National and Kapodistrian University of Athens

# *Ancient Greek Optical instruments, Lenses, Mirrors and possibly Telescopes*

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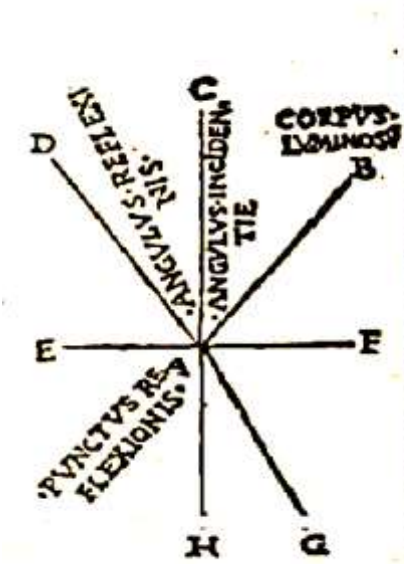


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## Περιεχόμενα



• Φιλολαος ὁ Πυθαγορειος, ἁλοειδη τον ἡλιον, δεχομενον μεν τον εν τῳ κοσμῳ πυρος την ανταυγειαν, διηθουντα δε προς ἡμας το τε φως και την αλεαν, ὡστε τροπον τινα δισσους ἡλιους γιγνεσθαι, το, τε εν τῳ ουρανῳ πυρωδες, και το απ' αυτου πυροειδες κατα το εσοπτροειδες· ει μη τις και τριτον λεξει την απο του εναντιου κατ' ανακλασιν διασπειρομενην προς ἡμας αυγην.

## Abstract

A study of ancient optical instruments mirrors and lenses and combinations of them, which even allowed performing astronomical observations, has been performed and presented. It seems that such optical devices were available and used by philosophers and craftsmen that enable them to perform observations and create miniatures like seals. Philosophers and scientists observe astronomical and other natural phenomena, like thunders, clouds, and rainbow and perform studies in laboratories. In parallel philosophers like Euclid, Hero and Diocles study in the laboratory and I theory and establish the qualities of the mirrors and possibly lenses.

This study is based on both actual data of existing ancient lenses that are in Greek Museums and Greek, Latin and Arabic literature. Some of them have been measured and their optical characteristics are known. In parallel I this study have been used ancient scientific books by Greek philosophers, with texts referred to optics, lenses, mirrors and multiple refection instuments. These facts and texts have been neglected or misinterpreted up to now and even some specialists ignore the existence of lenses, spherical mirrors and optical instruments.

The oldest of the lenses that has been measured for this study is probably 4000 years old, from Crete, Greece, while the

others are of various time periods of antiquity. Several other lenses of various focal lengths of the 8th or 7th century BC from Rhodes are also presented. These have several focal lengths and magnifications and are provided with handles to be held by the user, who is probably an artist who designs and manufactures minatures, seals, jewellery.


There are ancient texts refered to complex optical systems made up of more than one mirror or, possibly, lenses from the Greek philosophers and even a theatrical writer like Aristophanes with many detailed descriptions and studies by prominent ones like Euclid and Hero both from Alexandria. Ancient natural philosophers and other authors mention optical systems of two or more mirrors, concave and convex,

that have appropriate qualities that enable the user to create real or imaginary idols, that they call images and spectra respectively. In some of these texts it is evident that they were in use for astronomical purposes to see “stars”, as they write, they name comets, and we can assume they possibly mean planets.

All these prove that humans in Greece have developed complex optical systems, possibly used for observations of objects at the Earth and celestial bodies like comets and the moon.

## Introduction to ancient optics

Astronomy is part of our culture from prehistoric times. Humans admire and study the sky initially by unaided eye, they observe the motion of the stars, the Sun, the Moon, the planets, they notice the changes of the season, the yearly change of the altitude of the sun, the changes of the position of sunrise and sunset, and eventually they develop various instruments, poles, simple stelae, buildings and cities of various astronomical orientations, with orientations. These astronomical observations probably lead to the development of reasoning, the notion of causality and with it the laws of physics that are described by appropriate mathematics to describe and even predict prorperly nature, to “save the

phenomena[1]". The mathematicl formulation of a law of nature changes with time as more and especially better, more accurate data ecome available and bettermathematical methds are developed or used in purpose.

Our effort to understand the sky, the nature of celestial objects makes us humans, Plato says. Observing the sky and trying to understand the motions and the nature celestial objects humans develop mathematical and physical models and this is the beginning of science and philosophy at the same time. Humanity makes an enormous step with the advent of astrophysics and cosmology, as this effort to understand nature in terms of nature is the beginning of reason, logic, of causality, of the existence of laws of physics, explanation and prediction of some natural phenomena like the phases of the moon, the position of the sun, the beginning of the year, the position of the planets, the eclipses etc. It is a miracle that humans understand the correct nature of the stars that are made of concentrations of hot gasses; they understand the existence of gravitational forces and its

[1] In Heraclides Ponticus (c390–310 BC) τὴν γῆν καὶ κύκλῳ κινουμένην, τὸν δὲ οὐρανὸν ἠρεμεῖν Ἡρακλείδης ὁ Ποντικὸς ὑποθέμενος *σώζειν ᾤετο τὰ φαινόμενα*, Eudemus (270-300 BC), the oldest historian of science, mathematician, astronomer and student of Aristotle who edited his techer;'s books before been published, writes *σώζειν τὰ φαινόμενα* and it is repeated by Plutarch (46-120AD) in his book *On the Face in the Orb of the Moon*, … φαινόμενα σῴζειν…

significance in various cosmic scales, both in the creation of a star, they wonder on the generation of energy, of light. We especially wonder how humans understood all that and if they had means like telescopes, that enable them to observe at least the moon and comets that enabled them to start understanding nature. It is known the Greeks and other people had lenses and mirrors from prehistoric times.

This theoretical scientific method using theory, intellectually, using their brain with reason, and without using material [immaterially, ἀύλως καὶ νοερῶς][2] to understand what they observe [τὰ θεωρήματα], as Hero states[3]. Theorems and proofs are probably the most important advancement in science and this theoretical method is used to study mirros and their applcations including optical systems with more than one mirrors.

[2] [Pythagoras] τὴν περὶ αὐτὴν φιλοσοφίαν εἰς σχῆμα παιδείας ἐλευθέρου μετέστησεν ἄνωθεν τὰς ἀρχὰς αὐτῆς ἐπισκοπούμενος καὶ ἀύλως καὶ νοερῶς τὰ θεωρήματα διερευνώμενος, ὃς δὴ καὶ τὴν τῶν ἀνὰ λόγον πραγματείαν καὶ τὴν τῶν κοσμικῶν σχημάτων σύστασιν ἀνεῦρεν.

[3] Hero *Definitiones* μετὰ δὲ τὸν Θαλῆν Μαμέρτιος ὁ Στησιχόρου ποιητοῦ ἀδελφὸς καὶ Ἱππίας ὁ Ἠλεῖος καὶ μετὰ ταῦτα ὁ Πυθαγόρας ἄνωθεν τὰς ἀρχὰς αὐτῆς ἐπισκοπούμενος καὶ ἀύλως καὶ νοερῶς τὰ θεωρήματα διερευνώμενος καὶ μετὰ τοῦτον Ἀναξαγόρας καὶ ὁ Πλάτων καὶ Οἰνοπίδης ὁ Χῖος καὶ Θεόδωρος ὁ Κυρηναῖος καὶ Ἱπποκράτης πρὸ τοῦ Πλάτωνος.

Based on ancient Greek texts and actual finds it is evident that they do not only have lenses and mirrors of various types, but they even studie then with scientific methods, experimental and theoretical as it I described in Euclid of Alexandria book o Catoptrics. Perhaps the most famous quotation on the use of lenses in antiquity is the one theatrical writer of comedies Aristophanes mentions in one of his comedies that the Greeks have been using lenses that you can buy from a pharmacy to light a fire[4], or to falsify the minutes of a curt from a distance

[4] ἤδη παρὰ τοῖσι φαρμακοπώλαις τὴν λίθον ταύτην ἑόρακας, τὴν καλήν, τὴν διαφανῆ, ἀφ' ἧς τὸ πῦρ ἅπτουσι; and also Socrates τὴν ὕαλον λέγεις; Aristophenes, *Clouds.* Strepsiades: Have you seen the transparent stone that you can buy from the pharmacy to light up a fire? Socrates: yes, you mean the glass (lens), you can use it to melt and delete from a distance the writings of your suit in the court.

using a lens. The minutes of proceedings of the court were written on tablets covered with a thin layer of wax that *Strepsiades* will delete from a distance focusing sunrays on the layer of wax. For Aristophanes to use lenses in a comedy implies that the use of them is known to the general public. Several lenses and many mirrors are in Greek and other archaeological museums[5], but there are many more important ancient texts about optics, especially mirrors.

## Ancient Optics

Optics, called *catoptrics* by the Greeks, as it was initially the study optics of the mirrors that are called Katoptra (Κάτοπτρα) in Greek. Optics becomes a science mainly in Alexandria probably before the time of Euclid. Euclid's *Catoptrics* explains theoretically with theorems relfection, multiple reflection and the formation of iages, reversed, magnified etc. Euclid explains why certain mirrors reverse the image, making it left and right handed or inverse, up and down, why images appear diminished and warped in convex mirrors, how can be seen in concave mirrors[6]. Another very important theoretical study is

[5] Twyman, F. (1942, 1952, 2nd ed.). Prism and Lens Making, Hilger.

[6] Georgia L. Irby (editor), (2016), A companion to science, technology, and medicine in ancient Greece and Rome, 2016 John Wiley & Sons, Inc.

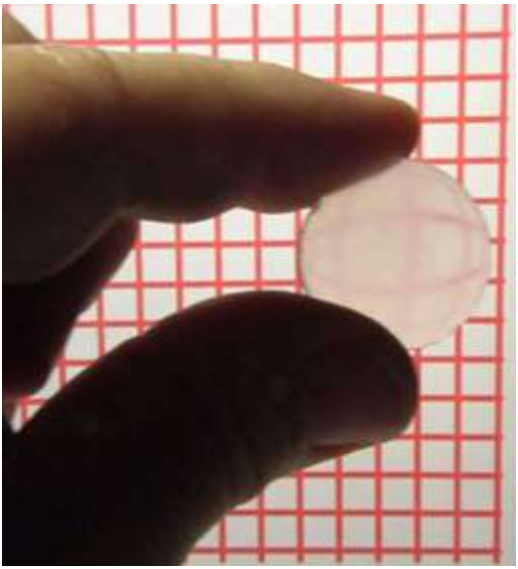
the one on burning mirrors by Diocles (c240–c180 BC)[7] of which an Arabic translation exists extensively studied by Toomer and proves that they treat optics purely theoretically using geometry without involving the eye of the observer or vision. Diocles was an important mathematician that solved in a way the Delian problem of doubing of the cube volume, introduced the cissoid of Diocles, wrote the book of optics specialized *on Burnig mirrors* has been saved in the book with comments of Archimedes' book (now lost) *On the Sphere and the Cylinder* written by the mathematician Eutocius (480- 540 AD) who has studied and worked in Alexandria with Ammonius.

