics and astronomy. He engaged in a harsh controversy with **Christaan Huygens** about the structure of the system of Saturn. He established himself in Rome in 1646 and kept in close contact with Michelangelo Ricci (1619-1682). He was a correspondent with the Accademia del Cimento and with important figures such as Gottfried Wilhelm Leibniz (1646-1716), René Descartes (1596-1650) and Marin Mersenne (1588-1648).

3.4.3. Robert Hooke (1635-1702)

Born in Freshwater on the Isle of Wight, Robert Hooke was one of the most brilliant and versatile English scientists of the seventeenth century. He attended the University of Oxford, although without graduating, where he came into contact with a group of scholars (John Wilkins, John Wallis, Christopher Wren, Robert Boyle, among others) who subsequently constituted the first nucleus of the Royal Society. He was an extremely capable inventor and constructor of scientific instruments (his name is linked to a type of microscope). Furthermore, he formulated a wave theory of light that he clearly announced in his *Micrographia* (1665). After having carried out the job of curator of experiments at the Royal Society for almost 15 years (1662-1677), he became Secretary, keeping the role until 1682. In the field of pneumatics, Hookes's name is particularly linked to the construction of a perfected version of Otto von Guericke's (1602-1680) air-pump, later described by Boyle (1627-1691) – whom Hooke assisted between the years 1657 and 1662 – in *New Experiments Physico-Mechanical* in 1660. Through an ingenious series of experimental proofs conducted with this instrument, Boyle and Hooke demonstrated that the observable effects of the Torricellian experiment were truly due to the pressure of air, that sound was impossible inside a void, and that air could be characterised by its constant elasticity.

3.4.4. Christiaan Huygens (1629-1695)

As a great research figure in the field of physico-mathematics, astronomy and optics, Christiaan Huygens was amongst the founders of mechanics and of optical physics. In *his Traité de la lumière* [Treatise on light] of 1690 he formulated his own hypotheses regarding lightwaves. Thanks to the telescope that he perfected, Huygens discovered Saturn's ring and carried out astronomical observations of the planets, of the nebula of Orion and of the Moon, illustrated in his *Systema Saturnium* (The Hague, 1659), dedicated to Prince Leopoldo de' Medici. Huygens engaged in correspondence with the Tuscan scientific community at the time of the Accademia del Cimento above all on the nature of the ring surrounding Saturn. A discussion was launched regarding Saturn's system proposed by Honoré Fabri, who was famous in Europe. Another controversy arose with Vincenzo Viviani, who vindicated the Galilean priority of the discovery of the application of the pendulum clock, presented by the Dutch scientist as his own invention. Huygens is also remembered for his invention of the eyepiece that was named after him.

3.4.5. Athanasius Kircher (1602-1680)

Born in Geisa, Germany, Athanasius Kircher entered the Society of Jesus in 1616. He was Lecturer of mathematics and philosophy at Wurzburg, then transferred to Avignon and finally to Rome, when around 1638, he was called to teach mathematics in the

Collegio Romano. As a prolific writer famed all over Europe, he was author of many works dedicated to various fields of knowledge: philology, physics, sacred liturgy, astronomy, natural history, mathematics, music, Egyptology, geography and Chinese civilisation. Amongst his scientific works are *Magnes, sive de ars magnetica* (1641), the *Ars magna lucis et umbrae* (1645), the *Mundus subterraneus* (1665), the *Organum mathematicum* (1668) and the *Musurgia universalis* (1650). In the latter, Kircher narrates how he completed an experiment that convinced him of the impossibility of creating a void in nature. The experiment, conducted in collaboration with Gasparo Berti (c. 1600-1643), consisted of the introduction of a bell inside the part of the barometric tube, in which – according to the "vacuists" –should be produced a void. By means of the external use of a magnet, the hammer of the bell works, and, according to Kircher, the sound is distinctly perceptible, certifying the presence of air in the tube. A similar experiment was carried out with the airpump by Robert Boyle (1627-1691), but with a different outcome. Boyle revealed that after the sucking out of air, the sound could no longer be heard.

3.4.6. Henry Oldenburg (1615?-1677)

Henry Oldenburg was a very active Secretary for the Royal Society of London between 1662 and 1677, the year of his death. He had a stable and important friendship with Baruch Spinoza (1632-1677) and was in correspondence with Europe's greatest thinkers. In 1665 he founded the first European scientific journal, the "Philosophical Transactions", which quickly became an extraordinary medium for the diffusion of new scientific ideas.

3.4.7. Michelangelo Ricci (1619-1682)

As a student of Benedetto Castelli (1578-1643) in Rome, Michelangelo Ricci was a fundamental Roman point of reference for the development of the Galilean School. He was nominated Cardinal in 1681. Ricci maintained strong relationships first with Torricelli (1608-1647), and subsequently with Viviani and Leopoldo de' Medici, also participating in the activities of the Accademia del Cimento, although only through correspondence. He intervened repeatedly to mollify the threats of interference by the ecclesiastical censors against these representatives of new scientific ideas. He was a fine mathematician, as shown by his only publication from Rome in 1666, the *Geometrica exercitatio* [Geometrical exercise] and his intense written exchange with Torricelli. Ricci had a relevant role in the theoretical and experimental debates that preceded and accompanied Torricellian's discovery of the pressure of air. In addition to participating in some experiments completed in Rome by Gasparo Berti (c.1600-1643), he was the recipient of the only two documents (the letters of June 11 and 28, 1644) in which Torricelli described his barometric experiment, explaining the role of the pressure of air as the cause of the suspension of mercury in the tube.

3.4.8. Nicolas Steno (1638-1686)

Nicolas Steno was a Danish student of medicine in Copenhagen, Amsterdam and Leiden. After a year in Paris, Steno alternated between long periods of stay in Tuscany and Denmark. During his first stay in Tuscany (1666-67), he performed important anatomical dissections and in 1667 published his fundamental work on the structure of muscles (*Elementorum myologiae specimen, seu Musculi descriptio geomentrica*) including an appendix on the famous and memorable dissection of a shark's head. In addition to his description of the structure of muscles, Steno also applied himself to the study of the glandular and lymphatic systems, and the anatomy of the brain. He discovered the excretory duct of the parotid gland, which he described in the *Observationes anatomicae* (Leiden, 1662). In 1669, while still in Florence, his *De solido intra solidum naturaliter contento dissertationis prodromus* came out, which has always been considered a landmark work in the history of geology. In this work he recognised the organic origin of fossils and sketched a theory of geological strata, with an attempt to apply that theory to the reconstruction of Tuscany's geological development. In 1675, eight years after converting from Lutheranism to Catholicism, he was ordained as priest. He dedicated the last part of his life above all to religious activities, almost completely abandoning his scientific studies.

4. THE QUESTION OF THE VACUUM

> *"That famous experiment with the quicksilver that in 1643 presented itself before the great intellect of Torricelli is now known in every part of Europe, as is also the high and wonderful idea that he formed about it when he began to speculate upon the reason for it."*
>
> (*Saggi di naturali esperienze*, Florence 1667)

4.1. THE VACUUM IN GREEK THOUGHT

Natural philosophy was dominated for almost two thousand years by Aristotle's (384-322 BC) ideas, which were then reinterpreted by the Scholastics who rendered them compatible with the dogmas of the Christian faith. In his *Physics*, Aristotle claimed that to affirm the existence of the vacuum – as Democritus (fifth century BC) had done – represented a violation of the princliple of non-contradiction. For Aristotle, a space deprived of matter (that is, a vacuum) does not correspond to 'nothing,' but has its own permanent existence. For Aristotle, the void cannot even be considered as an immaterial entity, since natural philosophy has as its object only existence insofar as it exists. While perceiving the universe as finite, Aristotle still resolutely denied that a void existed beyond the confines of the world. Furthermore, the Greek philosopher considered the sublunary realm to be composed of four elements (fire, air, earth and water) and he maintained that each belonged in its natural place and could only be moved by a violent force. In their natural place, the elements did not possess weight. Therefore, according to the Greek philosopher and his many followers, air did not possess weight and did not exert pressure.

4.2. ABHORRENCE OF THE VOID

Many of Aristotle's followers found it difficult to reconcile some of the Greek philosopher's conclusions with the dogmas of the Church. Aristotle's thesis regarding the logical impossibility of the void is an example of this. In the thirteenth century, Scholastic philosophers and theologians contested the concept that they saw as the denial of divine omnipotence: if God wanted to, he could produce a vacuum. Nevertheless they confirmed that it was impossible to produce a void "naturally". Developing the concepts in Aristotle's *Physics*, some medieval authors elaborated the theory of nature's *abhorrence of the void*: that nature's repugnance of the vacuum induced it to function in every way to avoid it being produced. The theory on the abhorrence of the void was used to interpret diverse natural phenomena: the difficulty of separating two perfectly smooth surfaces pushed together; the difficulty of opening a perfectly fitted cover; the way water will not come out of small holes in the bottom of a full container whose lid is tightly closed; and finally, the limited height that water reaches when raised by a suction pump or siphon. The abhorrence of the void also explained why freezing a sealed bottle full of water broke it. It was erroneously thought that freezing the water would diminish its volume and as a consequence it was supposed that nature provoked the rupture of the bottle to avoid a vacuum from being created following the contraction of volume.

4.3. TORRICELLI'S EXPERIMENT

The Aristotelian theories on the void and the elements began to be discussed and contested in a lively manner in the mid-sixteenth century. In the process, the rebirth of atomism continued to gain higher ground, propounding the existence of the void as a central and essential doctrine. Meanwhile, the development of experimental activity contributed to once again put the debate about the weight of air in the spotlight. In 1630 a notable experimentalist, Jean Rey (1582-c.1645), interpreted the increase in weight observed on tin treated with lime as caused by the absorption of air by the metal during calcination. The pressure of air remained substantially misunderstood until the beginning of the 1600s, despite the intuitions of some notable medieval authors. Amongst the first to propose innovative ideas about the void and the pressure of air was the Dutch Isaac Beeckman (1588-1637). In fact, he admitted the existence of the void and recognised that the air pushed in every direction. He was also amongst the first to introduce the concept of the elasticity of air. Beekman communicated these innovative ideas to Descartes (1596-1650), who resolutely denied the void, and the two of them developed a lively and interesting discussion,. One of the greatest achievements of Evangelista Torricelli (1608-1647), one of Galileo's (1564-1642) disciples, was to force the theory of the *horror vacui* – which had already been discussed, but inconclusively, by numerous authors – into crisis. In a greatly renowned and extraordinarily simple experiment, carried out in Florence in the spring of 1644, Torricelli not only showed that nature did not abhor the vacuum, but that it was instead easily produced.

