ANTHONY VAN LEEUWENHOEK AND HIS MICROSCOPES[1]

By Professor G. H. PARKER
HARVARD UNIVERSITY

WHAT the telescope is to the astronomer the microscope is to the biologist! Since the physical requirements of both these instruments are much the same, it is not surprising to find that the improvement and increased applications of one follow much the same path as do those of the other. Long before microscopes had been invented, however, simple lenses were in use. These lenses, doubtless employed for the inspection of small objects, were certainly known to the ancients. Pieces of rock crystal ground into biconvex forms were found by Layard in the ruins of Assyrian Nimrud, and Seneca tells us that hollow spheres of glass filled with water were used by the Romans to produce large images. The cutting of gems, an art which reached such high perfection in antiquity, must have been done under some kind of magnifier. In later times Roger Bacon (1214–1294) described a crystal lens as "useful to old men and to those whose sight was weakened, for by this means they will be able to see the letters sufficiently enlarged however small they may be." Spectacles were known to Chaucer (1340–1400), for he puts into the mouth of the wife of Bath the saying that poverty is a spectacle through which a man may see who are his real friends.

Yet notwithstanding these applications of lenses to the affairs of daily life, early science does not seem to have used such devices. The truly wonderful observation of Aristotle on the developing chick appear to have been made exclusively by his unaided eye, for he gives no intimation in his writings, so far as I am aware, that he ever used any artificial means as an aid to his vision. Pliny in his natural history has much to say about lentils but nothing about lenses.

The simple microscope, a biconvex glass mounted in a metal carrier, appears first to have come into general use at about the time of the Thirty-Years War (1618–1648). This instrument gained great popularity in that it was the means by which the movements of diminutive living creatures could be exhibited. Of these none was more frequently shown than the flea; hence the name of this device "vitrum pulicare" or, in common language, flea glass.

With the advent of the simple microscope there sprang up in Europe during the seventeenth century a flourishing school of workers, the early micrographers, who became enthusiastically engaged in the study of the minutiae of nature and who, by the use of the microscope, opened up a whole world of living forms never dreamed of by their predecessors. Chief among these early enthusiasts were Marcello Malpighi (1628–1694) of Italy, Robert Hooke (1635–1703) and Nehemiah Grew (1641–1712) of England, and last but not least Jan Swammerdam (1637–1680) and the subject of this essay, Anthony van Leeuwenhoek (1632–1723), both of Holland.

The lives of these two Dutchmen were almost exactly coincident with the golden age of the Netherlands. Following the struggles of William of Nassau the Dutch Republic gained its effective

[1] The author is under great obligation to Mr. Clifford Dobell for permission to quote freely from his recent volume, "Anthony van Leeuwenhoek and His Little Animals."

independence in 1609 and from that time onward it grew immensely in power and in riches. The middle of the seventeenth century may be taken as the culmination of this growth. At that time Amsterdam was the greatest trading center of Europe and the Dutch East India Company and the West India Company were the most powerful and successful commercial enterprises in the world. From a soil thus enormously enriched by commerce there arose an unprecedented artistic and intellectual efflorescence. Social life expanded, the arts flourished and science blossomed as never before. This was the time of the great Dutch painters Jan Vermeer, Jan Steen, Franz Hals and, above all, Rembrandt, At this time flourished the celebrated Dutch physicist, astronomer and mathematician, Christian Huygens, and the anatomists Franciscus Sylvius, Nicolaus Steno and especially Reinier de Graaf. Even the unassuming, excommunicated lens-grinder, Spinoza, brought to philosophy during this period a novel exaltation. Into this ferment of new life and ever-increasing activity were born the Dutch micrographers already named, Swammerdam and Leeuwenhoek. Although they were sons of one civilization their positions in life could hardly have been more in contrast.

