Crystals and Lenses in the Graeco-Roman World

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Abstract

This paper examines the archaeological and literary evidence concerning crystals and lenses in classical antiquity. Lens-shaped objects were produced in the eastern Mediterranean since the Bronze Age, and it is commonly assumed that their function was to serve as magnification tools. It is argued here that ancient craftsmen, like gem cutters, had to rely on skill and experience rather than magnification implements to do their work; that popular science provided only a vague understanding of optical phenomena; and that, although in the Hellenistic period physics and mathematics were sufficiently developed to include concepts like angular magnification, philosophers and physicians failed to understand the physiology of the human eye and the mechanics of vision and, therefore, could not correct defective eyesight. Scientific breakthroughs did not always find applications in day-to-day practice, which was governed by traditional convictions and superstition. Accordingly, most ancient "lenses" must have been decorative.*

The Hellenistic period was a time of considerable scientific and technological progress.[1] In ca. 300 B.C. Euclid was working on his *Elements*, a coherent and systematic work on mathematical principles and demonstrations. Later in the third century B.C., the pioneering work of Archimedes further promoted mathematics, along with physics and significant breakthroughs in engineering. Eratosthenes of Cyrene, a contemporary of Archimedes working in Alexandria, applied mathematical method to geography with impressive success, and Apollonios of Perge developed earlier work in his systematic treatise *Conics*, an impressive and lasting achievement. Apollonios was also an astronomer and developed the models of epicyclical and eccentric motion for planetary movement. Also in the third century B.C. Aristarchos of Samos formulated his heliocentric hypothesis, and produced detailed calculations on the size of the sun and the moon, and their distances from earth. Developments in mathematics and optics enabled astronomers like Hipparchos (second century B.C.) and Hero of Alexandria (first century A.D.) to develop more sophisticated instruments and thus realize further achievements in observational astronomy.

The striking success of Hellenistic science stands in strong contrast with its failure to make a positive, practical, and lasting contribution to society in the terms in which it was developed. Allowing for the severe lack of technical equipment and of the possibility to develop it, as well as the pitfalls of traditional religion, philosophy, and superstition, part of the responsibility for this failure must lie with the scientists themselves. Great minds of the ancient world were notoriously resentful of the practical application of their knowledge: Archimedes himself allegedly snubbed mechanics as mere trivialization of geometry (Plut. *Mar.* 14.4; 14.6; and 16.4) and as a part of military arts rather than engineering (although some of his extant writings can be used to dispute this accusation). The field of medicine was also permeated by a rather elitist attitude, which widened the gap between what physicians knew and what they could or would do to improve the quality of life of their patients.

Our admiration for the achievements of Hellenistic science is inevitably tarnished by the failure of its supporting ideology. Even if one does not necessarily side completely with its most outspoken critics,[2] the inability of Greek science to develop practical applications is evident and disappointing. Technology in the modern world is determined by its aim to achieve labor efficiency, an objective that was unnecessary in antiquity when labor was cheap (and organic to political and social structures). In the words of Seneca (*Ep.* 90.7–9), the task of scientific knowledge (*philosophia*) is not to create machinery

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[1] For an account of the development of science in the Hellenistic period, see chiefly G.E.R. Lloyd, *Greek Science after Aristotle* (New York 1973).

[2] Cf. P. Green, *Alexander to Actium: The Hellenistic Age* (London 1990) 467–73.

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(*fabricae*); moreover, he resented devices designed to economize in labor or promote comfort as they encouraged idleness and complacency (*luxuria*).

In this paper I examine the evidence concerning the use of magnification implements by ancient craftsmen and, in a wider scope, the possibility that optical aids were ever developed by Greek physicians for the comfort of people with failing eyesight. There is a considerable amount of evidence suggesting that lenses and their properties were known in antiquity, but a striking absence of it concerning their use in medicine. Considering the archaeological and literary evidence available, I suggest that since matters of day-to-day and practical medicine were the domain of traditional practitioners rather than accomplished physicians, it is in the direction of inherited knowledge and superstition that we must turn in order to clarify the use of objects that have survived from the Greek and Roman world.

The question of the use and manufacture of magnifying lenses in antiquity can be approached by two different avenues: first, the study of a number of objects, usually cut in glass, sometimes in rock crystal, that seem to have magnifying properties and could be used as optical aids; second, the assumption put forward by many that miniature craft work, such as we admire on gems and coins, or even miniature writing on papyri, can only have been executed with the help of magnifying implements.

In physics, a lens is recognized as a piece of transparent material bound by two spherical surfaces. Lenses can be convex or concave on both sides, or have one flat side. A lens with one side flat and the other convex is termed plano-convex; the vast majority of the objects discussed in this paper fit that description. A plano-convex lens is most suitable for magnification, but also for use as a burning glass.

ROCK CRYSTAL LENSES

Lens-shaped crystals have long been known from Bronze Age contexts and are usually recognized as short-focus magnifying lenses. It has always been suspected, however, that they might in fact have been decorative inlays, since some of them have been discovered with similar decorative material, occasionally themselves having metallic foil, often gold, on the back (i.e., the flat side). Their magnifying properties would have been used to enhance the color of the foil and the entire design.[3] In 1921 Evans reported the discovery of such objects in the Middle Minoan IIIB Temple Repositories at Knossos, along with a "royal Draught Board" with ivory and crystal inlays backed with silver foil.[4] "Three bossed crystal discs" were discovered by Forsdyke in the Mavrospelio cemetery (Late Minoan II–IIIA) a few years later.[5] In 1987 Sines and Sakellarakis reported the existence of 23 lenses on display in the Herakleion Archaeological Museum "and many more in storage."[6] Although Evans believed that the lens-shaped objects from the Knossos repositories were inlays, Forsdyke suggested tentatively that their probable use was as optical aids rather than as ornaments, and in 1928 Beck expanded upon that idea.[7] He compared the Cretan examples with a lens that had been discovered in 1854 at Pompeii (see below) and a similar example from Roman London.[8] All these objects are made of rock crystal and are of what is described as "optical quality," that is, able to provide some magnification without too much distortion. An example illustrated by Sines and Sakellarakis (fig. 1) has a diameter of 14 mm, a thickness of 4 mm, and a focal length of 22 mm; these measurements suggest a *nominal* magnification of 11×, a figure that should have been considerably lower in view of the inevitable distortion (even though the authors suggest that by dipping the lens in water, refraction could be minimized).[9]

The corpus of Bronze Age lenses, if such it may be called, is completed by the 40 or so examples discovered by Schliemann at Troy, which he never published. Incidentally, the lack of proper publication seems to hinder this particular subject more than others, since the objects (and their probable significance) often escape the attention of excavators, only to be mentioned casually, unreferenced, in unexpected places. This situation results in a series of subsequent publications simply referring to one another, their authors unable to cite original find-

[3] Cf. Pliny, *HN* 37.106 on translucent stones backed with gold foil: *quae brattea aurea sublinuntur.*

[4] A. Evans, *The Palace of Minos* I (London 1921) 469–72; cf. the eye of the steatite bull's-head rhyton from the Little Palace at Knossos: Evans, *The Tomb of the Double Axes etc* (London 1914) 82.

[5] E.J. Forsdyke, "The Mavro Spelio Cemetery at Knossos," *BSA* 28 (1926–1927) 243–96, esp. 288.

[6] G. Sines and Y.A. Sakellarakis, "Lenses in Antiquity," *AJA* 91 (1987) 191.

[7] H.C. Beck, "Early Magnifying Glasses," *AntJ* 8 (1928) 327–30.

[8] Pompeii: found during the excavations of the Via Stabia, in the so-called "House of the Engraver" (D. 65 mm; Th. 12 mm); E. Gerspach, *L'art de la verrerie* (Paris 1885) 41–42. London: fragmentary biconvex glass lens of light green color (D. 53 mm; Th. 93 mm); H. Syer Cuming, "On Spectacles," *The Journal of the British Archaeological Association* 11 (1855) 144–49.

[9] Sines and Sakellarakis (supra n. 6) 191, fig. 3.