4.4. THE ACADEMICIANS AND THE VOID

Torricelli's 1644 experiment produced epoch-making consequences, and the discovery of the void caused profound trauma on a scientific, philosophical and cosmological level. The great philosophers, scientists and theologians of Europe dedicated themselves to intense reflection and experimentation to either confirm or contest the existence of the void and atmospheric pressure. In the mid seventeenth century, during the heart of the Scientific Revolution, the debate regarding the void and atmospheric pressure represented one of the nodal points in the discussions about the constitution of matter and the nature of the universe. Galileo (1564-1642), Descartes (1596-1650), Gassendi (1592-1655), Hobbes (1588-1679), Pascal (1623-1662) and Newton (1642-1727) all used these delicate issues. The analysis and the experimental verification of the void fully occupied the Cimento academicians. As well as replicating the Torricellian experiments with many variations, they examined the behaviour of various objects placed inside the void, from the form assumed by drops of water to the attraction of a magnet, from the "mysterious" inflation of a bladder to the movement of smoke. They did not hesitate to imprison birds, butterflies, flies, crickets, lizards and fish inside the void to observe their reactions, nearly always resulting in death. In a meeting in June 1660, they even hypothesised about "making a bigger vacuum to be able to hold a man" while at the same time discussing the possibility of producing an adequate instrument for this experiment. Scientific curiosity united with a strong determination to perform experiments, giving a clear sign of the assimilation of Galileo's lessons.

5. SCIENCE AND ART

> *"It* [the thermometer] *is entirely of fine crystal glass, made by those workmen who, using their own cheeks as bellows, blow their breath into a glass tube at the flame of a lamp, either with one wick, or several small ones. Gradually blowing, as the necessities of their work require, they succeed in forming the most delicate and marvellous works in glass. We call such a craftsman the glassblower."*
>
> (*Saggi di naturali esperienze*, Florence 1667)

5.1. THE CIMENTO'S INSTRUMENTS

After belonging personally to Prince **Leopoldo de' Medici**, the Accademia del Cimento's instruments were long-forgotten until, in 1839, Vincenzo Antinori (1792-1865), the director of the Museum of Physics and Natural History of Florence, recovered them in a storeroom of the Pitti Palace. In 1841 they were set up in the Tribuna di Galileo, adjacent to the modern Museum of the Specola. The Gallery was supplied with an evocative display including frescos and bas-reliefs portraying the protagonists of the advancements of the experimental sciences. A fresco inside the Gallery presents a perfect recreation of an Accademia meeting.

Many of the Cimento's experimental apparatuses exist even today. It is worth noting a very beautiful pedometer, an excellent condensation hygrometer, a large astronomical quadrant, and the first thermometers ever constructed, like the straight and the spiral thermometers, called "geloso" [jealous] because of their extreme sensitivity. And also the thermometers used to ascertain the different cooking times of eggs and to create the first artificial incubator, thermometers also defined as "slothful", that is, lazy, because of their poor sensitivity. Another extraordinary glass is the so-called "ranocchietta" ["little frog"], the first clinical thermometer; tied to the patient's wrist, it indicated the variations in temperature through the slow movement of the glass balls immersed in alcohol. Finally, the hydrometers used to measure the specific weights of fluids are also notable; as well as the elegant and graceful glass hydrostatic balance. The Accademia del Cimento's collection of instruments, today preserved in the Institute and Museum of the History of Science in Florence, are evidence of the great importance experimental science assumed for the Medici Court during the course of the seventeenth century. Their refinement reflects the full integration and continued exchange between art and science in the court culture of the baroque age.

5.2. GLASS: BETWEEN ORNAMENT AND ART

The profitable exchange between art and science is widely documented from the rich imagery that accompanies the extraordinary Medicean glasswork. Since the end of the sixteenth century, and particularly between 1628 and 1670, the granducal furnaces produced glass of extreme complexity and of great beauty. The artists that planned and designed these showpiece delicate objects of bizarre and playful shapes and intricate structures, also had the Accademia del Cimento's research and experiments in mind, and made treasures relating to the scientific principles that were debated in that era. On the other hand, the same scientists used vases, chalices, and beakers, transforming them into scientific material for experiments, such as containers and "equipment". Furthermore, the talented glassblowers, the "Gonfia" in the service of the Grand Duke, applied the same stylistic schemes and baroque "tastes" typical of the era, to the construction of true and proper scientific instruments.

The vases and the cups that are part of the glassware collection of the Accademia del Cimento show a precise typology, also traceable to contemporary designs, in certain cases typical of Venetian glass work. They were used substantially as palace table furnishings, but in some cases were also used scientifically, such as containers with substances used in particular experiments.

5.3. THE CIMENTO'S ARTISTS

If the beautiful glass designs by Stefano Della Bella are testament to the direct participation of the artists in the Cimento's adventures, the Accademia's decade of life coincided with a particularly lively period in the figurative art field. The heritage left by the protagonists of the first half of the century – from Jacopo Ligozzi, to Empoli, to

Baccio del Bianco, to Cesare Dandini – just like the refined collections by Ferdinando II, Giovan Carlo and Leopoldo de' Medici, indicate still-life as a privileged genre. The "flower paintings" of Agnolo Gori, Bartolomeo Ligozzi and Carlo Dolci, with their constant attention to "the natural", show a scientific connotation linked to the experimental approach characterised by the Cimento's proposals and anticipates the extraordinary work of Bartolomeo Bimbi. The more scientific combination was the relationship between Francesco Redi and the painter Filizio Pizzichi, who expressed and visualised his experiments.

6. NATURALIST STUDIES

"September 6, 1657. It is not true that toads are generated from rain, although at that time they reveal themselves and appear more abundant, as has been diligently observed in those places. In the morning they go outside into the fresh air of the Aurora, although none appear at night."

(Diary manuscript)

6.1. THE GENERAL PICTURE

Within the encyclopedic research program devised by Prince Leopoldo for his own scientific academy, anatomical, physiological and naturalist studies and investigations occupied an apparently lateral position, although not quite an ancillary one. The series of experiments on the void and atmospheric pressure, on the speed of sound and light, on so-called 'freezing', and on astronomical observations and measurements, are dynamically articulated. Yet a vein, maybe not very rich, but certainly continuous and persistent, marked the interests in the nature of life, the structures and the forms of animate bodies, and the sensibilities and the physiological complexity of parts of the organism. This position was substantiated and justified because of the characteristics of the cultural education of some of the Accademia's members and the direction of their specific research interests. But it is also motivated and explained by the historical context in Italy and in Europe, where scientific disciplines decisively centred on medical subjects and anatomical explorations in particular had been carried out since the start of the sixteenth century.

6.2. STUDIES IN THE DIARY

Galileian Manuscript 263 in the National Central Library of Florence preserves, among other things, a folder containing some ten letters with a collection of a series of *Osservazioni sopra la digestione di animali diversi* [Observations of the digestion of different animals], written between January 14 and May 15, 1659. It contains a sequence of experimental records registering the digestive behaviour of some types of birds following the ingestion of balls made from inedible materials (glass, tin, wood, and other similar materials). The records are limited to finding, as far as was possible and practical, the internal route and the acidic transformation of these balls inside the animal's body. This reduced the experiment to an exhibition of observed data, without any kind of theorising or hypothesising, even biased or off-the-cuff. Nevertheless, the apparent omissions in the indexing of the material tend to hide, at least partially, the programmatic intention that supports the protocol., This is clearly understandable if one focuses on the repetition of the kind of observations recorded in the experiments and the data that could be deduced from them. For this reason, it appears legitimate to consider the records on digestion as partial and residual sections of a longer and systematic research program concerning the life sciences, which in their entirety made part of the vast experimental scheme of the academicians.

6.3. STUDIES IN THE CORRESPONDENCE

Amongst the different testimonies that one could extract from the correspondence of the academicians, there are at least two that certainly appear worthy of special mention and of attentive consideration. The first (preserved in Galileian Manuscript 277 in the National Central Library of Florence) is a letter from the English anatomist John Finck addressed to Prince Leopoldo on December 26, 1664. At the start of that year in Florence, Finck was a protagonist in a controversy against the young and already promising Marcello Malpighi (1628-1694), concerning the priority in the discovery of the optic nerve. Here, Borelli, in a letter addressed to the Grand Duke Ferdinando II, directly gave his opinion in defence of the precedence set by the Bolognese anatomist.

Once Finck left Florence for Padua, he sent the Prince, whose interest in literary news in the field of medicine he was well aware of, a detailed letter concerning the contents of Thomas Willis' *Cerebri anatome nervorumque descriptio et usus*. This work appeared simultaneously in *editio princeps* in London and Amsterdam, but had not yet arrived in Florence or in other parts of the Italian peninsula. In his letter, the English physician paid particular attention to the passages from Willis that were mostly concerned with the production of animal spirits in the brain and their diffusion through the nervous system to sensitive peripheral organs. In his references and in his selection of passages from the *Cerebri anatome*, you can see a desire, almost an urgency, to precisely communicate in detail ideas which were both current and important and also needed more discussion. He even wished to weave together arguments and useful material to clear and confirm a position he had sustained publicly a few weeks earlier before the Grand Duke, the Prince, and the entire body of scientists and courtiers gathered together in Florence.