Swammerdam, whose life has been completely sketched by Miall, was a native of Amsterdam and born into reasonable affluence. His father, a well-to-do apothecary, had established a private museum of natural history. Swammerdam the son was intended for the ministry, but he finally prevailed upon his family to let him study medicine. Meanwhile natural history became his passion and insects his special care. He attended the University of Leiden, where he made the acquaintance of Steno, de Graaf and Sylvius. He then traveled in France. On his return to Amsterdam he continued his anatomical and medical studies and perfected himself in methods of delicate dissection and injection under the simple microscope. In 1668 Cosmo, duke of Tuscany, visited Amsterdam, and when Swammerdam opened for him a fully grown caterpillar and showed him the wings, legs and other parts of the future butterfly in process of formation and packed away under the larval skin, Cosmo was so impressed that he offered Swammerdam a large sum of money for the latter's collections, provided that Swammerdam would come to Florence and settle there under the patronage of the duke. This offer Swammerdam finally declined, probably on religious grounds. In 1669, when he was thirty-two years old, he published his "General History of Insects." His health was far from robust, and disagreements with his father, who looked upon natural history as not a gainful occupation, led to difficulties. He was ambitious to complete further work on the insects and particularly on the day-flies and the hive-bee, and this he did despite a certain amount of parental opposition. His account of the day-flies was published in 1675. Five years later, in 1680, after serious illness and many financial worries, he died at the early age of forty-five. Thus Swammerdam's life reached its conclusion, the life of a man academically trained, reasonably traveled, cultured, dependent chiefly upon his family and short in years, in almost every respect the very opposite of that of his compatriot Leeuwenhoek.

Anthony van Leeuwenhoek was born at Delft in 1632. His life and doings have been most sympathetically and delightfully recorded in a recent memorial volume by Clifford Dobell, a scholar to whom all others are indebted for this labor of love. The parents of Leeuwenhoek were of good Dutch stock, his father a basket-maker of no personal or social distinction, his mother the

daughter of a well-to-do Delft brewer. Of their seven children Anthony was the fifth, born in the tenth year of their married life. The father died in 1638 when Anthony was five years old, and the mother, after a second marriage, lived till 1664. About the time of his mother's remarriage Anthony was sent to school at Warmond near Leiden. Apparently he never looked forward to a university career, for at the age of sixteen he went to Amsterdam, where he entered a linen-draper's shop to learn the business. While he was in Amsterdam it seems probable, according to Dobell, that he made the acquaintance of Swammerdam some five years his junior. After six years' apprenticeship in Amsterdam Leeuwenhoek returned to Delft, where he lived for the rest of his days. The Thirty Years War had ended, peace was reasonably assured for the time being, and Leeuwenhoek settled down into the quiet life of his native place.

Much of the quaintness and beauty of old Delft still remains. To the stranger of to-day, wandering along its quiet canals and shaded streets, it is easy to imagine scenes such as must have inspired the brush of an artist like Vermeer. In fact Vermeer's "View of Delft" and his "House on the Street," now both well-known classics in art, may be taken as evidence of how little the modern town has changed from that of the seventeenth century. It is a strange coincidence that on the death of Vermeer, which occurred at Delft in 1675, Leeuwenhoek was appointed official receiver to settle the greatly reduced estate of this noted artist. Life was even more circumscribed in those days than it is now.

In 1654, when Leeuwenhoek was twenty-two, he married. From this union were born five children, three sons and two daughters, only one of whom, Maria, lived beyond infancy. Leeuwenhoek's marriage year was notable in several respects. It was the year in which the great powder magazine in Delft exploded, killing hundreds of people and destroying many houses. This year likewise was the year in which peace was declared between England and Holland. It is not surprising then that at this time Leeuwenhoek should have bought in Delft a house and a shop and set himself up in business as a draper. According to bills now extant, he was buying and selling cloth, silk, ribbons, tape, buttons and the like. In 1666 his wife died, but in 1671 he married again, his second wife living till 1694. After her death his household was managed by his only surviving daughter, Maria, who is described by Dobell as devoted to her father. She cared for him in his old age when he was weak and infirm, and over his grave she raised a fitting memorial. She herself lived to be an aged woman, for she attained her eighty-ninth year. On her death her body was interred in her father's tomb.

