ISTITUTO E MUSEO
DI STORIA DELLA SCIENZA

Galileo's microscope

Here you will find all of the texts on application,
compiled by the *Institute and Museum of the History of Science*, Florence.

INDEX

1 HISTORY

1.1 THE COMPOUND MICROSCOPE

The first microscopes were produced around the same time as the telescope. They also had two or more lenses, but with an objective lens of shorter focal length.

The invention is attributed to Galileo (1564-1642), although, in the 17^{th} century, the claim was contested by others. In *Il Saggiatore* [The Assayer] (Rome, 1623), written between 1619 and 1622 and published in 1623, the Pisan scientist mentioned a “telescope modified to see objects very close”. In 1625 a member of the Accademia dei Lincei and friend of Galileo, Johannes Faber (1574-1629) conferred on the instrument, until then called “occhialino”, “cannoncino”, “perspicillo”, and “occhiale”, the name of “microscope”.

The first microscopes of the Galilean type had, like the telescope, a concave lens and a convex one mounted in a rigid tube. Thanks to these simple optical devices the philosophers of nature could now gaze on a new and marvelous world, which was later to allow the development of both medical-biological disciplines and naturalist ones.

The fame of Galileo's optical instruments inspired a search for new solutions. In the 1620s, microscopes of the Keplerian type, composed of convex lenses that furnished a reversed image, were developed. In the second half of the century, remarkable results were achieved by the Italian instrument-makers Eustachio Divini (1610-1685) and Giuseppe Campani (1635-1715), while in England levels of excellence were reached by Robert Hooke (1635-1702/03). During this same period some important treatises on the construction techniques of microscopes appeared, of which *La dioptrique oculaire* (Paris, 1671), published in 1671, by the Capuchin monk Chérubin d’Orléans (1613-1697) is a splendid example.

In the 18^{th} century the instrument became popular among the upper classes, who used it as a refined intellectual *divertissement*. The English instrument-makers introduced some innovations, especially in the mechanics of the instrument. Its optical performance was, in fact, still mediocre, because of spherical aberration and chromatic aberration, which were eliminated only in the first half of the 19^{th} century, thanks also to the work of Giovan Battista Amici (1786-1863).

IMAGES AND CAPTIONS

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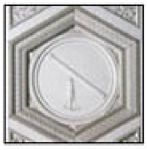
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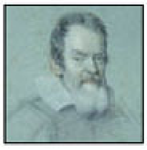
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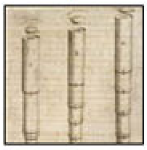
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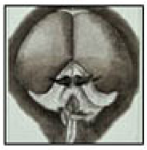
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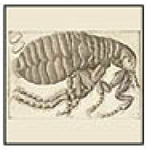
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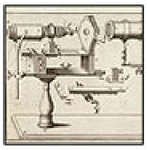
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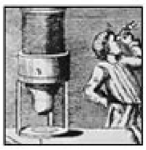
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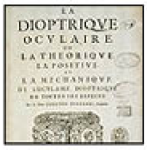

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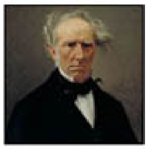

1. Bas-relief by Luigi Giovannozzi depicting the Galilean telescope and microscope - Florence, Tribune of Galileo, apse, left pilaster strip.
In this nineteenth-century bas-relief, the microscope and telescope are shown together. The origins of these optical instruments, which can be traced starting from the first decades of the 17th century, are in fact closely linked.

2. Galilean compound microscope, designed by Galileo Galilei and constructed by Giuseppe Campani [attr.] (Second half of the 17th century), Florence, Istituto e Museo di Storia della Scienza.
The microscope, built of cardboard, leather and wood, is inserted in an iron mount with three curved legs. The mount, while stabilizing the instrument, allowed it to be focused by sliding the tube inside the ring.

3. Galileo's telescope (late 1609 - early 1610), Florence, Istituto e Museo di Storia della Scienza.
Original telescope of Galileo (1564-1642) composed of a main tube at the ends of which are inserted two separate sections bearing the lens and the eyepiece. Federico Cesi (1585-1630), founder of the Accademia dei Lincei, proposed the name "telescopio" [from the Greek words *tele* (distant) and *scopeo* (I see)] for this instrument.

4. Portrait of Galileo Galilei, drawing (pencil on paper) by Ottavio Leoni. Florence, Biblioteca Marucelliana.

Galileo Galilei (1564-1642), by some considered the inventor of the microscope, was probably the first to adapt the telescope he had perfected "to see minute things close up".

5. Galileo Galilei, *Il Saggiatore*, Rome, 1623 - frontispiece.
In *Il Saggiatore* [The Assayer], an important work by Galileo promoted by the Accademia dei Lincei, the Pisan scientist mentions, for the first time, "a telescope modified to see objects very close".

6. Emblem of the Accademia dei Lincei
The lynx, an animal possessing remarkably keen vision, exemplifies the spirit of observation and investigation with which the members of the Academy engaged in their research. Johannes Faber (1574-1629), in a letter to Federico Cesi (1585-1630) dated 1625, gave the name "microscope" to the instrument designed by Galileo (1564-1642).

7. Manuscript folio illustrating the "Manner of using the microscope", Biblioteca Apostolica Vaticana, Vatican City.
Some of the first microscopes were formed of a series of telescopic tubes for focusing. Eustachio Divini (1610-1685), a renowned builder of excellent optical devices, also constructed microscopes of this kind.

8. A fly's eye, engraving.
Robert Hooke, *Micrographia, or, Some physiological descriptions of minute bodies made by magnifying glasses: with observations and inquiries thereupon*, London, 1665.
Thanks to the microscope, the philosophers of nature could gaze upon an unknown world, which showed marvelous structures impossible to observe through the senses alone.

9. *Persio tradotto in verso sciolto e dichiarato da Francesco Stelluti*, Rome, 1630, p. 52.

10. Drawing of a louse observed under the microscope.
Filippo Bonanni, *Musaeum Kircherianum*, Rome, 1709.
The microscope soon acquired a set of accessories designed to make the instrument increasingly efficient. Spectacular drawings showed what could be seen under the microscope.

11. Lamphouse microscope
Filippo Bonanni, *Musaeum Kircherianum*, Roma, 1709.
The microscope designed by Filippo Bonanni (1638-1725) was a horizontal version. The light of an oil lamp was concentrated on the stage by two convex lenses, mounted at the ends of a little tube (mobile condenser).

12. Portrait of Johannes Kepler, copy from the Jovian Collection, Florence, Istituto e Museo di Storia della Scienza.
Johannes Kepler (1571-1630), great astronomer and optician, designed a microscope with convex lenses furnishing a reversed image.

13. Johannes Kepler, *Dioptrice*, Praga, 1611 - frontispiece.
In this work Kepler (1571-1630) described for the first time his instrument, later called the Keplerian telescope, which had two flat-convex or biconvex lenses. This type of configuration, although having the drawback of showing a reversed image, provided a larger visual field.

14. Eustachio Divini's microscope.

Eustachio Divini (1610-1685) is considered one of the best makers of telescopes and microscopes in the second half of the 17th century.

15. Giuseppe Campani's microscope.
In over fifty years of activity, Giuseppe Campani (1635-1715) produced many optical instruments, with lenses of excellent workmanship. His telescopes frequently showed themselves more powerful than those built by Christiaan Huygens (1629-1695) and Eustachio Divini (1610-1685).

16. Robert Hooke's microscope.
Robert Hooke (1635-1702/3), the great British scientist and ingenious inventor of scientific instruments, designed a microscope featuring innovations in the optical system, in its more sophisticated lighting system and in the stand.

17. Portrait of Robert Hooke.
Robert Hooke (1635-1702/3) was for some fifteen years the curator of the experiments conducted by the Royal Society, the world-famous London scientific association founded in 1660. From 1677 to 1682 he was secretary of the Academy.

18. Chérubin d'Orléans, *La dioptrique oculaire*, Paris, 1671 – plates 30, 31.
Plates depicting some of the mechanical parts of a microscope. The microscopes produced during this period, often of highly refined workmanship, especially as regards the mechanical parts, were not free from flaws in the optical components.

19. Chérubin d'Orléans, *La dioptrique oculaire*, Parigi, 1671 - frontispiece.
A Capuchin monk and outstanding physicist, Chérubin d'Orléans (1613-1697) was chiefly engaged in studying optics and the problems of vision.