The second testimony (also in Galileian Manuscript 277 in the National Central Library of Florence) is a letter from Giovanni Alfonso Borelli in Pisa, to Leopoldo de' Medici on December 29, 1666. The epistle contains a concise criticism of the principles and the methods used by the Jesuit Honoré Fabri, another correspondent of Leopoldo and, through him, a collaborator with the Accademia del Cimento, in the *Tractatus duo: quorum prior est de plantis et de generatione animalium; posterior de homine*. (Paris, Mugnat 1666). The treatises, over-structured, complicated and obscure, were sent by Leopoldo directly to the Neapolitan scientist. Leopoldo was interested in receiving accurate and competent opinions which would permit him to appreciate them to the full. Borelli's typical scientific rationality, clearly noted by Leopoldo, depended on principles and criteria radically different from those of Fabri, so the Prince's request must have appeared to Borelli, as it was perhaps intended, as a sort of invitation to a duel. The letter that Borelli wrote to the Prince is a small masterpiece of intelligence and irony. It was profound but concise, as light and smooth as the Jesuit's work appeared congested and chaotic under scrutiny. It is without a doubt an eloquent testimony of the vitality and the great importance that the medical and naturalist issues generated between Pisa and Florence during the restless years of the Cimento.

6.4. AN EXTRAORDINARY DECADE

The one fact, more than any other, that clearly displays the causal and enduring ideological relationship binding together the Academy's experimental programme and 'soft' scientific disciplines, is the huge mass of tracts of medicine and natural philosophy that came out in the 1660s by authors from Leopoldo's circle. Some of the most important treatises of modern medical history were published in Florence and Bologna between the years 1661 and 1666, beginning with *De pulmonibus observationes anatomicae* by Marcello Malpighi (1628-1694) and ending with the *Esperienze intorno alla generazione degli* *insetti* [Experiences surrounding the procreation of insects] by Francesco Redi. These writings were concerned with subtle and experimental comparative anatomy, and human and animal physiology. Other than the two works mentioned above, the *Exercitatio anatomica de structura et usu renum* (1662) by Lorenzo Bellini (1643-1704), the *Tetras anatomicarum epistolarum de lingua et cerebro* (1665) by Malpighi and Carlo Fracassati (1630-1672), the *Gustus organum* (1665), also by Bellini, and the *Canis carchariae dissectum caput* (1667) by Nicolas Steno, also deserve to be remembered. Among Malpighi, Fracassati and Bellini, only the latter was a granducal subject, but they all followed Borelli to his research in Pisa. Through Borelli, they appeared more and more often at the Medici Court, absorbing its atmosphere and intellectual exuberance. Inside the rooms of the granducal palace reserved for anatomy demonstrations, and inside the large halls in which the thousands of books that formed the princes' library were amassed, they could use the availability of resources and time to focus on and outline the issues and the problems necessary to give substance to the entire supporting framework of their subsequent, and very rich, medical reflections. During the critical years of the Cimento's existence they were able to test, in the shadow of the activities carried out by their more senior teachers, the value and the efficacy of the principles and methods of traditional knowledge.

Nicolas Steno arrived in Tuscany from France in the first months of 1666, already aware of the research habits and the scientific program in Leopoldo's Academy. He immediately entered the Court, developing his arguments and bringing some of his works to maturity in Tuscany. Although no document can attest to his direct participation in the last of the Accademia's meetings, he had contact, and at times also controversies, with some members, and wrote a memorable defence in favour of some experimental descriptions published in the *Saggi di naturali esperienze*. In Florence in 1667 he published his long thought-out and delayed geometrical description of the structure of muscles of the human body, in which he decided to enclose the narration of a dissection of the head of a shark caught in October 1666 in the waters near Livorno. The study of the animal's teeth was decisive in finally denying, once and for all, the so-called anti-venom properties of the "glossopetra" ["tongue stones": fossils that resembled tongues], identifying these mythical stony materials with the teeth of the shark and demonstrating their organic origins.

Francesco Redi also settled into this same line of examination, revision, and on numerous occasions, open retraction of traditional beliefs. From the Accademia del Cimento, Redi inherited the most pure method of investigation and perfect application of the experimental spirit. In 1668, that is, one year after the date when the courtly meetings symbolically ended, Redi published a treatise in Florence on spontaneous generation in the form of a long epistle addressed to Carlo Roberto Dati. As is known, with this work he definitively resolved the question that was for centuries totally framed by theoretical and authoritative thought. Although supported by ample and substantial literary sources, Redi systematically introduced the experimental methodology typical of the Cimento, to biological research. He was the first scientist of his time, surrounded by many contradictors, who managed to cast into doubt all the theories that accredited the possibility of the origin of life to organic material and to putrefied organic substances, while decisively demonstrating their unequivocal sources.

7. METEOROLOGY

"It is very useful, indeed necessary in making experiments on nature, to have an exact knowledge of the transformations of air."

(*Saggi di naturali esperienze*, Florence 1667)

"December 12, 1661. During a calm winter night, it was noted that the coldest hour was at sunrise, and at that time the thermometer of 300 degrees went down sometimes 4 or 5 degrees, lower than at any other time of the night."

(Diary manuscript)

7.1. THE ACCADEMIA'S METEOROLOGY

Numerous apparatus and instruments designed and produced specifically for the experimental sessions were used in studies on the atmosphere.. The elegant and remarkable glass instruments were blown in the furnace in the Boboli Garden, or were directly imported from Venice. The 'slothful' thermometers, so-called because of their poor sensitivity, and "jealous' long neck thermometers, so-called because of their extreme sensitivity, offer wonderful examples of the abilities of the granducal craftsmen. In addition to 50-degree thermometers, the academicians used different types of hygrometers in their research on the atmosphere, and the condensation hygrometer invented by Ferdinando II attracts considerable interest. Furthermore, the Princes and the academicians committed themselves to the instrumental measurement of the humidity air in relation to the direction of the wind.

The academicians worked out various thermometric scales and entrusted the production of thermometers divided into 30, 50, 100 and even 300 or 420 degrees, to the ability of the Court craftsmen. The scale of the Florentine thermometers was the standard used for two measured temperatures considered invariable by the academicians: the lowest fixed point corresponded with the temperature of melting ice, while the highest fixed point equaled the maximum temperature reached by the instrument exposed to the sun during the summer heat. The 50-degree thermometer, used for detecting meteorological conditions, showed 11-12 degrees "in the most piercing cold of winter" and close to 40 degrees " in the fiercest heat of our summer."

The table compares the Accademia's readings of a 50-degree thermometer with the corresponding (estimated) reading from the Celsius scale (1742) and the Fahrenheit scale (1714).

Accademia	Celsius	Fahrenheit
0°	-20ºc	-4ºf
13.5º	0ºc	32ºf
30º	25ºc	77ºf
50º	55ºc	131ºf

7.2. THE MEDICEAN METEOROLOGICAL NETWORK

In 1654, as a passionate researcher of meteorology, Grand Duke Ferdinando II established the first international meteorological network. The simultaneous collection of data and instruments related to the atmospheric conditions derived from different places (such as Vallombrosa near Florence, Warsaw, Innsbruck), sanctioned the birth of synoptic meteorology, and attached a practical aim to the setting up of this scientific cooperation. Luigi Antinori, Court chaplain, coordinated the meteorological stations, supplying them with homogeneous instruments and insisting that uniform recording procedures be adopted. Antinori distributed whatever was necessary to the collaborators of the Medicean network to verify "how many degrees it takes to reach maximum heat and the maximum coldness in different regions" – a couple of Florentine thermometers divided in 50 degrees, instruments recognised for their trustworthiness and comparability, produced in a way that, should they be "surrounded by the same environment, they would always work in the same way." The tabulations of the meteorological records until 1667 remain today.

- **Florence:** From December 14 1654 until March 31 1670, the Florence's thermometric data reached the Court from the Camaldolite Convent of the Angels.
- **Vallombrosa:** Meteorological observations from Vallombrosa (January 2, 1656 – January 1, 1668)
- **Milan:** Meteorological observations from Milan (December 1655 – February 1656)
- **Bologna:** Meteorological observations from Bologna (December 1654 – March 1656)
- **Parma:** Meteorological observations from Parma (December 1654 – December 1660)
- **Cutigliano:** Meteorological observations from Cutigliano (March 1658 – February 1659)
- **Pisa:** From November 1657 to May 1658 Vincenzo Viviani made daily annotations in his *Diario delle mutazioni di tempo* [Diary of weather changes] about the amount of temperature, atmospheric pressure and humidity.
- **Paris:** Series of observations in *Ad Thermometrum observationes anno 1658 Parisiis; theormomentrum Florentiae fabricatum*, recorded by the astronomer Ismael Boulliau.
- **Warsaw:** The meteorological observations from Warsaw are limited to the period of May 10-16, 1655.
- **Innsbruck:** Meteorological observations from Innsbruck (March 6 – April 30, 1655)

7.3. THE METEOROLOGICAL OBSERVATORY

Three and a half centuries ago, a meteorological network was established under Medicean protection for the constant, standardized observation of temperatures, with stations located in various European countries. Furthermore, the Cimento academicians dedicated much attention to atmospheric phenomena and the perfection of their meteorological instruments, contributing to the success of modern meteorology. To witness this important phase and illustrate how much modern meteorology is indebted to the first measurements carried out with the instruments of that era, a virtual meteorological station has been equipped that uses reconstructed 17th century instruments. It must be mentioned that in the Accademia's activities, experiments were normally carried out upon only one atmospheric parameter, such as temperature or humidity, using one instrument at a time.

The meteorological instruments in use during the second half of the seventeenth century:

Spiral thermometer

A thermometer with a tube bent by heat and wound in a spiral. This intricate procedure renders the instrument more transportable and less fragile, but also less accurate, because the internal thickness of the glass bent by the flame, tends to be reduced in some places and enlarged in others, rendering an uneven flow of alcohol inside the instrument.

Thermometer with a long stem

A crystal thermometer, similar to those produced in large quantities by the glass-works of Boboli and used for the Cimento's experiments. The measuring tube could be divided in scales of four hundred and twenty, three hundred, one hundred, thirty or fifty degrees. The latter, smaller and more reliable, was used for observations by the Medicean meteorological network.