The usual belief [see for example Neugebauer][8] that Greek texts show that Greek philosophers understanding the nature of vision assuming that the human eye emits rays of light is based on a misunderstanding of the Greek texts where the simply mention the mathematical method to draw lines to study and understand vision. The confusion is probably due to the use of term *opsis (όψις)* which has three meanings at least

[7] Toomer, G. J. (2012). Diocles, On Burning Mirrors: The Arabic Translation of the Lost Greek Original (Vol. 1). Springer Science & Business Media.

[8] 0. Neugebauer, (1975) *A History of Ancient Mathematical Astronomy In Three Parts,* Springer-Verlag Berlin Heidelberg

a) the eye, b) the vision, and c) the rays of light and the straight lines used in the theory of optics[9].



The mere fact that optics, that Greek Philosophers call it catoptrics, is part of geometry, where they do not mention the human eye or vision, but the straight lines they use o study optics, proves that. This is mentioned by Medaglia and Russo[10]

[9] C.f. Thibodeau, P. (2016). *Ancient Optics: Theories and Problems of Vision*, in A Companion to Science, Technology, and Medicine in Ancient Greece and Rome, First Edition. edited by Georgia L. Irby. John Wiley & Sons, Inc. pp 130–144.

[10] Medaglia, S. M., & Russo, L. (1995). Sulla prima "definizione" dell'Ottica di Euclide". Bollettino dei classici, 41-54.

where they present two almost identical sentences from Euclid and Hero[11] on the geometry of vision that prove that the notion that all Greek philosophers believe that vision is based on light rays that are emitted from the eye is wrong. Euclid in his *Optica* states *let us draw straight lines form the eye that deviate as the distance increases* and even introduces the solid angle as a cone[12]. Geminus and Theon give the same geometrical description, almost the same sentence. Heron in his book *Definitiones[13]* says that light rays are straight lines that deviate from the eye and the same is repeated by Geminus in his *Fragmenta optica*[14].

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[11] Hero of Alexandria (1900) *Opera quae supersunt Omnia. Mechanica et catoptrica*, ed. L. Nix and W. Schmidt. Leipzig: B. G. Teubner.

[12] Euclide Optica: Ὑποκείσθω τὰς ἀπὸ τοῦ ὄμματος ἐξαγομένας εὐθείας γραμμὰς φέρεσθαι διάστημα μεγεθῶν μεγάλων. καὶ τὸ [μὲν] ὑπὸ τῶν ὄψεων περιεχόμενον σχῆμα εἶναι κῶνον τὴν κορυφὴν μὲν ἔχοντα ἐν τῷ ὄμματι τὴν δὲ βάσιν πρὸς τοῖς πέρασι τῶν ὁρωμένων. [soled angle]καὶ ὁρᾶσθαι μὲν ταῦτα, πρὸς ἃ ἂν αἱ ὄψειςπροσπίπτωσι, μὴ ὁρᾶσθαι δέ, πρὸς ἃ ἂν μὴ προς-πίπτωσιν αἱ ὄψεις.

[13] Heron: Ὅτι ὑποτίθεται ἡ ὀπτικὴ τὰς ἀπὸ τοῦ ὄμματος ὄψεις κατ' εὐθείας γραμμὰς φέρεσθαι, καὶ τοῦ ὄμματος περιφερομένου συμπεριφέρεσθαι καὶ τὰς ὄψεις, καὶ ἅμα τῷ ὄμματι διανοιγομένῳ πρὸς τὸ ὁρώμενον γίνεσθαι τὰς ὄψεις

[14] Geminus: ὅτι ὑποτίθεται ἡ ὀπτικὴ τὰς ἀπὸ τοῦ ὄμματος ὄψεις κατ' εὐθείας γραμμὰς φέρεσθαι καὶ τοῦ ὄμματος συμπεριφερομένου συμπεριφέρεσθαι καὶ τὰς ὄψεις καὶ ἅμα τῷ

Hero and Geminus divide *Optics* in three parts, as (a) *Optic,* (b) Catoptric and (c) *Scenographic*[15]*.* **Geometrical optics** is used for reflection of light on reflecting surfaces like water, metallic plates, and also for refraction in crystal and lenses[16] .

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ὄμματι διανοιγομένῳ πρὸς τὸ ὁρώμενον τὰς ὄψεις γίνεσθαι. ὑποκείσθω τὰς ἀπὸ τοῦ ὄμματος ὄψεις κατ'εὐθείας γραμμὰς φέρεσθαι διάστημά τι ποιούσας ἀπ'ἀλλήλων

[15] Geminus and Heron says exactly the same, using the same phrase in fact ὀπτικῆς μέρη λέγοιτο μὲν ἂν κατὰ τὰς διαφόρους ὕλας καὶ πλείω, τὰ δὲ γενικώτατα τρία· τὸ μὲν ὁμωνύμως τῷ ὅλῳ καλούμενον ὀπτικόν, τὸ δὲ κατοπτρικόν, τὸ δὲ σκηνογραφικόν. κατοπτρικὸν δὲ λέγεται ὁλοσχερέστερον μὲν τὸ περὶ τὰς ἀνακλάσεις τὰς ἀπὸ τῶν λείων, οὐ μόνον περὶ ἓν κάτοπτρον, ἔστι δ' ὅτε καὶ περὶ πλείω στρεφόμενον, ἔτι μὴν καὶ περὶ τὰ ἐν ἀέρι δι' ὑγρῶν ἐμφαινόμενα χρώματα, ὁποῖά ἐστι τὰ κατὰ τὰς ἴριδας. ἕτερον δὲ τό τε θεωροῦν τὰ συμβαίνοντα περὶ τὰς τοῦ ἡλίου ἀκτῖνας ἔν τε κλάσει καὶ φωτισμοῖς αὐτοῖς καὶ σκιαῖς· οἷον ὁποία τις ἡ διορίζουσα γραμμὴ τὴν σκιὰν ἐν ἑκάστῳ σχήματι γίνεται. ὁποία γὰρ ἡ τῶν ὄψεων πρόπτωσις, τοιοῦτος καὶ ὁ καταφωτισμὸς ὑπὸ τοῦ ἡλίου γίνεται· καὶ τοτὲ μὲν κατ' εὐθείας ἀκλάστους, τοτὲ δὲ κατὰ διαδυομένας ὥσπερ ἐπὶ τῶν ὑέλων – κατακλώμεναι γὰρ καὶ εἰς ἓν συννεύουσαι ἐξάπτουσι παρὰ τὰ ποιὰ σχήματα –τοτὲ δὲ κατὰ ἀνάκλασιν ὥσπερ οἱ ἀχιλλεῖς φαίνονται ἐπὶ τῶν ὀροφῶν· ὥς τ' ἀπὸ πάσης τῆς ὄψεως ἡ θεωρία, καὶ ἀπὸ παντὸς μέρους τοῦ ἡλίου ὁ φωτισμὸς γίνεται.

[16] ἡ δ' ἐπὶ τῶν ὑδάτων καὶ τῶν ὑμένων τὰ κατὰ διάδυσιν θεωροῦσα ὀπτικὴ ἐλάττω μὲν θεωρίαν ἔχει, αἰτιολογεῖ δὲ τὰ ὑπὸ τοῖς ὕδασι καὶ ὑμέσι [thin plates of metal] καὶ ὑέλοις [lenses] ὁπότε

Light follows **straight lines or at times refracted as in lenses [**ἀκλάστους, τότε δὲ κατὰ δυομένας, ὥσπερ ἐπὶ τῶν ὑέλων]. **Spectroscopy (Ιρις)** is the study of colours that appear in air, water, shadows, around the rays of the sun[17] , **Scenography** is part of optics that studies the images of buildings[18] in 3 dimensions, i.e. projective geometry and descriptive geometry, that are suitable and important for design, architecture, engineering and in art with perceptiveness, which is evident already in the frescos of Akrotiri of Thera, at the royal tombs of Philip at Vergina, Roman mural paintings.

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διασπαραττόμενα φαίνεται τὰ ἠνωμένα καὶ σύνθετα τὰ ἁπλᾶ καὶ τὰ ὀρθὰ κεκλασμένα καὶ τὰ μένοντα κινούμενα.

[17] ἔτι μὴν καὶ περὶ τὰ ἐν ἀέριδι' ὑγρῶν ἐμφαινόμενα χρώματα, ὁποῖά ἐστι τὰ κατὰ τὰς ἴριδας· ἕτερον δὲ τό τε θεωροῦν τὰ συμβαίνοντα περὶ τὰς τοῦ ἡλίου ἀκτῖνας ἔν τε κλάσει καὶ φωτισμοῖς αὐτοῖς καὶ σκιαῖς, οἷον ὁποία τις ἡ διορίζουσα γραμμὴ τὴν σκιὰν ἐν ἑκάστῳ σχήματι γίνεται, καὶ τὸ περὶ τὰ πυρεῖα προσαγορευόμενον σκοποῦν περὶ τῶν κατὰ ἀνά-

κλασιν συνιουσῶν ἀκτίνων, αἳ κατὰ σύννευσιν ἀθρόαν τῆς τοῦ φωτὸς ἀνακλάσεως παρὰ τὴν ποιὰν κατασκευὴν τοῦ κατόπτρου εἰς ἓν συνιοῦσαι ἢ κατὰ γραμμὴν εὐθεῖαν ἢ κυκλοτερὲς ἐκπυροῦσί τινα τόπον. αὗται δ' αἱ θεωρίαι τὰς αὐτὰς ὑποθέσεις ἔχουσαι τῇ περὶ τὰς ὄψεις τὸν αὐτὸν ἐκείνῃ τρόπον ἐφοδεύονται· ὁποία γὰρ ἡ τῶν ὄψεων πρόπτωσις, τοιοῦτος καὶ ὁ καταφωτισμὸς ὑπὸ τοῦ ἡλίου γίνεται, καὶ τότε μὲν κατ' εὐθείας

[18] Τί τὸ σκηνογραφικόν; Τὸ σκηνογραφικὸν τῆς ὀπτικῆς μέρος ζητεῖ, πῶς προσήκει γράφειν τὰς εἰκόνας τῶν οἰκοδομημάτων·

Claudius Ptolemy has written five extensive books about optics[19], on mirrors and reflection and we can conclude that it was a very detailed study of a science that was very advanced at the Hellenistic times.