Although Leeuwenhoek's business must have taken much of his time, he accepted in 1660 an appointment as Chamberlain of the Council-Chamber of the Worshipful Sheriffs of Delft. The duties implied in this appointment may be gathered from the wording by which it was ordered and which has been translated by Dobell as follows:

> Their Worships the Burgomasters and Magistrates of the Town of Delft have appointed and do hereby charge Antony Leeuwenhoek to look after the Chamber wherein the Chief Judge the Sheriffs and the Law Officers of this Town do assemble: to open and to shut the foresaid Chamber at both ordinary and extraordinary assemblies of the foresaid Gentlemen in such wise as shall be required and needful: item to show towards these Gentlemen all respect honour and reverence and diligently to perform and faithfully to execute all charges which may be laid upon him and to keep to himself whatever he may overhear in the Chamber: to clean the foresaid Chamber properly and to keep it neat and tidy: to lay the fire at such times as it may be required and at his

own convenience and carefully to preserve for his own profit what coals may remain unconsumed and see to it that no mischance befall thereby nor from the light of the candles: and he shall furthermore do all that is required of and that pertaineth to a good and trusty Chamberlain. For the which service the foresaid Antony Leeuwenhoek shall enjoy such wages benefits and emoluments as the foresaid lamented Jan Strick his predecessor in office did enjoy and shall enter into his duties upon the morning of the 24th of January 1660 and his wages shall be paid upon the same terms as those whereon the foresaid Jan Strick's were paid. Ordered by the Burgomasters in Council assembled this 26th day of March 1660 and signed by

J. CAMERLING. *Pensionary.*

In return for the performance of the duties as Chamberlain, Leeuwenhoek received 314 florins a year, a sum later increased to 400. Subsequently he added to this position that of "Generaalwijkmeester" or alderman, for which he received an additional annual stipend of 50 florins. Both these appointments, according to Dobell, were probably sinecures and their duties were performed by proxy. In 1669 Leeuwenhoek was admitted as a surveyor within the jurisdiction of the Court of Holland, a step which he could not have taken, had he not had considerable knowledge of applied mathematics. He was now in his thirty-seventh year, a well-established and respected tradesman in Delft.

Thus far Leeuwenhoek had had no outward connections with the learned world, but in 1673 he began those associations with the Royal Society of London that were to extend throughout half a century and were to be terminated only by his death. How these associations arose has been fully narrated by Dobell. The Royal Society of London, founded about 1660 for the promotion of natural knowledge, was desirous of getting into communication with all those who sympathized with its aims. To this end its first secretary, Henry Oldenburg, carried on a voluminous correspondence with savants the world over, and among these was Reinier de Graaf, the friend and townsman of Leeuwenhoek. Through Oldenburg, de Graaf learned of the new and remarkable microscope made by Eustachio Divini in Italy, by which the inventor had been able to discover "an animal lesser than any of those seen hitherto." That Holland should not be outdone by Italy de Graaf addressed the following words to Oldenburg as translated by Dobell:

That it may be the more evident to you that the humanities and science are not yet banished from among us by the clash of arms, I am writing to tell you that a certain most ingenious person here, named Leewenhoeck, has devised microscopes which far surpass those which we have hitherto seen, manufactured by Eustachio Divini and others. The enclosed letter from him, wherein he describes certain things which he has observed more accurately than previous authors, will afford you a sample of his work: and if it please you, and you would test the skill of this most diligent man and give him encouragement, then pray send him a letter containing your suggestions, and proposing to him more difficult problems of the same kind.

De Graaf's letter was accompanied by a sample of Leeuwenhoek's work, which included observations on mould, the sting, mouth-parts and eye of the bee, and the louse. These observations so interested the members of the Royal Society that its secretary was instructed to communicate with Leeuwenhoek, who replied as follows:

I have oft-times been besought, by divers gentlemen, to set down on paper what I have beheld through my newly invented *Microscopia:* but I have generally declined; first, because I have no style, or pen, wherewith to express my thoughts properly; secondly, because I have not been brought up to languages or arts, but only to business; and in the third place, because I do not gladly suffer contradiction or censure from others. This resolve of mine, however, I have now set aside, at the intreaty of Dr. Rag. de Graaf; and I gave him a memoir on what I have noticed about mould, the sting and sundry little limbs of the bee, and also about the sting of the louse. This memoir he (Mr. de Graaf) conveyed to you; whereupon you sent me back

an answer, from which I see that my observations did not displease the Royal Society, and that the Fellows desired to see figures of the sting and the little limbs of the bee, whereof I made mention. As I can't draw, I have got them drawn for me, but the proportions have not come out as well as I had hoped to see 'em; and each figure that I send you herewith was seen and drawn through a different magnifying-glass. I beg you, therefore, and those Gentlemen to whose notice these may come, please to bear in mind that my observations and thoughts are the outcome of my own unaided impulse and curiosity alone; for, besides myself, in our town there be no philosophers who practise this art; so pray take not amiss my poor pen, and the liberty I here take in setting down my random notions.