'Slothful' thermometers

Small glass balls of different densities were placed in one or more test tubes filled with alcohol. Upon the rise in the external temperature, the alcohol in the test tubes increases in volume and therefore diminishes in density. As a consequence, the balls no longer receive the same push towards the top from the fluid in which they are immersed and one after the other fall to the bottom, beginning with the most dense.

50-degree thermometer

Because of the reliability and comparability of these thermometers, usually constructed in series, they were used to record temperatures by the Accademia del Cimento's meteorological network.

Balance hygrometer

The proverbial capacity of the sponge to absorb water is used in this instrument to measure the air's humidity. If a hygroscopic material (a sponge) and a material that does not absorb water (wax), are placed on the two pans of the balance, and the two elements are weighed in a manner that the balance is equilibrated when the air is dry, it will be verified that, at the increase of humidity, the pan with the sponge will become heavier and will move the balance.

Rope hygrometer

A simple instrument measuring the humidity of the air which exploits the hygroscopic properties of certain materials. The length of the rope made from hemp, or sometimes from animal intestines, changes according to the variation of the air's humidity. The changes in the dimension of the rope, kept in tension by a weight, can be quantified with the aid of an empirically indexed scale.

Condensation hygrometer

This type of hygrometer, invented upon the observation of the phenomenon of condensation, was used widely by the Cimento academicians.

Rain-gauge

This simple instrument is used today to measure the amount of precipitation registered during the course of one week. Benedetto Castelli, a student of Galileo Galilei, describes a similar instrument in a letter to his master on June 18, 1639: "I took a glass vase of a cylindrical shape, about 22 cm. high and only half as wide. I diligently made note of the mark of the height of the water in the vase, and then I exposed it to the open air to receive the rain water that fell in…"

Anemoscope

In some experiments, the Cimento academicians used this instrument to determine the direction and even the approximate force of the wind (the anemometer is the instrument used to determine the velocity of the wind). They usually used a windrose or weathervane as a system of reference.

Table, Diary observation

The lack of recording instruments was compensated for by the meteorological observers from the second half of the 1600s with the patient and rigorous compilation of forms and tables, where the data from the descriptive observations and on instruments used, were methodically annotated.

Barometer

A meteorological instrument of prime importance which, following Evangelista Torricelli's epoch-making experiment in the spring of 1644 in Florence, was used to measure the variations in air pressure and to identify the corresponding atmospheric changes.

8. ASTRONOMY

"According to the custom of Your Serene Highness, which is to investigate truth through experimental evidence, we have inviolably observed it …, at least for that which could be reduced to an Experience of things so remote from our senses."

G.A. Borelli, from *"Parere degli Accademici del Cimento sopra il Sistema di Saturno"* [The Accademia del Cimento's opinion on the system of Saturn]

8.1. TESTING THE STARS

The condemnation of Galileo Galilei in 1633 proclaimed Copernicanism heretical but not the astronomical use of the telescope that had already uncovered unimagined celestial phenomena.

in these circumstances the Accademia del Cimento assumed the role of a high scientific tribunal – chaired by Prince Leopoldo de' Medici – called upon to resolve astronomical disputes centred on the performance of new telescopes. For example, the academicians verified to what measure the strange telescopic appearances of Saturn derived from the quality of the instruments used by Christaan Huygens (1629-1695) and by Eustachio Divini (1610-1685). In later similar circumstances, in addition to their involvement in the immediate encounter between Divini and Giuseppe Campani (1635-1715) to judge the superiority of the best optical expert of the time, the academicians searched for an objective method to measure the quality of a telescope.

In this field of research, as in others mentioned, the academicians were always careful not to enter into conflict with the religious authorities. That explains why the opinions of the

Accademia, especially if they tended towards heliocentricism, were not released into the public domain until 1780.

8.2. THE COMPARISON OF TELESCOPES

Following a tradition initiated by Galileo, the first century of the telescope's history saw the superiority of Italian optical experts. In particular, in the late 1640s, Eustachio Divini (1610-1685) began to assert himself and his fame soon spread all over Europe. He returned to studies of Saturn, which to some degree had clouded his reputation as an optical expert, some years after confronting the emergence in Rome of an artisan firmly intent on stealing his supremacy.

His name was Giuseppe Campani (1635-1715), who had began his career as a clockmaker, then dedicating himself to the production of lenses around 1660. In 1662, together with his brother Matteo, he produced a looking glass the length of ten 'palmi' (about 2.2 metres) that provoked great interest for its optical quality and laid down a challenge regarding the undisputed superiority of Divini's telescopes.

A fierce rivalry was sparked between the two craftsmen that opened the season for *'paragoni'* [comparisons], as these direct confrontations between telescopes constructed by different artisans were called.

In the Spring of 1664, Campani's glasses had lead to important astronomical discoveries. In Florence, the Cimento academicians, who had so far used only Divini's telescopes, now wished to ascertain whether, and to what degree, Campani's telescopes were superior. They printed a chart that quotes ten lines taken out of verses from famous literary works, with the characters decreasing in size. The chart – illuminated by two torches placed on either side and shielded so as not to disturb the vision – was read from a distance of 100 Florentine 'braccia' (about 58.4 metres) with telescopes of varying lengths. They carefully noted how far down the sheet each telescope could read. In autumn of that same year, the chart was sent to Paolo Falconieri in Rome, with precise instructions, so that, read in the same conditions and with glasses of the same length, the results produced would be comparable with those obtained in Florence.

From their first attempts to create test charts, the academicians realised that the use of famous verses could convince "those who make the observations by reading and distinguishing with the eyes that which only their memory can bring to mind". They also ascertained that the letters with vertical strokes – for example the *p* or the *d* – are more easily distinguishable from those without, which at times made it possible to guess entire words, above all in context. On the basis of these considerations, the academicians prepared two new test charts: one labeled “A”, contained only letters without vertical lines used to form words without meaning; the other, labeled “B”, still quoted characters without vertical lines, but rather than in words, uniformly spaced along any line. Then, to attain a better view, the lines were “typed because when printed, the ditch made by the characters were filled with a shadow, […] and outlined the word with a shade.” Thanks to this series of realisations, the academicians framed something very similar to the modern *optotypes* today commonly adopted for eye-tests. Herman Snellen from Holland (1834-1908) introduced the optotypes only in 1862.

8.3. THE STRANGE APPEARANCES OF SATURN

Science-fiction films and telefilms (*2002 the Second Odyssey*, *Saturn 3, Star Trek Voyager*, etc) have made the cinematographic and television viewing public familiar with travels through Saturn’s rings completed by fictional astronauts.

But in 1609, when Galileo pointed the telescope to the luminous planets – Jupiter, Saturn and Venus – he began to unveil the totally unexpected nature of objects, believed until then to be “wandering stars”.

Therefore, it should not be surprising that Saturn, often because of the weak quality of the first optical instruments, as well as being surrounded by hundreds of rings made of debris, appears in an incredible number of strange ways.

Huygens and Saturn’s ring

In 1659 Christaan Huygens published a work titled *Systema Saturnium*, where in order to explain the strange appearances of the planet, he placed a large, solid, thick ring around it. According to Huygens, other people’s telescopes blurred and deteriorated the quality of the image of the ring, especially when it was seen with its edge toward the Earth. So the two curving lines, at times even reduced to circular areolae, remained interpreted erroneously as spherical bodies beside the planet.

Fabri and the apparent satellites of Saturn

In 1660 Honoré Fabri denied Huygens’ hypothesis that had obvious Copernican implications, and worked out his own, according to which four large satellites orbited Saturn. Two light-reflecting satellites explained the tri-spherical appearance; two light-absorbing ones sometimes eclipsed the light-reflecting ones, giving the appearance of curving lines.

According to Fabri, the flaws in Huygens' telescopes distorted the image, generating illusions connecting the curving lines to Saturn's body. Such fictitious arcs gave the impression that a ring circled the planet.

The Cimento academicians resolve the problem

In the summer of 1660, to clarify the problem the Cimento academicians prepared a model of Saturn according to Huygens' hypothesis. The model was placed at the end of a gallery and illuminated by four torches placed in such a way that they could not dazzle the observer. It was observed from a distance of 128 Florentine 'braccia' (about 74 metres) with two telescopes of varying quality.

In a second experiment the observation took place during the day from the distance of 37 'braccia' (about 21 metres). So that their judgement was not spoiled by their familiarity with the model, the academicians called upon people who had never seen it up close to perform the observations. Apart from some exceptional visual performances and others who attempted to guess, the majority distinguished Saturn as tri-spherical. In this sense the experiments brought the academicians to the conclusion that the true form of Saturn was Huygens had proposed.

8.4. THE FIRST FIFTY YEARS OF TELESCOPES

During the first half of the seventeenth century different optical combinations were worked out for astronomical telescopes. An objective convergent lens (either plano-convex or double convex)is usually put together with one of the following:

1 - a single divergent lens (plano-concave) in Galileo Galilei's eyepiece;

2 – a single convergent lens in Johannes Kepler's eyepiece;

3 - two convergent lenses in Christiaan Huygens' eyepiece;

4 - one convergent lens behind a focal adjustment with two convergent lenses in Giuseppe Campani's eyepiece.

Each combination, with its own peculiar merits and flaws, was devised above all to boost the telescope's magnification. But it also served to widen the field of vision, right an upside-down image and eliminate the main flaws in the lenses: spherical aberration (images being out of focus or deformed towards the edge of the lens) and chromatic aberration (coloured haloes around objects observed).

Galileo's Eyepiece

The telescope with a single divergent lens in the eyepiece was used by Galileo Galilei (1564-1642) from 1609, and empirically perfected by him.

Kepler's Eyepiece

Johannes Kepler (1571-1630) proposed a telescope with a single convergent lens eyepiece in his text *Dioptrics*, published in 1611, as a practical application of his studies inoptical geometry.

Huygens' Eyepiece

Christaan Huygens (1629-1695) constructed this type of eyepiece around 1662, that is, after having discovered one of Saturn's satellites and its ring with a Keplerian telescope.

Campani's Eyepiece

Giuseppe Campani (1635-1715) constructed his own telescope with a focal adjustment towards the end of 1662 when, together with his brother Matteo, he presented it in Rome, claiming that it was a Dutch product.

