ISTITUTO E MUSEO
DI STORIA DELLA SCIENZA

Galileo's microscope
Anthology

Some anthological passages on Galileo's microscope and seventeenth-century microscopy in general, selected by the *Institute and Museum of the History of Science* in Florence, are presented here.

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JOHN WEDDERBURN: PRECIOUS TESTIMONY TO GALILEO'S MICROSCOPE (1610)

The first descriptions of the compound microscope date from the early 17th century. John Wedderburn, an admirer and disciple of Galileo Galilei, attested through his words that the Pisan scientist had built a microscope and conducted observations with it already in 1610. It is probable that the first Galilean microscopes were built by combining a convex lens and a concave one. The original text is in Latin.

... a few days ago I heard the Author himself [Galileo] telling His Excellency Signor Cremonino, Philosopher and Cardinal, various things greatly deserving to be known, and among others, how he distinguishes perfectly with his Telescope the organs of motion and those of the senses in the most minute animals; and particularly in a certain insect that has each eye covered by a thick membrane, which, however, is pierced by seven slits like the visor of a fully-armoured warrior, leaving the way open to visible species. And here is a new proof that the lens, by concentrating the rays, enlarges the object [...]

J. Wedderburn, *Quator problematum quae Martinus Horky contra Nuntium Sidereum de quatuor planetis novis disputanda proposuit. Confutatio per Joannem Vuodderbornium Scotobritannum*, Padua, 1610. The translation is taken from G. Govi., *Il microscope composto inventato da Galileo*, [The compound microscope invented by Galileo] "Proceedings of the R. Academy of physical and mathematical sciences", no. 1 (1888), pp. 1-2.

GALILEO GALILEI: "A TELESCOPE ADJUSTED TO SEE OBJECTS VERY CLOSE UP" (1623)

Written between 1619 and 1622 and published in 1623, *The Assayer* is the challenging response to Orazio Grassi who, in 1619, under the pseudonym of Lotario Sarsi, had published the *Libra astronomica ac philosophica*, [Astronomical and philosophical weighing scales] in which he attacked Galileo's interpretation of the phenomena relevant to comets. In the text there is a very brief reference to the microscope, described as "a Telescope adjusted to be able to see objects very close up". This first type of Galilean microscope probably consisted of the elongated tube of a telescope with two lenses.

I would say to Sarsi something that is perhaps new, if anything new can be told him. Let him take any material, whether stone, or wood, or metal, and holding it in the sunlight, observe it with the greatest attention, and he will see all of colours divided into tiny particles, and if he will use, for observing it, a Telescope adjusted to see objects very close up, much more distinctly will he see what I am saying without need of any proof, that those bodies dissolve into dew, or into humid vapour.

G. Galilei, *The Assayer*, Rome 1623, pp. 105.

GIOVANNI FABER: GALILEO "IS ANOTHER CREATOR" (1624)

The letter addressed by Giovanni Faber to Prince Federico Cesi, founder of the Accademia dei Lincei, conveys an idea of the enthusiasm aroused by the microscope in academic circles. Faber expresses his intention of putting himself at the disposition of the Pisan scientist, who just at that time was perfecting the construction of the compound microscope. The letter refers to the meeting held in Rome on May 10, during which Galileo gave Cardinal Federico Eutel of Zollern a microscope for the Duke of Bavaria, with which he showed those present the magnified image of a fly.

... Yesterday evening I was at the home of our Sig. Galilei, who lives near the Madalena. He gave a beautiful "ochialino" to Sig. Cardinal of Zoller for the Duke of Bavaria. I saw a fly that Sig. Galileo himself showed me. I was astonished, and I told Sig. Galileo that he is another Creator, since he makes appear things that no one knew had been created until now. I offered to do everything I could for him; but he did not inform me of any of his affairs. However, I will remain at his command, and I will see him often [...]

Letter from Giovanni Faber to Federico Cesi, Rome, May 11, 1624, in G. Galilei, *Opere* [Works], national ed. edited by A. Favaro, Florence 1968, vol. XIII, pp. 177-178.