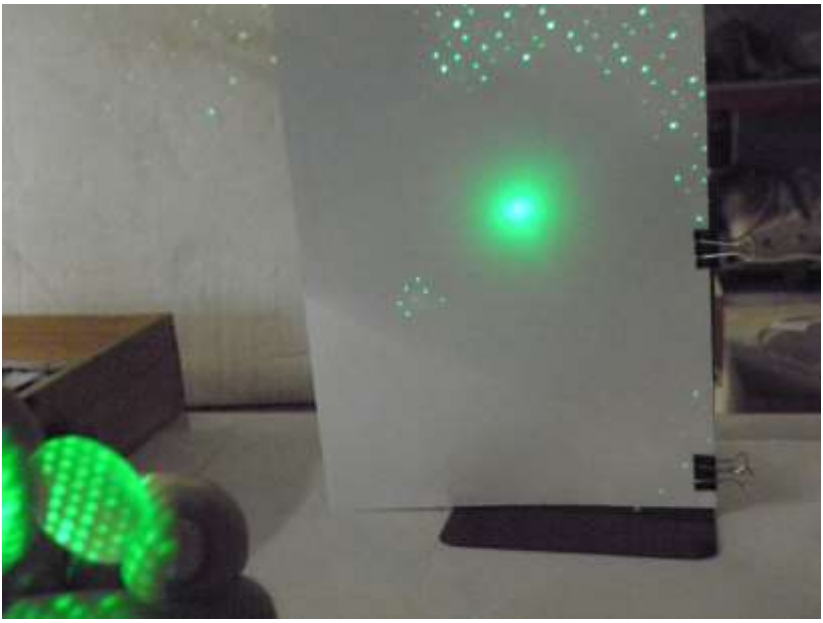
## Ancient lenses

There have been several studies and presentations of ancient lenses mainly by archaeologists. Sines and Sakellarakis (1987) and Sakelarakis, (1999), present lenses from prehistoric Greece, Crete, lenses have been found in Knossos, and Enoch

[19] L'Optique de Claude Ptolémée 5 books edited by Albert Lejeune (1956), version latine d'après l'arabe de l'émir Eugène de Sicile, édition critique et exégétique augmentée d'une traduction française et de compléments, Louvain, Bibl. Universitaire.

(1998, 2000) presents a lenticular crystal made object that he considers that it was simply ornamental. Giovanni Pettinato (Willach, 2008) believes that this Assyrian lens discovered by Sir John Layar in 1850, was possibly used for magnification of objects. Ancient lenses are described by Irby-Massie and Keyser (2002) in their book about Greek science of the Hellenistic era and especially by Russo (2013) who is his famous book about the scientific revolution in the Greek World gives an account for ancient lenses from various places. Russo reviews the scientific presentation of lenses in antiquity. Russo discusses the refraction presentation by Ptolemy who gives tables with refraction angles of media. The most beloved pupil of Aristotle and his successor as head in his Philosophical School in Athens, the Peripatetic School or Lyceum, which has been discovered recently in Athens, Theophrastus (~371 BC to 287 BC) discusses on how a lens can be used to light a fire. Russo discusses the possible existence of even telescopes in antiquity. Russo stresses that Hoppe in his book of the history of optics and Giovanni Pettinato based on the accuracy of their astronomical measurements states that telescope were possibly in use by Mesopotamian astronomers during the late Assyrian period.

The Archaeological Museum of Heraklion, Crete, Greece, there are more than 20 lenses some from around 2000 BC, that I have studied some of them that are intact and in good condition. I have measured the quality of several lenses. Their focal lenses range around some tens of cm. The image these lenses produce is reasonable, more than just acceptable. Despite their distortion, the lenses give images that can be useful, suitable for practical purposes. The magnification is suitable for engraving and to work with small objects for the construction of jewels and seals like seal the ones the Greek world produces from prehistoric times.



Another 20 magnifying lenses with handles made of copper are available at the Archeological Museum of Rhodes, which are believed to be of the 8th century BC. Most probably these were lenses used in a workshop, or they were ready for sale from a workshop. I will measure their focal lengths and is more than one or two lenses have the same magnification we can probably conclude that the lenses are meant for sale, possibly even to mitigate presbyopia, the aging eye condition. Around forty lentoid, lens-like crystal objects found by H. Schliemann at Troy are now at the Pushkin Museum, Moscow. These are assumed to be meant probably for decoration of a ceremonial suit of royalty or something equivalent. One of the lenses though is definitely a lens with good quality image. All these lenses are converging lenses with one spherical and a

plane surfaces. Some lens-like objects are real lenses used for magnification[20] and perhaps other are perhaps just for decoration[21]

[20] Sines, G., & Sakellarakis, Y. A. (1987). Lenses in antiquity. American Journal of Archaeology, 191-196., believe that are lenses for magnification.

[21] Plantzos (1997) suggests that lent-like objects are just for decorative purpose.

At least two or three very impressive lenses that are suitable to mitigate myopia, near-sightedness or short-sightedness, have been on display at the exhibition of objects from Vergina at the Archaeological Museum of Thessaloniki, which I have applied to study.

The use of magnifying lenses by ancient people is evident from the details of seals that are numerous from many time periods including the Hellenistic period in Alexandria. A recently discovered seal form a ring of the 15th century BC from Pylos proves that humans managed to construct immaculate details that can be seen in the seal. The fingers of one of the warriors are accurately displayed with an accuracy of 0.2mm, i.e. half the diameter of a human hair, with details that are only visible with special photography techniques like photomicroscopy[22].

The theory of optics progresses rapidly and during the Hellenistic period Heron and Ptolemy flourish in Alexandria together with mathematics, astronomy, geography, physics, mechanics, architecture, ship building robotics (automata). Refraction has been studied on a theoretical basis and understood. Heron Heron of Alexandria in his *Definitiones* explains how refraction happens as the rays of light following straight lines enter from one transparent medium to another

[22] Davis, Jack L. and Stocker, Sharon R., (2016), *The Lord of the Gold Rings: The Griffin Warrior of Pylos*, Hesperia: The Journal of the American School of Classical Studies at Athens, 85, pp. 627-65.

denser, like water, glass or films or membranes[23]. Euclids in his book Catoptrica gives the theory of constructin of images from spherical mirrors[24] and he gives details on the left handed images and right handed images from spherical mirrors and that the image is smaller and he is referred on the use of more than one spherical mirrors nd he gives mathematical explanation why the image from the smaller spherical mirror will be smaller[25].

Diogenes Laertius in his *Vitae philosophorum* and at the *Lexicon Suda* they mention that in philosophical schools they study the physics of the creation of virtual image[26].

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[23] καὶ καθ' ἕτερον δὲ τρόπον ὑποτίθεται τὰ μὲν δι' αἰθέρος καὶ ἀέρος ὁρώμενα κατ' εὐθείας γραμμὰς ὁρᾶσθαι· φέρεσθαι γὰρ πᾶν φῶς κατ' εὐθείας γραμμάς· ὅσα δὲ διαφαίνεται δι' ὑέλων ἢ ὑμένων ἢ ὕδατος, κατὰ κεκλασμένας, τὰ δὲ φαινόμενα ἐν τοῖς κατοπτρίζουσι κατὰ ἀνακλωμένας γωνίας.

[24] Ἐν τοῖς κοίλοις ἐνόπτροις ἕκαστον τῶν ὁρωμένων κατὰ τὴν ἀπὸ τοῦ ὁρωμένου εἰς τὸ κέντρον τῆς σφαίρας ἀγομένην εὐθεῖαν ὁρᾶται. And φανερὸν οὖν, ὅτι ἀπὸ τοῦ κυρτοῦ ἐνόπτρου τὸ εἴδωλον ἔλασσον φαίνεται τοῦ ὁρωμένου and Ἐν τοῖς κυρτοῖς ἐνόπτροις τὰ ἀριστερὰ δεξιὰ φαίνεται καὶ τὰ δεξιὰ ἀριστερά, καὶ τὸ ἀπόστημα ἀπὸ τοῦ ἐνόπτρου τὸ εἴδωλον ἔλασσον ἔχει.

[25] Ἐν τοῖς κυρτοῖς ἐνόπτροις ἀπὸ τῶν ἐλασσόνων ἐνόπτρων ἐλάσσονα φαίνεται τὰ εἴδωλα. ἔστω σφαῖρα μείζων μὲν ἡ ΑΓ, ἐλάσσων δὲ ἡ ΕΛ περὶ τὸ αὐτὸ κέντρον τὸ Θ, ὄμμα δὲ τὸ Β …

[26] αἰτία τῆς κατοπτρικῆς φαντασίας

## Ancient mirrors

The Greeks use three terms of mirrors: *Κάτοπτρον, Ἔσοπτρον* and *Ἔνοπτρον*. In Greek Ἔσ, Εν means inside, *Κάτ* means against, *οπτ* means to look and–τρον, means an instrument, so these three terms mean an instrument to look trough or against.

According to Greek mythology the first mirror has been made by god Vulcan for god Dionysus as described Proclus In *Platonis Timaeum commentaria*[27]. Construction of a convex mirror is described by Agathias in *Historiae* who states that the convex mirror focuses the rays of the sun on a point [αἴγλη, focal point][28].

It is well known that ancient people, even prehistoric people, have and use bronze mirrors in Minoan and Mycenaean times that can be seen at the Archaeological Museums in Crete and the National Archaeological Museum at Athens. There are indications that some terracotta shallow vessels, the so called

[27] δὲ καὶ τοῖς θεολόγοις τὸ ἔσοπτρον ἐπιτηδειότητος παρείληπται σύμβολον πρὸς τὴν νοερὰν ἀποπλήρωσιν τοῦ παντός· διὸ καὶ τὸν Ἥφαιστον ἔσοπτρόν φασι ποιῆσαι τῷ Διονύσῳ, εἰς ὃ ἐμβλέψας ὁ θεὸς καὶ εἴδωλον ἑαυτοῦ θεασάμενος προῆλθεν εἰς ὅλην τὴν μεριστὴν δημιουργίαν.