20. Silver microscope.
In the 18th century the microscope entered the drawing rooms of the upper classes, who used it as a highly refined but also spectacular intellectual *divertissement*.

21. Cuff-type microscope (c. 1750), Florence, Istituto e Museo di Storia della Scienza.
Cuff-type compound microscope mounted on a wooden box foot containing many accessories. The brass body-tube is supported by a square-sectioned pillar on which it travels thanks to a threaded rod for focusing.

22. Cuff-type microscope, engraving.
The British instrument-maker John Cuff (1708-1772), at the suggestion of the naturalist Henry Baker (1698-1774), made some innovations concerning primarily the composite lateral pillar, the screw focus system, and the range of lenses furnished as accessories. These microscopes were then imitated and perfected on the Continent.

23. A fly's foot (*Scatophaga*). Microphotograph by Giorgio Roster.
This microphotograph, taken by Giorgio Roster (1843-1927), has been purposely deformed to show the effect produced on the image by spherical and chromatic aberration, which significantly impaired the optical performance of the first microscopes.

24. Portrait of Giovanni Battista Amici by Michele Gordigiani, Florence, Galleria d'Arte Moderna, Palazzo Pitti.

Giovanni Battista Amici (1786-1863) constructed numerous optical systems of the highest quality. In particular, he designed a compound reflection microscope in which the effects of chromatic aberration were eliminated.

1.2 THE SIMPLE MICROSCOPE

Although the compound microscope originated with two or more lenses, the first research on insects, worms and organisms invisible to the naked eye was conducted with the simple microscope, which, coming into use in the second half of the 17^{th} century, provided greater magnification and a higher degree of resolution.

The Dutch Antoni van Leeuwenhoek (1632-1723) built some 550 microscopes consisting of a single, tiny double-convex lens. Still today, nine of these extraordinary instruments exist, the best of which has a magnification power of about 270 diameters. However, some details of his drawings suggest that he owned more powerful ones, with which he could observe, starting from 1677, red blood cells, spermatozoids, rotifers, and bacteria.

Even his compatriot Jan van Musschenbroek (1687-1748), for entomological research, used a simple microscope mounted on an articulated arm that proved extremely effective. Adopted by Abraham Trembley (1710-1784), it established itself as the "aquatic" microscope of choice for observing flora and fauna from the outside of a glass vessel. In 1740 Trembley, using this type of microscope, observed the particular behavior of the “freshwater polyp” or hydra, noting also its surprising ability to regenerate parts that had been amputated.

The next development in the simple microscope was Pieter Lyonnet's (1708-1789) "anatomical tablet", used, among others, by Lazzaro Spallanzani (1729-1799) for minute dissections. However, for entomological research, the Italian naturalist probably used the microscope designed by James Wilson (1655-1730) and built by John Cuff (c.1708-1772) c. 1742, also called "portable" or "pocket" microscope. A compound microscope only in appearance, this model enabled — among other things — Spallanzani in 1773 to discover tardigrades and their ability to experience repeated death/revival cycles. The phenomenon, now called anabiosis, marked one of the major turning points of 18th-C. theoretical biology.

IMAGES AND CAPTIONS

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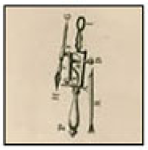

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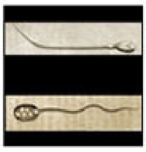

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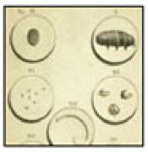

1. Compound microscopes (second half of the 17th century), Florence, Istituto e Museo di Storia della Scienza.
The compound microscope is one of the most important inventions of the scientific revolution. The instruments displayed at the Istituto e Museo di Storia della Scienza illustrate its evolution from the first compound microscopes of the Galilean type to the highly complex ones with many accessories built during the 19th century.

2. Photographic reproduction of X-ray image of Galilean compound microscope.
Federico Allodi, *Descrizione di un microscopio: nota preventiva,* Florence, 1956.
Iconographic document of historic importance realized in 1956 under the guidance of Federico Allodi, showing the components of the microscope called "Galilean", exhibited at the Istituto e Museo di Storia della Scienza of Florence.

3. Observations under the microscope.
Lazzaro Spallanzani, *Opuscoli di fisica animale e vegetabile*, Modena, 1776, plate V.
As compared to the compound microscope, the simple microscope offered better optical performance. For this reason, starting from the second half of the 17th century, it was preferred by naturalists, especially for research in the field and for the practice of dissection.

4. Plate depicting a botanical simple microscope.
George Adams Senior, *Micrographia illustrata*, London 1747.
The simple microscope is a converging optical system (often a simple lens), which reduces the distance of observation and thus increases the apparent size of an object.

5. Botanical simple microscope, Florence, Istituto e Museo di Storia della Scienza.
The botanical microscope is a simple but very manageable type of microscope. It owes its name to the fact that it was used for observation of plant species.

6. Antoni van Leeuwenhoek in his study holding the microscope that bears his name; 17th century painting.
The Dutchman Antoni van Leeuwenhoek (1632-1723) built many microscopes consisting of a single tiny biconvex lens. In this famous painting, the small size of the instrument is apparent.

7. Antoni van Leeuwenhoek's simple microscope.
With instruments of this type Antoni van Leeuwenhoek (1632-1723) managed to attain remarkably high magnification. In spite of their elementary construction, these instruments allowed him to make innumerable discoveries.

8. Spermatozoids observed under the microscope.
Antoni van Leeuwenhoek, *Opera omnia, seu, Arcana naturae*, Leyden, 1722.
In 1676 Antoni van Leeuwenhoek (1632-1723) sent the prestigious Royal Society of London some of his microscopic observations conducted on hairs, grains of sand, sperm, blood, insects, the flora and fauna of a pond, accompanied by numerous explanatory drawings.

9. Musschenbroek's simple microscope.
In all of the simple systems the image appears right side up, as seen by the naked eye, and not upside down. This makes it possible to coordinate movements easily when handling the specimen under observation.

10. Plate illustrating the operation of the simple aquatic microscope.
The aquatic microscope is formed of an optical tube held in the horizontal position by an articulated arm. It was very popular among naturalists for observing the organisms contained in an aquarium, from outside of the glass wall.

11. Simple aquatic microscope (second half of the 18th century), Florence, Istituto e Museo di Storia della Scienza.
Simple aquatic microscope, very similar to the one used by the naturalist from Geneva, Abraham Trembley (1710-1784). The wooden base is plated with ivory and supports an articulated arm with ball joints bearing the ring that carried the lens (now missing).

12. Plate representing the "freshwater polyp" or "Hydra".
Abraham Trembley, *Mémoires pour servir à l'histoire d'un genre de polypes d'eau douce*, Leyden 1744.
Digital processing image of two different plates taken from the *Mémoires pour servir à l'histoire d'un genre de polypes d'eau douce* (Leyden, 1744) by Abraham Trembley (1710-1784), representing some observations of the freshwater polyp: its way of moving, and its bizarre ability to grow back missing parts.

13. Lyonnet's microscope.
Pierre Lyonnet, *Beschryving van een microscoopstel, Verhandelingen Uitgegeeven door de Hollandse Maatschoppy der Weetenschappen*.
A microscope of this type was used by the famous naturalist Lazzaro Spallanzani (1729-1799).

14. Portrait of Lazzaro Spallanzani.
At a time when biology did not yet enjoy the status of science, Spallanzani (1729-1799) conducted fundamental research on animal procreation and decisively contributed to the affirmation of the experimental method, employing the microscope for his observations.

15. Plate depicting simple microscopes.

George Adams Senior, *Micrographia illustrata*, London, 1747.
The *Micrographia illustrata* (London, 1747), by George Adams Senior (1709-1772), was a significant eighteenth-century work dedicated mainly to the construction and operation of microscopes.

16. Observations under the microscope.
Lazzaro Spallanzani, *Opuscoli di fisica animale e vegetabile*, Modena, 1776, plates IV and V
Digital processing of two different plates taken from the *Opuscoli di fisica animale e vegetabile* (Modena, 1776) by Lazzaro Spallanzani (1729-1799).

1.3 MICROSCOPIC ANATOMY

Microscopic anatomy began during the course of the 17th century with Federico Cesi (1585-1630) and Francesco Stelluti (1577-1651) in the *Apiarium* (Rome, 1625), a work covering a single folio of extraordinary size, containing detailed descriptions of naturalist, historical-erudite and literary nature on bees.