GALILEO GALILEI: DESCRIPTION OF THE MICROSCOPE (1624)

The letter, bearing the date September 23, 1624, was written from Bellosguardo, where the scientist lived from 1617 to 1631. It contains the most detailed description of the microscope to be found in the writings of Galileo. It discusses the problems of lighting the objects to be observed and the mode of adjusting the focus, concluding with some "naturalist" observations.

Most Illustrious and Excellent Lord and Patron

I am sending Your Excellency an "occhialino" to see the tiniest things close up, which I hope will afford you much pleasure and entertainment, as has been the case with myself. I delayed in sending it because I had not yet brought it to perfection, having had difficulty in finding a way of grinding the lenses perfectly. The object is attached to the mobile circle, which is in the base, and is moved about so as to see all of it, since what is seen at one look is only a small part. And because the distance between the lens and the object must be very precise, to look at objects in relief it must be possible to bring the glass closer or further away, according to whether one is looking at this or that part; and so the tube has been made mobile in its foot, to be guided as we wish. It must also be used in very calm, bright air, and better in sunlight itself, so that the object is very well lit. I have contemplated a great many tiny 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 it is that 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. In brief, one can contemplate infinitely the grandeur of nature, and how subtly she works, and with what indescribable diligence.
[...] The body tube is in 2 pieces, and can be lengthened or shortened as desired.

Letter from Galileo Galilei to Federico Cesi, Florence, September 23, 1624, in G. Galilei, *Opere* [Works], national ed. edited by A. Favaro, Florence 1968, vol. XIII, pp. 208-209.

GIOVANNI FABER: THE NAME "MICROSCOPE" (1625)

In a letter dated April 13, 1625, Giovanni Faber, a friend of Galileo and like him a member of the Accademia dei Lincei, proposed to Prince Federico Cesi that the new instrument, until then called "occhialino", "cannoncino", "perspicillo", "occhiale", be named microscope [from the Greek *mikrós* (small) and *scopeo* (I see)]. Cesi himself had suggested in 1611 the name "telescope" [from the Greek *tele* (distant) and *scopeo* (I see)] for the instrument that was the symbol of the astronomical revolution.

... I wished to recommend this too to Your Excellency, that you look only at what I have written about the new inventions of Sig. Galileo. I have included everything; or if there is anything to be omitted, may you do so as you please. And because I also make mention of this new "ochiale" for seeing minute things, and I call it "microscope", may Your Excellency see if this name pleases him, and I may add that the Lyncei, since they named the first one, telescope, have wished to give an appropriate name to this one too, and with good reason, since they were the first here in Rome to have it [...]

Letter from Giovanni Faber to Federico Cesi, Rome, April 13, 1625, in G. Galilei, *Opere* [Works], national ed. edited by A. Favaro, Florence 1968, vol. XIII, pp. 264.

VINCENZO VIVIANI: GALILEO INVENTOR OF THE MICROSCOPE (1654)

Vincenzo Viviani assisted Galileo with affection from October 1639 to the death of the Pisan scientist. In 1654 he compiled an excellent *Racconto istorico della vita di Galileo* [Historical account of the life of Galileo], written in the form of a letter to Prince Leopoldo de' Medici, which remained unpublished until 1717. In the passage quoted here Viviani seems to attribute Galileo with the invention of both the compound microscope and the simple one. We are, however, in the realm of "hagiographic" biography.

Considering in the meantime Sig. Galileo that the faculty of his new instrument was only that of bringing closer and enlarging in appearance those objects which without other artifice, when it was possible to approach them very closely, would be seen just as distinctly or more so, he then thought of a way of perfecting our sight much more to let it perfectly discern those minutiae which, although situated at a short distance from the eye, are imperceptible to it; and so he invented microscopes with a convex and a concave [lens], and also with one or more convex [lenses], applying them to the scrupulous observation of the tiniest components of matter and the admirable structure of the parts and members of insects, in the smallness of which it is marvelous to see the greatness of God and the miraculous works of nature.