[28] δίσκον μὲν γάρ τινα ἐσόπτρου δίκην ἐσκευασμένον καὶ ἠρέμα ὑποκοιλαινόμενον ταῖς τοῦ ἡλίου ἀντερείδων ἀκτῖσιν ἐνεπίμπλα τῆς αἴγλης·

frying pan vessels of the 4th and 3rd millennium BC, found around the Aegean and mainly in Cyclades, peculiar containers for liquids, painted black inside could have been used as mirrors[29]. They fill the vessels with water and use them as mirrors. There are references on mirrors in the classical theatrical plays and this means that the spectatros must be familiar woth the ue of mirrors, hence mirros were not only for the very rich people and everybody is familiar with reflections and on the formation of the image.

Apollonius in his work *Apotelesmata* gives a recipe on how to construct a metallic mirror alloy using copper, mercury, silver, gold, lead, tin and crystal[30].Mirrors have many applications.

[29] Tsountas, C., 1899, Cycladic, Κυκλαδικα II, ArchEph, 74–134.; Coleman, J. E., 1985, 'Frying pans' of the Early Bronze Age Aegean, American Journal of Archaeology, 89, 191–219.; Papathanassoglou, D. A., & Georgouli, C. A. (2009). The 'frying pans'of the early bronze age aegean: an experimental approach to their possible use as liquid mirrors. Archaeometry, 51(4), 658-671.; Tsikritsis, M., Moussas, X., & Tsikritsis, D. (2015). Astronomical and mathematical knowledge and calendars during the early helladic era in aegean" frying pan" vessels. Mediterranean Archaeology & Archaeometry, 15(2).

[30] Περὶ κατασκευῆς ἐσόπτρου δι' οὗ ὡς μυστήρια πάντα φαίνεται Λαβὲ δὲ παρὰ χαλκοῦ, ὑδραργύρου, ἀργύρου, χρυσοῦ, μολίβδου, κασσιτέρου καὶ κρυστάλλου, ἐξ ἴσου ἀμφότερα, καὶ χωνεύσας κατασκεύασον ἐξ αὐτῶν κάτοπτρον οἵου μέτρου βούλει, ὁμοία δὲ ἔσται αὐτοῦ ἡ χροιὰ κρυστάλλῳ οὗ ἔφυ. See English translation

Naturally they are meant and used for cosmetics, to mirror oneself, but also for reflecting light as in the case of Pharos of Alexandria, to burn the fleet of Marcellus, as Archimedes did, possibly to have images of astronomical objects, as it is presented in the following and even for hunting, trapping animals as Athenaeus in his book Deipnosophistae states many times[31].

According to the literature the first scientists to understand the physics and mathematics of reflection are Pythagoras and his followers, as the so called Pseudo-Galenus (Galen) states in his book on the history of science (De historia philosophica)[32] and he continues by saying that Democritus and Epicure have studied the formation of images produced by reflection on

[31] περὶ δὲ τῆς τῶν ὀρτύγων θήρας ἰδίως ἱστορεῖ Κλέαρχος ὁ Σολεὺς ἐν τῷ ἐπιγραφομένῳ περὶ τῶν ἐν τῇ Πλάτωνος Πολιτείᾳ μαθηματικῶς εἰρημένων γράφων οὕτως *οἱ ὄρτυγες περὶ τὸν τῆς ὀχείας καιρόν, ἐὰν κάτοπτρον ἐξ ἐναντίας τις αὐτῶν καὶ πρὸ τούτου βρόχον θῇ, τρέχοντες πρὸς τὸν ἐμφαινόμενον ἐν τῷ κατόπτρῳ ἐμπίπτουσιν εἰς τὸν βρόχον* a description that Atheneaus repeats three times in his book, information that is repeated by Eustathii archiepiscopiin his book *Thessalonicensis commentarii ad Homeri Iliadem pertinentes*.

[32] Pseudo-Galenus, De historia philosophica οἱ ἀπὸ Πυθαγόρου κατὰ τὰς ἀντανακλάσεις τῆς ὄψεως.

mirrors, plane or spherical and how the images they produced are inversed[33].

Plato [*Theaetetus*] uses such an expression *ὥσπερ εἰς κάτοπτρον ἢ ὕδωρ*, referred to an image produced by reflection. Aeschylus in a now lost tragedy says that we use mirrors made of copper [κάτοπτρον εἴδους χαλκός], hence mirrors to be used in a theatrical play have to be common place, known to all. It is evident that there are mirrors made of various materials as Aristoteles[34] in his treatise on colours refers to various colour of various mirrors, and we can conclude that he has in mind mirrors made of water in a container with black bottom onside, polished black stones, copper, silver, gold even. Apollonius the Philosopher in the book *Apotelesmata* part of Patrologia Syriaca[35] gives the

[33] Δημόκριτος καὶ Ἐπίκουρος τὰς κατοπτρικὰς ἐμφάσεις γίνεσθαι κατ' εἰδώλων ἐπιστάσεις, ἅτινα φέρεσθαι μὲν ἀφ' ἡμῶν, συνίστασθαι δὲ ἐπὶ τοῦ κατόπτρου κατὰ ἀντιστροφήν.

[34] Aristoteles *De coloribus* διὸ καὶ καθ' ὕδατος ὑδατοειδῆ μᾶλλον φαίνεται, καὶ τὰ ἐν τοῖς κατόπτροις ὁμοίας ἔχοντα χρόας ταῖς

τῶν κατόπτρων, in water the image is rather water-like, and in mirrors it has the colour of the mirror.

[35] Apollonius, *Apotelesmata, Patrologia Syriaca* Περὶ κατασκευῆς ἐσόπτρου δι' οὗ ὡς μυστήρια πάντα φαίνεται. Λαβὲ δὲ παρὰ χαλκοῦ, ὑδραργύρου, ἀργύρου, χρυσοῦ, μολίβδου, κασσιτέρου καὶ κρυστάλλου, ἐξ ἴσου ἀμφότερα, καὶ χωνεύσας κατασκεύασον ἐξ αὐτῶν κάτοπτρον οἵου μέτρου βούλει, ὁμοία δὲ ἔσται αὐτοῦ ἡ

ingredients necessary to create a mirror, copper, mercury, silver, gold, lead, tin and crystal..

A very important description of astronomical observations with a kind of telescope, a set of mirrors used as a telescope to observe celestial objects is given by Flavius Arrianus (c. 85 to c. 160 AD) who wrote the history of Alexander the Great [*Alexandri anabasis*] in his *Fragmenta de rebus physicis [about physics]* where he is referred to Democritus, the teacher of Hippocrates using this "telescope" to observe planets and the he observed their images[36] and he managed to understand the constituents of the comets. Very interesting is the reference to a wrong story about Democritus by Plutarchus in *De curiositate* where is evident that the great scientist uses burning mirrors, but of course not to punish, kill himself or to become blind[37]. We can infer that Democritus at least

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χροιὰ κρυστάλλῳ οὗ ἔφυ. Θὲς δὲ ὄπισθεν αὐτοῦ πλάκας μικρὰς διαργυρᾶς καὶ γράψον ταῦτα ἐναργῶς·

[36] Δημοκρίτου δὲ ὁ λόγος λεγόμενός ἐστιν, ὡς κατ' ἀντίλαμψιν τῶν πλανωμένων ἀστέρων πρὸς ἀλλήλους τε καὶ τοὺς ἀπλανεῖς οἱ κομῆται ξυνίστασθαι δοκοῦσι, καθάπερ πλειόνων κατόπτρων ἀντιλαμπόντων σφίσιν ἤδη τινὰ ὤφθη ἀστεροειδῆ φαντάσματα.

[37] Plutarchus De curiositate ὅθεν ἐκεῖνο μὲν ψεῦδός ἐστι, τὸ Δημόκριτον ἑκουσίως σβέσαι τὰς ὄψεις ἀπερεισάμενον εἰς ἔσοπτρα πυρωθέντα καὶ τὴν ἀπ' αὐτῶν ἀνάκλασιν δεξάμενον, ὅπως μὴ παρέχωσι θόρυβον τὴν διάνοιαν ἔξω καλοῦσαι πολλάκις, ἀλλ' ἐῶσιν ἔνδον οἰκουρεῖν καὶ διατρίβειν πρὸς τοῖς νοητοῖς, ὥσπερ παρόδιοι θυρίδες ἐμφραγεῖσαι· τοῦτο μέντοι παντὸς μᾶλλον

observed the Sun using mirrors and that naturally avoided destruction of his vision by looking directly at the sun, as he has studied the possibilities of image formation using concave mirrors and he knew how to project images and the Sun is an excellent example that we use even today for students today. Philosopher Apollonius in his book Apotelesmata states that we cannot know everything that happens on the Earth at all latitudes and the sky unless we use a mirror to see clearly[38].Te

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ἀληθές ἐστιν, ὅτι τὴν αἴσθησιν ὀλίγα κινοῦσιν οἱ πλεῖστα τῇ διανοίᾳ χρώμενοι. καὶ γὰρ τὰ μουσεῖα πορρωτάτω τῶν πόλεων ἱδρύσαντο, καὶ τὴν νύκτα προσεῖπον ’εὐφρόνην’, μέγα πρὸς εὕρεσιν τῶν ζητουμένων καὶ σκέψιν ἡγούμενοι τὴν ἡσυχίαν καὶ τὸ ἀπερίσπαστον. [Moralia, first published in 1939. The Greek text and the English translation (by W. C. Helmbold), pp 469-517 of Vol. VI of the Loeb Classical Library, http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Plutarch/Moralia/De_curiositate*.html,

Consequently, though that story about Democritus is false, that he deliberately destroyed his sight by fixing his eyes on a red-hot mirror and allowing its heat to be reflected on his sight, in order that his eyes might not repeatedly summon his intellect outside and disturb it, but might allow his mind to remain inside at home and occupy itself with pure thinking, blocking up as it were windows which open on the street; yet nothing is more true than this, that those who make most use of the intellect make fewest calls upon the senses]

[38] Apollonius in his book Apotelesmata Ὅτε οὖν βούλει τὰ ἐπὶ τοῖς κλίμασιν πᾶσιν τῆς γῆς γινόμενα καὶ ἐν οὐρανῷ καὶ γῇ εἰδέναι, βλέψον καθαρῶς καὶ ἱλαρῶς μετὰ τοῦ ἐσόπτρου καὶ βλέπε ταῦτα.

great mathematician and astronomer Eudoxus hs written a popular stronomy book entited *Mirror* (*ENOPTRON* in Greek) where he gives a description of the sky. One can assume that he uses the title mirror for a book that describes the sky, because they use mirrors to observe the sky.