Later, Giovanni Battista Hodierna (1597-1660) published, in *L'occhio della mosca* (The fly's eye) (Palermo, 1644), a text dedicated to the anatomy of insects, a masterly example of naturalist research conducted with the aid of the microscope; Marco Aurelio Severino (1580-1656), in his *Zootomia Democritaea* (Nuremberg, 1645), justly considered the first treatise on comparative animal anatomy, proposed an atomistic conception of animal structures developed on the basis of microscopic observation.

Gradually, the microscope helped to disclose the causes of the functioning of organisms, which were explained by extending to the biological sphere the rigorous style of geometric analysis employed by Galileo (1564-1642) in studies on mechanics. This aspect was developed especially by René Descartes (1596-1650) and by Giovanni Alfonso Borelli (1608-1679). The latter, in particular, described in a mechanical perspective the muscular movements involved in walking, running, and lifting weights, as well as the internal motions of the body.

Microscopic anatomy was however developed in all of its potentiality by Marcello Malpighi (1628-1694). As Galileo had launched exploration of the great machine of the universe with the telescope, so Malpighi aimed to reveal the hidden structure of the machine that was the human body with the microscope. He observed the alveolar structure of the lungs, the papillary receptors on the tongue, the connection between arterial and venous blood vessels, identified the red blood cells and described precisely the first stages in the embryonic development of a baby chick.

The combination of “thin” anatomy and microscopic magnification soon led to a succession of remarkable discoveries. Thomas Bartholin (1616-1680) identified the lymphatic ducts; Lorenzo Bellini (1643-1704) revealed the structure and function of the kidneys, furnishing an explanation of the mechanical type; Francesco Redi (1626-1697) illustrated the extraordinarily complex organization of insect life; Thomas Wharton (1614-1673) formulated the theory of the glands as secretory organs; Niels Steensen (1638-1686) conducted accurate microscopic observations of muscle fibers; Thomas Willis (1621-1675) and then Albrecht von Haller (1708-1777) studied the structure of the nervous system and the dynamics of neuro-muscular functions.

IMAGES AND CAPTIONS

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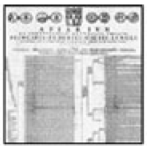
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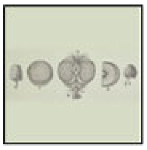
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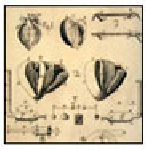
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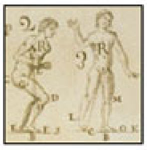
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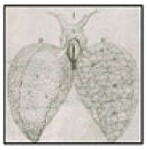
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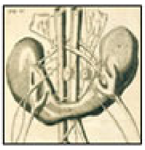
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1. Plate showing the operation of Campani's microscope.
Giuseppe Campani (1635-1715), an outstanding maker of optical instruments, contributed to the development of the microscope's potentialities. The superiority of Campani over Eustachio Divini (1610-1685) and other instrument-makers was recognized by the better performance of his lenses.

2. Portrait of Federico Cesi attributed to Simon Vouet. Accademia Nazionale dei Lincei, Palazzo Corsini.
Cesi (1585-1630) was one of the most important figures in Italian cultural life of the early 17^{th} century. Founder of the Accademia dei Lincei, he studies botany and the naturalist field in general.

3. Federico Cesi, *Apiarium,* Rome, 1625.
The *Apiarium* occupies an important place in the vast cultural program promoted by the Accademia dei Lincei. This work represents a meeting point between the erudite taste of the early 17th century and the requisites of the most advanced scientific research. Described on this enormous folio are the results of the first microscopic observations of bees carried out by members of the Academy.

4. Details of a fly's eye.
Giovanni Battista Hodierna, *L'occhio della mosca*, Palermo, 1644.
A priest and scholar of optics and astronomy, Hodierna (1597-1660) was also interested in the animal world. He developed a special type of microscope with which he conducted accurate observations on a fly's eye.

5. Portrait of Marco Aurelio Severino
Surgeon and anatomist, Severino (1580-1656) is especially known for his studies on the dissection of animals.

6. Marco Aurelio Severino, *Zootomia Democritaea*, Nuremberg, 1645
In this work, the comparative method is applied to animal anatomy. Based on his investigations with the microscope, Severino (1580-1656) reproposed a Democritean atomistic concept of animals' anatomical structures.

7. Galilean compound microscope, designed by Galileo Galilei and constructed by Giuseppe Campani [attr.] (Second half of the 17th century), Florence, Istituto e Museo di Storia della Scienza.
The microscope, built of cardboard, leather and wood, is inserted in an iron stand with three curved legs. The stand, in addition to stabilizing the instrument, allows it to be focused by sliding the cylinder inside the ring.

8. Giovanni Alfonso Borelli, *De motu animalium Io. Alphonsi Borelli ... opus posthumum*, Roma, 1680-1681 - tome I, plate XVII
Detail of the heart.

9. Giovanni Alfonso Borelli, *De motu animalium Io. Alphonsi Borelli ... opus posthumum*, Roma, 1680-1681 - tome I, plate IV
Borelli (1680-1691) organized the study of human and animal skeletons on mechanical bases.

10. Portrait of René Descartes
In his *Traité de l'Homme* Descartes (1596-1650) set forth his own mechanistic concept of the human body.

11. Portrait of Giovanni Alfonso Borelli, copy after the Jovian Collection. Florence, Istituto e Museo di Storia della Scienza
In the ten years he spent in Tuscany (1608-1679), Borelli (1680-1691) was a reference point for much of the scientific-experimental activity carried out by the Accademia del Cimento.

12. Giovanni Alfonso Borelli, *De motu animalium Io. Alphonsi Borelli ... opus posthumum*, Rome, 1680-1681 - tome I, plate XI
The *De motu animalium* by Borelli (1608-1679) is a treatise on mechanistic physiology which represents the attempt to extend to the biological world the rigorous style of geometric analysis applied by Galileo (1564-1642) in the mechanical sphere.

13. Giovanni Alfonso Borelli, *De motu animalium Io. Alphonsi Borelli ... opus posthumum*, Rome, 1680-1681 - tome I, plate VI
Borelli (1608-1679), during his stay in Tuscany (1656-1666), encouraged numerous scientists to conduct investigation with the microscope, among them Marcello Malpighi (1628-1694), Claude Aubery (1607-1658/9), Carlo Fracassati (1630-1672) and Lorenzo Bellini (1643-1704).

14. Carlo Cignali, Portrait of Marcello Malpighi, second half of the 17th century. Galleria Borghese, Rome
Malpighi (1628-1694) was one of the first to use the microscope systematically for conducting studies in anatomy. Specifically, the hypotheses on the circulation of the blood, formulated by William Harvey (1578-1657) in the first decades of the 17th century found confirmation in Malpighi's microscopic observations of capillaries.

15. Portrait of Galileo Galilei. Oil on canvas, Filippo Furini, 1620. Vienna, Kunsthistorisches Museum.

16. Galileo showing the Medicean planets to the personifications of Optics, Astronomy and Mathematics.
Galileo Galilei, *Opere*, Bologna, 1656. Antiporta.
The first microscopes were produced around the same time as the telescope. Thanks to these two instruments of new concept, the macrocosm of the universe and the microcosm of the human body rapidly became focal points for exploration.

17. Marcello Malpighi, *Opera omnia*, London, 1686-1687. Frontispiece.
Malpighi (1628-1694), one of the outstanding observers during the second half of the 17th century, was the founder of microscopic anatomy.

18. Anatomical plate representing the pulmonary alveoli, detail.
Marcello Malpighi, *De pulmonibus epistola altera*, Bologna, 1661.
The microscope allowed Malpighi (1628-1694) to describe for the first time the alveolar structure of the lungs.

19. Anatomical study of the structure of the tongue.
Marcello Malpighi, *Tetras anatomicarum epistolarum de lingua et cerebro..*, Bologna, 1665.
Malpighi (1628-1694) offers an example of the great potentiality the microscope used in scientific research.

20. Anatomical plate representing the pulmonary alveoli, detail.
Marcello Malpighi, *De pulmonibus epistola altera*, Bologna, 1661.
Malpighi (1628-1694) combined microscopic observations with the art of preparing tissues for examination, allowing him to put in evidence a great number of structures otherwise invisible to the naked eye.