V. Viviani, *Racconto istorico della vita del Sig.r Galileo Galilei* [Historical account of the life of Galileo Galilei], in G. Galilei, *Opere* [Works], national ed. edited by A. Favaro, Florence 1968, vol. XIX, pp. 609-610.

ACCADEMIA DEL CIMENTO: AN OBSERVATION UNDER THE MICROSCOPE (1657)

An experiment recorded in the manuscript "Diaries" of the Accademia del Cimento is reported, in which the use of the microscope is documented. The description, although brief, fully conveys the sense of immediate "amazement" that results from an observation made with the new instrument.

September 6, 1657.
Among the leaves of the Branches of Elm are to be found some cocoons, which when opened reveal a quantity of pure white Worms, which under the Microscope appear as transparent as Crystal, with wings resembling those of Flies, and in the midst of them is very often found a white Vesicle full of humour. With the Microscope the same is found to be born from the Egg, as some of them can be seen still emerging from it.

G. Targioni Tozzetti, Notizie degli aggrandimenti delle scienze fisiche accaduti in Toscana nel corso di anni LX del secolo XVII, [News of the progress of the physical sciences occurring in Tuscany in the year LX of the 17th century] Florence 1780, Tome II, Part II, pp. 680-681.

CARLO ANTONIO MANZINI, THE CONQUESTS OF THE MICROSCOPE (1661)

This passage, taken from *L'occhiale all'occhio* [The lens to the eye] by Carlo Antonio Manzini, shows the enthusiasm felt for the microscope about half a century after it had come into use as a scientific instrument. Thanks to this prodigious instrument, new horizons were opened, with an "infinity of living animals" discovered in vinegar, milk, cheese, blood and many other substances.

... and now thanks to microscopes (these are little telescopes, which enormously enlarge objects very close up) that disembowel, so to say, the atoms themselves, and disclose to our eyes the interior, it will be possible to conduct more logical discourse on the marvels of nature. They agree with me, those who have by this means discovered in very strong vinegar, living and darting about, innumerable tiny eels or snakes; and in milk, in the blood of feverish patients, and in powdered cheese, an infinity of living animals; and almost in competition with the aforesaid "occhiale" of Galileo, discoverer of innumerable little stars mentioned by Democritus but not seen, in the Milky Way in Heaven, have discovered on Earth just as many living souls that were unknown to men, whose eyes were not made by nature keen enough to discover those tiny bodies. The paper on which we write, which on its apparently smooth surface easily allows the pen to disseminate, infused in ink, the deepest thoughts of our mind, that same paper has also been discovered by the microscope to resemble coarse blankets made of the hairiest woolen thread; a spectacle that, although seen, could not be thought possible, because the sense of tact judges it a trick of the glass; and also to the reason this possibility seems feasible, since we know that paper is composed of nothing else but threads of linen and hemp rags soaked in water and pounded; but again, there is nothing in that thread but enlargement. From these principles of things known to us we can argue that it will be easier to investigate the principles of natural things through these instruments of the practical dioptric art modernly invented.

C.A. Manzini, *L'occhiale all'occhio. Dioptrica pratica ...* [The lens to the eye, practical dioptrics…], Bologna 1660. The passage is taken from L. Belloni, *Il microscopio applicato alla biologia da Galileo e dalla sua Scuola (1610-1661)* [The microscope applied to biology by Galileo and his School (1610-1661)] in *Saggi su Galileo Galilei* [Essays on Galileo Galilei] (edited by C. Maccagni), Florence, 1972, pp. 729-730.

ROBERT HOOKE: AN EXTENSION OF THE DOMAIN OF THE SENSES (1665)

In 1665 Robert Hooke, one of the most brilliant and versatile British scientists of the 17th century, published in London the *Micrographia*. The beauty of the plates that illustrated it, depicting insects, leaves and small objects, and the precision of the observations exerted a striking impact on the scientific community. Microscopic reality showed a new side of nature. In this passage Hooke points out the utility for science of mechanical instruments and, at the same time, insists on the value of "real philosophy, mechanical and experimental".