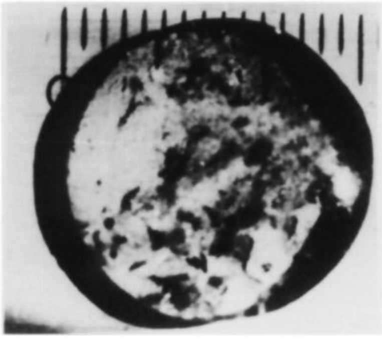

Fig. 1. Plano-convex lentoid (D. 14 mm) from the Palace of Knossos. Herakleion, Archaeological Museum. (Photo courtesy Y. Sakellarakis)

spot or current whereabouts. The lenses found by Schliemann were particularly elusive; they were published only recently with the rest of the rediscovered Trojan treasures.[10] Vaguely cited by King,[11] they are mentioned in a 1904 publication of the excavation of Gordion (where more examples, not dated, were found).[12] In 1921 four of them were illustrated in a study of antique spectacles.[13] Their diameters are given as 24 mm (two examples), 50 mm, and 55 mm. The last lens was estimated to have a focal length of 150 mm.

Of the "lenses" recently published, the vast majority have a diameter between 23 and 25 mm. Significantly, one of the "lenses," with a diameter of 54 mm and maximum thickness of 6 mm, bears a 9-mm hole in its center.[14] Dörpfeld, who dated the objects to ca. 2200 B.C., accepted that the largest among them were used as magnifying glasses.[15] Forbes accepted that the Trojan crystals were lenses, with the exception of the example with the central perforation.[16] Sines and Sakellarakis suggest that this lens in particular could still be used as a burning glass and speculate on the convenience of carrying one around by a cord through its central perforation.[17] It is unlikely, however, that such a useful tool would not have been given a more appropriate mount than a central perforation, which would obviously have limited its effectiveness; it should also be remembered that burning glasses were useless at night (as opposed to drilling or striking flints). The perforation of the rock crystal "lens" resembles those on other stone objects — of an obviously decorative character — from the same assemblage.[18] The most likely function of the "lenses" from Troy is that they were attached to objects made of different materials, either by means of nailing (hence the perforation) or by soldering: one of the "lenses"[19] preserves its original bronze backing.

The four rock-crystal lentoids found in Amathous (fig. 2)[20] and the two similar objects discovered in the Idaean Cave by Sakellarakis (fig. 3)[21] provide evidence for the production and use of lens-shaped objects in Greece in the historical period. The Amathous examples were found in surface layers during the excavation of the Temple of Aphrodite, and although they cannot be dated, it is evident that they were deposited there as votives, along with several other small objects, gems, amulets, and beads.[22] The Cretan specimens seem to date from the Archaic period. Their diameters are 8 and 15 mm, and their focal lengths 12 and 25 mm, respectively. Their nom-

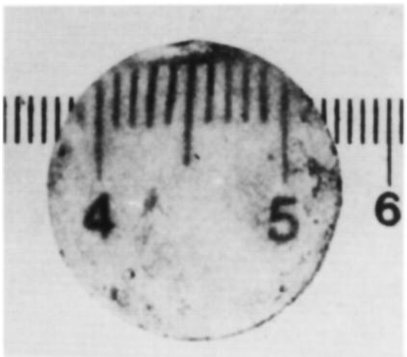

Fig. 2. Plano-convex lentoid (D. 19 mm) from Amathous, inv. no. 79.933.234. (After P. Aupert and A. Hermary, *RDAC* 1980, pl. 32.6)

[10] V. Tolstikov and M. Treister, *The Gold of Troy: Searching for Homer's Fabled City* (London 1996) nos. 176–216, 230.

[11] H.C. King, "Glass and Lenses in Antiquity," *The Optician* 136 (1958) 221–24.

[12] G. Körte and A. Körte, *Gordion: Ergebnisse der Ausgrabung im Jahre 1900* (Berlin 1904) 147, 151, 174; see Sines and Sakellarakis (supra n. 6) 191, n. 5, 192.

[13] R. Greeff, *Die Erfindung der Augengläser* (Berlin 1921) 24–25.

[14] Tolstikov and Treister (supra n. 10) no. 230.

[15] A. Götze, in W. Dörpfeld ed., *Troja und Ilion* I (Athens 1902) 138–39, 374–75.

[16] R. J. Forbes, *Studies in Ancient Technology*² (Leiden 1966) 190.

[17] Sines and Sakellarakis (supra n. 6) 193–94.

[18] Cf. the rock-crystal pommels from Troy, Tolstikov and Treister (supra n. 10) nos. 170–75.

[19] Tolstikov and Treister (supra n. 10) no. 215.

[20] M.-F. Boussac in P. Aupert and A. Hermary, "Travaux de l'École française à Amathonte en 1979," *BCH* 104 (1980) 809, fig. 12; Aupert and Hermary, "Amathonte: Rapport préliminaire (1975–1979)," *RDAC* 1980, 237, pl. 32.6.

[21] Sines and Sakellarakis (supra n. 6) 191–92, figs. 1–2.

[22] Boussac (supra n. 20) 809 accepts that two objects were probably used as lenses and assumes the existence of a gem workshop near the sanctuary.

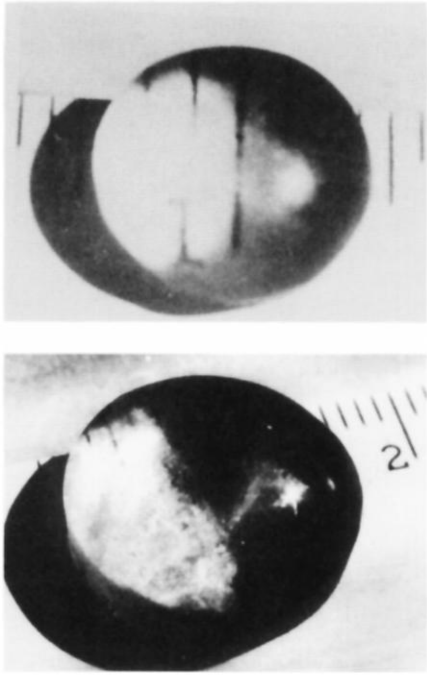

Fig. 3. Plano-convex lentoids (above, D. 8 mm; below, D. 15 mm) from the Idaean Cave. (Photos courtesy Y. Sakellarakis)

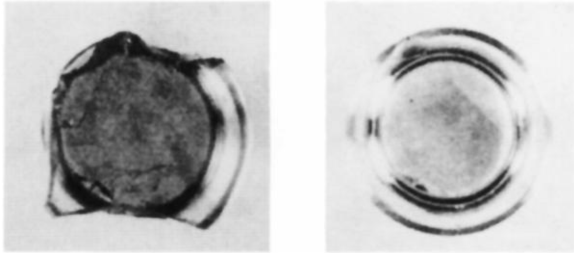

Fig. 4. Ear studs from the Artemision at Ephesos, inv. nos. 71/K44 and 71/K58. (After B. Freyer-Schauenberg, *Anadolu* 17 [1973] pl. 18)

inal magnification capacities are estimated at 20 × and 10 ×, their useful magnification, however, being considerably lower (7 × and 2.5 ×). The two lenses from Amathous have diameters of 20 and 25 mm, and both are 5 mm thick.

The cache of rock-crystal discs and lentoids found by Hogarth in the Archaic levels of his excavation at the Artemision of Ephesos illustrates some of the problems posed by such objects and might indicate reasonable answers (fig. 4).[23] Hogarth himself noted the remarkable quality of these objects and rightly assumed that they had been turned on a lathe, a technique that would provide evenly cut surfaces and a perfectly spherical shape. The Artemision lenses, however, are plano-concave, not plano-convex, and consequently they cannot be used as magnifying or burning glasses; they do not magnify, but reduce, some as much as 20%, without much distortion.[24] Whatever their optical quality, therefore, they would be of no use as optical aids. Their findspot in the deposit of the Archaic Artemision encourages their identification as ornaments rather than tools. Hogarth's educated guess was that they were in fact *pièces de jeu*, game counters, a possibility to which I return below. In view of the findspot of the lenses, and their association with objects of different shape (unsuitable for use as lenses) but similar technique, Brein's recent interpretation of the Artemision discs as parts of ear ornaments seems to be confirmed. Comparisons with Archaic sculpture support this identification.[25] As in the case of the perforated lentoid from Troy mentioned above, some of Hogarth's discs bear grooves by which they were attached to other parts.