The philosophers observing comets[39] realize that they contain gasses, jets of gasses, which they rotate. Perhaps the symbol of swastika is a rotating comet with jets emerging and being bend by a change of the solar wind. The conclusion that comets are made of gasses is generalized and this way the Greeks understood correctly that the stars are concentrations of hot gasses. It seems that Anaxagoras observed carefully comet Halley and understood the nature of stars and for this we suggest that comet Halley to be renamed comet Anaxagoras. Another astronomical use is mentioned by the very influential philosopher Aristoteles[40] in his book De Mundo (Περί Κόσμου) when referred to the spectrum of light (Ίρις) writes that iris, the spectrum, appears in the reflection of a part of the Sun or of the Moon when it is in a humid and

[39] Moussas, X. (2014). Early Greek astrophysics: the foundations of modern science and technology. American Journal of Space Science, 1(2), 129.

[40] Aristoteles De mundo Ἶρις μὲν οὖν ἐστιν ἔμφασις ἡλίου τμήματος ἢ σελήνης, ἐν νέφει νοτερῷ καὶ κοίλῳ καὶ συνεχεῖ πρὸς φαντασίαν, ὡς ἐν κατόπτρῳ, θεωρουμένη κατὰ κύκλου περιφέρειαν.

hollow cloud[41]. The same description of observations of spectra seen with mirror is given by Posidonius in his book Meteorologica description given by Diogenes Laertius, as the original book by Posidonius has been lost. It seems that, as Plutarch in the life of Demosthenes describes there were large sized mirrors too.[42] A similar description of Iris is given by the successor of Hippocrates Galen[43]. Anaximander explains the spectra of the Halo around the Sun in terms of reflection of the light from the sensed cloud around the Sun[44].

[41] νοτερῷ καὶ κοίλῳ καὶ συνεχεῖ πρὸς φαντασίαν, ὡς ἐν κατόπτρῳ, θεωρουμένη κατὰ κύκλου περιφέρειαν

[42] Plutarchus, Demosthenes "Plutarchi *vitae parallelae …* εἶναι δ' αὐτῷ μέγα κάτοπτρον οἴκοι, … he has a large mirror at home. Demetrius the historian, mentions a large mirror used at home, and we can cinclude that large mirrors were somewhat common εἶναι δ' αὐτῷ μέγα κάτοπτρον οἴκοι, καὶ πρὸς τοῦτο τὰς μελέτας ἐξ ἐναντίας ἱστάμενον περαίνειν.

[43] Galenus in *De placitis Hippocratis et Platonis*, ὅπως ἡ ἶρις γίγνεται καὶ ὅπως ἄλως ἤτοι περὶ τὸν ἥλιον ἢ τὴν σελήνην οἵ τ' ἀνθήλιοι καὶ οἱ παρήλιοι καλούμενοι τά τε διὰ τῶν κατόπτρων ὁρώμενα διερχόμενος, εἰς ἀνάκλασιν ὄψεως ἀναφέρει πάντα

[44] Anaximander: περὶ ἴριδος ἀνάκλασιν ἀπὸ νέφους πυκνοῦ τῆς ἡλιακῆς περιφεγγείας, καταντικρὺ δὲ τοῦ κατοπτρίζοντος αὐτὴν ἀστέρος διὰ παντὸς ἵστασθαι. παραπλησίως δὲ αἰτιολογεῖται τὰ καλούμενα παρήλια, γινόμενα δὲ κατὰ τὸν Πόντον.

Apollonius of Laodicia in his astrological book *Astrologia Apotelesmatica* says that we use mirros as telescope to see crearly object in the sky and on the ground[45].

Plutarchus in the book *De facie in orbe lunae* stresses that concave mirrors can be used to lit fire covex mirrors not[46]. Plutarch uses the term concave mirror, in his moralia on De Pythiae oraculis where he states that one can have distorted images using mirrors plane and concave[47], in fact the is referred to imaginary images [φασμάτων] and real images [εἰδώλων]. An even more interesting observation going back to Thales observing the eclipse using a mirror, i.e. the earliest predicted eclipse according to Greek literature, is given by the so called Pseudo-Plutarchus, in *Placita philosophorum* in the

[45] Καὶ εἰ τὰ ὑποχθόνια ὁρᾶν θέλεις, βλέψον κάτωθεν τοῦ ἐσόπτρου, καὶ εἰ τὰ ἐν οὐρανῷ,

θέασαι εἰς τὸ ἀνώτερον μέρος τοῦ ἐσόπτρου καὶ ἴδοις ἐξαίσια, καὶ εἰ τὴν ὄψιν μὴ ἀπο-

στρέψεις, ἐν ἀγωνίᾳ γενήσει.

[46] καὶ γὰρ ἄλλως τὰ μὲν κοῖλα τῶν ἐσόπτρων εὐτονωτέραν ποιεῖ τῆς προηγουμένης αὐγῆς τὴν ἀνακλω-

μένην, ὥστε καὶ φλόγας ἀναπέμπειν πολλάκις, τὰ δὲ κυρτὰ καὶ τὰ σφαιροειδῆ τῷ μὴ πανταχόθεν ἀντερείδειν ἀσθενῆ καὶ ἀμαυράν

[47] ἐν κατόπτροις ἐπιπέδοις τε καὶ κοίλοις καὶ περιαγέσι φασμάτων [imaginary image] καὶ εἰδώλων [real image] ἀφ' ἑνὸς εἴδους μυρίας παρατυπώσεις

section about eclipses of the Sun[48], where it is written that Thales first predicted the eclipse of the Sun by the Moon and underlines that during the solar eclipse one can see the earth-like nature of the Moon (as one can see the irregularities of the mountains of the Moon). Albinus in the book Epitome doctrinae Platonicae or Didascalicus[49] is referred to plane concave and convex mirrors that define the type of images that can be formed.

The Greeks study methodically the physics and use of mirrors. Lucianus in his book *Hippias*[50] says that children study the theory of optics concerning the reflections on mirrors and astronomy. Eudoxus has written a treatise on mirrors[51].

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[48] Pseudo-Plutarchus, in Placita philosophorum Περὶ ἐκλείψεως ἡλίου. Θαλῆς πρῶτος ἔφη ἐκλείπειν τὸν ἥλιον τῆς σελήνης αὐτὸν ὑποτρεχούσης κατὰ κάθετον, οὔσης φύσει γεώδους·βλέπεσθαι δὲ τοῦτο κατοπτρικῶς ὑποτιθεμένῳ τῷ δίσκῳ.

[49] Albinus in *Epitome doctrinae Platonicae* or *Didascalicus* κατὰ τῶν κατόπτρων εἰδωλοποιΐας καὶ τῶν ἄλλων ὅσα διαφανῆ καὶ λεῖα οὐκ ἄλλως ἢ κατὰ ἀνάκλασιν συντελεῖσθαι, ὡς ἂν ἔχῃ τὸ κάτοπτρον κυρτότητος ἢ κοιλότητος ἢ μήκους· διάφοροι γὰρ ἔσονται φαντασίαι, ἀνταπωθουμένων τῶν φώτων πρὸς τὰ μέρη τὰ ἕτερα, ἀπολισθαινόντων μὲν τῆς κυρτότητος, εἰς δὲ τὴν κοιλότητα συνιόντων.

[50] τὴν μὲν γὰρ περὶ ἀκτίνων καὶ ἀνακλάσεων καὶ κατόπτρων θεωρίαν, ἔτι δὲ ἀστρονομίαν

[51] Εὐδόξου ἐπιγραφόμενον βιβλίον *Κάτοπτρον* δόντος αὐτῷ καὶ ἀξιώσαντος τὰ ἐν αὐτῷ καταλογάδην λεχθέντα περὶ τῶν

Euclids in *Catoptrica*[52] describes geometrically the reflection of light on a spherical mirror without the involvement of an eye and this proves that the notion of rays emitted by the eye is a misunderstanding of interpreters. He takes the sun as a sorce of light to have parallel beams of light and describes the focusing of these lines (rays).

The theory of multiple relfections is studied in Euclids *Catoptrica*. It no surprise that Archimedes[53] constructs

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φαινομένων μέτρῳ ἐντεῖναι καὶ ἅμα εἰπόντος, ὡς «εὐδοξότερον ποιεῖς τὸν Εὔδοξον ἐντείνας τὰ παρ' αὐτῷ κείμενα μέτρῳ.

[52] Ἐκ τῶν κοίλων ἐνόπτρων πρὸς τὸν ἥλιον τεθέντων πῦρ ἐξάπτεται. ἔστω κοῖλον ἔνοπτρον τὸ ΑΒΓ, ἥλιος δὲ ὁ ΕΖ, κέντρον δὲ τοῦ κατόπτρου τὸ Θ, καὶ ἀπό τινος σημείου τοῦ Δ ἐπιζευχθεῖσα μὲν ἐπὶ τὸ Θ κέντρον ἡ ΔΘ ἐκβεβλήσθω ἐπὶ τὸ Β, προσπεπτωκέτω δὲ ἡ ΔΓ ἀκτὶς καὶ ἀνακεκλάσθω ἐπὶ τὸ Κ. ἀνακλασθήσεται δὴ ἐπάνω τοῦ Θ κέντρου· …

[53] Diodorus Siculus in his, Bibliotheca historica … ὁ γέρων … ἐξάγωνόν τι κάτοπτρον ἐτέκτηνεν ὁ γέρων· ἀπὸ δὲ διαστήματος συμμέτρου τοῦ κατόπτρου μικρὰ τοιαῦτα κάτοπτρα θεὶς τετραπλᾶ γωνίαις κινούμενα λεπίσι τε καί τισι γιγγλυμίοις, μέσον ἐκεῖνο τέθεικεν ἀκτίνων τῶν ἡλίου μεσημβρινῆς καὶ θερινῆς καὶ χειμεριωτάτης.