"The great advantage of mankind over the other creatures is that we are not only able to contemplate the works of nature or simply to sustain our lives by means of them, but that we also have the power of considering them, comparing them, altering them, treating them and perfecting them for various uses. And because this is the specific privilege of human nature in general, it is capable of progressing so far with the aid of art and experience that we may see some men, for their observations and deductions, excel over the rest almost as much as the latter over the beasts. With the aid of such instruments and artificial means, we have also, in some way, the chance to remedy the damage and imperfections that men cause themselves due to negligence or intemperance or due to voluntary or superstitious abandoning of the precepts and laws of nature. Every man, in fact, for the intrinsic corruption that is innate and born with him, but that also develops and degenerates with the man, is subject to falling into errors of all kinds.

The only path remaining to us to reacquire a certain degree of our past perfection seems to consist of rectifying the operations of the senses, the memory and the reason so that, through their force, integrity and just correspondence and all the light by which our actions were guided, may be renewed, and our power over things restored.

[...] Every uncertainty and error in human actions proceeds, in fact, either from the narrowness and confusion of our senses, or from the weakness and inconstancy of the memory, or from the limitation or rash impulsiveness of the intellect, so that no marvel is aroused by the fact that our power over causes and natural effects reaches perfection so slowly. We must, in fact, struggle not only with the obscurity and difficulty of the things on which we operate and think, but also against the forces of our own spirit that conspire to betray us. Now, if these be the dangers in the process of human reason, the remedies can come only from real philosophy, mechanical and experimental, which possesses this advantage over the philosophy of discourse and argumentation: that while they tend fundamentally to the subtlety of their deductions and conclusions without regard for the work that must be carried our previously by the sense and the memory, the other seeks to find for the correct ordering of all these faculties and truths to make them useful to one another.

The first thing to which we must attend in this arduous work is surveillance over errors and an extension of the domain of the senses. [...] The first thing to do as concerns the senses is to attempt to make up for their infirmity with instruments, and that is, to add artificial organs to the natural ones. Now, this has been achieved in regard to one of the senses – with prodigious benefits to every sort of useful knowledge – through the invention of optical lenses. By means of the telescope, nothing is so far away that it cannot be presented to our sight, and with the aid of the microscope nothing is so small that it can escape our investigation. A new visible world has been discovered for thought. Through such means the skies have opened and in them have appeared a vast number of new stars, of new motions and new realities that were totally unknown to all of the ancient astronomers. Thanks to this instrument the earth itself, which lies so close to us under our feet, appears to us as an entirely new thing, and in each tiny particle of its matter we now observe a great variety of creatures, as many as we could have counted in the whole universe before.

As regards the continuation of this method in research in physics, I have here and there gathered a certain number of observations, in collecting which I have made use of the microscope as well as some other lenses and instruments whereby the senses are perfected. I have taken this path not because there were not a multitude of useful and pleasant things – not hitherto investigated – to be easily observed without the aid of art, but only so as to promote the use of the mechanical aids to the senses. They allow us to examine the world already visible, and to discover many other worlds up to now unknown, and can make us realise that we have not yet obtained possession of a world when there still remain many others to be discovered. Each considerable perfecting of the telescope or of the microscope produces, in fact, new worlds and unknown lands for our sight."

R. Hooke, *Micrographia or some physiological descriptions of minute bodies made by magnifying glasses. With observations and inquires thereupon*, London 1665, pp. 177-178, in Paolo Rossi (edited by), *La rivoluzione scientifica da Copernico a Newton* [The scientific revolution from Copernicus to Newton], Turin, Loescher, 1973, pp. 75-78.

ANONYMOUS: "MODE OF USING THE MICROSCOPE" (1665-1667)

This is an important anonymous manuscript that describes the use of the sliding-tube microscope. The text, accompanied by precise iconographic material, furnishes instructions for three configurations with increasingly greater magnification and, contextually, describes the delicate operations to be carried out for putting the object to be observed in focus.