In general, Bronze Age and early Greek finds do not warrant an unequivocal interpretation as optical tools. Some of the examples from Knossos still preserve their original backing foil, which suggests their use in inlay.[26] An impression of considerable optical quality is created by their meticulous cutting, typical of the high standards of Greek glyptic from the Bronze Age through the Hellenistic period. Their excellence in material and workmanship enhances their decorative appeal. At the same time, their imperfect surfaces limited their potential use as optical aids since they would distort the magnified image. Even nominal magnification as high as 10 × or 20 ×, as estimated for some examples (but considerably lower in real terms), would not, considering the serious distortion of the lens, be enough to aid in producing miniatures.[27]

The most famous, unjustly it would seem, among the objects identified as antique lenses is the so-called

[23] D.G. Hogarth, *Excavations at Ephesus: The Archaic Artemisia* (London 1908) 210–11, pl. 46.

[24] B. Freyer-Schauenberg, "Die Glassfunde aus Pitane," *Anadolu* 17 (1973) 141–75, pl. 18.

[25] F. Brein, "Ear Studs for Greek Ladies," *AnatSt* 32 (1982) 89–92.

[26] See Evans 1921 (supra n. 4) 471, fig. 337.G for a crystal disc (D. 108 mm) backed with silver foil. Because of the disc's slightly convex shape, it was probably unsuitable as a mirror, and it was, along with the "lens" and several more petal-shaped crystals, used for inlays.

[27] J. Boardman, *Greek Gems and Finger Rings* (London 1970) 382; on the unlikely use of magnifying lenses by Minoan craftsmen, see R.D.G. Evely, *Minoan Crafts: Tools and Techniques* 1 (Göteborg 1993) 152, n. 44.

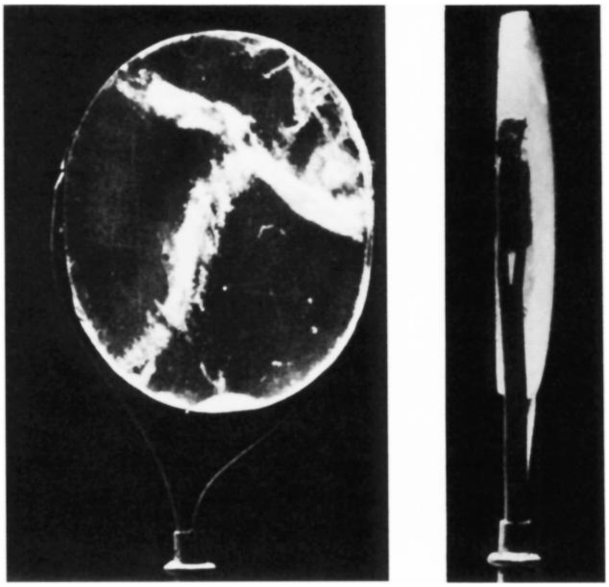

Fig. 5. Plano-convex lentoid (40 × 35 mm) from Nimrud. British Museum, inv. no. 90959. (Photo Museum)

"Loupe of Sargon," a plano-convex rock-crystal lentoid excavated by Layard at Nimrud in the 1850s (fig. 5).[28] The object is oval (40 × 35 mm) and of uneven thickness (max. th. 22.5 mm). Its focal length has been calculated at 112.5 mm. Its nominal magnification is about 2× but, owing to its imperfect surface, it would be useless as a tool.

GRAECO-ROMAN GLASS LENSES

With few exceptions, Hellenistic and Roman lentoids are made of glass.[29] Ancient glass consisted of three basic components: silica (usually in the form of sand with quartzite inclusions); lime (natural limestone); and an alkali (usually natron in the form of natural soda).[30] These ingredients were melted together to produce a highly viscous liquid that solidified at high temperatures. The proper ratio of silica, lime, and natron gives glass its translucence and hardness. Imperfect melting would result in the final product being opaque. Pliny (*HN* 36.190–99) devotes a long section to glass, which he classifies as a rock. He knew the importance of sand (alkaline earth with silica inclusions) and soda. He also reports the use of crushed rock crystal to make glass in India (*HN* 36.192), in which case the stone would have provided the silica required (rock crystal is a type of quartz). Glass was thus considered to share the qualities of rock crystal but, being man-made and easier to cut, was less costly.

Small lentoids, some of optical quality, have been discovered at several Late Hellenistic and Roman sites. A plano-convex lens, 45 mm in diameter, was discovered set in gold in a "Greek tomb" at Nola.[31] The light green lens from Pompeii (65 mm in diameter) was discovered among engraved gems in what has been recognized as an engraver's workshop.[32] A similar example, now in Vienna, comes from a Roman site in Mainz.[33] Other lenses, ostensibly from workshops, have been found in Egypt. Petrie found two plano-convex glass lenses in a house identified as that of an artisan at Tanis (fig. 6).[34] The destruction of the house (house 44) was dated by its excavator to A.D. 174. Petrie discovered two similar objects, also from a second-century A.D. context, at Hawara in the Fayum: one is a white plano-convex lens like those from Tanis, and the other is slightly yellow and has a more conical shape.[35] On the basis of experiments he conducted with the better-preserved conical lens, Petrie reached the conclusion that this lens, as well as the Tanis specimens, was not used to magnify but to condense light from a lamp or candle. A number of lentoids were found at Carth-

[28] British Museum inv. no. 90959. A.H. Layard, *Discoveries in the Ruins of Nineveh and Babylon* (London 1853) 197–98 (commentary by D. Brewster); W.B. Barber, "The Nineveh Lens," *British Journal of Physiological Optics* 4 (1930) 4–9; L. Gorelick and A.J. Gwinnett, "Close Work without Magnifying Lenses?" *Expedition* 23:2 (1981) 33, fig. 7a–b.

[29] Exceptions: a rock-crystal lens from "the ruins of Tyre," of uncertain date, ca. 300 B.C., cf. R. Greeff, "Drei Aufsätze über Funde von vorgeschichtligen Brillen und Lupengläsern II: Die phönizische Brillenindustrie," *Optische Rundschau und Photo-Optiker* 24 (1933) 255; three rock-crystal lentoids (among several glass ones) reported in Carthage, Lavigerie Museum (dating from the fourth to the sixth centuries A.D.), cf. Forbes (supra n. 16) 189 and A. Krug, "Neros Augenglas: Realia zu einer Anekdote," *Archéologie et médecine: VIIèmes Rencontres internationales d'archéologie et d'histoire d'Antibes, 23–25 octobre 1986* (Juan-les-Pins 1987) 463, fig. 1.

[30] See, in general, Forbes (supra n. 16) 112–74.

[31] H. von Minutoli, *Über der Anfertigung und der Nutzanwendund des farbigen Gläser bei den Alten* (Berlin 1836) 4–5.

[32] Gerspach (supra n. 8) 41.

[33] Vienna, Kunsthistorisches Museum inv. no. XI 835 (D. 55 mm; Th. 5 mm); Krug (supra n. 29) 463, n. 17.

[34] W.M. Flinders Petrie, *Tanis* I (London 1883–1884) 49, pl. xii.30; both lenses are today in the British Museum, inv. nos. 22522 and 27639; J.D. Cooney, *Catalogue of Egyptian Antiquities in the British Museum* IV: *Glass* (London 1976) nos. 1804 and 1817. BM 22522 is 66 mm in diameter and of pale green color; BM 27639 is described as "finer" than its counterpart.

[35] W.M. Flinders Petrie, *Hawara, Biahmu, and Arsinoe* (London 1889) 12, pl. 20.9–10; no. 9, today in University College London, inv. no. 16764 (D. 53 mm); no. 10, in Manchester, Krug (supra n. 29) 463, n. 20.