According to Dobell, a week before Leeuwenhoek sent to the Royal Society the letter just quoted Constantijn Huygens, diplomat and father of the physicist, wrote as follows to Hooke:

Our honest citizen, Mr. Leewenhoeck—or Leawenhook, according to your orthographie—having desired me to peruse what he hath set down of his observations about the sting of a bee, at the requisition of Mr. Oldenburg, and by order, as I suppose, of your noble Royal Society, I could not forbear by this occasion to give you this character of the man, that he is a person unlearned both in sciences and languages, but of his own nature exceedingly curious and industrious, as you shall perceive not onely by what he giveth you about the bee, but also by his cleere observations about the wonderfull and transparent tubuli appearing in all kind of wood. . . . His way for this is to make a very small incision in the edge of a box, and then tearing of it a little slice or film, as I think you call it, the thinner the better, and getting it upon the neddle of his little microscope—a machinula of his owne contriving and workmanship—brass. . . . I trust you will not be unpleased with the confirmation of so diligent a searcher as this man is, though allways modestly submitting his experiences and conceits about them to the censure and correction of the learned. . . .

Thus through these several agencies was Leeuwenhoek introduced to the Royal Society and thus began that remarkable series of communications in which he contributed to the society a fund of knowledge made possible by the use of his microscopes.

It seems quite clear that for some years previous to 1673, when Leeuwenhoek became known to the Royal Society, he had been grinding lenses and making microscopes, but when and how these activities began no one appears to know. Suffice it to say that in the year mentioned he had gained no small degree of skill in this practise and that this skill and its results were recognized by such men as de Graaf and the elder Huygens.

The instruments commonly designated as Leeuwenhoek's microscopes are fortunately fairly well known to us. At his death, as can be ascertained from the auction list of certain of his effects, it is known that he left 247 completely finished microscopes and 172 mounted lenses, or 419 pieces in all. The great majority of these have disappeared, including the "little cabinet, lacquered black and gilded that comprehendeth within five little drawers wherein lie inclosed 13 long and square little tin cases which I have covered over with black leather, and in each of these little cases lie two ground magnifying glasses making 26 in all everyone of them ground by myself and mounted in silver." This cabinet was bequeathed by Leeuwenhoek to the Royal Society, safely received by it, not infrequently inspected by its Fellows, but finally duly and totally lost. In fact Dobell reports that of the 419 lenses known to exist at the time of Leeuwenhoek's death, at present only eight can be accounted for with certainty and all these are held on the continent, England and America possessing none. These eight, however, with the descriptions of others, give us ample ground for reconstructing the instrument.

This consisted of two parallel plates of metal, brass, silver or even gold, held together by rivets and carrying between them in their upper central part one of the precious lenses held firmly opposite holes in the plates, so that the observer could put his eye next the united plates

and peep through the aperture with its contained lens at any object held on the opposite side. Such object was not supported by the hand but by a metal point which terminated a rod itself attached to the lower part of the plate in such a way that it could be moved by threaded screws into appropriate position for inspection and clear focus. The object to be examined was either mounted on the metal point by being stuck there with glue or it was placed on a bit of thin glass or mica or between two pieces of such material or in a capillary tube. These partial mounts were attached of course to the metal point. Thus a great variety of substances could be brought under inspection. Leeuwenhoek's method of demonstration was such that he usually made a microscope for each object and having set up the whole, he retained it in that form for inspection instead of changing the object under the glass, as was later commonly practised.

