it has further departed, not only from the terrestrial *Epilobium glandulosum,* which it superficially closely simulates, but from all other species in eastern America by altering its seeds, so that, instead of being brown and only minutely pebbled, they are gray and covered with ridges of coarse papillae. Here, at last, nature has evolved a species, *Epilobium ecomosum.*

From a purely academic view-point it would be possible to argue that *Epilobium ecomosum* is the only surviving remnant of an ancient series of subaquatic plants which, taking to the land, have, all over the world, evolved the coma as an adaptation for wind-dispersal. But, compared with the great geological age of the habitats of some typical *Epilobia,* that of the estuary of the St. Lawrence, available only since at least the first Pleistocene invasion, is comparatively modern. Furthermore, did time permit, I should like to discuss from the same estuary of the St. Lawrence a beggar tick (*Bidens*) which has no awns, such as regularly characterize the terrestrial species of *Bidens* and supply the generic name. Of what use would awns be in such a habitat? On land they indiscriminately seize hold of the fur or the coats of every passing animal, but the fish of the lower St. Lawrence are too smooth to function as dispersal-agents, even for *Bidens.*

We may reason that in these and several other similar cases, one of the numerous predetermined variations of *Epilobium* or of *Bidens* or of some other genus fortuitously sprang into being in the estuary of the St. Lawrence and in this satisfactory environment has found opportunity to prosper, or we may prefer to view the peculiar environment itself, as so often seems to be the case, as molding an old species into something more fitted to the special surroundings. Whichever interpretation we choose, the simple fact remains that the field-botanist who would look successfully for thoroughly differentiated local species and pronounced geographic varieties (incipient species) has learned (as Charles Darwin did before him) to go to restricted areas which for ages have been ecologically or physiographically unique or which for at least a thousand millenniums have had remote or insular or peninsular isolation.

DEVELOPMENT OF OUR EARLY KNOWLEDGE CONCERNING MAGNIFICATION

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ANY clear transparent object with one convex surface and one flat surface or two convex surfaces acts as a magnifier, and the statement is often made that the use of such materials for magnification goes back many centuries. Thus large convex pieces of rock crystal were found by Layard in the ruins of a palace at Nimrud below the ancient city of Nineveh in Assyria. It is now agreed that such pieces of crystal could not have been used as lenses to enlarge the size of objects because of their uneven surfaces and bands, but that they probably served as ornaments to be worn on the chest. Various references to spectacles can be found in ancient Chinese writings, but such glasses were undoubtedly employed for the protection of the eyes and not as an aid to vision. A knowledge of the principle of magnification may be very old, however. Euclid in the third century B.C. investigated the laws of refraction, and Seneca apparently grasped the idea. In his "Questiones Naturales," written about 63 B.C., he states that "letters, however small and dim, are comparatively larger and distinct when seen through a glass globe filled with water." The appreciation of this principle is also closely associated with the manufacture of spectacles with the distinct purpose of improving the sight. These probably arose among the Venetian glass workers, and their discovery is usually attributed to Salvino d'Amarto degli Amarti of Florence and Allesandro della Spina of Pisa. The evidence for this is not entirely satisfactory. Cole[1] says that Francesco Redi (1626–1697), physician, naturalist, poet, mentions probably the first written reference to spectacles in a manuscript, dated 1289, written by a monk who says that he could neither read nor write without the glasses called *occhiali* for the improvement of his vision. Rolleston,[2] however, says that the "Lilium Medicinae" of Bernard de Gordon of Montpelier, published in 1305 or 1306, contains the first notice of spectacles.

How far back in history the use of simple lenses goes is equally doubtful. It has sometimes been claimed that ancient gems could not have been cut and fashioned into jewelry without an aid to the sight, and that engraved and illuminated texts required some magnification for their preparation.

[1] Cole, Ann. Med. Hist., viii: 4, 347–359, 1926.

[2] Rolleston, "Internal Medicine in Clio Medica," p. 35, 1930.

Locy[3] states that George Hoefnagel published in 1592 a set of fifty plates of insects engraved on copper. These pictures were drawn by his son Jacob, and some indicate the use of magnifying glasses. These plates of Hoefnagel are, as far as known, the earliest printed figures of magnified objects. The naturalist Mouffet also probably employed simple lenses (Locy[3]). His "Theater of Insects" (*Insectorum sive animalium minimorum theatrum*) was prepared in manuscript as early as 1590, but was not published till 1634. Some of the illustrations in this book show magnification.