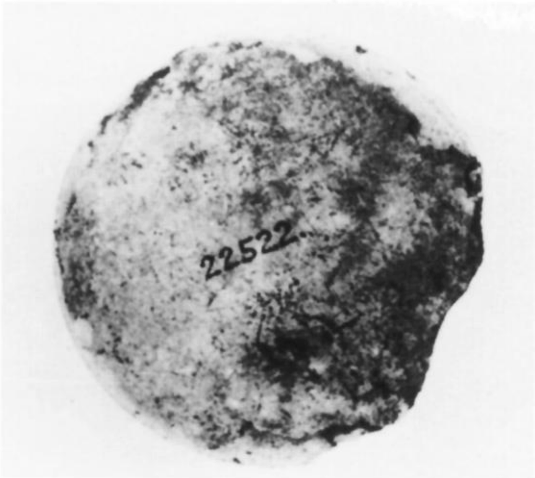

Fig. 6. Plano-convex lentoid (D. 66 mm) from Tanis. British Museum, inv. no. 22522. (Photo Museum)

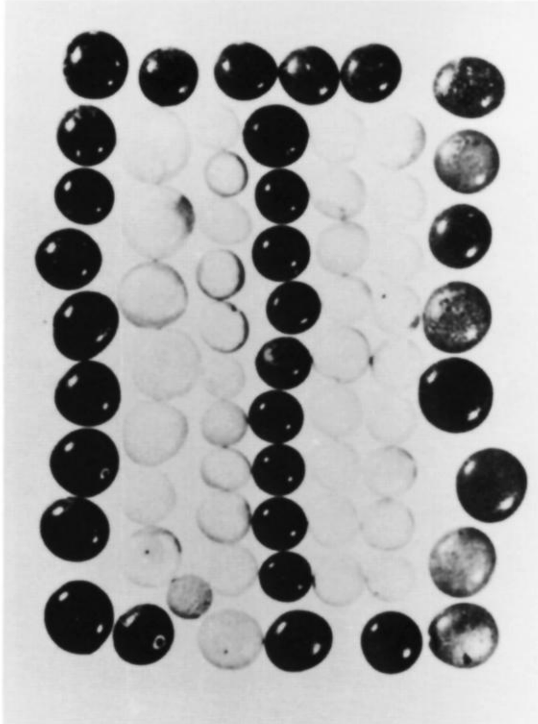

Fig. 7. Glass game counters from Rome. Berlin, Staatliche Museen, inv. no. 30891N. (Photo Museum)

age, some in burials, but from mixed contexts of the fourth–sixth centuries A.D.[36] Six of them are made of glass, in various sizes and colors, and three are made of rock crystal.

Not all ancient lentoids are real lenses, that is, of any significant optical quality. Their color, above all, suggests otherwise, although in antiquity some types of colored stone were thought to benefit the eye. Hogarth's old interpretation of the Artemision pieces as game counters merits our attention, especially for the Hellenistic and Roman examples (some quite opaque) from Carthage and elsewhere. Bone, glass, and gem game counters were quite common in the Graeco-Roman world, and were casually mentioned in literature: Martial and Ovid refer to the game of *latrunculi*, usually translated "robbers" or "soldiers," a game for two players with gem or glass pieces placed on a board, a predecessor to our checkers.[37] A large group of about 70 game counters of white and colored glass was excavated north of Rome in a young woman's tomb dating to the early first century A.D. (fig. 7).[38] The pieces, ranging in diameter from 10 to 20 mm, are very similar to examples in other contexts that have been called "lenses," especially to examples from Carthage, some of which were also discovered in burials. Other interpretations are also possible: small, colorful pieces of glass—or stone—were used to decorate furniture or to enhance the appearance of works of art. Among the surviving examples is the ivory lining of a *kline* from Kul-Oba in the form of a column capital, inset with two "plano-convex lenses" made of glass (fig. 8).[39] Glass lentoids were also used to decorate eyes of statues, mostly in Egypt (fig. 9).[40] Pliny was probably referring to such pieces when he remarked that shards of broken glass can be melted into globules, "like the glass pebbles sometimes called 'eyeballs,' which have a variety

[36] Krug (supra n. 29) 463, fig. 1 and ns. 22–23; Forbes (supra n. 16) 187; R.P. Delattre, *Les Grandes sarcophages anthropoïdes du Musée Lavigerie à Carthage* (Paris 1904) 12, n. 2; Delattre, "Carthage, nécropole punique," *CRAI* 1903, 21.

[37] Martial (14.18[20]) makes the allegorical observation that a "gem soldier" (*gemmeus miles*) can change from being your mercenary to your enemy; cf. 7.72.8; 12.40.3. Also Ovid *Ars Am.* 2.208: *Fac pereat vitreo miles ab hoste tuus.*

[38] Berlin, Staatliche Museen inv. no. 30891N; R. Zahn, "Das sogenannte Kindgrab des Berliner Antiquariums," *JdI* 65–66 (1950–1951) 264–86, esp. 280–81, fig. 1; *Antikenmuseum Berlin: Die ausgestellten Werke* (Berlin 1988) 269, no. 78, pl. 268.

[39] St. Petersburg, Hermitage; M.J. Artamonov, *Treasures from Scythian Tombs in the Hermitage Museum, Leningrad* (London 1969) 132, no. 258.

[40] Cf. British Museum inv. no. 16627: glass eye of the Ptolemaic or Roman period; Cooney (supra n. 34) no. 925. For the statue of a lion with inserted eyes made of *smaragdus* (in this case most likely *not* an emerald), see Pliny, *HN* 37.66.

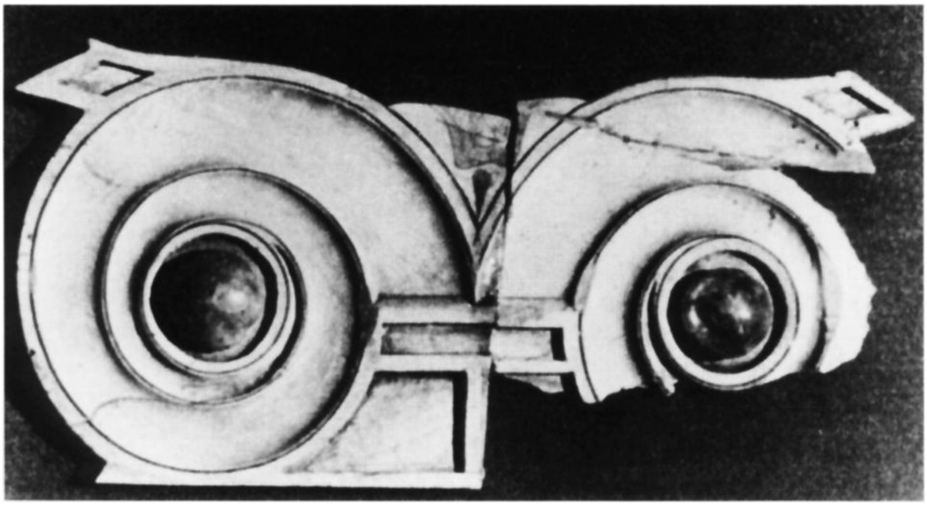

Fig. 8. Ivory decoration for a kline from Kul-Oba. Hermitage. (Photo Museum)

of color in different patterns" (*HN* 36.199: *veluti cum calculi fiunt quos quidam ab oculis appellant*). It is quite likely that some of the "lenses" found in graves came from furniture like the Kul-Oba kline or similar objects that perished.[41] Pliny's comment helps explain the presence of glass lentoids in (assumed) engravers' workshops, or at least in the context of other glyptic works, since the same people produced both glass and gems.

MAGNIFYING LENSES IN ANCIENT WORKSHOPS?

The body of evidence for the production of lenses in antiquity is thus meager and dubious. Finds from houses are taken to indicate the presence of a workshop, following the example of the early excavations at Pompeii, where a "lens" was found among a considerable number of glyptic works. To determine the use of such objects, we need to investigate if their use as lenses was, first, desirable and then, possible; to identify and study other possible uses, from decorative to medical; and finally, to investigate the extent to which optics and magnification were understood in the Hellenistic and Roman periods.

It has long been assumed that magnifying lenses were used by ancient gem engravers. Lorenz Natter, an 18th-century gem engraver who also published on gem-cutting techniques, believed that "the ancients made use of glasses, or microscopes" to compensate for eyestrain and advanced age.[42] Several modern scholars share the same view.

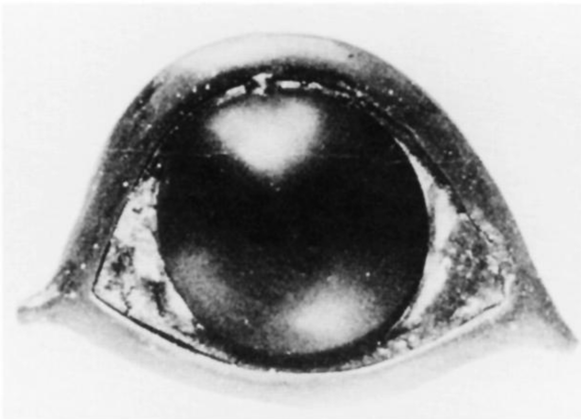

Fig. 9. Glass eye (L. 84 mm) from an Egyptian statue. British Museum, inv. no. 16627. (Photo Museum)

Gems were cut using a series of metal drills of various shapes: wheels, points, and balls.[43] The tools were rotated horizontally with a lathe (perhaps operated by an apprentice), and the artist held the stone in his fingers, presumably attached to a wooden tack. A gem engraver's tombstone dating from the Roman period shows a bow drill fixed on a horizontal lathe

[41] Cf. the several glass "eyeballs" from the decoration of klinai found in tombs at Pella: M. Lilimbaki-Akamati, "Από τα νεκροταφεία της Πέλλας," *Archeologiko Ergo sti Makedonia kai Thraki* 3 (1989) 93.