Instrument called Microscope and fabricated of five tubes, which are marked with three sorts of numbers, that is I - II – III, so as to be able to use it. Its proper utilization is for seeing distinctly very tiny objects, to which the eye cannot arrive. To facilitate this use, it is shown with the three following figures.

Firstly with figure C in which all of the Tubes are fixed, except for the first one, that is, the largest, which must be raised until the number I on the first Tube coincides with the number I on the second Tube, and thus all of the numbers I, of which there are six in said figure C, will be united, and in this way it will magnify less, and the image will be very clear, and will serve expressly for the most visible objects.

The instrument thus adjusted, its foot will be set on a flat place, firm and with a good light, and the object that is to be seen will be placed under the lower glass, as for example in E, taking care that lighter objects are placed above a black field, and dark objects above a white field, so that there is no confusion; and because the objects are not all of the same height, no precise sign can be given, and no true establishing of the distance of the lower glass from the object. It will be necessary, in looking into the Instrument, to hold the ring of the foot with one hand and hold the smaller Tube marked D with the other hand, taking care that the hand does not cast a shadow on the object, and said Tube D will be raised or lowered little by little, until the eye finds the best point for viewing the object, without removing the eye from its sight.

Secondly, when it will be raised to the numbers II, of which there are eight, as shown in figure B, the object will be much more enlarged, always by raising, or lowering the said Tube D, as has been explained, until the eye finds the best point.

And lastly, when it will be raised to the numbers III, of which there are also eight as shown in figure A, by raising or lowering the said Tube D as explained above, having found the point, it will magnify enormously, and will serve for objects imperceptible to the eye.

And since it may happen, that the Instrument does not show with the usual clarity and distinction, this will be because the glasses, which are fixed, will receive humidity, and thus it will be necessary to take them out and clean them with a clean cloth, but lightly, without exerting force, because this could damage the polish and surfaces of said glasses.

Anonymous, *Modo di adoperare il microscope* [Mode of using the microscope], 1665-1667, ms. Chigi Family Archive, Vatican Secret Archive, Rome.

LORENZO MAGALOTTI: DIGESTION IN SOME ANIMALS (1667)

Published in 1667, the *Saggi di naturali esperienze* [Essays in natural experiments] presents a synthesis of experimental work carried out over the span of a decade (1657-1667), marking at the same time the end of the activity of the Accademia del Cimento. The book encountered notable success, with the first English translation appearing in 1684 and a Latin edition in 1731. Despite the presence of illustrious microscopists in the Academy, in the *Saggi* we find only one passage (the one quoted here, on the digestive behavior of various species of birds) which explicitly refers to an experiment carried out with the aid of the microscope.

Admirable is the force of the digestive system in hens and ducks, which, after having been fed solid glass beads, were shot by us many hours later, and when their entrails were opened to the sun, they appeared to be lined with a gleaming tunic, which when viewed under the microscope was recognised as nothing more than extremely fine, impalpable pulverized glass.

In some that had also been fed glass beads, but hollow and finely perforated, we were amazed to see the aforesaid beads already crushed and ground up, and others having only begun to crack and filled with a certain white matter resembling clotted milk, which had entered through that tiny hole. And we observed that those that have in their entrails the greatest amount of swallowed pebbles, grind up food better than the others. Thus it is less surprising that they crush and pound cork and other harder woods, such as cypress and ash, and grind and finally break into tiny slivers olive seeds, very hard pine nuts and pistachios which they had been made to swallow with the hulls. Birdshot we found notably crushed after twenty-four hours, and of some hollow tin quadrels, we found some of them whole but twisted and partially crushed in from one side to the other.

L. Magalotti, *Saggi di naturali esperienze fatte nell'Accademia del Cimento* [Essays in natural experiments conducted by the Accademia del Cimento], Florence 1667, pp. 268-269.

FRANCESCO REDI: RECTIFICATION OF AN ACTIVITY OF THE ACCADEMIA DEL CIMENTO (1671)

In this passage of the *Esperienze intorno a diverse cose naturali* [Experiments on various natural things] Francesco Redi tries to understand the interior passage and transformations undergone by glass beads in the bodies of some birds, rectifying what had been stated on the same subject in the *Saggi di naturali esperienze* [Essays in natural experiments] (cf. above passage). Note however that, Redi himself, who had proven his ability to combine experimentation with utilization of the microscope in his naturalist research, participated in the experimental sessions of the Accademia.