It will be seen at once from this brief description that Leeuwenhoek's so-called microscopes were little more than simple lenses and that they bore no resemblance whatever to the compound microscope of even his day. This instrument, in which one lens or lens-system magnifies the image formed by another, was indeed known at his time, but it was so imperfectly developed that even the relatively crude magnifier made by Leeuwenhoek far outran it in efficiency. The great success that Leeuwenhoek's microscopes attained turned, it appears, on the marvelous skill with which he ground his lenses. In early times, when many of these lenses were available, they were carefully examined by expert opticians and were pronounced by them as unusually free from optical defects, notwithstanding that they were of relatively high power. His better lenses are known to have magnified 270 diameters, and it is possible that some of his best products, of which he seems to have been very choice, reached as much as 300 diameters.

A perusal of Leeuwenhoek's letters and the comments of his contemporaries show that he guarded his best work with a certain jealousy and secrecy. He often implies in the accounts of his observations that he could see what many others could not. He intimates further that he possessed methods of manipulation which placed him personally at an advantage over others and which he was loath to impart to them. This professional secrecy, if such it was, formed a part of his psychology and Dobell has rightly called attention to it. What it was all about is not easy to surmise. It is, however, certain that he observed and figured many bodies that it would be very difficult for even an unusually skilful observer to make out with the equipment ordinarily attributed to Leeuwenhoek. That he had certain remarkable lenses at his disposal that never were allowed to come to light is very unlikely. His secret, if he had one, was probably in his method of manipulation. Dobell has suggested that he may have used some form of indirect illumination, a step entirely possible with his apparatus. When it is recalled how greatly this method would have improved the possibilities of viewing very minute objects, such as bacteria and the like, it seems more than probable that Dobell is correct in his surmise and that this was the step in Leeuwenhoek's manipulation that set him so far in advance of his competitors and that he was so loath to reveal. In support of this suggestion Dobell quotes Leeuwenhoek, who in reply to a criticism remarks, "but I can demonstrate to myself the globules (corpuscles) in the blood as sharp and clean as one can distinguish with one's eyes, without any help of glasses, sandgrains that one might bestrew upon a piece of black taffety silk." Precisely this comparison would hardly have occurred to Leeuwenhoek had he not been accustomed to view microscopic objects on a dark background, such as is produced by in-

direct illumination. His vision was known to have been remarkably acute, but added to this there must have been some other turn in manipulation which gave him supremacy, and indirect illumination may have been that turn.

Equipped with unusual apparatus and technique, filled with a burning curiosity about all natural objects, and with fifty years of life ahead, Leeuwenhoek at the age of forty-one began a scientific career of remarkable discovery and accomplishment. His physical needs were met by the income from his shop and his town appointments. His time was largely his own and he was thus free to follow the passion of his later life.

During these fifty years Leeuwenhoek spread his scientific discoveries by writing letters mostly to the Royal Society, and many of these were published in its *Transactions*. In 1680 he was elected a fellow of the society, an honor which gave him great satisfaction. As a result of his work he became more and more widely known and was visited by celebrities as well as by others from all over the learned world. As Dobell writes, "kings and princes, philosophers and physicians and men of science, statesmen and clergymen and even common men went to see him and to look through his wonderful glasses." The visit of Peter the Great of Russia has been recorded with much detail. This monarch was so interested in what Leeuwenhoek had to show him that he detained Leeuwenhoek no less than two hours and on taking his leave shook Leeuwenhoek by the hand and assured the micrographer of his special gratitude. But Leeuwenhoek was not to be lionized. His heart was in his work and visitors took his time. Finally many were denied admittance, but he always endeavored to make himself accessible to those who came from the Royal Society. In this respect the following comment concerning visitors from Sir Hans Sloane, then secretary of the society, is not without interest. "Mr. Hans Sloane recommended Mr. Stuart to me, in his letter, as a curious Gentleman who has travelled through many countries; and the same Gentleman had two other Scottish gentlemen in his company, all of whom I gladly received, and so will I do all those who have an introduction from Mr. Sloane." Mr. James Petiver, however, was less fortunate. After an unsuccessful attempt to visit the micrographer in 1711, Petiver received from Leeuwenhoek a letter, from which the following significant extract is taken:

> I have received your Letter of the 2nd of August anno 1711, wherein you are displeased at not being welcomed at my house. I beg you please not take it ill, seeing that we send off everyone who tries to visit me unless they have some sort of introduction. . . . If you had kept by you the letter from Mr. Hans Sloane, you would not have missed a friendly entertainment at my house. And you were sent away especially because you were not known, and because some 8 or 10 days earlier no less than 26 people came to see me within four days, all of them with introductions (except a Duke and a Count with their Tutor): which made me so tired, that I broke out in a sweat all over.