[42] L. Natter, *Traité de la méthode antique de graver de pierres fines comparée avec la méthode moderne* (London 1754) viii.

[43] J. Ogden, *Jewelry of the Ancient World* (London 1982) 148–50; M. Maaskant-Kleibrink, "The Microscope and Roman Republican Gem Engraving: Some Preliminary Remarks," in T. Hackens and G. Moucharte eds., *Technology and Analysis of Ancient Gemstones. Proceedings of the European Workshop Held at Ravello, European University Centre for Cultural Heritage, November 13–16, 1987* (Rixensart 1989) 189–204.

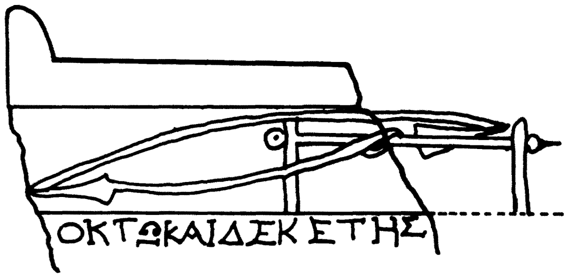

Fig. 10. Roman tombstone showing an engraver's lathe (restored). (After J. Boardman, *Greek Gems and Finger Rings* [London 1970] fig. 316)

(fig. 10).[44] The gem engraver's name was Doros, and he died at the age of 18. He is described as "the cutter of intaglios"—*daktylokoiloglyphos.* The introduction of the fixed drill made more detailed engraving possible, while hand-held drills and tools remained in use for less demanding jobs. Theophrastos (*On Stones* 41) writes about stones that differ in hardness, some of which can be drilled through (πριστοὶ), engraved (γλυπτοὶ), or worked on the lathe (τορνευτοὶ). Wheel-cutting in a horizontal axis remained in use, virtually unchanged, until the 20th century. Since the drills used in gem-cutting were made of iron or copper, they would have had no effect on the much harder stones, unless an abrasive substance was also employed. Sand, powdered emery, or stone chippings were used in a mixture with heavy oil, in which the drills were dipped.[45] Engraving depended upon highly skillful handling and long experience but, it seems, not much else. During the cutting itself not much was visible anyway, since both drill and stone were covered in a messy, thick liquid.[46] By cleaning the stone at regular intervals, progress could be inspected, as well as by occasionally taking impressions (in clay or other soft substance).

Assuming that "the ability of ancient craftsmen to effect minute detail" needed further explaining, Gorelick and Gwinnett, two scientists working in the fields of biology and orthodontics, respectively, suggested a new hypothesis, based on anthropological evidence, namely, that close work was the domain of myopic craftsmen whose eyes were able to focus at closer distance.[47] Myopic eyes are larger than normal, and their focal length is shorter. Accordingly, a myope needs to bring objects closer to his eyes so that he can see them clearly. This action, based on simple laws of geometrical optics, results in what is called angular magnification, whereby the image formed on the eye's retina becomes larger the closer the object is brought to the lens. Gorelick and Gwinnett suggested on the basis of natural selection and population genetics that miniature crafts were limited to certain families or castes in society, where myopic eyesight was passed on genetically. It is true that shortsightedness offers the advantage of magnified vision. According to his biographers, Sir Arthur Evans was heavily myopic, and this handicap gave him the ability to examine small objects, such as sealstones, in microscopic detail.[48] In the days before microscopes, however, magnification must not have been missed and, despite suggestions to the contrary,[49] eyeglasses were not necessary for the inspection of seals and ring devices. Myopic craftsmen, or myopic archivists for that matter, could benefit from their defective eyesight; they could carry out their work, however, without artificial magnification. As explained above, in gem cutting magnification would not be of much use. Further, it should be remembered that young eyes are more flexible than those of older people and that, accordingly, they can focus on shorter distances. Doros, whose tombstone was mentioned above, died at the age of 18 and is already

[44] From Philadelphia, in Asia Minor; the stone is of Doros from Sardis; A.E. Kontoleon, "Επιγραφικά," *AM* 15 (1890) 333; Boardman (supra n. 27) 381, fig. 316 (restored).

[45] Cf. Theophrastos *On Stones* 41: "Some stones are so hard and indestructible that they cannot be worked by means of iron tools, but with other stones"; on emery: Pliny, *HN* 36.51–54.

[46] Cf. the statement by the 15th-century Florentine architect Antonio di Piero Averlino (Filarete), who did not try to hide his admiration for the exquisite gems in the collection of the Medici family, his patrons. In his *Treatise on Architecture*, written in Florence ca. 1460, he comments on the cutting of intaglios (in gems, as well as in metal) as follows: "This kind of engraving is the most difficult of all. It required greater skill [i.e., than cutting of reliefs], because everything must be made in reverse. You do it with your eyes closed, so to speak" (xxiv.185r); J.R. Spencer ed., *Filarete's Treatise on Architecture* (New Haven 1965) 316.

[47] Gorelick and Gwinnett (supra n. 28) 28–29, fig. 5.

[48] Cf. the description by his sister, J. Evans, *Prelude and Fugue: An Autobiography* (Oxford 1964) 94: "My brother was very short-sighted, with the microscopic vision for things held very close which helped him, as it had my father before him, to become a collector of coins and gems." A simple example of natural selection at work, one might think, since shortsighted men would have to turn elsewhere to make a living or build a career. In modern times it has been noticed that genetic and environmental factors condition a child's intellectual interests and his or her physical abilities. Bespectacled readers might be happy to read that "doctors have demonstrated that there is a statistical relationship between academic success, intellectual interests and myopia" (*The Times*, 1 February 1996 [T. Stuttaford]).

[49] Sines and Sakellarakis (supra n. 6) 91.

referred to as "a gem cutter," having presumably finished his apprenticeship. Trained when young, craftsmen would be able, when older, to substitute their failing vision with experienced skill.

HELLENISTIC SCIENTIFIC THEORY — AND PRACTICE

Another question to consider is whether lenses were ever used as optical aids by people whose sight was impaired. The total silence of the sources—with the exception of a single dubious reference to which I turn below—suggests that spectacles or even less sophisticated optical aids were unknown. The extent to which optics and magnification were understood in the Hellenistic period should also be investigated. We need to determine whether or not the causes of defective eyesight were recognized and if geometrical optics were used to make corrections, as in modern ophthalmology. Euclid was not only a mathematician, but also a physicist and the author of the *Optics*, a work providing definitions and proofs concerning the laws of vision that became the basis of geometrical optics.[50] In this work, sight is assumed to be achieved by means of a cone of rectilinear visual rays, in Greek called ὄψεις or ἀκτῖνες, emanating *from the eye to the object.* In describing this, Euclid follows several post-Aristotelian Peripatetics and mathematical authors who were distinguished by later writers from authorities like Plato, according to whom light from the eye coalesces with light from the object to form a single body of light transmitting vision.[51]

Euclid was also credited by some ancient authors and scholiasts with the authorship of the *Catoptrics*, a work on mirrors. Heiberg's belief that a surviving *Catoptrics* was a Late Antique work of inferior quality[52] has been accepted by most 20th-century scholars,[53] although recently some have restated the case for a Hellenistic date, and perhaps Euclidean authorship, for the work.[54] Regardless of the specific problems concerning the authorship and transmission of the texts, it is clear that, ultimately, the determination of the laws of refraction by Ptolemy in his second-century A.D. *Optics* depended on Euclidean geometry and was based on Euclid's definition of rays as straight lines.[55]

Apart from geometrical optics, where vision and the properties of lenses in particular were studied as strictly mathematical problems, the effects of lenses were also observed empirically. The power of clear glass or crystal to concentrate rays of light was known to the Greeks and Romans. In Aristophanes' *Clouds* (766–68), Strepsiades refers to "the beautiful, transparent stone with which they light fires." The word used in the text is *hyalos*, which can be taken to mean "glass" or "crystal"— or in this case, "rock crystal." Theophrastos observed that a fire could be kindled by means of a burning glass from the sun's rays, but not from another fire (*On Fire* 73). Pliny (*HN* 36.199) also knew that glass balls filled with water (*cum addita aqua vitreae pilae*) could set clothes on fire when placed in line with the sun; he attributed this, however, to the rise in temperature in the vessel and not to its refractive properties. The power of a globe of water to act as burning glass appears also in the writings of Lactantius (*De Ira Dei* 10) and Titus Bostrensis (*Adversus Manichaeos* 2.31).