21. Digital processing image of the stages of embryonic development of a baby chick.
Marcello Malpighi, *De ovo incubato observationes*, London, 1673. Plates V, VI, VII.
Through systematic observation of the development of a chick inside an egg, Malpighi (1628-1694) recognized a fetal structure already sketchily formed only a few days after fecundation.

22. Frontal representation of the human trunk, with view of the internal organs.
Thomas Bartholin, *Anatome quartum renovata […]*, Lione, 1684. Plate XLIII, XXVI.

23. Portrait of Thomas Bartholin.
Thomas Bartholin, *Anatome quartum renovata […]*, Lyon, 1684. Antiporta.
A Danish anatomist, Bartholin (1616-1680) discovered the lymph ducts in 1643.

24. Frontal representation of the human trunk, with view of the internal organs.
Thomas Bartholin, *Anatome quartum renovata […]*, Lyon, 1684. Plate XVIII.

25. Portrait of Lorenzo Bellini.
Bellini (1643-1704) offered an explanation of kidney function based on exclusively mechanical premises.

26. Table of human anatomy showing the renal canals.
Lorenzo Bellini, *Exercitatio anatomica de struct~~y~~ura et usu renum*, Amsterdam, 1665.

27. Portrait of Francesco Redi, copy after the Jovian Collection, Florence, Istituto e Museo di Storia della Scienza.
Redi (1626-1697) was capable of combining utilization of the microscope with experimentation. He also introduced into the scientific method the serial procedure and comparison between research experiments and control experiments.

28. Mosquito, watercolor by Filizio Pizzichi, after the Palatino example in Francesco Redi's book, *Esperienze intorno alla generazione degli insetti*, Florence, 1668.
In his naturalist research, Redi (1626-1697) called upon artists to faithfully illustrate what had been observed by means of optical magnification, showing the close link between science and art prevailing at the time, so close as to speak of the art of microscopic observation.

29. Plate illustrating the "glandula maxillaris" and the "ductus salivalis" discovered by Thomas Wharton.
The British scientist Thomas Wharton (1614-1673) was one of the first anatomists to study the glands.

30. Portrait of Niccolò Stenone, copy after the Jovian Collection, Florence, Istituto e Museo di Storia della Scienza.
Of Danish origin, Niels Steensen (Niccolò Stenone, 1638-1686) studied medicine at Copenhagen, Amsterdam and Leyden. In 1667 he became court physician to the Grand Duke of Tuscany Ferdinando II. In addition to describing the structure of the muscles, he also studied the glandular and lymphatic system and the anatomy of the brain.

31. Portrait of Thomas Willis.
Thomas Willis (1621-1675) was a British anatomist and physiologist.

32. Portrait of Albrecht von Haller.
The Swiss Albrecht von Haller (1708-1777) is considered the father of modern physiology.

33. The arteries of the mesenterium
Albrecht von Haller, *Iconum anatomicarum corporis umani,* Fasc. III, Gottingen, 1756.

1.4 A CENTURY OF DISCOVERIES

1610: PRECIOUS TESTIMONY
The first descriptions of compound microscopes date from the early 17th century. John Wedderburn (1583-1651), a disciple and admirer of Galileo Galilei (1564-1642), testifies that, by this year, the Pisan scientist had already built a microscope and conducted observations. It is probable that the first Galilean microscopes featured the combination of a convex and a concave lens.

1614: GALILEO SPEAKS OF THE MICROSCOPE
In mid-November Galileo is visited in Florence by Giovanni Tarde (1561/62-1636), to whom he speaks of his microscope and shows the ephemerides of the Medicean Planets.

1619: DREBBEL'S MICROSCOPES
In England, between 1619 and 1623, the Dutch physicist and mechanist Cornelius Drebbel (1572-1633) constructs several microscopes, none of which have survived. They seem to have been Keplerian microscopes, that is, with convex lenses showing a reversed image. One of these microscopes was brought to Rome in December 1623, and was examined by Galileo in 1624.

1623: A TELESCOPE TO SEE OBJECTS CLOSE UP
In *Il Saggiatore* [The Assayer], written between 1619 and 1622 and published in 1623, Galileo mentions “a telescope adjusted to see objects very close up”. This first type of Galilean microscope probably consisted of the elongated cylinder of a telescope with two lenses.

1624: A "THING OF GREAT CONSEQUENCE FOR MEDICINE"
In a letter dated October 4, Bartolomeo Imperiali (?-1655) informs Galileo that a physician in Genoa "says that with this *occhialino* we will know for sure the site of a certain tiny particle of the heart, which it has never been possible to see with simple vision, and which will show itself to be a thing of great consequence for medicine ...".

1624: GALILEO'S GIFT TO CESI
Galileo perfects the construction of the compound microscope. On May 10, on the occasion of a meeting held in Rome, the Pisan scientist donates to Cardinal Federico Eutel of Zollern a microscope with which he shows those present the magnified image of a fly. On September 23 he sends Federico Cesi (1585-1630) an "*occhialino* to see minute things close up". Galileo observes, "I have contemplated a great many animals with infinite admiration; among them, the flea is most horrible, the mosquito and the moth are beautiful; and with great satisfaction I have seen how flies and other tiny creatures can walk attached to mirrors, and even upside down. But Your Excellency will have occasion to observe thousands and thousands of details, of which I request you to notify me of the most curious things."

1625: THE NAME OF THE INSTRUMENT
In a letter dated April 13 to Federico Cesi (1585-1630), Johann Faber (1574-1629), a member of the Accademia dei Lincei, called "microscope" the "new eyepiece to see minute things ". Writes Faber: "…and I call it microscope, if it may please Your Excellency, and may I add that the Lyncei, since they named the former instrument, the telescope, have wished to give a suitable name to this one too, and deservedly, because they were the first here in Rome to have it...".

1625: THE COPY OF THE APIARIUM
On September 26, 1625 Prince Federico Cesi (1585-1630) sends Galileo in preview a copy of the *Apiarium*, a text on bees, which constitutes a significant chapter in the naturalist, historical-erudite and literary program of the Accademia dei Lincei.

1625: THE MELISSOGRAFIA
The first iconographic document realized with the aid of the microscope is printed in Rome. It was a gift from the Accademia dei Lincei to Pope Urban VIII. This document, known as the *Melissographia,* presents the observations conducted by Francesco Stelluti (1577-1651), a member of the Accademia dei Lincei, whose subject is a bee observed supine, in profile and on its back, surrounded by an abundant corona of its dissected parts. The great plate was engraved by Matthaus Greuter (1566-1638).

1625: THE APIARIUM
The *Apiarium* is published in Rome. This work, covering a single folio of extraordinary size (63X101 cm), contains much information of historical, scientific and poetic nature on these hymenoptera. Prince Federico Cesi (1585-1630) thus pays homage to Pope Urban VIII (1568-1644), whose coat of arms was emblazoned with bees.

1628: GALILEO SENDS A MICROSCOPE TO PHILIP OF HESSE
From Florence, Galileo sends one of his microscopes to the Landgrave Philip of Hesse (1581-1643).

1630: GALILEO SENDS A MICROSCOPE TO THE KING OF SPAIN
Galileo sends a microscope to the King of Spain.

1630: THE GRAIN WEEVIL
Francesco Stelluti (1577-1651), a member of the Accademia dei Lincei, with an illustration of the "aphis" or grain weevil, portrayed both in natural size and magnified by the microscope, inaugurates an iconographic practice that will be followed by many microscopists for at least two centuries.

1631: THE DRAWING OF THE COMPOUND MICROSCOPE
One of the earliest drawings of the tripod-type compound microscope dates from 1631 and is found in the diary of the Dutch scientist Isaac Beeckman (1588-1637). Copernican in his cosmology, Beeckman shared the ideas of William Harvey (1578-1657) on the circulation of the blood, and developed a tendentially atomist perspective in physics.

1633: MICROSCOPIC IMAGE OF A PLANT
The work *De florum cultura* by Giovan Battista Ferrari (1584-1655) is published in Rome. It contains the first image of vegetal matter, a hibiscus seed, drawn on the basis of microscopic observation.

1642: DEATH OF GALILEO
On January 8th, Galileo dies at the Villa il Gioiello at Arcetri near Florence. Galileo's experimental method was to be continued, to various degrees and in different directions, by his many pupils and admirers.