9. THE EXPERIMENTS

> *"We wished to put this opinion to the test of experiment, and it seems to us that it holds up very well. Therefore we shall relate what little we can say that we have certainly seen in this light."*
>
> (*Saggi di naturali esperienze*, Florence 1667)

9.1. PNEUMATICS

9.1.1. Barometric Experiment

In the spring of 1644 in Florence, Torricelli produced the extremely famous experiment with quicksilver. It proved two fundamental concepts: that nature does not abhor the void and that air has weight.

This experiment opened an era of revolutionary transformations for science, at that time still founded on Aristotle's principles of physics.

Experiment's Articles

- Basin containing mercury in which the barometric tube was immersed.
- The mercury, also called *quicksilver*, was the liquid used by Torricelli in the famous barometric experiment. Its density allowed the creation of the void in relatively small and manageable tubes. In fact, to carry out the experiment with water required a tube of almost 11 metres.
- Glass barometric tube almost 1 m long open at one end.
- Membrane from an animal's bladder used by the Cimento academicians to hermetically close the tube's mouth. Torricelli instead closed the end of the barometric tube with a finger.
- Glass funnel which, completely inserted inside the tube, permitted the admission of liquid from the bottom towards the top. This way the formation of bubbles of air inside the column of mercury was avoided as much as possible.

Experiment

- Torricelli filled a glass tube open only at one end with mercury. Then, after closing the mouth of the tube, he tipped it upside down in a basin also containing mercury.
- Uncovering the mouth of the tube, he observed that the column of mercury, under its own weight, only partially descended, stopping at a height of about 76 cm above the surface of the mercury in the basin. Torricelli was convinced that the space left free from the descent of the mercury in the tube was empty, and that the fact that the column of mercury stayed up was the consequence of the contrast exercised by the weight of the air on the mercury in the basin.
- The academicians tried many variations of the experiment. For example, they observed that, varying the inclination of the barometric tube, the level of the column of mercury remained constantly at the height of 76 cm.
- The experiment that Torricelli performed with the mercury had already been carried out with water by Gasparo Berti. Using water, which has a density 13.6 times less than mercury, Berti had to rely on an extremely hard to manage metal barometric tube of almost 11 metres.
- Upon opening the valve placed at the bottom end of the tube, the water was free to flow down the vase. He noticed that the column of water in the tube settled at a height of 10.3 metres.

9.1.2. Pascal's Experiment

With the famous experiment of Puy de Dôme (a mountain of almost 1400 m. in the Massif Central of France) in 1648, Blaise Pascal showed that atmospheric pressure diminishes with an increase in altitude. In 1657 the Cimento academicians replicated the experiment in the Artimino Villa and at the Palazzo Vecchio.

Experiment's Articles

- Palazzo Vecchio, where the Cimento academicians replicated Pascal's barometric experiment.
- One of the glass barometric instruments used by the academicians to replicate Pascal's experiment. The instrument showed one U-shaped tube with a double scale marked by little enamel beads. One end of the tube had a trumpet mouth, while the other end was inserted into two connected spheres, the top one ended with a very narrow sprout.
- Mercury, also called *quicksilver*, was the liquid used by the academicians in many barometric experiments. Its greater density permitted the use of relatively small tubes.
- Ropes and pulleys to lift the barometric apparatus from the floor of the Piazza della Signoria to the top of the tower of the Palazzo Vecchio.

Experiment

- The Cimento academicians poured a small quantity of mercury into the barometric apparatus. They observed that the liquid rose to the same height in both branches of the U-shaped tube.
- They took the instrument to the Piazza della Signoria beneath the Palazzo Vecchio, and they left it with both ends of the tube open for the amount of time necessary for the volume of mercury to settle according to the temperature of the environment. They then sealed the instrument's spout with a flame and took note of the level of the mercury in both branches.
- They tied the instrument to a rope and with the pulley they slowly lifted it towards the top of the tower of the Palazzo Vecchio.
- At the top of the tower, the level of the mercury in the open arm of the tube was higher than before, while in the other arm it had fallen. They interpreted this phenomenon as a result of the lower weight of air pushing on the mercury in the

open tube at this altitude, compared to the weight of air at piazza level imprisoned in the spheres which still exerted pressure on the mercury in the other arm.

9.1.3. The Magdeburg Hemispheres

Around 1655, Otto von Guericke set up a pump to extract air from tightly sealed containers. Thanks to this new instrument, in 1657 he was able to prepare a spectacular experiment in Magdeburg with the assistance of an enormous number of fellow citizens.

Experiment's Articles

- Separate, but perfectly fitting together bronze hemispheres. If the void is produced inside these hemispheres, a considerable external force must be applied in order to separate them.
- Air pump capable of sucking out the air inside the tightly sealed tin containers, conceived by Otto von Guericke in 1655.
- Opposing pull from horses used in an attempt to separate the two hemispheres.
- Leather packing to guarantee the perfect fitting together of the two hemispheres.

Experiment

- In 1657 von Guericke prepared a famous and spectacular experiment in Magdeburg in front of the Imperial Diet, with the assistance of an enormous number of fellow citizens. Von Guericke used two perfectly matching bronze hollow hemispheres of about 50 cm in diameter. He firmly fitted them together to form a sphere. He subsequently used a valve to extract the air from the sphere through an air pump.
- Once the void was made and the connections on the outside of the sphere removed, von Guericke was able to show the dismayed onlookers that the force of two pairs of eight horses pulling in opposite directions, was just enough to separate the two empty hemispheres. So the force of atmospheric pressure unimpeded by the internal pressure of the hemispheres was shown. To separate them it was merely necessary to reintroduce air.
- About 2000 kilograms of force is necessary to open a compound sphere with a diameter of 50 cm, similar to the one in Magdeburg.

- The force needed is obtained by multiplying the measurement of the area of the largest section of the sphere by the difference between the pressure exerted from the air upon it and the residing internal pressure (F = πr2P). The force, equaling the pressure, is proportional to the square of the radius.

9.1.4. The Bladder in the Void

In August 1657 the Cimento academicians verified the behaviour of a bladder placed inside a glass vessel in which a void had been created. The experiment was a direct application of the noted Torricellian experiment in 1644.

Experiment's Articles

- Basin containing mercury in which the barometric tube was immersed.
- The mercury, also called *quicksilver*, was the liquid generally used by the academicians for barometric experiment. Its density allowed the creation of the void in relatively small and manageable tubes.
- Glass barometric tube open at both ends. The top part terminates with a vessel, in which the bladder is inserted.
- The glass lid that covers the vessel. The mouth at the top was opened and during the experiment, was sealed with the animal bladder.
- Glass funnel which, completely inserted inside the tube, permitted the admission of liquid from the bottom towards the top. This way the formation of bubbles of air inside the column of mercury was avoided as much as possible.
- Lamb's bladder almost completely deflated. It inflated once the void was made.
- Membrane from an animal's bladder used to close the mouth at the bottom of the tube.
- Membrane from an animal's bladder used to close the mouth at the top of the lid.

Experiment

- The academicians sealed the vessel placed at the end of the barometric tube with a lid, to which they tied a lamb's bladder, almost completely deflated.
- They closed the bottom end of the barometric apparatus with a membrane and using the funnel, they poured the mercury into the tube until it was completely full. In the end, they closed the mouth at the top of the lid with another membrane.

- They immersed the barometric tube in the basin containing mercury and removed the fastening placed at the bottom end. They observed that at the same time that the mercury partially descended into the basin, the bladder "magically" began to inflate. That depended on the fact that as the void was created by the descent of mercury, the little air remaining in the deflated bladder expanded, no longer impeded by the pressure of the air.
- They also reproduced the evidence for the basis of this explanation. By re-opening the mouth at the top of the lid, the air re-entered the vessel: the bladder immediately inflated again and the mercury still present in the tube immediately fell into the container below.

9.1.5. The Smoke in the Void

In June 1660 the Cimento academicians verified the movement of the smoke inside a glass vessel in which a void had been created. The experiment, conceived by Giovanni Alfonso Borelli, provoked an ample exchange of correspondence between the academicians and their correspondents.

Experiment's Articles

- Basin containing mercury in which the barometric tube was immersed.
- The mercury, also called *quicksilver*, was the liquid generally used by the academicians for barometric experiment. Its density allowed the creation of the void in relatively small and manageable tubes.
- Glass barometric tube open at both ends. The top part terminates with a vessel, in which a smoke-producing tablet is inserted.
- Glass funnel which, completely inserted inside the tube, permitted the admission of liquid from the bottom towards the top. This way the formation of bubbles of air inside the column of mercury was avoided as much as possible.
- Membrane from an animal's bladder used to close the mouth at the bottom of the tube.
- Membrane from an animal's bladder used to close the mouth at the top of the tube.
- Dark combustible smoke-producing tablet which was inserted inside the vessel.
- Burning mirror used to concentrate the Sun's rays on the smoke-producing tablet. Sometimes the academicians used a convergent lens in place of the mirror.

Experiment

- After fastening the combustible smoke-producing tablet inside the vessel, the academicians closed the mouth at the bottom of the tube with a membrane. Using the special funnel they poured the mercury into the tube until it was completely full. Finally, they closed the mouth of the vessel.
- They immersed the barometric tube in the basin also containing mercury and removed the membrane placed at the bottom end. The liquid, like in the famous Torricellian experiment, began to descend and it settled at a height of 76 cm, leaving the empty space at the top with the smoke-producing tablet empty.
- They positioned the stand with the burning mirror at a certain distance from the barometric apparatus. They tilted it so that the Sun's rays were concentrated on the smoke-producing tablet, causing its combustion. The smoke generated in the void, instead of rising, descends towards the bottom, no longer suspended by the air.
- Once the vessel's cover was removed, air re-entered the tube causing the complete descent of the column of mercury into the basin below and pushing the smoke towards the top of the vessel.