Seneca, on the other hand, was aware of the ability of such vessels to act as magnifying lenses: in a passage discussing atmospheric phenomena (*Q Nat.* 1.6.5) he observes that "all objects seen through water appear enlarged. Writings, small and indistinct as they are, appear larger and more legible when seen through a glass ball filled with water." (He continues with more examples.) In the same vein, Strabo (3.1.5) compares atmospheric refraction with those hyaloi that show objects magnified. These observations were made empirically and usually also found an empirical explanation. Rock crystal, as was noted above, was thought to share properties with glass. Pliny's comment on the production of glass with the use of rock-crystal chippings (*HN* 36.192) implies as much

[50] See J.L. Heiberg, *Euclidis opera omnia* VII: *Euclidis Optica, Opticorum recensio Theonis, Catoptrica, cum scholiis antiquis* (Leipzig 1895) vii, xvi–xxix for a discussion of the manuscripts; also, W.R. Knorr, "On the Principle of Linear Perspective in Euclid's *Optics*," *Centaurus* 34 (1991) 194–95; and A. Jones, "Peripatetic and Euclidean Theories of the Visual Ray," *Physis* 31 (1994) 49–56 for a revision of Heiberg's views.

[51] Cf. the scholia of Alexander of Aphrodisias on Aristotle *Sens.* 438a25: *Commentaria in Aristotelem graeca* III.1 (Berlin 1882) 27–28; Jones (supra n. 50) 47–49, 72.

[52] J.L. Heiberg, *Literargeschichtliche Studien über Euklid* (Leipzig 1882) 129–33.

[53] Cf. A. Lejeune, *Recherches sur la Catoptrique grecque d'après les sources antiques et médiévales* (Brussels 1957) 5, 54–67.

[54] W.R. Knorr, "Pseudo-Euclidean Reflections in Ancient Optics: A Re-examination of Textual Issues Pertaining to the Euclidean *Optica* and *Catoptrica*," *Physis* 31 (1994) 22–28.

[55] Ptolemy's *Optics*: A. Lejeune, *L'Optique de Claude Ptolémée dans la version latine d'après l'arabe de l'emir Eugène de Sicile* (Louvain 1956); Lejeune, "Les Lois de la réflexion dans l'optique de Ptolémée," *AntCl* 15 (1946) 242–59; and A.M. Smith, "Saving the Appearances of the Appearances: The Foundations of Classical Geometrical Optics," *Archive for History of Exact Sciences* 24 (1981) 73–99.

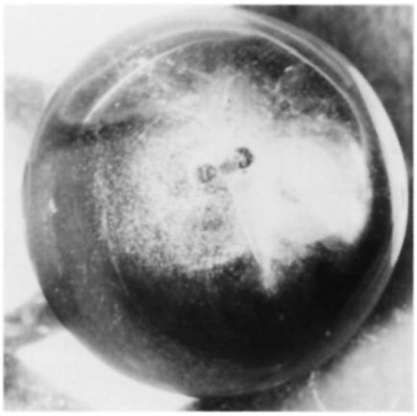

Fig. 11. Rock-crystal sphere (D. 41 mm). Berlin, Staatliche Museen, inv. no. 22x. (Photo author)

(he obviously believed that glass owed its vitreous quality to the stone's transparency rather than its chemical structure). Rock crystal was in turn thought to be crystallized ice (κρύσταλλος is Greek for both "crystal" and "ice"), and Pliny says that colorless and transparent glass is the most valuable, since it most closely resembles rock crystal (*HN* 36.198).

There is some evidence for the use of burning glasses in medicine. Pliny describes clear crystal balls (*crystallina pila*), "placed in such a way as to intercept the sun's rays," used by doctors to cauterize wounds or blemishes (*HN* 37.29). Pliny attributes this phenomenon to the clear core of the material, and the fact that it consists of crystallized moisture. Strepsiades, it should be remembered, obtained his *hyalos* "from the pharmacists" (*Clouds* 766). A rock-crystal sphere (41 mm in diameter) fitting Pliny's description can be found in the collection of the Pergamon Museum in Berlin (fig. 11).[56] Two round holes (2 mm in diameter) on its surface, drilled 2 mm apart, are the ends of a suspension channel. The object has no recorded provenance and offers no indication of its original function; its similarity to Pliny's description, however, makes it likely that it is a medical implement.[57]

Gemstones had many uses in ancient medicine, mostly based on sympathetic magic rather than their natural properties. Folklore and conventional wisdom infiltrated the writings of Theophrastos and Pliny. The medicinal properties of gemstones were fully systematized by the first-century A.D. pharmacologist Dioskorides of Anazarbus. The fifth book of his *Materia medica* offers an exhaustive list.[58] These, however, were uses based on superstition rather than natural observation; the teachings of Euclid and Archimedes would find little application here. But were lenses used in empirical ophthalmology?

Eye defects were common in Greece and Rome, so much so that they became a standard example for the fragility of the human condition and the pains of old age.[59] Pliny had observed short- and long-sightedness, although he attributed some cases of myopia to the brilliance of the sun, or the lack of it (*HN* 11.142). Inflammations of the eye were also quite common, in Greek summarily included in the term *ophthalmia*. In Rome, such an inflammation was known as *lippitudo*.[60] Ophthalmia is frequently mentioned in the writings of Hippocrates and Galen. Galen's *De re medicina* (6.6; 7.7) offers a long discussion. It is usually understood as an inflammation of the eye, often seasonal, that blurs the vision. Cicero complained often about it.[61] Pliny the Younger also suffered from it and had to avoid direct sunlight, which rendered it more painful (*Ep.* 7.21.1). In Greek and Latin literature it is often associated with soldiers.[62]

Emerald (*smaragdus*) was thought in antiquity to have a soothing effect on strained or aching eyes.[63] Theophrastos (*On Stones* 24) states that the stone's green color is good for the eyes (πρὸς τὰ ὄμματα ἀγαθή), and that people wear it in their rings "so that

[56] Berlin, Staatliche Museen inv. no. 22x; G. Bruns, *Schatzkammer der Antike* (Berlin 1946) 32.

[57] A similar rock-crystal object, in the form of an eikosahedron (Ht. 25 mm) was found in the same tomb as the game pieces mentioned above (n. 38); Berlin, Staatliche Museen inv. no. 30891ss; *Antikenmuseum* (supra n. 38) 269, no. 59, pl. 268.

[58] Cf. *Materia medica* v. 126: *aematites*, drunk in powder form, is recommended for bowel problems; *sappheiros*, also in potions, for scorpion bites; and all varieties of *iaspis* can serve as amulets and charms for a quick delivery during childbirth.

[59] N. Horsfall, "Rome without Spectacles," *GaR* 42 (1995) 49–56, esp. 49 with ns. 6–10.

[60] On eye diseases in Rome: G. Penso, *La médecine romaine* (Paris 1984) 397–404.

[61] *Q Fr.* 2.2.1; *Att.* 8.13.1, 10.14.1, 17.2; Horsfall (supra n. 59) 51.

[62] Hdt. 7.229; Plaut., *Mil.* 2.3, 9, 21; also Arist. *Frogs* 192 for a former oarsman. Jonathan Bardill tells me that the last reference might well be a joke about the man's rear, since *ophthalmos* is often used by Aristophanes as a euphemism for the anus (the joke in the passage being that the man's suffering had little to do with his eyes); see J. Henderson, *The Maculate Muse* (Oxford 1975) 201, 447a; cf. Arist. *Clouds* 193.