All evidence of this character, tending to show rather indirectly that simple lenses must have been used at various early periods in the world's history, is of little importance. The real development of the knowledge of magnification came from the work of the mathematicians and the physicists, beginning with Euclid in the third century B.C. Ptolemy of Alexandria, about A.D. 153, in his mathematical and astronomical investigations probably was the first to study the laws of the refraction of light thoroughly. We owe our knowledge of the optical properties of curved mirrors primarily to the Arabian Alhazen or Al Haitham (Haṣan ibn al Hasan ibn al Haitham, Abu Ali, 965–1038). Locy gives 1052 A. D. as the date of his manuscript. Simple lenses were familiar to Roger Bacon (1214–1294), who cleared up many of the laws of reflection and refraction of light and suggested their use for bettering the vision. He is indeed sometimes called the "Father of Microscopy." Leonardo da Vinci (1452–1519) also studied the optical properties of lenses and developed the camera obscura, Maurelico the mathematician (1494–1575) in his turn investigated them and Niblo of Poland made a very complete study of the refraction produced by air, water and glass.

Simple microscopes, *i.e.,* simple lenses attached to crude stands, were in all probability first described by Descartes in 1637 in his Dioptrique. This instrument had a magnifier and a concave mirror with the concavity towards the objects to be examined. In 1671 Athanasius Kircher, a Jesuit priest, made a crude simple microscope by attaching the object studied to a stage with a kind of rest. This instrument gave an enlargement of about 32 diameters, and Kircher was apparently the first individual to note the use of simple lenses for the study of living materials. He may also have had a kind of compound microscope with lenses made of small glass globules.

The greatest development of simple microscopes, and we even say their perfection, came at the hands of Antony (Antoni) van Leeuwenhoek of Delft (1632–1723). He was descended from a good Dutch family of brewers and at the age of 16 went to Amsterdam and became bookkeeper and cashier in a clothing establishment. He returned to Delft after a few years, married at the age of 22 and six years later took a minor office as "Chamberlain of the Sheriff" in the Delft Court. The position was that of a beadle and the pay amounted to £26 a year. This post Leeuwenhoek held for 39 years and the stipend continued to the end of his days.

Early in life Leeuwenhoek became interested in the manufacture of lenses, having observed that by grinding them with diamond dust he could greatly improve their usefulness. He preferred small ones of short focal distance, fastened them to various types of stages and manufactured a large number, owning 419 instruments, including 247 simple microscopes and 172 lenses set between pieces of metal. These lenses were all of glass, except three of quartz or rock crystal. Half of them were mounted in silver, three in gold. At Leeuwenhoek's death he bequeathed 26 simple microscopes, made from lenses ground by himself and set in silver, to the Royal Society of London. They were examined by Henry Baker and described by him in "The Microscope Made Easy" in 1742. He states that the lenses in these 26 microscopes were all of the double convex variety and not spheres or globules. Soon after Baker's description these instruments were lost sight of and they have never been recovered. An original Leeuwenhoek microscope now exists in the University of Utrecht.

Charles Singer[4] believes that the highest magnification obtained in Leeuwenhoek's microscopes was 160 diameters, and it varied from 40 to 133 diameters. It is interesting to note that the front lens of the modern oil immersion objective is practically the same in structure as Leeuwenhoek's simple lens. No one has ever seen as much as he did with simple microscopes, and soon after his work appeared compound instruments began to be improved and offered greater optical advantages to the scientist. The simple microscope has survived, however, as the hand lens of the physician and the dissecting microscope of the laboratory. It is not without interest that Charles Darwin took one with him on the voyage of the *Beagle* in 1832.

The empirical discovery of the compound microscope is ultimately bound up with the discovery of the telescope, and there are three claimants to the honors. Singer states that these are Zacharias Jansen, Jan Lippershey and James Metius, also known as Jacob Adrianzoon. The date of the discovery of the microscope may be placed between 1591 and 1608.

[3] Locy, "Growth of Biology," p. 199, 1925.

[4] Singer, "Steps Leading to the Invention of the First Optical Apparatus," in "Studies in the History and Method of Science," Vol. II, p. 385, 1921.