9.1.6. The Sound in the Void

The first experiments carried out with the Torricellian tube showed that sound was transmitted in the void. The Cimento academicians tried to ring a bell inserted in the section of the Torricellian tube left empty by the descent of the mercury. The sound from the bell could be clearly heard. This effect seemed to show that the tube was not vacuous. If it had been so, the transmission of sound would not have been possible. Using a glass vessel made vacuous by a pump and with a bell placed inside, Robert Boyle (1627-1691) was the first to show through experiment that sound could not be heard.

Experiment's Articles

- Glass container inside of which a void was produced.
- Brass bell.
- Suction pump conceived by Robert Boyle. Worked more effectively than the its precedent conceived by Otto von Guericke.

Experiment

- In 1660 Robert Boyle prepared an apparatus to experimentally show the impossibility of transmitting sound in the void. First he began to draw air out from the sphere with a suction pump, while the bell inside the vessel was rung.
- While the pump sucked out the air, the sound of the bell weakened until it disappeared completely. In fact, the sound is transmitted exclusively through a medium, like air. With the air taken away, the sound therefore cannot be propagated.
- Boyle also gave evidence fundamental to this explanation. With the sealing bladder removed the air re-entered and slowly the sound of the bell returned.

9.1.7. The Void in the Void

In 1648 Roberval, Auzout and Pascal, and later, Boyle and the Cimento academicians, produced in different ways the so-called "void in the void" experiment conclusively confirming the existence of atmospheric pressure. The experiment consisted of the replication of the Torricellian experiment in 1644 in a vacuous environment. If the column of mercury descended completely in the tube, this would have been evidence of the causal role of atmospheric pressure.

Experiment's Articles

- Basin containing mercury in which the barometric tube was immersed.
- Mercury was the liquid used by the academicians for many barometric experiments. Its high density allowed the creation of the void in small and manageable tubes.
- Glass lid to close the vessel of the bottom barometric tube. A hole was made to insert the top barometric tube and a lateral spout.
- Glass beaker that acted as a barometric basin for the top tube.
- Glass tube the length of 116cm open at both ends. This was the tube for the top barometric apparatus.
- Glass barometric tube open at both ends. The top part terminated with a vessel in which the beaker was inserted.
- Membrane from an animal's bladder used by the Cimento academicians to hermetically close the mouths of the apparatus.

Experiment

- After placing the beaker inside the vessel, the academicians inserted the top tube into the hole in the lid and they fastened it so that it would not touch the bottom of the beaker. Once the mouth at the bottom of the apparatus was closed, they immersed it in the basin containing mercury. This way two Torricellian barometers were obtained, one inside the other.
- Through the top mouth they poured enough mercury to fill the entire beaker, the bottom tube and the vessel, and then they sealed the spout with a bladder. They continued to pour mercury until the top tube was full, and then closed the mouth with another bladder. This way they were certain that no air had remained inside the apparatus.
- By removing the bottom bladder, the mercury began to descend, settling in the bottom tube at the height of 76 centimetres and leaving the vacuous space at the top. The mercury in the beaker was still held back. The top barometer, in contrast to the bottom one, was thus in a vacuum and the mercury, no longer impeded by the air pressure, descended completely into the beaker.
- By re-opening the spout, the air re-entered the vase. Because of the air, the mercury in the bottom tube descended into the basin; simultaneously, the mercury remaining in the beaker rose in the top tube, until reaching the height of 76 centimetres. By removing the last bladder, the mercury in the top tube fell into the beaker.

9.2. METEOROLOGY

9.2.1. Thermometric Scales

The Cimento academicians perfected the Galilean thermoscope and conceived various types of thermometers. They adopted alcohol (quicksilver) as their thermometric liquid and worked out various thermometric scales to obtain reliable measures of "*heat and cold*".

Experiment's Articles

- The 50-degree thermometer consisted of a glass bulb connected to a small, long and subtle tube. The small tube, also made of glass and sealed, was divided into 50 subdivisions stressed by enamel beads. A white bead marked every 10-degree interval, while the single degrees were coloured black

- The alcohol (quicksilver), thanks to its strong sensibility to variations in temperature, was used by the academicians as a thermometric liquid.
- Melting ice, that is, in the process of melting, with a temperature that remains constant until its complete dissolution. The academicians, thanks to their experience, were conscious of this principle and so they immersed the thermometers in the ice to calibrate them.

Experiment

- The academicians immersed the instrument in a basin containing melting ice. As an effect of the consistent temperature of the melting ice, the alcohol settles at 13.5 degrees. This level became considered as the lowest fixed point of the thermometric scale.
- The academicians' thermometric scales did not have a highest fixed point. The maximum empirical value was obtained when the level of alcohol in a thermometer was exposed to the summer Sun. In such circumstances the alcohol contained in a 50-degree thermometer almost always reached the level of about 40 degrees, the maximum temperature registered.
- To guarantee the comparability of the results, the 50-degree thermometers were constructed in series so that all "the fierce heat of our summer" would not surpass, or would barely surpass, 40 degrees, and "in the most piercing cold of winter" it would arrive at 12 or 11 degrees. In any case, the effective degree of comparability between the different thermometers depended on the ability of the glass blowers.

9.2.2. Comparing Thermometers

The Cimento academicians calibrated the thermometers containing alcohol according to various scales: from thermometers divided into 50 degrees to thermometers with so-called "long necks", because of the long tube divided into as many as 420 degrees. Furthermore, the academicians constructed thermometers "a chiocciola" (spiraled), with a long spiraled tube, and the so-called thermometers "infingardi" (slothful), so defined because of their poor sensibility to the variations in temperature.

Experiment's Articles

- The Accademia's thermometers consisted of a glass bulb connected to a sealed tube also made of glass, of different dimensions. The tube was divided in a scale of 30 to 420 degrees, marked by small, coloured, enamel beads.
- The thermometers "a chiocciola" or "a spirale" consisted of a glass bulb connected to a very long graduated tube, bent by the flame and wound into a spiral.
- The alcohol (named quicksilver by the academicians) was used as a thermometric liquid because of its clear sensitivity to variations in temperature.
- The "infingardi" thermometers consisted of glass balls of different density and colour, immersed in one or more tubes full of alcohol, moving according to the variation in the temperature.

The behaviour of the thermometers.

50-DEGREE THERMOMETER

The dilations or contractions of the alcohol inside the 50-degree thermometer, adopted by the Medicean meteorological network because of its reliability, were indicative of the variations in temperature. During the harshest winter days the level of the alcohol descended to 12-11 degrees, while during hotter summer days it barely passed 40 degrees.

100-DEGREE THERMOMETER

The dilations or contractions of the alcohol inside the 100-degree thermometer were indicative of the variations in temperature. During harsh winter days the level of the alcohol descended to 17-16 degrees, while during hotter summer days it did not pass 80 degrees. This instrument was more sensitive and faster than the 50-degree thermometer, but also less accurate.

300-DEGREE THERMOMETER

The 300-degree thermometer, consisting of a very long and subtle tube, was particularly sensitive to thermic variations. It was four times faster then the 100-degree thermometer, but also less accurate.

THERMOMETER "A CHIOCCIOLA"

The thermometer "a chiocciola" or "a spirale" (spiraling) was sensitive and fast, but also very inaccurate. The uneven thickness of the tube, due to its difficult construction procedure, actually impeded the uniform movement of the alcohol. The instrument was constructed essentially for playful ends, "through the curiosity to see the liquid run through tens of degrees when it is simply breathed on."

THERMOMETER "INFINGARDO"

The "infingardo" (slothful) thermometer was very slow compared to the others and registered only considerable variations in temperature. The density of the alcohol diminished progressively from the increase in temperature. As a consequence, the spheres, after receiving a small push upwards, fell one after the other towards the bottom, beginning with the heaviest.

9.2.3. The Condensation Hygrometer

The invention of the condensation hygrometer is attributed to the Grand Duke Ferdinando II. The idea behind the instrument was founded on the simple observation of the formation of condensation on cold surfaces and was used by the academicians to "*to determine changes in air humidity*".

Experiment's Articles

- The condensation hygrometer consisted of a glass vase in the shape of an upside down cone and was mounted on a wooden stand.
- Finely crushed ice poured into the instrument to keep the temperature of the walls low.
- Small glass graduated beaker used to collect the drops of condensation.
- Bifilar pendulum to determine the duration of the observations so that they could be compared.
- Medicean residence at Artimino, near Carmignano, where the academicians carried out various hygrometric experiments.

Experiment

- The vase was filled with crushed ice. Because of the lowered temperature the humidity in the atmosphere became condensed on the outside of the glass, forming drops of water. These drops slid down the outside of the glass and fell from its edge into the graduated beaker below. The greater the humidity in the atmosphere, the stronger the phenomenon of condensation and dripping. The results of the hygrometric measurements were determined by the quantity of water collected in the small beaker during a determined period of time, measured by calculating the oscillations of the pendulum.

- Together with the academicians, the Grand Duke conducted various hygrometric observations at the royal villa at Artimino. To determine the degree of humidity in different environments, the hygrometer was set up in rooms inside the villa and also outside, in different wind conditions.

- **Kitchen**: It was found that the hygrometer in the kitchen made 3 drops per minute.
- **Chamber**: It was found that the hygrometer in the chamber made only four drops per minute.
- **Cellar**: It was found that the hygrometer in the cellar made 15 drops per minute.
- **Northerly wind**: "*the north wind prevailing, the sweating gradually ceased, and in little more than half an hour the glass was dry*".
- **South-westerly wind**: "*when southerly winds prevail the glass sweats most copiously, [and…] in a strong south-westerly gale we have collected as much as 35 or even 50 drops per minute*".

9.3. LIQUIDS

9.3.1. The Hydrometer

The Cimento academicians produced many experiments to determine the specific weights of liquids. With that aim they constructed glass hydrometers, also called hydrostats, liquid-balances, gravimeters, or densimeters, in various dimensions and fashions.

Experiment's Articles

- Hydrometer with a graduated tube and a bulb containing grains of lead that acted as a counter-weight. Various enamel beads marked the graduations on the tube. The academicians also used other types of hydrometers that were calibrated to operate with the liquid being weighed.
- 50-degree thermometer used to determine the temperature of the liquids from which it was hoped their specific weights would be found. In fact, the liquid – as the academicians note in their Diary – "*always need to be at the same hot or cold*

temperature because the cold makes them heavier and the heat makes them lighter". Hydrometers with alcohol inside were also constructed to carry out the roles of both thermometer and hydrometer.