Thus was poor Leeuwenhoek in his seventy-ninth year pestered by an importunate public.

Yet notwithstanding interruptions work went forward. In 1717 Leeuwenhoek really thought his end was near, and he wrote what he believed to be his last letter to the Royal Society, concluding with

> Methinks these will be the last observations I shall be able to send to you honourable Gentleman; because my hands grow weak, and suffer from a little shakiness, which is due to my advanced years, a good 85 having passed by me. And so I send you with this my deep thankfulness, because in the year 1679 you were so kind as to elect me, quite beyond my competence, a Fellow of the most worthy College of the Royal Society; and to send me a Diploma, together with two letters from the Secretaries of the Society, which likewise made known to me my election, by all the votes of the Fellows, then gathered together at a very full meeting.

I thank you also for the *Philosophical Transactions,* which Your Excellencies have been so good as to send me from time to time.

For all these honours and gifts aforesaid, I herewith convey to you my gratitude once more.

Yet after this letter Leeuwenhoek lived nearly six more years and sent to the society in that time no fewer than eighteen more epistles. But the end finally did come on the twenty-sixth of August, 1723. The Reverend Mr. Peter Gribius notified the fellows of the Royal Society of Leeuwenhoek's death, and his daughter, Maria, arranged his funeral and carried out his last wishes. Leeuwenhoek was buried in the Old Church of Delft on Sunday the thirty-first of August, 1723, "with 16 pallbearers and with coaches and tollings of the bell at 3 intervals." In 1739 his daughter Maria erected a monument to his memory in another part of the church where he now lies. Here she too was later buried. Thus concluded the life of a man who without a vestige of university training and utterly devoid of academic associations contributed to the scientific advance of his day as did scarcely another.

What these advances were may be mentioned only briefly. Leeuwenhoek confirmed and extended Malpighi's observation that the arteries connected with the veins by a system of very fine vessels, the capillaries. These Leeuwenhoek demonstrated in the tail of the tadpole and the eel, in the web of the frog's foot, and in the membrane of the bat's wing. He pointed out significant differences in the blood corpuscles of various animals. He was first to note the cross-striation of muscle fiber and the fibrous structure of the lens of the eye. Following the initial observation of Hamm, he began a study of spermatozoa, of which he believed he could distinguish two kinds, one giving rise to male offspring and the other to female, an anticipation of the modern doctrine but on wholly erroneous grounds. He studied cilia in the edible mussel and the embryos of the fresh-water clam and was a vigorous opponent of spontaneous generation. He studied the life history of the plant-louse and discovered viviparity. He watched fleas hatch from their eggs and showed that the so-called eggs of ants were their pupae. He plunged into the question of the nature of cochineal, and finally declared in favor of the view that it is a dried insect. He showed that the compound eye as such occurred in crustaceans as well as in insects. He studied the structure and breeding habits of spiders and watched them hatch from their eggs. He discovered rotifers and showed that they could undergo desiccation without consequent death. In the dried state he believed them carried from place to place as dust in the wind. He first described the fresh-water hydra, volvox, and so many of the flagellate and ciliate infusorians that he is usually regarded as the father of protozoology. He described the yeast plant and was the first to observe bacteria. These he studied and described from his own mouth, where he found them in and about his teeth. Such materials and a host of others claimed Leeuwenhoek's ingenious attention and afforded subject-matter for his eager, inquiring mind. Neither trained nor informed in speculative science he at times laid himself open to violent attacks from his opponents but, skilled beyond all others in direct observation, he amassed and handed down a body of knowledge prodigious in amount and unbelievable in importance. A simple, earnest, inquiring soul, in outward form an unassuming tradesman, in inward truth a burning flame of purest science.