And Cassius in his book Historiae Romanae καὶ τέλος σύμπαν τὸ ναυτικὸν τῶν Ῥωμαίων παραδόξως κατέπρησε. κάτοπτρον γάρ τι πρὸς τὸν ἥλιον ἀνατείνας τήν τε ἀκτῖνα αὐτοῦ ἐς αὐτὸ εἰσεδέξατο καὶ τὸν ἀέρα ἀπ' αὐτῆς τῇ πυκνότητι καὶ τῇ λειότητι τοῦ κατόπτρου πυρώσας φλόγα τε μεγάλην ἐξέκαυσε καὶ πᾶσαν αὐτὴν ἐς τὰς ναῦς ὑπὸ τὴν τοῦ πυρὸς ὁδὸν ὁρμούσας ἐνέβαλε καὶ πάσας κατέκαυσεν.

hexagonal mirrors that he can move (in four variable angles, probably two for every hexagonal mirror and two angles for the system of all mirrors together) remotely and direct them from a distance, regardless of the position of the Sun, using strings to focus at a target in the way we use today, even NASA for the James Webb Space Telescope[54]. Anthemius describes focusing light in burning mirrors, using seven convex mirrors each one with each own fire, like the cluster of mirrors used by Archimedes, possibly similar to the Pharos system o mirrors[55]. Anthemius describes another complex optical

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And in another version we read ὡς Μάρκελλος δ' ἀπέστησε βολὴν ἐκείνας τόξου, ἐξάγωνόν τι κάτοπτρον ἐτέκτηνεν ὁ γέρων, ἀπὸ δὲ διαστήματος συμμέτρου τοῦ κατόπτρου μικρὰ τοιαῦτα κάτοπτρα θεὶς τετραπλᾶ γωνίαις κινούμενα λεπίσι τε καί τισι γιγγλυμίοις μέσον ἐκεῖνο τέθεικεν ἀκτίνων τῶν ἡλίου μεσημβρινῆς καὶ θερινῆς καὶ χειμεριωτάτης.

[54] Gardner, J. P., Mather, J. C., Clampin, M., Doyon, R., Greenhouse, M. A., Hammel, H. B., ... and Lunine, J. I. (2006). *The James Webb space telescope*. *Space Science Reviews*, 123, 485-606.

[55]κάλλιον δὲ ἡ αὐτὴ ἔξαψις γενήσεται, εἰ τέτρασιν ἢ καὶ πέντε ἐσόπτροις δοθείη τὰ τοιαῦτα πυρία ἀνὰ ἑπτὰ ὄντα τὸν ἀριθμὸν καὶ ἀφεστῶσι σύμμετρον ἀλλήλων διάστημα κατ' ἀναλογίαν τοῦ τῆς ἐξάψεως διαστήματος, ὥστε τὰς ἀκτῖνας τὰς ἀπ' αὐτῶν τεμνούσας ἀλλήλας πλέον δύνασθαι ποιεῖν τὴν εἰρημένην ἐκπύρωσιν· ἐν ἑνὶ γὰρ τόπῳ τῶν ἐσόπτρων ὄντων κατ' ὀξυτάτας γωνίας αἱ ἀνακλάσεις ἀλλήλας τέμνουσιν, ὥστε σχεδὸν πάντα τὸν περὶ τὸν ἄξονα τόπον θερμαινόμενον δια πυροῦσθαι καὶ μὴ πρὸς τὸ δοθὲν καὶ μόνον σημεῖον γίνεσθαι τὴν ἐκπύρωσιν. διὰ μὲν οὖν τῆς τῶν εἰρημένων ἐσόπτρων ἤτοι πυρίων κατασκευῆς ἥ τε ἔξαψις πρὸς τὸ δοθὲν

system with several mirrors.[56] Anthemius describes an interesting practice at war with strearable mirrors attached on shields of the soldiers and used to dazzle and blind the army of the opponents by reflecting easily the sunlight to the eyes of the soldiers of the enemy[57], so it seams that reflecting the sunrays in a coherent way was common practice.

This type of seven hexagonal or more mirrors is in use in modern astronomy and even the *James Webb* new space telescope will be using this technique. The Byzantie hilosopher and historian Michael Psellus (c. 1017 to c. 1096) in the book *Oratoria minora* 1017 or 1018, and is believed to have died in

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διάστημα δύναιτο γίνεσθαι καὶ τὰ ἄλλα τὰ ῥηθέντα· καὶ γὰρ οἱ μεμνημένοι περὶ τῶν ὑπὸ Ἀρχιμήδους τοῦ θειοτάτου κατασκευασθέντων ἐκκαῦσαι οὐ δι' ἑνὸς ἐμνημόνευσαν πυρίου ἀλλὰ διὰ πλειόνων, καὶ οἶμαι μὴ εἶναι τρόπον ἕτερον τῆς ἀπὸ τούτου τοῦ διαστήματος ἐκκαύσεως.

[56] εἰ τοίνυν ἐν τῷ αὐτῷ ἐπιπέδῳ τοῦ μέσου κατόπτρου ποιήσομεν εἶναι καὶ τὰ πέριξ ἕσοπτρα, ἡ ἀνάκλασις δηλονότι ὁμοίως τῇ πάσῃ συνθέσει γενήσεται

[57] δύναται δὲ διὰ τῆς τῶν αὐτῶν ἐπιπέδων ἐσόπτρων κατασκευῆς καὶ τὴν τῶν πολεμίων ἀμαυροῦσθαι ὄψιν, ὡς μὴ καθορᾶν, ὅπου βαδίζουσιν, εἰ ἐπέρχονται τῶν τοιούτων κατόπτρων ἐπιπέδων ἔχοντὰς κατασκευὰς πηγνυμένων τε ἐν τοῖς ὑπεράνω μέρεσιν τῶν ἀσπίδων καὶ ἔσωθέν πως περιαγομένων, ὥστε πρὸς τοὺς πολεμίους, καθὰ εἴρηται, τὰς ἡλιακὰς ἀνακλάσεις τρέπεσθαι καὶ διὰ τοῦτο εὐχερῶς [to reflect easily] δύνασθαι, ὡς εἴρηται, αὐτῶν καταγωνίζεσθαι

1078, although it has also been maintained that he remained alive until 1096 adds to the description of burning mirrors that tArchimedes mirrors can that focus automatically can set fire at a distance[58] and he adds that [cat]optrician and engineer has not olny to follow the appropriate education but theoretical proofs too[59]. Psellus adds that mirrors made of glass with a layer of tin are much better as the anomalies of the surface of glass are very small and tin doubles the reflectability of the mirror and tat all smooth bodies reflect light regardless if they are a coin, or mage of ilver or proper mirrors and this shows that theory of reflection is taught during the Christian times in the Byzantium[60].

The theory on the applications of hexagonal mirrors is given by Anthemius of Tralles (c. 474 – 533 or 558) an excellent mathematician and renown architect in Constantinople, the capital of the estern Roman Empire, the so called Byzantium that with Isidorus of Miletus designed and constructed the

[58] κάτοπτρόν τέ μοι ἐξείργαστο ἀφ' οὗ δὴ πῦρ αὐτομάτως ἐξαλλόμενον τὸ ἐκ διαστήματος παρατιθέμενον παραδόξως τεφροῖ.

[59] ὁ δέ γε κατοπτρικὸς καὶ μηχανικός, ἢ ὅστις ἕτερος ὑπὸ τὰ τέσσερα τελοίη μαθήματα, πολλοῦ γε δεήσει γνῶναι τὰ ὑποκείμενα μὴ χρησάμενος εἰς ἀπόδειξιν ταῖς ὑπερκειμέναις ἀρχαῖς.

[60] Michael Psellus *Opuscula psychologica, theologica, daemonologica* Πᾶν σῶμα τὴν τοῦ φωτὸς δεχόμενον ἐνέργειαν πέφυκε καὶ αὐτὸ τὴν αὐτὴν ἀντιπέμπειν, ἐξαιρέτως δὲ τὰ λεῖα, ἀργύριον, ἔσοπτρον, ὕδωρ.

Hagia Sophia (532-537) at te time of emperor Justinian. Anthemius wrote an important work on *On surprising mechanisms* (Περὶ παραδόξων μηχανημάτων) in which he gives theoretical proofs of theorems concerning reflection on mirrors[61]. Anthemius describes the burning mirros of Arrchimedes (without mentioning the great mathematician) with uptiple reflections on many hexagonal mirrors moved remotely with a system of strings and blades used to burn from a distance[62].

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[61] ἐπεζεύχθω γὰρ ἀπὸ τοῦ Α ἐπὶ τὸ Γ εὐθεῖα, τετμήσθω ἡ ὑπὸ ΒΑΓ γωνία δίχα τῇ ΑΔ εὐθείᾳ, καὶ διὰ τοῦ Α νοείσθω ἐπίπεδον ἔσοπτρον τὸ ΕΑΖ πρὸς ὀρθὰς τῇ

ΑΔ εὐθείᾳ· δῆλον ἔσται αὐτόθεν ἐκ τῶν προδεδειγμένων, ὡς ἡ ΒΑ ἀκτὶς προσπίπτουσα ἐπὶ τὸ ΕΑΖ ἔσοπτρον ἀνακλασθήσεται ἐπὶ τὸ Γ· ὅπερ ἔδει ποιῆσαι.

[62] On surprising mechanisms by Anthemius of Tralles, whose manuscript tradition depends entirely on the opening bifolium of the Vat. gr. 218 (critical editions in MGM, 78–87, andCG, 349–59), ἵνα δὲ μὴ δυσχεραίνωμεν πλείοσιν τοῦτο ἐπιτάττοντες εὑρίσκομεν γὰρ, ὡς οὐκ ἔλαττον κδ ἀνακλάσεων χρῄζει τὸ ὀφεῖλον ἐξαφθῆναι· κατασκευάσωμεν οὕτως·ἔστω ἐπίπεδον ἐξαγωνικὸν ἔσοπτρον τὸ ΑΒΓΔΕΖ καὶ τούτῳ παρακείμενα ἕτερα ὅμοια ἔσοπτρα ἐξαγωνικὰ καὶ συνημμένα τῷ προτέρῳ κατὰ τὰς εἰρημένας ΑΒ, ΒΓ, ΓΔ, ΔΕ, ΕΖ, ΖΑ εὐθείας ἀπὸ ἥττονος ὀλίγῳ διαμέτρου, δυνάμενα δὲ κινεῖσθαιπερὶ τὰς εἰρημένας εὐθείας ἢ λεπίδων συναπτῶν προσκολλιζομένων αὐτοῖς ἢ τῶν λεγομένων γιγλυμίων. … ἔστω ἐπίπεδον ἐξαγωνικὸν ἔσοπτρον τὸ ΑΒΓΔΕΖ καὶ τούτῳ παρακείμενα ἕτερα ὅμοια ἔσοπτρα ἐξαγωνικὰ καὶ συνημμένα τῷ προτέρῳ κατὰ τὰς εἰρημένας ΑΒ, ΒΓ, ΓΔ, ΔΕ, ΕΖ, ΖΑ εὐθείας ἀπὸ ἥττονος ὀλίγῳ

Plutarchus in *De facie in orbe lunae* describes convex mirrors or pairs of mirrors inclined at an angle to give four images, two of them inversed two right handed and two left handed[63].