[63] The terms σμάραγδος and *smaragdus* were in antiquity applied to a wide range of green stones, from prase and turquoise to some varieties of malachite and what we today call emerald, a deep green variety of beryl.

they can look at them" (διὸ καὶ τὰ σφραγίδια φοροῦσιν ἐξ' αὐτῆς ὥστε βλέπειν). Theophrastos does not specify the reasons for this, and his phrasing suggests that there was a certain power (δύναμις) in the stone that was good for the eye, not that emeralds were used to make lenses. His comments are explained by one of the Aristotelian *Problemata* (31.19), where it is stated that intense gazing on solid objects overexerts our sight. Looking at objects "containing moisture" (i.e., transparent), on the other hand, like green objects that "are only moderately solid and contain a considerable amount of moisture," is beneficial for the eyes, "since there is nothing in them to restrict the vision."[64] A much later, but suggestive, passage shows how Theophrastos's *sphragidia* may have been used: in a central scene from John Webster's *The Duchess of Malfi*, a ring is offered as a remedy for a bloodshot eye:[65]

DUCHESS
One of your eyes is bloodshot, use my ring to't,
They say 'tis very sovereign: 'twas my wedding ring,
And I did vow never to part with it,
But to my second husband.
ANTONIO
You have parted with it now.
DUCHESS
Yes, to help your eyesight.
(Act I, scene II, 323–26)

Pliny confirms Theophrastos's information about the smaragdus and its properties. He states (*HN* 37.63) that smaragdi allow vision to penetrate them owing to the ease with which light passes through them, as in water. The notion is present in Theophrastos, when he states that "smaragdus emulates water" (*On Stones* 23: "τοῦ τε γὰρ ὕδατος . . . ἐξομοιοῦται τὴν χρόαν ἑαυτῇ"). According to Aristotle (*Sens.* 438a5–b16) the human eye is made of water (τὴν ὄψιν εἶναι ὕδατος), and vision affects the eye because of its transparency. Air is the prime medium of vision but water, Aristotle believed, is more easily confined (εὐφυλακτότερον) and more easily condensed (εὐπιλητότερον), hence it is water and not air that makes up our eye.

In a related passage, Pliny states that "smaragdi are [usually cut in?] concave shape, in order to concentrate the vision" (*ut visum conligant*; *HN* 37.64). This cryptic reference might indicate that Pliny, or his sources, knew about the property of concave lenses to converge the rays of light. His general discussion, however, seems to be devoted to the color of the stone rather than its shape. Magnifying (concave) mirrors were known in antiquity and had found practical applications in engineering projects like the Pharos in Alexandria, which were copied by other ancient lighthouses.[66] It is possible that Pliny had noticed the reflective properties of a smooth, concave surface. That he is referring to the color rather than the transparency of the object is indicated by another passage, where he states that a certain variety of smaragdus, although not transparent, satisfies the eye with its pleasant color, even though it is not possible to see through it (*sed iucundi tenoris visum inplere, quem non admittant*; *HN* 37.69). "Because of their qualities," Pliny adds, "people have decided that smaragdi must be preserved in their natural state and that they should not be engraved" (*HN* 37.64). In this he differs from Theophrastos: whereas the latter talks about signets (*sphragidia*) cut in emerald, Pliny insists that smaragdi ought to be plain.

Pliny also believed that the color green had a soothing effect on strained eyes: "after straining our sight by looking at another object, we can restore it to its normal state by looking at a smaragdus." Gem engravers, he adds, tend to focus on it to rest their tired eyes—so soothing is "the mellow green color of the stone" (*HN* 37.63). Until much later periods, emeralds were thought to improve poor eyesight.[67]

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[64] The *Problemata* is a collection of speculations on natural questions, including many involving optics. Specific passages are attributed to various philosophers among the early Peripatetics: see Jones (supra n. 50) 69–75.

[65] The play, like many of its period, reveals an intriguing mixture of scientific knowledge and current superstition: the scene discussed here is combined with information about "that fantastic glass invented by Galileo the Florentine" (act II, scene IV). The belief that "all things are written in the stars" is answered with the somewhat taunting "if we could find spectacles to read them" (act III, scene I). A Hellenistic audience would perhaps appreciate Webster's "scientific" interests more than modern ones do.

[66] On the Pharos, P.A. Clayton, in Clayton and M.J. Price eds., *The Seven Wonders of the Ancient World* (London 1988) 138–57, esp. 145–46. A citation of a *Catoptrica* by Archimedes in Apuleius's *Apologia* (16) prompted Heiberg to associate Archimedes with a proposition on burning mirrors, presumably of a parabolic form; cf. J.L. Heiberg, *Geschichte der Mathematik und Naturwissenschaften im Altertum* (Munich 1925) 77. Burning mirrors are mentioned in Apuleius's passage, but not with direct reference to Archimedes, so the association is rather tenuous; see W.R. Knorr, "Archimedes and the Pseudo-Euclidean *Catoptrics*: Early Stages in the Ancient Geometric Theory of Mirrors," *Archives internationales d'histoire des sciences* 35 (1985) 28–36; and Knorr, "Geometry of Burning Mirrors in Antiquity," *Isis* 74 (1983) 53–73.

[67] Cf. W. Shakespeare, *A Lover's Complaint* 31.213–14: The deep-green emerald, in whose fresh regard/Weak sights their sickly radiance do amend.

This might explain a long-standing query from a dubious passage in the *Greek Anthology* (6.295). In a poem by Phanias, we are given the description of Askondas the tax collector and his work tools: a penknife, a sponge to wipe the pens, a ruler, a paper weight, an inkhorn, a pair of compasses, smoothing powder, and what is referred to as "the blue kallais-stone with the soothing light" (line 6: καὶ τὰν ἀδυφαῆ πλινθίδα καλλαΐναν). This line has been thought to refer to the man's spectacles in Paton's translation for the Loeb series,[68] a translation tentatively accepted by others.[69] The stone known to Phanias as *kallaina plinthos* is mentioned in Pliny's *Natural History* (*callais*: 37.151). It is described as having a light blue color, "like that of the sea by the shore."[70] From the context of the poem, and from the information provided by Theophrastos and Pliny on the use of emeralds to soothe strained eyes, it is evident that similar stones, of light blue or green color, were used by scribes as well as craftsmen who had to spend long hours working at close range. Incidentally, it is unlikely that if gem engravers were indeed using magnifying lenses or similar devices to facilitate their job, Pliny would not have mentioned them when talking about the measures they take to avoid straining their eyes.

Having discussed the capacity of smaragdus to relieve the strained eye, Pliny concentrates on the reflective properties of the stone. "When smaragdi that are tabular in shape are laid flat, they reflect objects just as mirrors do" (*HN* 37.64). He then adds that Nero used to watch the gladiatorial games in a smaragdus (*Nero princeps gladiatorum pugnas spectabat in smaragdo*). An alternative reading of the text (*smaragdo* instead of *in smaragdo*) would suggest that Nero was using some kind of lens, but this possibility is not supported by the context or the evidence available.

In a recent article, Krug suggested that what Pliny had in mind was a ring set with an emerald. She even identified the type in two rings from the Petescia treasure, excavated in 1876 in Rome (fig. 12).[71] The two rings were found in graves with other jewelry

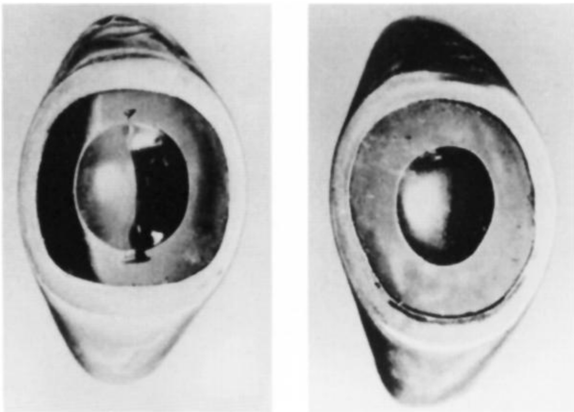

Fig. 12. Emerald intaglios set in gold rings (left, 13 × 12 mm; right, 14 × 12 mm). Berlin, Staatliche Museen, inv. nos. misc. 7075 and 7076. (Photo Museum)

from the Augustan period and must date from the beginning of the first century A.D.[72] Their stones are intriguingly engraved with two plain, almost abstract patterns. One is a fruit-like shape, with two attachments on top and bottom.[73] The other is plainer, a mere concavity across the surface of the stone.[74] The stones fit Pliny's statement that smaragdi ought to be left plain (although strictly speaking these are not) and his preference for concave shapes that "concentrate the vision"—although one could not see through these rings, just look *at* them. These rings would appear to illustrate Theophrastos rather than Pliny, since the former claimed that people wear smaragdi in their rings so that they can look at them. Their iconography remains a puzzle, however. Simple themes are often found on gems, and a similarly plain ring, depicting an oinochoe, was excavated from the same grave (fig. 13).[75] A garnet intaglio, also from Rome, shows a sheaf of wheat—a simple but obvious symbol (fig. 14).[76] The two rings from Petescia are perhaps too plain to represent anything, but one feels that if their intaglios were meant for the eye to focus on they might have been larger. The ridge along the cavity of the two intaglios (better appreciated in im-

[68] W.R. Paton, *The Greek Anthology* (Cambridge, Mass. 1927).