- Cylindrical vase containing alcohol usually used by the academicians as a thermometric liquid.
- Cylindrical vase containing water used by the academicians in experiments on "freezing" and sometimes in barometric experiments. The academicians also used the water as a thermometric liquid, in comparison with alcohol.
- Cylindrical vase containing mercury used by the academicians in barometric experiments, but also as a thermometric liquid, in comparison with alcohol.
- Cylindrical vase containing white wine used by the academicians in experiments in combination with other liquids.
- Cylindrical vase containing oil used by the academicians above all in experiments on "freezing".
- Cylindrical vase containing Chianti used by the academicians in experiments in combination with other liquids.

Experiment

- The hydrometer is an instrument that, immersed in any liquid, indicates its specific weight. The higher the degrees marked on the tube by the surface of the liquid, the greater its specific weight. For example, in water, the hydrometer descends to the sixth mark.

Liquid specific weight

- In alcohol, which has a very low specific weight, the hydrometer descends completely.
- In oil the hydrometer descends to the last marks on the tube.
- In water the hydrometer falls to the sixth mark on the tube.
- In white wine the hydrometer falls to the fourth mark on the tube.
- In Chianti the hydrometer falls to the first mark on the tube. Thanks to measurements of this type, the academicians maintained that "the sweater the wine, the heavier its weight."
- In mercury, which has a higher specific weight, more than 13 times higher than water, the hydrometer floats.

9.3.2. The Incompressibility of Water

Thanks to repeated experiments, the Cimento academicians demonstrated the impossibility of compressing liquids. Through experiments they verified that even if water is subjected to strong pressure, its volume remains unaltered.

Experiment's Articles

- Cylindrical glass vessel partially graduated with a lateral spout an opening at the top.
- Glass tube about 2½ m long open at both ends. It was strengthened by a lead wrapping to support the weight of the mercury that was poured in.
- Water (substance used to demonstrate the incompressibility of liquids).
- Mercury (used to exert pressure on water).
- Hollow silver metal ball closed hermetically with a screw cap.

Experiment

- The academicians poured water into the vessel up to a certain level. They inserted a tube, which they fastened to the mouth of the vessel with stucco in a way that the bottom end of the tube would remain raised from the bottom of the vessel to allow the liquid to flow freely.
- They poured mercury in the vessel using the tube, making the level of the water rise and emitting the air through the spout. When the vessel was full to the brim with water and mercury, they sealed the spout with the flame. At this point they noted the level reached by the mercury.
- After continuing to pour mercury in the tube until it reached a total weight of about 27 kilograms, they observed that the level of the mercury in the vessel remained stable and despite the strong pressure, it did not compress the volume of water.
- More evidence for the incompressibility of water was obtained with another experiment. The academicians had a sphere, cast of silver, filled with cold water and sealed. They then beat it violently with a mallet to deform it, causing its reduction in volume. Not being compressible, the water oozed out through the walls of the sphere.

9.3.3. Freezing

The freezing of liquids was a phenomenon verified by many experiments by the Cimento academicians, using various types of instruments. The results obtained were noted in special tables at the same time as the variations in temperature in the transition from a state of liquid to solid took place.

Experiment's Articles

- Glass instrument used by the academicians to verify the movement of liquids during the freezing process. It consisted of a bulb, with a long thin tube graduated 116cm long. The instrument was a type of water thermometer open at the top end of the tube.
- Table of the freezing process on which the academicians reported the data from the experiments.
- Container with crushed ice in which the bulb of the instrument was immersed.
- Counting pendulum used for a precise calculation of time. It was calibrated to complete 65 oscillations per minute.
- Alcohol was a substance which, sprayed over the ice, had the capacity to keep it frozen.
- Pulverised ammoniac salt (similar in many cases to ammoniac chloride) was a substance that, infused in ice, had the capacity to keep it frozen.
- Fountain water used in many experiments on freezing.

Experiment

- The academicians poured water into the instrument while in the table they noted the degrees it reached. They named this first phase *natural state*.
- They inserted the instrument in a container with crushed ice and simultaneously began to oscillate a pendulum with a spring. They observed an evident rise in the water and named this phase *the jump upon immersion*. As Borelli asserted, this was not caused by the increase in volume of water but from the contraction of the glass caused by the cold.
- After the initial *jump*, the water in the tube descended slowly because of the cold.
- Once the descent of the water ended, the academicians did not note any movement for some time. They then called this phase *the point of rest*. To maintain the temperature low, they sprayed alcohol and salt on the ice.

- Following *the point of rest* the water rose slowly, which the academicians called *rise*, recognising the progressive rise in the volume of water when approaching freezing.
- After the slow rise during the process of freezing, the water in the tube unexpectedly jumped. They called this phenomenon *the jump upon freezing*. Afterwards the water continued to rise until finally, once the freezing process was over, the water, transformed into ice, broke the tube and burst the bulb.

TABLE OF THE *FREEZING* PROCESS		
Wonderful phenomena	**Degrees in vessel**	**Vibrations of the pendulum**
Natural state	142	-
Jump upon immersion	143 ½	23
Fall	120	255
Point of rest	120	330
Rise	130	462
Jump upon freezing	166	471

9.4. MISCELLANEOUS

9.4.1. The Speed of Sound

Referring to previous experiments by Pierre Gassendi, the Cimento academicians tried to measure the speed of sound, obtaining a result not far from being correct. They indicated that amongst the useful applications that they hoped to make from the knowledge of the speed of sound included establishing the exact distance between two different places. This could be achieved through the measurement of time taken to transmit sound between them.

Experiment's Articles

- Violas used to study the diffusion of sound.
- Bow.
- Straw to observe the vibrations of the cords of the viola.
- *Springal* [small cannon] to study the speed of sound

- Bifilar pendulum with which the academicians measured and compared the interval of time between a visual perception of the flash and the explosion of the sound.

Experiment

THE DIFFUSION OF SOUND

- The academicians lined up three violas laid horizontally at a distance of 4 metres one from the other, after tuning them in unison. On the cords of the two violas on the sides they rested a thin straw thread. They then used the bow on the middle viola, observing from the vibration of the straw that the other two violas sounded simultaneously. From this experiment they concluded that sound is diffused uniformly in all directions.

THE SPEED OF SOUND

- To measure the speed of sound, the academicians set up a springal on high ground. At a distance of one mile they set up a pendulum.
- Firing one blow of the springal, they observed that from the flash of the explosion to the perception of the sound there passed ten oscillations of the pendulum, each one corresponding to half a second. It seemed that the sound took 5 seconds to travel the distance of one mile. They replicated the same experiment at half the distance, verifying that the pendulum completed exactly half of the vibrations. They concluded that the sound is transmitted with a uniform velocity.

A "FANTASTIC" EXPERIENCE

- They hypothesised about some curious applications deriving from determining the speed of sound, including "to know how far away the clouds are and at what distance from the earth thunder is made, measuring the time from when the lightning is seen until we hear the thunder."

9.4.2. The Bifilar Pendulum

Galileo established the fundamental laws on the motion of the pendulum, starting, as the legend goes, from the casual observations of the oscillations of an oil lamp suspended inside the Duomo in Pisa. The Cimento academicians, who submitted many of Galileo's ideas to scrutiny, produced a pendulum with a double thread and changeable lengths, to alter its period.

Experiment's Articles

- Metal pendulum stand
- Sliding tab that made it possible to set the desired length of the bifilar pendulum. By varying the length of the thread, a consistent variation of the period was obtained. In fact, the period depends only on the length and not on the mass of the pendulum's ball.
- Bracket to fasten the pendulum's double thread.
- Metal ball, which hangs on the double thread by a hook, made it possible for the system to be pushed into oscillation.
- Stop for the sliding tab.
- The pendulum's double thread. The pendulum's thread had to not stretch and be extremely thin. The academicians preferred the double thread in comparison to the single thread because of its capacity to maintain itself on the same plane of oscillation and therefore to conserve the constant movement of the oscillations for a longer time.

Experiment

- The time it takes for the pendulum to complete one oscillation (or period) is proportional to the square root of the length of the thread. Therefore, if the length of the thread is quadrupled, the period doubles.

9.4.3. The Pedometer

The pedometer, a word of Greek origin that means "measurement of the foot", is an instrument used to measure the distance traveled. The Cimento academicians used it to attempt to measure the arc of the terrestrial meridian and in the experiments – such as those to establish the speed of sound – for which an exact calculation of the distance was necessary.

Experiment's Articles

- Wooden wheel with a circumference of 3 Florentine 'braccia' and one 'soldo', equal to 179 cm. This measurement represented a *geographic step*, that is, a fraction of the arc of the terrestrial meridian.
- Wooden handle with an axis inside transmitted the motion of the wheel to the disc-meter.
- Brass disc-meter with a revolution counter needle.

Experiment

- To carry out some of their scientific experiments the academicians used a pedometer to measure distances. They pushed it along and at the end the instrument's quadrant indicated the number of revolutions that the wheel completed. To calculate the distance it was enough to multiply this number with the circumference of the wheel, which is 1 metre and 79 cm.

- A cogged ring is mounted in the center of the pedometer's wheel. An axis is connected to the ring that transmits the motion of the wheel to a reel placed on the other end of the handle. Upon its turning, this reel interlocks with a cogged ring inside the disc-meter, making a needle that indicates the number of revolutions completed by the pedometer advance on the quadrant.

9.4.4. The Motion of Projectiles

At the tower of the Fortezza Vecchia in Livorno, the Cimento academicians carried out some experiments to investigate if projectiles take the same time to reach the ground, as Galileo had affirmed, depending on whether or not they are fired horizontally or dropped vertically downwards,.

Experiment's Articles

- Tower of the Fortezza Vecchia in Livorno from which the academicians launched their projectiles.
- Short and thin cannon of a small caliber called *falconet* used by the academicians to launch projectiles.
- In order to jam the cannon perfectly and improve its shot, these iron balls were generally wrapped with a cloth, leather, or something else.