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διαμέτρου, δυνάμενα δὲ κινεῖσθαι περὶ τὰς εἰρημένας εὐθείας ἢ λεπίδων συναπτῶν προσκολλιζομένων αὐτοῖς ἢ τῶν λεγομένων γιγλυμίων. εἰ τοίνυν ἐν τῷ αὐτῷ ἐπιπέδῳ τοῦ μέσου κατόπτρου ποιήσομεν εἶναι καὶ τὰ πέριξ ἔσοπτρα, ἡ ἀνάκλασις δηλονότι ὁμοίως τῇ πάσῃ συνθέσει γενήσεται. εἰ δὲ μένοντος τοῦ μέσου ὡσανεὶ ἀκινήτου διά τινος ἐπινοίας εὐχερῶς προστιθεμένης ἅπαντα τὰ πέριξ ἐπὶ τὸ μέσον ἐπινεύσομεν, δῆλον, ὡς καὶ αἱ ἀπ' αὐτῶν ἀνακλώμεναι ἀκτῖνες ἐπὶ τὸν μέσον τόπον τοῦ ἐξ ἀρχῆς ἐσόπτρου παραγίνονται. τὸ αὐτὸ δὴ ποιοῦντες καὶ ἕτερα πέριξ περιτιθέντες τῶν εἰρημένων ἔσοπτρα καὶ δυνάμενα νεύειν ἐπὶ τὸ μέσον καὶ τὰς ἀπ' αὐτῶν ἀκτῖνας εἰς τὸ αὐτὸ συναγάγωμεν, ὥστε συναγομένας ἁπάσας κατὰ τὸν εἰρημένον τρόπον τὴν ἔξαψιν ἐν τῷ δοθέντι τόπῳ ποιῆσαι.

see Acerbi, F. (2011). The geometry of burning mirrors in Greek antiquity. Analysis, heuristic, projections, lemmatic fragmentation. Archive for History of Exact Sciences, 65(5), 471–497. https://doi.org/10.1007/S00407-010-0076-8.

[63] Plutarchus in De facie in orbe lunae … δ' εἰπεῖν ὅτι τὸ πρὸς ἴσας γίνεσθαι γωνίας ἀνάκλασιν πᾶσαν οὔτε φαινόμενον αὐτόθεν οὔθ' ὁμολογούμενόν ἐστιν, ἀλλὰ διαβάλλεται μὲν ἐπὶ τῶν κυρτῶν κατόπτρων [convex mirrors], ὅταν ἐμφάσεις ποιῇ μείζονας ἑαυτῶν πρὸς ἓν τὸ τῆς ὄψεως σημεῖον, διαβάλλεται δὲ τοῖς διπτύχοις κατόπτροις [double mirrors, pair of mirrors], ὧν ἐπικλιθέντων [inclined] πρὸς ἄλληλα καὶ γωνίας ἐντὸς γενομένης ἑκάτερον τῶν ἐπιπέδων διττὴν ἔμφασιν ἀποδίδωσι καὶ ποιεῖ τέτταρας εἰκόνας [four images] ἀφ' ἑνὸς προσώπου, δύο μὲν ἀντιστρόφους τοῖς

Plutarch describes multiple reflection o convex mirrors with light rays following straight lines ending in our eyes. Olympiodorus in his comment on Aristotle's meteora[64] says that we should not observe the Sun with a mirror, as we can do observing thw iris (spectrum) of a cloud.

There are around 1000 references to mirrors in religious texts, the New Testament by Paul the Apostle in his First Epistle to the Corinthians and numerous more by prominent theoligians, like Basilius, Joannes Chrysostomus, Gregorius Nyssenusm, Gregorius Nazianzen, wich probably means that all the common people know very well the use of mirrors, as they are frequently referred to the qualities of the image for example,

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ἔξωθεν ἀριστεροῖς μέρεσι, δύο δὲ δεξιοφανεῖς ἀλλ' ἀμαυρὰς ἐν βάθει τῶν κατόπτρων, and repeats διαβάλλεται μὲν ἐπὶ τῶν κυρτῶν κατόπτρων, ὅταν ἐμφάσεις ποιῇ μείζονας ἑαυτῶν πρὸς ἓν τὸ τῆς ὄψεως σημεῖον, διαβάλλεται δὲ τοῖς διπτύχοις κατόπτροις, ὧν ἐπικλιθέντων πρὸς ἄλληλα καὶ γωνίας ἐντὸς γενομένης ἑκάτερον τῶν ἐπιπέδων διττὴν ἔμφασιν ἀποδίδωσι καὶ ποιεῖ τέτταρας εἰκόνας ἀφ' ἑνὸς προσώπου, δύο μὲν ἀντιστρόφους τοῖς ἔξωθεν [ἀριστεροῖς] μέρεσι, δύο δὲ δύο δὲ δεξιοφανεῖς ἀλλ' ἀμαυρὰς ἐν βάθει τῶν κατόπτρων. ὧν τῆς γενέσεως τὴν αἰτίαν Πλάτων εἴρηκε γὰρ ὅτι τοῦ κατόπτρου ἔνθεν καὶ ἔνθεν ὕψος λαβόντος ὑπαλλάττουσιν αἱ ὄψεις τὴν ἀνάκλασιν ἀπὸ τῶν ἑτέρων ἐπὶ θάτερα μεταπίπτουσαν. εἴπερ οὖν τῶν ὄψεων εὐθὺς πρὸς ἡμᾶς …

[64] Olympiodorus in Aristotelis meteora commentaria ἐνοπτρίζεσθαι ἐν τῷ νέφει ὥσπερ ἐπὶ τῶν κατόπτρων, καὶ οὐ πρὸς τὸν ἥλιον, ὡς γίνεσθαι τὴν ἶριν.

that depends upon the anomalies of the surface and to the reflecton of the Sun on a mirror that they compare with tht image of God or Jesus that we perceive. Almost all comments are refered to the Apostole Paul epistule to the Corinthians sentence on mirror « now we see as in a dazzled, blurred mirror and we have unexplained riddles ».

## Complex ancient optical instruments, multiple reflections, possibly telescopes

The use of multiple mirrors is mentioned by many philosophers. The Astronomer Geminus in his *Fragmenta optica* defines catoptrics as the science that studies multiple reflections[65], even around turning mirrors.

Is it really possible that ancient people, philosophers and scientists constructed complex optical systems, instruments and even telescopes? We tend to belittle, to underestimate, the ancient people, despite the fact that all the foundations of our present day civilization have been prepared very carefully by the ancient philosophers and scientists, we tend to forget that today's philosophy, technology, science, medicine, architecture and everything are just the continuation of the ancient. We do not expect the ancient people to have

[65] κατοπτρικὸν δὲ λέγεται ὁλοσχερέστερον μὲν τὸ περὶ τὰς ἀνακλάσεις τὰς ἀπὸ τῶν λείων, οὐ μόνον περὶ ἓν κάτοπτρον, ἔστι δ' ὅτε καὶ περὶ πλείω στρεφόμενον

developed optics either. Alexandrian philosophers and scientists in fact have developed all the means, theoretical and practical in optics. In ancient Greece they use the term catoptrics for optics of today, as the mainly deal with mirrors. The wealth of scientific and philosophical terminology proves the advancement of science and philosophy. Hesychius of Alexandria, who lived during the 5th or 6th century AD has written an old Encyclopaedia[66] based on previous similar work by Aristarchus of Samothrace, Apion of Alexandria and and Heliodorus of Alexandria, where he defines of 50,000 rare Greek terms that he has prepared using the Library of Alexandria, many of them of philosophy, science and technology. Hesychius gives an account of spectacles, in his lexicon that describes a scientific instrument called *astravister* (ἀστραβιστήρ), the etymology means an instrument that makes it right, or that it corrects the vision, usually assumed to be an instrument used in levelling for architecture and surveying and opening tunnels. Hesychius explains that it is an instrument like dioptron[67]. He also describes the *diaetron*

[66] called Συναγωγή Πασῶν Λέξων κατά Στοιχεῖον έκ των Άριστάρχου και Άπίωνος και Ηλιοδώρου

[67] Hesychius, *Lexicon* [Συναγωγὴ Πασῶν Λέξεων κατὰ Στοιχεῖον], entry 7886: *ἀστραβιστήρ* ὄργανόν τι, ὡς δίοπτρον and he writes in entry δίαιτρον (something that consists of two items, that it is a dioptron [δίοπτρον] that is transparent [διαφανές] and for the term κάτοπτρα[assumed to be mirrors in plural, he explains that it is a dioptron δίοπτρον.

(δίαιτρον) which is another optical instrument that consists of two items, possibly lenses, which it is a dioptron [δίοπτρον] that is transparent [διαφανές] and for the term catoptra (κάτοπτρα), assumed to be mirrors in plural, he explains that it is a dioptron δίοπτρον.

In another lexicon, an encyclopaedia by Pseudo-Zonaras we learn that *dioptra*[68] is an instrument with a mirror. Dioptra in Modern Greek means telescope and perhaps Zonaras is refered to an instrument that enables to see from a distance. It is a geodetic instrument too that enables to measure the hight of the walls of the enemy from a distance[69] and used in coonstructions too.

It is believed that Nero[70] had myopia and had to use a lens made of emerald[71] to see the games, the gladiators fighting.

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[68] Διόπτρα κάτοπτρον.

[69] ἢ μηχανικὸν τεχνούργημα, δι' οὗ οἱ γεωμέτραι ἀπεκρίβουν τὴν τῶν ἐπάλξεων ἐκ διαστήματος ἀναμέτρησιν

[70] Iidem," (Smaragdi) " plerumque et con- cavi, tit visum eolligant, Quapropter decreto hominum, its parcitur, scalpi vetitis. Quorum vero corpus externum est, eadem qua specula ratione, supini, imagines rerum reddunt. Emeralds are mostly concave, that they may collect the sight. Hence, by the common consent of men, they ...

[71]Nero's Emerald (1926)The British Journal of Ophthalmology 10.9: 489–494; Esser A. (1951) Nero's emerald glass, Klin Monbl Augenheilkd Augenarztl Fortbild.;118(2):185-7.; Markovic A., (1954)

The Greeks used spherical water containers made of glass for magnification[72]. Russo discusses the possible use of telescopes. Russo noticed that the term αυλός, tube, that might be a misprint of the term ύαλος (glass, and hence lens), to mean a telescope made with two lenses at the end of a tube.

Philolaus (probably c. 470 – c. 385 BC), the well-known Pythagorean philosopher that mentions a non-geocentric Cosmos, introducing a quasi-heliocentric system, discussing the nature of the Sun[73] states that the local star is made of a substance that is glass-like, that focuses the light of the cosmos and like a concave mirror. Hence we can conclude that at the time of Pythagoras the focusing qualities of both lenses and concave mirrors were well known to the scientific and philosophical community.