By this time both convex and concave lenses were well known and constantly used in the manufacture of spectacles. Zacharias Jansen (1580–16—?) was the son of a spectacle maker of Middleburg, Holland, and by accident discovered that if he put two lenses in a tube they increased the size of objects. This instrument was perhaps provided with two convex lenses, the lower one having a short focal length to look at near objects. Such an instrument was called a flea-glass or fly-glass, because it was employed to examine small objects like fleas or flies.

The claim of Jan Lippershey to the honor of the discovery of the telescope rests primarily upon the Acts of the States-General preserved in the Government Archives at the Hague. Here it is stated that on October 2, 1608, the Assembly of the States considered the petition of Jan Lippershey, a spectacle maker, native of Wesel and a resident of Middleburg, who had invented an instrument for seeing at a distance. He was subsequently employed to manufacture three of his instruments from rock crystal. Singer[5] believes that these were provided with convex objectives and concave eyepieces and did not invert the image. In the same month James Metius of Alkomar also petitioned the Assembly of the States for the exclusive right to sell an instrument of his invention to make distant objects appear larger and more distinct. This James Metius was the son of Adrian Metius, burgomaster of Alkomar in 1573. He also accidentally put two lenses together in a tube and found that he could see distant objects. The instruments of Lippershey and Metius were called spy-glasses, and their military importance called attention to their usefulness.

The Jansens began to manufacture both types of instruments, flea-glasses or fly-glasses (microscopes) and spy-glasses (telescopes) in the early part of the seventeenth century. According to the testimony of William Boreel (1591–1668), Dutch ambassador to France, given in a letter to Pierre Borel (1620–1671) the Jansens presented one of their instruments, probably the telescope, to Prince Maurice, the governor and supreme commander of the United Dutch forces. They also gave a microscope to the Austrian Archduke Albert, supreme governor of Holland. Afterwards, in 1619, when Boreel was ambassador to England, Cornelius Drebbel showed him this instrument which the archduke had presented to Drebbel, who was a mathematician. Drebbel himself began to manufacture microscopes in 1621.

The scientific discoverer of the telescope was Galileo (1564–1642), but some doubt still exists as to his relationship to the discovery of the microscope. In 1609 he heard a rumor of the invention by a Dutchman of an instrument by means of which a distant object could be made to appear distinct and near. Immediately he made use of his knowledge of the laws of refraction to construct a similar instrument along exact lines. He fastened two lenses at the ends of a leaden tube, one plano-concave, one plano-convex. Looking through the concave eyepiece he observed that objects seen were three times nearer and nine times larger than when observed with the naked eye. He rapidly improved the construction of the instruments, getting one through which objects were a thousand times greater and thirty-fold nearer than if observed by the unaided vision. Examples of Galileo's telescopes are still in existence, preserved in the Galileo Museum in Florence. It should be noted that the principle of the telescope is to have an objective which focuses at infinity (or far objects). As to Galileo's discovery of the microscope, *i.e.*, an optical instrument for seeing near objects magnified, our knowledge of his contributions is somewhat casual. John Wodderborn, a Scotch student who attended Galileo's lectures at Padua, stated in 1610 (see Fahie[6]) that he had often heard Galileo describe the employment of an instrument for the examination of insects, and similar evidence is given by the Frenchman, Jean Tarde (Fahie[7]). There is also some reason to believe that Galileo presented a microscope to the King of Poland in 1612. As stated above, Cornelius Drebbel began to manufacture microscopes in 1621 and Jacob Kuffler, a relative of Drebbel, brought such an instrument to Rome as a present from Nicholas Fabri de Peirese of Paris (1580–1637) to one of the cardinals. Two years later two others arrived. One of them was constructed of two lenses, and nobody in Rome could understand its use. At that time Galileo came to Rome, and on being shown the apparatus stated that he himself had previously made such instruments "which magnified things as much as 50,000 times, so that one sees a fly as large as a hen." He soon made some instruments showing objects erect and not inverted. These were called fly-glasses, *occhiale,* later *occhialino.* Unfortunately, we have no satisfactory knowledge of the construction of the fly-glasses. Two relics of them are in the Tribuna di Galileo, Florence, but the lenses are missing and there is some doubt as to the genuineness of the tubes.

The term "microscope" was introduced by Giovanni Faber in a letter of April 26, 1625, to the Academy

[5] Singer, *ibid.*, p. 408.

[6] Fahie, "The Scientific Works of Galileo (1564–1642)" in "Studies in the History and Method of Science," Vol. II, p. 206, 1921.