1643: THE LYMPHATIC VESSELS
The Danish anatomist Thomas Bartholin (1616-1680) publishes in Copenhagen *Vasa lymphatica*, in which he describes his discovery of the lymphatic vessels.

1644: THE MICROSCOPE 'A PERLINA'
It is very probably in this year that Evangelista Torricelli (1608-1647), mathematician to the Grand Duke, designs the microscope 'a perlina', a simple microscope formed of a small spherical lens placed at the end of an optical tube.

1644: **THE FLY'S EYE**
The close bond between the telescope and the microscope is shown by the fact that, in the first half of the 17th century, numerous astronomers occasionally conducted microscopic observations. In 1644, for example, the Sicilian astronomer Giovanni Battista Hodierna (1597-1660) publishes in Palermo *L'occhio della mosca*, [The fly's eye], a work in which the new technique of microscopic investigation of nature was shown to be an important aid to anatomy.

1645: **ATOMISM AND MICROSCOPY**
The *Zootomia democritaea, id est anatome generale totius animantium opifici* by Marco Aurelio Severino (1580-1656) is published in Nuremberg. In this work, on the basis of microscopic investigation, a Democritean atomistic concept of the anatomical structures of animals is proposed again.

1646: **THE ARS MAGNA LUCIS ET UMBRAE BY KIRCHER**
The *Ars magna lucis et umbrae* by the erudite Jesuit priest Athanasius Kircher (1602-1680) is published in Rome. The work includes, among other things, a precious record of the microscope 'a perlina' designed by Evangelista Torricelli (1608-1647). The microscopic findings reported by Kircher are extraordinary; tiny living organisms are observed in cheese, milk and vinegar.

1646: **FONTANA CLAIMS CREDIT FOR DISCOVERING THE MICROSCOPE**
Francesco Fontana (c.1585-1656) publishes his *Novae caelestium terrestriumque rerum observationes*, a text in which he claims to have invented the telescope composed of two convex lenses in 1608 and a compound microscope in 1618, consisting of two converging lenses, one functioning as objective, the other as eyepiece.

1654: **THE TESTIMONY OF VIVIANI**
Vincenzo Viviani (1622-1703) writes an excellent *Racconto istorico della vita del Sig. Galileo Galilei* [Historical account of the life of Galieo Galilei] in the form of a letter to Prince Leopoldo de' Medici (1617-1675), which remained unpublished until 1717. Viviani credits Galileo with the invention of both the simple and the compound microscope.

1655: **DUTCH ORIGIN OF THE INSTRUMENT?**
According to documents published by Pierre Borel (c.1620-1671) in his text *De vero telescopii inventore*, both the microscope and the telescope are alleged to have been invented around 1590 by two Dutch opticians, Hans and Zacharias Janssen (who may have been either father and son or brothers). This thesis appears plausible due to the fact that, toward the end of the 16th century, the Dutch spectacle makers were remarkably creative. Janssen's primitive instruments, fabricated by uniting several lenses inside a fixed cylinder, resting on a tripod, were capable of magnifying an object as much as thirty times. They were not employed for scientific purposes, however, but designed to be sold as curiosities to princes and notables.

1656: **THE GLANDULAR SYSTEM**
Thomas Wharton, in his *Adenographia, or a Description of the Glands of the Whole of the Body*, describes the glandular system.

1657: **FOUNDATION OF THE ACCADEMIA DEL CIMENTO**
The Accademia del Cimento is founded at the Medicean Court, with the objective of relaunching Galileo's scientific heritage. Although microscopy is not one of the particular activities carried out by the Accademia del Cimento, it is cultivated by two of its members: Giovanni Alfonso Borelli (1608-1679) and Francesco Redi (1626-1697).

Borelli, during his stay in Tuscany (1656-1666), stimulates numerous scholars to conduct investigation with microscopes; among them are Marcello Malpighi (1628-1694), Claude Aubery (1607-1658/9), Carlo Fracassati (1630-1672) and Lorenzo Bellini (1643-1704).

The Arezzo scientist Francesco Redi (1626-1697) shows himself capable of combining experimentation with utilization of the microscope. In his naturalist studies, he calls upon artists to faithfully illustrate what is observed by means of optical magnification, thus underlining the close relationship existing at the time between science and art, a bond so close that the term "art of microscopic observation" is used.

1658: THE RED BLOOD CELLS
The Flemish scientist Jan Swammerdam (1637-1680), one of the greatest masters in the art of microscopic observation in the second half of the 17th century, observes and describes the red blood cells. He is also one of the first to formulate the theory of preformation according to which an organism is entirely constituted from the beginning, and development consists only of a process of enlargement.

1658: A DISCOVERY MADE WITH THIN ANATOMY
The physician and anatomist of Lorraine origin Claude Aubery (1607-1658/9) publishes in Florence the pamphlet *Textis examinatus*, reporting observations on the canaliculated structure of the testicle. These observations are conducted through the art of "thin" anatomy and not with the microscope.

1660: THE ROYAL SOCIETY
The Royal Society for the Improvement of Natural Knowledge is founded, and is officially recognized by Charles II (1630-1685) about three years later. The prestigious London society is also attentive to research conducted using the microscopic.

1661: MALPIGHI'S STUDIES OF THE LUNGS
Marcello Malpighi (1628-1694), one of the outstanding observers in the second half of the 17th century and the founder of microscopic anatomy, publishes the *De pulmonibus observationes anatomicae. Epistulae ad Jo. Alphonsum Borellium*, a work in which he analyzes the mechanism through which venous blood is oxygenized by the lungs and transferred into arterial circulation. Through observation of the capillaries, he confirms the discovery of the principle of circulation of the blood postulated by William Harvey (1578-1657), described in the *Exercitatio anatomica de motu cordis et sanguinis in animalibus* (1628). The microscope allows Malpighi to describe for the first time the alveolar structure of the lungs. To microscopic investigation he combines the art of preparing tissues to be examined, thanks to which he puts in evidence a great number of structures otherwise invisible to the naked eye. But he does not always accompany his texts with illustrations, thus rendering them less effective.

1662: BELLINI'S STUDIES OF THE KIDNEYS
Lorenzo Bellini (1643-1704), at the age of only nineteen, publishes in Florence the *Exercitatio anatomica de structura et usu renum*. Superseding the theory of Galen (129-199), according to which the kidneys were composed of a "parenchymatic" substance and produced the urine thanks to a particular faculty, Bellini gives an explanation of purely mechanical type.

1665: HOOKE'S MICROGRAPHIA
Robert Hooke (1635-1703), one of the most brilliant and versatile English scientists of the 17th century, publishes the *Micrographia* in London. This work contains the detailed figure of a compound pillar-type microscope. The beauty of the illustrations, plates depicting insects, leaves

and small objects, and the precision of the observations exert a forceful impact on the scientific community, showing a new side of nature distinguished by microscopic realities. Hooke is the first to observe the cells of plants, although this discovery was to have no practical consequences.

1665: DIVINI'S MICROSCOPES

Around 1665, Eustachio Divini (1610-1685) builds a microscope consisting of a set of cardboard telescopic tubes that slide into one another for focusing. The instrument is mounted on a small tripod. Divini is also attributed with introducing the reflecting mirror to light the objects under observation.

1665: STUDIES ON THE TONGUE

The Bolognese physician and anatomist, Carlo Fracassati (1630-1672), publishes in Bologna the *Exercitatio epistolica de lingua ad J. Alf. Borellum*, a work in which he describes the anatomical structure and the functions of the tongue. In the same year the Florentine Lorenzo Bellini (1643-1704) publishes, also in Bologna, the *Gustus organum novissime deprehensum*, a work that proposes to explain the origin of the flavors, maintaining that they depend on the papillae of the tongue.

1665-1666: THE SENSORIAL RECEPTERS

In 1665 and 1666 Marcello Malpighi (1628-1694) publishes four pamphlets on neuroanatomy: *de cerebro*; *de lingua*; *de externo tactus organo*; *de cerebro cortice*. In the second and third pamphlet Malpighi describes the great discovery of the sensorial receptors: the papillae of taste and touch.
di Marcello Malpighi, «Physis», Year VIII (1966), pp. 253-266.

1667: END OF THE ACTIVITY OF THE ACCADEMIA DEL CIMENTO

With the publication of the *Saggi di naturali esperienze*, edited by the Secretary Lorenzo Magalotti (1637-1712), there concludes, after ten years, the experimental activity of the Accademia del Cimento, promoted as a development of Galileo's experimental method.