Now I will not fail to sincerely note on this subject a mistake found in the *Saggi di naturali esperienze dell'Accademia del Cimento* [Essays on natural experiments of the Accademia del Cimento], on page 265. We find written here: *Admirable is the force of the digestive system in hens and ducks, which, after having been fed solid glass bead, were shot by us many hours later, and when their entrails were opened to the sun, they appeared to be lined with a gleaming tunic, which when viewed under the microscope was recognised as nothing more than extremely fine, impalpable pulverized glass*.

Where the text reads *with solid glass beads*, it should have read *with hollow glass beads*. This is because solid glass beads are not ground up or pulverized in many hours, but require the time of many, many days, and even of many weeks; but those that are hollow and fabricated by lantern are crushed in a few hours. I recall that a hen was made to swallow four of such hollow beads, and in her entrails they were found six hours later, all reduced to tiny bits. Having made a capon swallow six of them, five hours later they killed it, and found all of them crushed in the entrails. In a large pigeon, four of them were crushed in less than four hours; but I having fed four others to each of two more large pigeons, after they had ingested them for three hours, in which time they ate but did not drink, I had them shot, and with the first pigeon I found in its crop a whole bead that had remained empty. Of the other three, in which the beads had descended into the entrails, two were crushed, and the third had remained intact and was filled with a white liquid resembling milk that is liquid and not clotted, with a mixed sour and bitter flavour. With the second pigeon, two of the beads had been broken into minute pieces in the entrails; and the other two, which had remained still whole, could be seen to be filled with ground-up birdseed and the aforesaid white liquid. These examples verify what is stated in the above-mentioned *Saggi di naturali esperienze*, i.e., that *in the entrails of ducks and hens were found beads of glass filled with a certain white matter similar to clotted milk, which had entered through a tiny hole*. As to where this white liquid may come from, I myself believe that it was secreted from those infinite papillae, which are situated in that interior of the esophagus in all birds, which is attached to the upper mouth of the entrails; and even more strongly I would believe it, since in other similar experiments I recall that the beads, filled only with that liquid with no food mixed with it, have always been found by myself in the upper mouth of the entrails; and the others, that were filled with food and the white liquid, I have found them in the interior cavity of these entrails. If then to this white liquid, something else is mixed that gives it a bitter taste, it is easy to conjecture what it is, since its function may be easily guessed. I believe that digestion in the entrails of birds is not carried out and perfected entirely by grinding, as some have declared, but that it also requires a fermenting agent to ferment, dissolve, thin and convert the already ground-up food into chyle. And I believe that the gravel swallowed by birds and moved about by the force of the muscles has no other function than the one that would be served by teeth. I have observed that for some fish, and particularly sea-locusts, which feed on hard things and swallow them whole, nature has provided teeth in the cavity of the stomach. Worthy and highly useful it is to read on this subject the most erudite *Progymnasma de nutricatione*, written by Tommaso Cornelio.

Hollow beads of glass are thus crushed in a few hours in the entrails of birds; but not solid beads, which, as I was saying, require a time of many weeks, before they can be totally reduced to powder. Having given to a capon four beads of solid glass, each of which weighed eight grains, and were of those commonly used to make necklaces or crowns, after twelve hours I found them in the entrails sound and entire, without even having lost their luster. The hole, however, through which these beads are threaded, was filled with ground-up food.

F. Redi, *Esperienze intorno a diverse cose naturali e particolarmente a quelle che ci son portate dall'Indie, fatte da Francesco Redi e scritte in una Lettera al padre Atanasio Chircher della Compagnia di Gesù*, [Experiments on various natural things and in particular on those that have been brought from India, carried out by Francesco Redi and described in a Letter to Father Atanasio Chircher of the Company of Jesus], Florence, 1671.