[69] Forbes (supra n. 16) 190–91.

[70] *Callais sappirum* (= lapis lazuli?) *imitatur candidior et litoroso mari similis.*

[71] Krug (supra n. 29) 470–71, figs. 4–5; A. Greifenhagen, *Schmuckarbeiten in Edelmetall* I: *Fundgruppen* (Berlin 1970) 80–81, pl. 60; E. Zwierlein-Diehl, *Die antiken Gemmen in deutschen Sammlungen* II: *Berlin* (Munich 1969) nos. 559–60.

[72] *Pace* Zwierlein-Diehl (supra n. 71); see A. Krug, *Heilkunst und Heilkult: Medizin in der Antike* (Munich 1984) 102.

[73] Berlin, Staatliche Museen inv. no. misc. 7075 (13 × 12 mm); Zwierlein-Diehl (supra n. 71) no. 560.

[74] Berlin, Staatliche Museen inv. no. misc. 7076 (14 × 12 mm); Zwierlein-Diehl (supra n. 71) no. 559.

[75] Greifenhagen (supra n. 71) 80.

[76] Munich, Antike Münzsammlung inv. no. A1563, set in a gold ring, 8 × 6 mm; E. Brandt, *Staatliche Münzsammlung, München* (*Antike Gemmen in deutschen Sammlungen* I.1, 1968) no. 381.

Fig. 13. Garnet intaglio set in a gold ring (13 × 10 mm). Berlin, Staatliche Museen, inv. no. misc. 7071. (Photo Museum)

Fig. 14. Impression of a garnet intaglio set in a gold ring (8 × 6 mm). Munich, Antike Münzsammlung, inv. no. A1563. (Photo of cast: author)

pression) helps create a three-dimensional effect; these could be fruits after all.[77] At any rate, it is clear that such rings were not what Nero used in order to watch the games. Pliny is referring to flat reflective surfaces, and it is unlikely that a small concave smaragdus would be of much help.

To be sure, Nero was shortsighted: this we know again from Pliny (*HN* 11.54), who says that Nero's eyes were dull (*hebetes*) and that he could only see something if it were brought very close to him. Furthermore, Suetonius claims that Nero's eyes were heavy, bleary, and dull, the last matching Pliny's description (*Ner.* 51: *oculis caesis et hebetioribus*). It is possible that, in addition to his myopia, Nero was suffering from *lippitudo* as well. One possibility is that he used the smaragdus in Pliny's anecdote as a mirror, perhaps a concave one, in order to relieve his myopic eyes from the strong sun in the amphitheater. In this case, according to the laws of catoptrics, the image reflected on the stone would be reduced in size and inverted.[78] A flat reflective surface would have produced an upright image (like any regular mirror) but would not have helped with Nero's shortsightedness, because the images produced by a plane mirror are produced at the same distance as the objects (virtual images). Alternatively, a smaller emerald, perhaps set in a ring, may have been used in the manner described by Theophrastos and Pliny in the passages cited above to relieve the emperor's aching eyes.

From the evidence presented above, it should be clear that gemstones and crystals were appreciated both for their magical and natural properties, although the latter were rather misunderstood. Philosophers and scientists accepted vision as the free movement of visual rays through a transparent medium like air or water, and attributed the empirically observed magnifying properties of lenses and crystals to their transparency rather than their refractive quality. This perspective explains why Seneca's observation that "lenses" could improve vision did not find a practical application. Emeralds, on the other hand, were thought to relieve suffering eyes because their color was thought to contain moisture, thus allowing vision to penetrate their mass.

In Euclidean optics, the "eye" according to which the laws of reflection and refraction are observed is an abstract and theoretically perfect tool, not an optical instrument itself. Accordingly, the laws of

[77] Still-life subjects, like fruit or simple objects, were included in the repertory of Greek gem cutters from an early date: cf. the fifth-century B.C. chalcedony scaraboid with the device of a hazelnut, Boardman (supra n. 27) no. 514.

[78] Concave mirrors converge rays of light and produce, for near objects, upright and magnified images; for distant objects (like the action in the amphitheater) they produce images that are inverted.

vision described by Euclid and his followers were of little consequence to ophthalmology.[79] Greek biologists, most notably the third-century B.C. anatomist Herophilos of Alexandria, made significant progress in this respect.[80] Herophilos, who along with his slightly younger collaborator Erasistratos gained some notoriety in antiquity for his practice of dissection and even vivisection, was able to distinguish the main parts of the human eye, although he does not seem to have described the lens. His descriptions and terminology for the cornea and retina, on the other hand, remain valid today. Herophilos was also able to observe the existence of the optic nerve connecting the eye with the brain, although he misinterpreted its function as a pipe for sensory spirit (*pneuma*).[81] The failure of ancient physicians to understand the human eye as a lens is fundamental in explaining their treatment of defective vision. In many ways, Greek and Roman pharmacology concentrated on traditional methods.[82] At the same time, physiology was heavily influenced by philosophy: lack of moisture on and around the pupil, brought on by old age or exertion, is named as the cause of failing eyesight in the *Problemata* (31.14). Myopic vision in particular, which modern ophthalmology understands as an abnormality of the eye's lens, was in antiquity attributed to the dispersal of visual rays when emitted from a wide open eye.[83]

Before this ground was covered, linking empirical observations about the properties of lenses with defective vision and its treatment was not possible. Exceptions may have occurred, when such objects were used to provide temporary relief for an eye ailment. These, however, would have been accidental incidents and are not alluded to in the texts. A breakthrough to universal treatment, or the development of implements such as spectacles, required a systematic analysis of the real causes behind the symptoms, not their ad hoc treatment. When spectacles were actually invented, in the 13th century A.D., it took parallel developments in Italy and China, and perhaps the genius of Roger Bacon,[84] to make their use relatively widespread.

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[79] It is only with the 11th-century Arab scientist Ibn al-Haytham that ocular anatomy was used toward the formulation of a physical theory of vision. In his *Optics* (I 73a–75a and 98b–100b), Ibn al-Haytham summarized the conclusions of earlier anatomists and medics, thus integrating ophthalmology with traditional optics. See S.B. Omar, *Ibn al-Haytham's Optics: A Study of the Origins of Experimental Science* (Chicago 1977) 42–44, 84–85; and A.I. Sabra, *The Optics of Ibn al-Haytham: Books i–iii: On Direct Vision* (London 1989) I, 55–57, II, 45–52 for an English translation and commentary.

[80] See Lloyd (supra n. 1) 77–78 for a general account.

[81] Only fragments of Herophilos's work survive, mentioned, often indirectly, by later medical writers. Most of what is preserved must have derived from his treatise *On Eyes*: see H. von Staden, *Herophilus: The Art of Medicine in Early Alexandria* (Cambridge 1989) 203–205, 317–18. His work on the human eye was continued by one of his many followers, Demosthenes Philalethes (ca. 20 B.C.–A.D. 50), whose treatise *Ophthalmicus* seems to have had a considerable impact on later ophthalmology: von Staden 570–78.

[82] The only certain passage from Herophilos's treatise *On Eyes* (in Aetius Amidenus, *Libri medicinales* 7.48) proposes to treat nyctalopy (night- or day-blindness) with an ointment made from gum, crocodile dung, vitriolic copper, and the bile of a hyena, possibly influenced by traditional Egyptian practices; von Staden (supra n. 81) 423–26.

[83] Two of the *Problemata* (31.15–16) discuss the instinctive reaction of shortsighted people to squint their eyes when trying to see at a distance, concluding that by bringing the eyelids together vision is improved, since visual rays are emitted in a concentrated form. In fact, tightening our eyelids is the result of flexing the ciliary muscles in the eye in order to change the focus of the lens. Following the same principle, some architects believed that views restricted by narrow windows were more satisfactory. Cf. Cicero *Att.* 2.3.2; see L. Balensiefen, "Die 'kyropädie' der Baumeisters Kyros und die antiken Sehtheorien," *JdI* 109 (1994) 301–19.

[84] A.C. Crombie, *Augustine to Galileo: The History of Science A.D. 400–1650* (London 1952) 205–206.