1667: OBSERVATIONS ON THE MUSCLES

The Danish Niels Steensen (Niccolò Stenone, 1638-1686), during his first stay in Tuscany (1666-1667), conducted important anatomical dissections and published in 1667 his fundamental work on the structure of the muscles (*Elementorum myologiae specimen, seu Musculi descriptio geometrica*) in the appendix to which he includes a famous memorandum on the dissection of a shark's head. In addition to describing the structure of the muscles, Stenone also studied the glandular and lymphatic systems and the anatomy of the brain. He discovered the excretory duct of the parotoid gland**,** which he described in his *Observationes anatomicae* (Leyden, 1662).

1668: REDI AND THE CONFUTATION OF SPONTANEOUS GENERATION

The *Esperienze intorno alla generazione degl'insetti* [Experiments on the generation of insects] is published in Florence. This text, Redi's true masterpiece (1626-1697), is to be a milestone in the history of modern science. He confutes the age-old theory of the spontaneous generation of insects through a successful experiment, which introduces into the scientific method the serial procedure and the comparison between research experiments and control experiments. The work is illustrated by numerous engravings of insects observed by the scientist under the microscope.

1669: MALPIGHI'S STUDIES ON THE SILK WORM

The *Dissertatio epistolica de Bombyce* by Marcello Malpighi (1628-1694), with a description of the anatomy and metamorphosis of the silk worm, is the first book dedicated to the anatomy of an invertebrate.

1669: SWAMMERDAM'S STUDIES ON INSECTS
The illustrious Flemish microscopist Jan Swammerdam (1637-1680), a master of microdissection, publishes a general study on insects.

1671: LA DIOPTRIQUE OCULAIRE
The Capuchin monk and valid physicist Chérubin d'Orléans (1613-1697) publishes *La dioptrique oculaire*, one of the first texts in an important body of works dedicated to techniques of constructing microscopes. In this work he also analyzes instruments for binocular vision.

1672: MALPIGHI'S STUDIES ON PLANTS
With the *Anatome plantarum* and its subsequent addendum in 1675 (*Anatome plantarum pars altera*), Marcello Malpighi (1628-1694) offers an example of the potentialities of the microscope used for scientific research.

1673: MALPIGHI'S STUDIES ON THE FORMATION OF BABY CHICKS
The prestigious Royal Society of London publishes the work of Marcello Malpighi (1628-1694) *De formatione pulli in ovo*. Through systematic, uninterrupted observations on the development of baby chicks inside the egg, Malpighi recognizes the formation of a primitive fetal structure, already visible only a few days after fecundation. This discovery was to lend credibility to his generation's belief in preformation, according to which ontogenetic development proceeds from an embryonic organism already endowed with its major parts (heart, brain, preliminary thoracic structure).

1674: LEEUWENHOEK DISCOVERS THE PROTOZOANS
Antoni van Leeuwenhoek (1632-1723) discovers the protozoans. A Dutchman who was a modest public employee and an incomparable lens-maker, he was not merely an amateur curious to discover the mysteries of the infinitely small, but also a great experimenter and scientist possessing a vast knowledge of anatomy and embryology. He fabricated many microscopes consisting of a single, tiny biconvex lens, extraordinarily efficient.

His fellow-countryman Johann van Musschenbroek (1660-1707), in addition to constructing microscopes for Leeuwenhoek, designed a model of a compass microscope. He was also the designer of special ball-and-socket joints, known as "Musschenbroek nuts". With this device, adjustable arms of different length could be built, used to support lenses or stages.

1677: LEEUWENHOEK'S MICROSCOPIC OBSERVATIONS
The Dutchman Antoni van Leeuwenhoek (1632-1723) sends the prestigious Royal Society of London some of his microscopic observations conducted on hairs, grains of sand, sperm, blood, insects, the flora and fauna of a pond, accompanied by numerous explanatory drawings. During these years he observes spermatozoids, at the time called "spermatic animalcules", red blood cell, rotifers, and bacteria.

1680: MICROSCOPY AND MECHANISM
The *De motu animalium* by Giovanni Alfonso Borelli (1608-1679) is published in Rome (1680-1691). It is a treatise of mechanistic physiology based entirely on the corpuscular nature of matter. It represents the attempt to extend to the biological sphere the rigorous style of geometric analysis employed by Galileo in the mechanist field.

1683: THE CATALOGUES
The sales catalogue of John Yarwell (1648-1712) is published in London. He is, with John Marshall (1663-1712), one of the most important English microscope builders of the late 17^{th} – early 18^{th}

century. The catalogues of the time advertise not only microscopes and telescopes, but also instruments such as burning glasses, magic lanterns, spectacles, prisms, concave and convex lenses. In the 18th century the compound microscope was to assume, as the evolution of seventeenth-century mechanics, three main forms: the tripod type, developed around 1725 by Edmund Culpeper (1660-1738); the cylinder or drum type, designed in 1738 by Benjamin Martin (1705-1782); the lateral pillar type, perfected in its design by Henry Baker (1698-1774) and fabricated by John Cuff (1708-1772). The latter model was to mark a crucial stage in the history of the microscope.

1683: LEEUWENHOEK DISCOVERS BACTERIA
The Dutchman Antoni van Leeuwenhoek (1632-1723) discovers bacteria with the microscope but, as in the case of spermatozoids, the great importance of his discovery is not fully recognized.

1683: THE LAWS OF MECHANICS IN PHYSIOLOGY
The Florentine Lorenzo Bellini (1643-1704) publishes in Bologna the *De urinis et pulsibus* in which, drawing inspiration from the works of Giovanni Alfonso Borelli (1608-1679) and Thomas Willis (1621-1675), he continues the attempt to apply the laws of mechanics to the study of physiology.

1684: REDI AND PARASITOLOGY
Redi publishes in Florence the *Osservazioni intorno agli animali viventi che si trovano negli animali viventi*, a treatise on parasitology and comparative anatomy that he planned to complete with a second section, which was however never written.

1685: THE BIBLIA NATURAE
The *Biblia Naturae* by the illustrious Flemish microscopist Jan Swammerdam (1637-1680) is published posthumously. It contains many zoological and entomological observations, as well as interesting illustrations of microdissection procedures. In 1737 the work was also published in German under the title *Bibel der Natur*, in commemoration of the centennial of the author's birth.

1686: CAMPANI'S MICROSCOPES
In the *Acta Eruditorum* the drawing of a microscope by Giuseppe Campani (1635-1715) is published. In over fifty years of activity he produced many optical instruments, among which the compound microscopes and the telescopes, with lenses of excellent workmanship, are outstanding for their high quality. Campani produces tripod-type microscopes, but also microscopes with a stage equipped with spring hooks and threaded tubes to allow more precise focusing than the sliding and friction system utilized up to then. More than for the design of his microscopes, Campani's superiority to Eustachio Divini (1610-1685) and the other instrument makers is recognized for the performance of his lenses.

1687: THE PARASITOLOGICAL NATURE OF SCABIES
The *Osservazioni intorno a' pellicelli del corpo umano* by Giovanni Cosimo Bonomo (1666-1696) is published, in the form of a letter/treatise addressed to Francesco Redi (1626-1697). Through microscopic observations on scabies conducted in collaboration with the Livornese physician Giacinto Cestoni (1637-1718), Bonomo recognizes the parasitological nature of scabies, until then deemed the consequence of alterations in the metabolism and the humours, and also describes the manner in which the scab mite penetrates into the skin through contagion, thus refuting the theses and therapies of Galenic medicine.

1691: THE HORIZONTAL MICROSCOPE
The Jesuit priest Filippo Bonanni (1638-1725) publishes the *Micrographia curiosa* in conjunction with the *Observationes circa viventia quae in rebus non viventibus reperiuntur*. Among the

illustrative plates, he includes the drawing of a refined horizontal microscope with which he conducts important observations. The instrument is composed of an eyepiece, a field lens and an objective lens; furnished with a device for focusing on the object examined, it extends horizontally. The light of an oil lamp is concentrated on the stage by two convex lenses, mounted at the ends of a small tube (mobile condenser). With this microscope he performs numerous observations. In the *Observationes circa viventia quae in rebus non viventibus reperiuntur* the Roman Jesuit returns to defending the thesis of the spontaneous birth of some animal species, in contradiction to the convictions of Marcello Malpighi (1628-1694), Francesco Redi (1626-1697) and the other critics of spontaneous generation.