- Galilean geometrical and military compass with which the academicians leveled the cannon in a way that the shots would be made *point blank*, that is, perfectly parallel to the horizon.
- Bifilar pendulum with which the academicians measured and compared the intervals of time between the shot and the projectile's drop into the water.

Experiment

- The academicians positioned the cannon's barrel parallel to the floor using the geometric compass. They then inserted an iron ball weighing 2½ kilos.
- Firing the cannon, they observed that the ball, after travelling in a parabolic trajectory, fell into the sea at a distance of about 1102 m in four and a half vibrations of the pendulum.
- The parabolic trajectory of the projectile derived from the composition of two motions that do not influence each other: a rectilinear uniform horizontal motion and the natural uniformly accelerating motion of the fall; it was only the latter that determined the time it took for the ball to drop into the sea.
- In fact, they dropped another ball from the tower without projecting it horizontally. They verified that this ball touched the ground in four vibrations of the pendulum, practically in the same time as the ball fired from the cannon because it experienced the same gravitational force. The academicians attributed the small difference in time between the two motions to the non-homogeneous resistance offered by the air on bodies that penetrate it.

10. THE DOCUMENTS

> *"June 21, 1662. The Accademia assembled in the house of Signor Lorenzo Magalotti for the purpose of repeating some experiments that seemed most necessary for the completion of the work that needs to be printed. When these become easy by practice, they will all be re-done in the presence of his Most Serene Highness".*
>
> (Diary manuscript)

10.1. THE *SAGGI DI NATURALI ESPERIENZE*

10.1.1. The Italian Editions

The publication of the *Saggi di naturali esperienze* [Examples of Natural Experiments] in 1667, signaled the end of the Accademia del Cimento's activities. The *Saggi*, put together by Secretary Lorenzo Magalotti, presented a selection of the academicians' experiments "to know the alteration of the air deriving from hot and cold", on the "natural pressure of air" and the void, on "artificial freezing", on the compression of liquids, on the magnet and the power of electricity from amber, on the propagation of sound and light, as well as a vast series of other natural phenomena.

The names of those responsible for individual contributions were purposefully not included, providing the image of teamwork and "harmony", a "harmony" that, pushed by Prince Leopoldo, was purely formal. In fact, Leopoldo imposed a compromise between the academicians' various inclinations, at the base of which the *Saggi* had to limit itself to presenting the simple narration of a series of experimental observations without drawing conclusions or general lessons. Nevertheless, there is no doubt that certain experiments still produced destructive results for some preserved Aristotelian doctrines.

The *Saggi* contained only one very small portion of the Cimento's research, compared with the many hundreds of experiments registered in the Accademia's *Diary* manuscript. For fear of provoking a reaction from the ecclesiastical authorities, observations regarding the true configuration of Saturn were excluded. This was a delicate topic because it was full of Copernican implications.

The book, sumptuously illustrated, had notable success. Great care was taken in the preparation of the illustrations, firstly sketched in drafts, often of high quality, then corrected in proof, and finally printed. On March 13, 1668, Magalotti presented the work to the Royal Society of London, handing a copy to Oldenburg. A second edition followed, printed in 1691 and dedicated to the Grand Duke Cosimo III de' Medici (1642-1723). Amongst the many other editions published, it is worth remembering one in particular, because of its editing and the circumstances surrounding its production. That was the edition released on the occasion of the Third Congress of Italian Scientist, held in Florence in 1841, edited by Vincenzo Antinori, director of the Museum of Physics and Natural History.

10.1.2. The Translations

The *Saggi di naturali esperienze* had notable international success. In 1684 in London, Richard Waller edited the first English translation of the *Saggi di naturali esperienze*. The frontispiece depicts the goddess of Nature showing her naked limbs to Aristotle and pointing out the *Saggi* held in the hands of a female figure (the Accademia del Cimento). This figure is handing the volume (that is, passing the baton) to another female figure representing the Royal Society. In 1731 the Dutch Petrus van Musschenbroek (1692-1761) edited a Latin edition (*Tentamina experimentorum naturalium captorum in Accademia del Cimento* …), published in Leiden. The Latin translation contains a long and profound comment in which the Dutch scientist illustrates the experimental developments and theories following the publication of the *Saggi*. Finally, from Musschenbroek's Latin edition, an edition in French was published in 1755.

10.1.3. The Literary Dimension

A scientific text written by a man of letters, undoubtedly amongst the best documents in contemporary science, was certainly not a novelty in the seventeenth century. Galileo, too, was a man of letters; Redi was even a "technician" of literature, a consultant on style for his contemporaries; and Magalotti was above all a man of letters. Naturally, it would then be necessary to define precisely what relationship science and literature had for these different figures.

But for today's public, for whom the separation between science and literature has assumed different proportions to some time ago, it is important perhaps to repeat that a text such as this one offers itself spontaneously to both groups of readers. The official account – the only publication – of the Accademia del Cimento's work, is a text that cannot be excluded from the history of Italian and European science (with all that it represents, such as philosophical and political implications and the attitude in the field of science during that era), while the literary skills of the writer, although still very young, have left unmistakable traces of his style and his expressions.

On the other hand, looking at it objectively, the scientific discourse in the *Saggi di naturali esperienze* still has the human dimension of contemporary science: not only does it describe a series of experiments and the instruments employed, but the thoughts that can be extracted from the experiments are also presented. It is understood – and it is known from the documents – that Leopoldo does not spare any expenses, instead he always produces differently shaped vessels, tubes, bladders, pendulums, "syringes", rings, magnets, amber, perhaps precious stones, water, mercury, alcohol and so on. "Plugging the mouth C with a finger and turning over the vessel […]": for us today this is a "domestic act", but this is the way that this science works; it is even open to those who don't know about it, and come to it fresh […]

It is known that the academicians Borelli, Viviani, Renaldini, and Michelangelo Ricci in Rome (1619-1682), were the editors of the *Saggi*'s scientific content (apart from the odd comment on other matters). Ottavio Falconieri and Pietro Sforza Pallavicino made literary, stylistic, linguistic and artistic observations. Meanwhile Francesco Ridolfi and Alessandro Segni revised the first drafts. So in addition to Magalotti's own scruples and delays, the continued thoughts of the editors may be added to the attention given to the literary style […]
Immediately following its publication and even after some time, the *Saggi* was well liked by Italian literary men, who considered it a splendid example the "polished language". "Purity" and "propriety" of the language, "elegance" in style, "precious and very fluent work", clarity: these are the praises unanimously given to the *Saggi*. So as was to be expected, it was cited as a source text in the third edition of the *Vocabolario della Crusca* (1691), the first released after the *Saggi*'s publication.
In effect, in its language and in its style, the text accepted, and completely mastered, its fundamental inheritance of the Tuscan literary tradition, enriched in a particular way by the example set by the stylistic experience of Galileo. In Galilean fashion, by generally avoiding the scholastic neologisms, the peculiar problems of scientific terminology are substantially resolved. Meanwhile, by comparison, a man of literature permits himself either the moderate acceptance of archaic voices and attitudes, or the use here and there of common Tuscan speech or the remarkably liked "Florentine idiom" (and as is known, both of these poles belonged to – in the different modulations and moments of the authors – precisely that literary tradition). Therefore, the *Saggi*, by remaining above all a text on experimental science, scrupulous, faithful and honest, is not covert in showing the preparation, the tastes and the literary ambitions of the author.

(Treatise to the Maria Teresa Poggi's introduction to *Saggi di naturali esperienze*, Milan 1976, pp. 7, 21-22, 24-25)

10.2. THE ACCADEMIA'S DIARY

The unpublished diary of the experiments narrated by the Cimento academicians is kept amongst the Galilean Manuscripts in the Biblioteca Nazionale Centrale in Florence. Accounts of some experiments carried out during the years 1657, 1658, 1660 and 1662 are collected in one codex (Gal. 260). These documents, which later may have served in the narration of the diary, are in various recognisable handwritings, mostly from Lorenzo

Magalotti, Carlo Renaldini, Alessandro Segni and Vincenzo Viviani. There is an incomplete copy of the 1657 diary in Viviani's handwriting. Furthermore, there are two other copies of the diary preserved in the library, both are only partial copies of the diary and in an unknown hand. The first (Gal. 261), presumably written during the Accademia's activities, only contains experiments carried out from June 19, 1657 to January 23, 1658, with brief descriptions and carefully illustrated instruments. The second (Gal. 262) consists of an entire volume in folio, intentionally elegant, narrated in double columns to allow the design of every instrument next to the experiment it refers to. Despite the gaps and errors in this text, this manuscript is the only extant version to cover the entire period of the Cimento's work, with experiments dating from June 19th 1657 to March 5th 1667. The original complete Cimento diary is missing, lost during the remarkable hardships that followed Alessandro Segni's death.

10.3. THE ACADEMICIANS' CORRESPONDENCE

That which remains of the Accademia del Cimento's correspondence is held amongst the Galilean Manuscripts in the National Central Library of Florence. According to the order given to documents at the beginning of the nineteenth century, the surviving material is divided in the following manner: letters to Prince Leopoldo (Gal. 275-281), Leopoldo's notes (Gal. 282), letters from the academicians to other scientists (Gal. 283-285), letters regarding Saturn's system (Gal. 289). To reconstruct the exchange of letters during the Accademia's few years of activity, the following documents may also be helpful: scientific letters to the Grand Duke (Gal. 286), Nicolas Steno's letters (Gal. 291), letters mixed in with meteorological observations (Gal. 296-307), a manuscript report of a journey (Gal. 292), and two manuscripts containing scientific accounts of various discussions (Gal. 293-294). This includes more than 1400 letters, in addition to the copies that occupy some of the volumes called the 'Favaro Appendix,' containing around 350 copies whose originals are lost. The huge volume of letters from numerous countries is a direct testimony that the Accademia, often represented by the Prince, was at the centre of a crowded network of relationships with the most eminent personalities of the Italian and European scientific world. It also a first hand documentation of the circulation of ideas and discussions regarding the major philosophical and scientific questions of the time.

10.4. BIBLIOGRAPHY

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