[7] Fahie, *ibid.*, p. 229.

of the Lincei and was applied to the instrument constructed by Galileo to look at small things and called by him *occhiale*. The lyceum also gave the name "telescope" to a similar instrument of Galileo's, but designed to look at objects at a distance.

Galileo's explanation of the path of light in the bilenticular system is usually regarded as unsatisfactory but was improved by Kepler (1571–1630) in his Dioptrice (Cologne 1611). Kepler suggested the construction of both telescopes and microscopes with two convex lenses, the theoretical forerunners of our modern instruments. Actually the manufacture of microscopes has followed in general the lines laid down by the Jansens. Instruments began to be made in considerable quantity in Holland by the middle of the seventeenth century. Fontana in 1646 improved the Jansen microscope by substituting a positive eyepiece for the negative, *i.e.*, one with the real image of the objective below all the lenses of the ocular, rather than with the real image between these lenses, and thus getting a magnification much greater than that obtained by the Jansens. This type of microscope evidently remained in use for some years, for Otto Fredrik Müller (1730–1784) used an instrument designed by the Jansens and improved by Fontana. It is said to have given a magnification of over 300 diameters. This increase of magnification over that given by Leeuwenhoek's best instruments, about 160 diameters, marked the doom of the simple microscope, certainly for the study of bacteria, and since then the chief efforts of physicists have been devoted to improving compound microscopes. Other types have been invented from time to time, among which may be mentioned those of Hooke (1665), Bonnani (1697) and Divini, who exhibited a kind of compound microscope before the Royal Society in 1668. To Hooke the credit of adding the field piece to the ocular is sometimes given. Huygens in 1660 was familiar with the field piece, however, for he manufactured negative oculars with the real image below the field piece and above the other lenses in the ocular. He used a plano-convex field piece and a plano-convex eyepiece, both convexities facing downward.

The chief difficulty in microscopes lies in the chromatic aberration. As lenses of shorter focal distance (less than 1 inch) and more nearly spherical are employed, the obliquity of the rays so greatly increases the aberration that false colors are introduced, and definition becomes defective. The limitation of the size of the aperture to keep down the chromatic aberration shuts out the light and makes the field too dark for successful vision. A similar difficulty arises with the telescope. The first achromatic telescope was probably made by Chester Moor Hall of Essex, England, in 1733. Hall combined lenses of different refracting indices and made a telescope which gave a vision of objects free from color. In 1759 Dollond, on the basis of Swedish investigations on the dispersion of refracted light, made a telescope with lenses of different kinds of glass with respect to the divergence of color. His object glasses gave almost complete correction of the chromatic aberration; later the spherical aberration was corrected by the same means.

Not until the early part of the nineteenth century, however, was this principle applied to the construction of microscopes. In 1812 Amici of Modena made the first attempt at an achromatization of the objectives along the lines marked out by Dollond. The chromatic aberration of the objectives was corrected by a combination of plano-convex lenses of flint glass with biconvex lenses of crown glass. He also employed a highly curved plano-convex front lens with a numerical aperture of 105. The spherical aberration was done away with by a combination of convex and concave surfaces of different curvatures. In 1830 Lister (the father of Lord Lister) worked out another principle for the correction of aberration by having the image point of one lens coincide with the object point of another and a few microscopes have been made with this design. Selligues and Chevalier of Paris superimposed three or four combinations, each of double convex lenses of crown glass cemented to plano-convex lenses of flint. By 1837 excellent microscopes were available, giving a high magnification and a clear definition. Amici discovered the principle of water immersion lenses and Andrew Ross in 1839 invented a collar adjustment for them. The water lens was greatly improved by Hartnack in 1855. The first microscopist to employ oil instead of water was apparently Wenham, who demonstrated the use of cedar oil before the Royal Microscopical Society in June, 1870.

A little later Stephenson in 1878 also employed the principle of oil immersion for lenses and at his suggestion Abbe manufactured the first effective immersion lens in which cedar oil was utilized. About this time a number of improvements in the construction of microscopes were made, chiefly by Abbe, who profited greatly by Helmholz's investigations on the undulatory nature of light. In 1886 he made an apochromatic objective in which the secondary spectrum was not noticeable and the spherical aberration corrected for three colors. This was used with a compensating ocular of Jena glass. Abbe also introduced the substage condenser which goes by his name, the final improvement in the construction of microscopes which has given us our modern high-powered instruments of such wonderful utility and beauty.