1.5 THE MICROSCOPE GAME

1. Galilean microscope
This instrument, indicated as a microscope of the Galilean type, may have been fabricated by Giuseppe Campani. The first Galilean microscopes were formed of two lenses, one concave, the other convex. They did not allow good lighting of the object. Galileo, in fact, recommended using them "in air that is very calm and bright, and better under sunlight itself". Subsequently, various optical configurations were tried (this model has three biconvex lenses).

2. Hooke type microscope
The prototype of numerous British and Continental microscopes is the compound microscope designed by Robert Hooke. It presented innovations in both the optical system (an objective, a field lens and a powerful eyepiece), and the sophisticated lighting system. It could be elongated by means of four sliding telescopic tubes.

3. Bonanni's horizontal microscope (Campani type)
This type of compound microscope extended horizontally. The optical components consisted of an eyepiece, a field lens and an objective. The instrument was equipped with a device for focusing on the object examined and an oil lamp which, thanks to a tube with convex lenses at the ends, condensed the light on the specimen. With this microscope Filippo Bonanni conducted important observations.

4. Culpeper type microscope
Microscope designed around 1725 by the English instrument-maker Edmund Culpeper, who innovated the tripod microscope of Italian origin by adding a reflecting mirror to the base below the stage. Often furnished with a pyramid-shaped case with a drawer containing the accessories, it was widely used in the 18th century.

5. Cuff type Microscope
The work of the English instrument-maker John Cuff, who made use of some suggestions from the naturalist Henry Baker, this microscope perfected the Culpeper model. The instrument was equipped with a lateral pillar, a precise screw focusing mechanism and a very long eyepiece. The microscope was generally mounted on a wooden base with a drawer holding the accessories.

6. Solar microscope
In a darkened room, the device was applied to a window shutter with a hole pierced in it. The rays of the sun, reflected by a flat mirror placed on the outside, traversed in sequence the hole in the shutter, the condenser lenses, the slide bearing the specimen and the objective lens, thus projecting the magnified image onto the opposite wall, which served as a screen.

7. Leeuwenhoek type simple Microscope
Antoni van Leeuwenhoek designed a microscope that was rudimentary but powerful. It consisted of a tiny biconvex lens inserted between two sheets of metal at the height of a hole through which he conducted observations. In spite of its elementary structure this type of instrument allowed him to make innumerable discoveries, thanks to its high magnification power.

8. Simple compass microscope
The salient feature of this simple microscope is that it has the stage mounted on an articulated arm, which also serves as a device for focusing on the specimen. It was used for observations of insects and plants, as well as in the practice of dissection. Often kept in a case holding numerous accessories, it was most widely used in the 18^{th} and the early 19^{th} century.

1.6 TEST

You can accede to the complete version of the test from the Resources section of the site "Galileo's microscope". Open the PDF file or download the RTF file. Good luck!

2 EXPLORE

2.1 THE INSTRUMENT

PERIOD AND ATTRIBUTION

Compound microscope of the Galilean type fabricated in the second half of the 17^{th} century in cardboard, leather, wood and iron. Of Italian workmanship, it was traditionally attributed to Galileo Galilei, but it now seems more plausible that it was fabricated by the famous instrument-maker Giuseppe Campani.

Name of the instrument: Galilean compound microscope
Inventor: Galileo Galilei
Maker: Giuseppe Campani [attr.]
Date: Second half of the 17th century
IMSS inventory no.: 3429
Place: Italian make
Materials: Cardboard, leather, wood, iron

DIMENSIONS

Total height: 200 mm
Height of body-tube: 166 mm
Diameter of body-tube: 49 mm
Height of support: 110 mm
Diameter of support: 55 mm
Eyepiece: aperture: 24 mm**; thickness at center:** 5 mm
Field lens: diameter: 30 mm**; thickness at center:** 4.7 mm
Objective: diameter: 11 mm**; thickness at center:** 3.5 mm

COMPONENTS

Body-tube
The main optical tube, inserted in the support, is the largest tube. Made of cardboard, it is covered in vellum decorated with gold tooling. It shows signs of use and bears markings for positioning it exactly on the support, thus fixing the distance between objective and object. The retractable tube and the cylinder housing the field lens slide inside it.

Retractable tube
The retractable optical tube slides inside the body-tube, with a leather ring serving as stop. Screwed onto the end is the eyepiece holder, with a wooden diaphragm inside. Some original inked markings on the tube facilitate coarse focusing, with an ample but poorly sensitive traverse, "without having to seek the point with fatigue".

Eyepiece guard
Boxwood cap that screws onto the outside of the eyepiece holder. It serves to protect the lens from dust. The instrument was fitted with a similar protective cap on the objective, now missing.

Eyepiece holder

Boxwood cap with internal and external thread. The internal thread serves to fasten the eyepiece holder to the retractable optical tube, while the protective cap screws onto the external one. The lens is inserted in the eyepiece holder, positioned 6 mm from the outer edge.

Eyepiece
The eyepiece is the lens (or system of lenses) through which the eye observes the image formed by the objective. In its simplest form, the eyepiece consists of a single converging lens of short focal length. This microscope has a biconvex lens with some bubbles in the glass.

Diaphragm
Wooden diaphragm with 16-mm hole. It is fixed to a light cardboard cylinder; the latter, which can be moved, has a travel of 40 mm. Next to the objective is another diaphragm with a 3-mm hole.

Field lens
The field lens is used to augment the visual field. This microscope has a biconvex lens placed at a distance of 70 mm from the eyepiece and inserted in a small mobile cylinder. The glass is amber-green, with air bubbles: it has a ground edge that is chipped.

Field lens cylinder
The mobile cylinder that houses the field lens rests on the bottom of the body-tube. It can be used correctly in one direction only, that is, with the section bearing the lens turned toward the eyepiece. It can also be removed and used alone, as a simple microscope.

Nosepiece
Made of boxwood, the nosepiece is shaped like an upside-down truncated cone. The larger base serves as support for the cylinder housing the field lens. Like the eyepiece holder, the nosepiece was fitted with a protective cap, now missing.

Objective
The objective is the lens positioned closest to the object observed, of which it forms a magnified image. The objective in this microscope consists of a biconvex lens whose glass has a high degree of transparency and few flaws; the edge is ground and is slightly chipped in places.

Support
The iron support consists of a ring with three curved legs fixed to it. The body-tube can slide into the ring, allowing "fine" focusing. In addition, there is a certain clearance on the nails fastening one of the legs to the ring, allowing the objective to be moved briefly nearer to or further away from the object to obtain a clearer image.

2.2 RADIOGRAPHIC EXAMINATION

In 1956 Federico Allodi published the results of a campaign of research and studies on the Galilean microscopes fabricated in wood and cardboard in the Florence Museum of the History of Science, at the time directed by Andrea Corsini.

Three instruments were classified as Galilean:

Inventory no.	Components	Name	Location no.
1309	two parts without lenses	Body-tube of compound	VIII.1

		microscope	
3247	two parts, one objective, leg	Compound microscope	VIII.3
3429	four parts, three lenses, leg	Galilean compound microscope	VIII.2

The instrument listed in the inventory under number 3429 was analyzed in particular. Both the mechanical part and the optical part were studied, applying four methods of investigation:

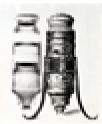
1) photography;
2) endoscope examination;
3) radiographic examination;
4) microphotography.

According to Allodi, "We may conclude that No. 3429 is a true Galilean microscope, which combines the perfected features of the other models of the time, although for its fabrication Galileo would have made use of the services of specialized workers in iron, paper, and wood, as well as goldsmiths, as was necessary and customary at the time."

This important instrument is still today indicated as "Galilean microscope", although more recent studies show that the famous instrument-maker Giuseppe Campani (1635-1715) should probably be credited with its construction. Accordingly, it was probably fabricated in the second half of the 17th century.

Images and captions

1.

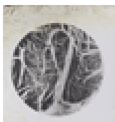


X-ray image and photograph of Galilean microscope no. 3429 in the Institute and Museum of the History of Science, Florence.

2.

Fragment of a moth's head. Microphotograph taken using Galilean microscope no. 3429 in the Institute and Museum of the History of Science, Florence.

3.



Changes in the myocardium according to Allodi. Microphotograph taken using Galilean microscope no. 3429 in the Institute and Museum of the History of Science, Florence.

In depth

1.
"In the X-RAY IMAGE are visible, from top to bottom, the protective cap on the eyepiece, the anterior chamber, the first eyepiece lens, and the mobile diaphragm. Continuing to observe the image, we find the second eyepiece lens mounted in a wood-and-cardboard cylinder that goes to rest in the seat provided by the nosepiece, and is removable. The distal section, in wood, which bears the objective, has three screw cylinders of different pitch; of these, the external one serves to mount the protective cap on the objective, the second to screw on the nosepiece spool, and the third to fix the last biconvex lens, between the two sections of the spool."

In the PHOTOGRAPH, on the larger cylinder of the tube can be seen the original inked marks traced to indicate the focal point. Visible above is the screw cap that protects the eyepiece, then a ring of decorated cardboard and, below it, a leather ring that serves as limit stop to the retractable cylinder and prevents contact between the mobile diaphragm and the part that supports the second eyepiece lens."

"The support consists of an open ring with three legs, and its function as micrometer screw can be observed. One of the three legs, in fact, has a certain clearance on the nails fixing it to the ring, and is brought closer to the other leg as response to the maneuver of approaching the legs in order to widen the ring, allowing the tube to slide in it."

F. ALLODI, *Descrizione di un microscopio*, "Rivista di storia delle scienze mediche e naturali", Vol. XLVII, no. 2, July-December 1956.

2.
On the date of September 23, 1624, Galileo sent one of his microscopes to his friend Federico Cesi in Rome. The Pisan scientist was then residing at Bellosguardo, near Florence. In the accompanying letter, in addition to some useful technical notes, he observed, "I have contemplated a great many animals with infinite admiration; among them, the flea is most horrible, the mosquito and the moth are beautiful; ... ".

This microphotograph, taken with Galilean microscope no. 3429 at the Institute and Museum of the History of Science, Florence, shows, in fact, a fragment of a moth's head.

3.
On the date of October 4, 1624, Bartolomeo Imperiali, from Genoa, wrote to Galileo on this subject: "… A physician here in Genoa, called Riccardo, very learned in all sciences, the brother of Dominichino, says that with this *occhialino* we will know for sure the site of a certain tiny particle of the heart, which it has never been possible to see with simple vision, and which will show itself to be a thing of great consequence for medicine."

Visible in this microphotograph, taken with Galilean microscope no. 3429 of the Institute and Museum of the History of Science, Florence, are the changes in the myocardium according to Allodi.

2.3 HOW IT WORKS

In its classic version, the microscope is composed of 3 optical elements: the objective, the eyepiece and the field lens.

The objective collects the light diffused by the image and forms an intermediate image. This image is a magnified image of the object, containing the details to be observed.
The eyepiece serves as magnifying lens, helping the eye to see the intermediate image produced by the objective. (*fig. 1*)

With these two lenses alone – the objective and the eyepiece – the microscope already carries out its functions. But one problem still remains. Some of the rays coming from the peripheral areas of the object (the "field" to be observed) are lost, not intercepted by the eyepiece or by the pupil of the eye. The useful field remains too small and is not well lighted. (*fig. 2*)

The field lens serves the function of correcting this problem, by deviating the rays so that they are all intercepted by the eyepiece, and enter into the pupil of the eye. (*fig. 3*)

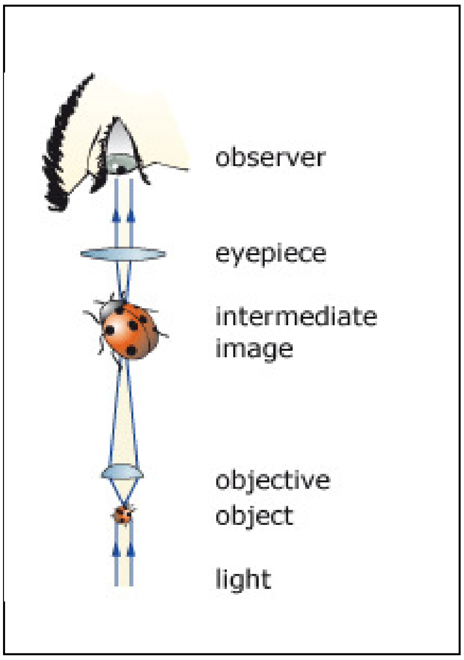


Fig. 1

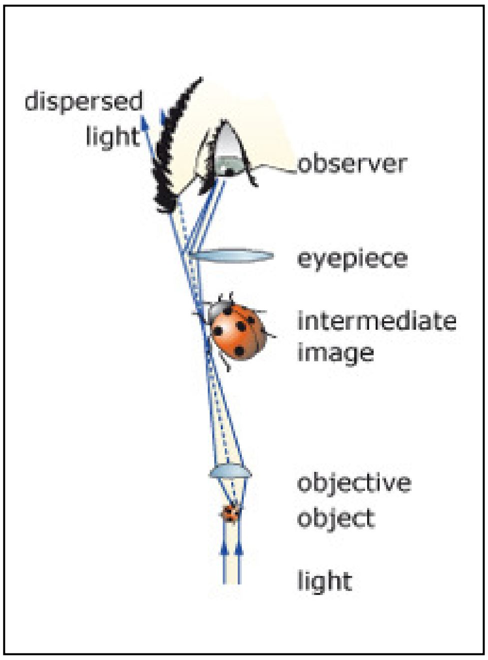


Fig. 2

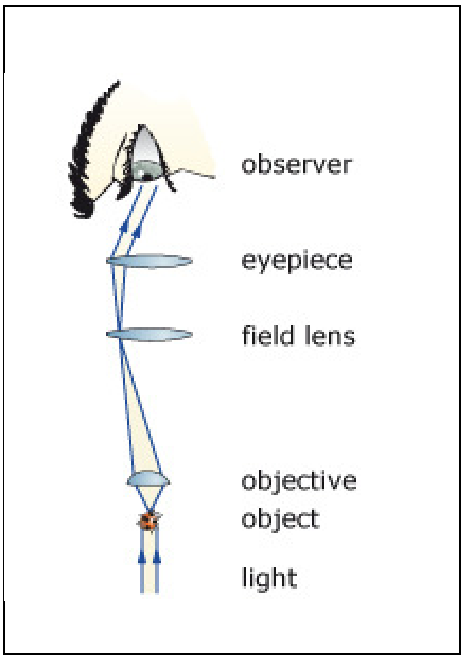


Fig. 3

2.4 THE MODERN "HOME" MICROSCOPE

Componenti

Components

Body-tube

Stage
Spring hooks to hold slides
Mirror for lighting
Focusing traverse
Arm of stand
Objective
Base of stand
Diaphragm
Nosepiece turret
Fine focusing device
Eyepiece
Screw to incline arm of stand

2.5 TEST

You can accede to the complete version of the test from the Resources section of the site "Galileo's microscope". Open the PDF file or download the RTF file. Good luck!

3 SIMULATION

3.1 MAGNIFICATION AND RISOLUTION

Magnification and resolution

The microscope has a dual function, magnifying and resolving, and both are determinant for observing distinctly the specimens to be studied.
Try to vary the capacity for magnification and resolution, and then discover the optical principles on which they are based.

Magnification

Magnification is a fact of purely geometrical nature: the image produced by the objective is larger in size than the object the greater is the image-objective distance (*L*, in the figure shown here) than the objective-object distance (*l*).

Magnification of objective = L/l

The eyepiece produces a further magnification, conventionally given by the ratio between the fixed distance of 25 cm and the focal length (f) of the eyepiece lens, measured in centimeters:

Magnification of eyepiece = 25 cm / f (cm)

The overall magnification of the microscope is given by the product of the magnification of the objective and that of the eyepiece:

Overall magnification= (Magnification objective) x (Magnification eyepiece)

For example, with an objective of 20x and an eyepiece of 5x, the overall magnification is 100x.

Resolution

Resolution consists of the capacity to show the minutest details of an object distinctly, and is determined by the aperture of the beam of light that enters the objective (the eyepiece in general has little effect on the resolution of the microscope).

The tiniest detail that can be observed has a size *d* that depends on the angle θ: the more open is this angle, the smaller is the detail that can be seen.

For example, the "side" *d* of the smallest "square" that can be seen with different angles θ is:

θ	*d*	
10°	3.9 µm	(1 µm equals 0.001 mm)
20°	2.0 µm	
30°	1.3 µm	
40°	1.0 µm	
50°	0.8 µm	