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The question of Nero's emerald representing a dioptric or a catoptric object, Wien Klin Wochenschr. 66(42):811-4. In German.;

[72] Rubin, M. L. (1986). Spectacles: Past, present, and future. Survey of Ophthalmology, 30(5), 321-327.

[73] Pseudo-Plutarchus*, Placita philosophorum*: Φιλόλαος ὁ Πυθαγόρειος ὑαλοειδῆ, δεχόμενον μὲν τοῦ ἐν τῷ κόσμῳ πυρὸς τὴν ἀνταύγειαν, διηθοῦντα δὲ πρὸς ἡμᾶς τὸ φῶς, ὥστε προσεοικέναι ἡλίῳ τὸ ἐν τῷ οὐρανῷ πυρῶδες τό τε δὴ ἀπ' αὐτοῦ καὶ ἐσοπτροειδές, καὶ τρίτον τὴν ἀπὸ τοῦ ἐσόπτρου κατ' ἀνάκλασιν διασπειρομένην πρὸς ἡμᾶς αὐγήν· καὶ γὰρ ταύτην προσονομάζομεν ἥλιον οἱονεὶ εἴδωλον εἰδώλου.

The great philosopher and statesman Posidonius that was an important astronomer and physicist with good knowledge of mathematics, who had a Philosophical School (University) at Rhodes, with many important students including Cicero informs us that Democritus[74] has observed stars and comets with complex astronomical instruments made with multiple reflections and concluded that the comets are made of many stars together. It seems that Democritus probably has observed a fragmented comet that passed near the Earth. Democritus and Anaxagoras in *Scholia In Aratum* are said to have used mirrors (in plural) to observe comets[75] that are made of two planets (movingbodies).

Posidonius in another fragment says that mirror observations and images include clouds, spectra (iris), halos, comets etc[76]. Posidonius trying to explain the phenomenon of coloured halo around the Sun or the Moon suggests a circular arrangement

[74] Posidonius: Δημοκρίτου δὲ ὁ λόγος λεγόμενός ἐστιν, ὡς κατ' ἀντίλαμψιν τῶν πλανωμένων ἀστέρων πρὸς ἀλλήλους τε καὶ τοὺς ἁπλανεῖς οἱ κομῆται ξυνίστασθαι δοκοῦσι, καθάπερ πλειόνων κατόπτρων ἀντιλαμπόντων σφίσιν ἤδη τινὰ ὤφθη ἀστεροειδῆ φαντάσματα.

[75] Δημόκριτος δὲ καὶ Ἀναξαγόρας κατὰ σύλληψιν δύο πλανωμένων ἠνίκα πλησίον ἀλλήλων γένωνται καθάπερ ἐσόπτρων ἀντιλαμπόντων ἀλλήλοις τοὺς κομήτας συνίσταςθαι λέγουσι.

[76] αἰτία τῆς κατοπτρικῆς φαντασίας, ὅπως νέφη συνίσταται, βρονταὶ καὶ ἴριδες καὶ ἅλως καὶ κομῆται καὶ τὰ παραπλήσια

of many small mirrors that construct a big circular mirror around the celestial object[77] and as they are very small all one can observe is the colour[78].

An interesting reference to a mirror and a dioptra made by the theologian Gregorius Nyssenus in the book *Adversus Arium et Sabellium de patre et filio* where he states that as we see our image in a mirror we can see too the Father with a dioptra[79].

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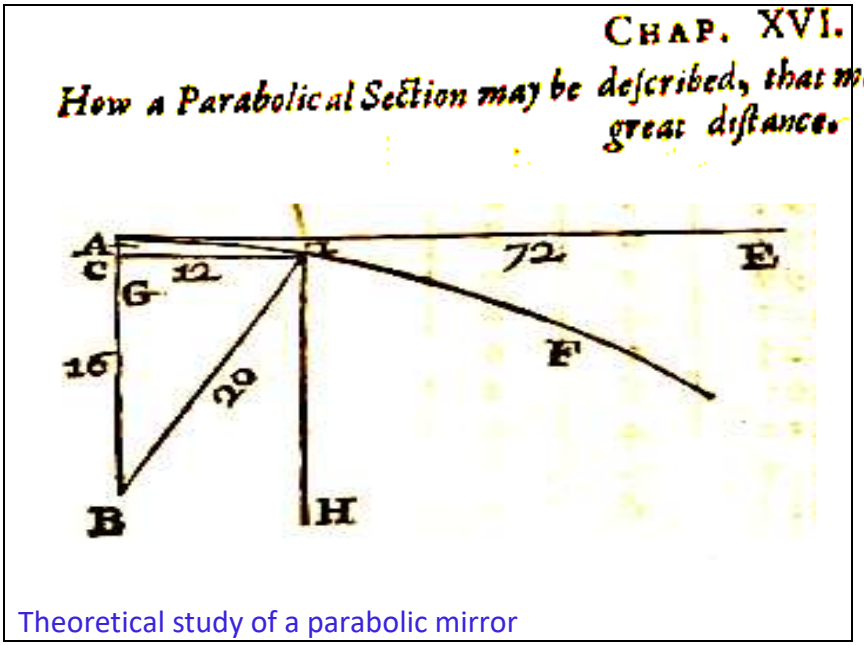
[77] ἀφ' οὗ τὸ ἐπέκεινα πάλιν μᾶλλον μὲν συνέστηκεν, ὁμαλὲς δ' ὂν καὶ μικρομερὲς συνεχῆ καὶ μικρὰ κάτοπτρα κατὰ τὴν τοῦ κύκλου περιφέρειαν ἴσχει, πρὸς ἃ κατὰ μὲν τοὺς τὴν τῆς ὄψεως ἀνάκλασιν αἰτιωμένους ἡ ὄψις προσπεσοῦσα ἀνακλασθεῖσα πρὸς τὸ ἄστρον τὴν τῆς ἄλω φαντασίαν ποιεῖ, κατὰ δὲ τὸ ἀληθὲς τὸ φῶς τὸ τοῦ ἄστρου προσπῖπτον τοῖς προειρημένοις κατόπτροις, ἔπειτα ἐπὶ τὴν ὄψιν τὴν ὁρῶσαν ἀνακλασθέν τε καὶ διαδοθὲν ποιεῖ τὴν φαντασίαν τῆς ἅλω.

[78] Ἶριν δὲ εἶναι αὐγὰς ἀφ' ὑγρῶν νεφῶν ἀνακεκλασμένας ἥ, ὡς Ποσειδώνιός φησιν ἐν τῇ Μετεωρολογικῇ, ἔμφασιν ἡλίου τμήματος ἢ σελήνης ἐν νέφει δεδροσισμένῳ, κοίλῳ καὶ συνεχεῖ πρὸς φαντασίαν, ὡς ἐν κατόπτρῳ φανταζομένην κατὰ κύκλου περιφέρειαν

[79] καὶ δι' ἑαυτοῦ ὥσπερ δι' ἐσόπτρου τὸ ὅλον ἡμῖν μέγεθος τοῦ θεοῦ παραφήνας, ἵν' ὥσπερ διόπτρᾳ τούτῳ χρησάμενοι καὶ τοῦ πατρὸς θεαταὶ γενώμεθα




Theoretical study of a parabolic mirror

## Optical systems at Pharos?

The renowned lighthouse of Alexandria, the Pharos, one of the Seven Wonders of the World, has been sheding light 50 km, some even say 300 km, to the sea guiding sailors in southern Mdeterranean sea. This remarkable building has been standing from 280 B.C. until 1350 A.D., when is has been

demolished by a serious earthquake[80]. There are some references and indications concerning possible optical systems used at the Pharos. An ancient Arab scholar, the geographer Al Muqaddisi (also el-Mukaddasi or al-Maqdisī, 945/946 - 991)), in his book "Guide for Alexandria" [p. 104] states that a mirror was used as a telescope at the top of the Pharos with which they could see every ship passing by at a distance. Here we have a similar detailed description of telescope made of a mirror of glass from another book *The Itinerary of Benjamin of Tudela*[81], a Jewish geographer (born at Tudela, Kingdom of Navarre, 1130 – Castile, 1173) *On the top of the tower there is a glass mirror. Any ships that attempted to attack or molest the city, coming from Greece or from the Western lands, could be seen by means of this mirror of glass at a distance of twenty days' journey, and the inhabitants could thereupon put themselves on their guard.* Benjamin continues describing how a Greek captain destroyed the telescope so that they could not see the Greek and other boats travellig in the Mediterranean and thereafter the Greeks could recapture Crete and Cyprus.

[80] H. Thiersch, (1909), Pharos, Antike Islam und Occident – Ein Beitrag zur Architekturgeschichte;B. G. Teubner, Leipzig und Berlin 1909.

[81] The Itinerary of Benjamin of Tudela, by Benjamin of Tudela, The Project Gutenberg EBook, Critical text, translation and commentary, By Marcus Nathan Adler, first published by Philipp Feldheim, Inc. The House of the Jewish book, New York, First edition: Henry Frowde, Oxford University Press, London, 1907

Al-Hassan al-Heitham[82], called Ptolemaeus Secundus (965 - 1040) has studied optics at Cairo, the eye the lenses as well as mirror focusing of convex, concave and especially cylindrical mirrors. It is very probable that the Pharos had a "cylindrical" mirror used as a telescope, based on the works of Archmedes. This type of cylindrical mirror at the top of the Pharos could have been a paraboliodal mirror probably combined with a hyperboloidal mirror. This hypothesis is based on the work of Archimedes that survived in Arabic translation by Thābit ibn Qurra (836–901) and into Latin by Gerard of Cremona (1114–1187).

Abū ʿAlī al-Ḥasan ibn al-Ḥasan ibn al-Haytham usually named Al-Hassan al-Heitham has written four books of which only one survived. One book summarizing Optics based on the two books of Euclid and Ptolemy, with he has added the notions, one book *Treatise on Burning Mirrors* and one more on the *Nature of Sight and How Vision is Achieved*[83], and three more

[82] Rashed, Roshdi (2007), The Celestial Kinematics of Ibn al-Haytham, Arabic Sciences and Philosophy, Cambridge University Press, R. Rashed (1968), Le Discours de la lumière d'Ibn al-Haytham (Alhazen), Traduction française critique, Revue d'histoire des sciences et de leurs applications. *21*, 3.

[83] Alhacen's theory of visual perception: a critical edition, with English translation and commentary, of the first three books of Alhacen's *De aspectibus*, the medieval Latin version of Ibn al-Haytham's Kitab al-Manazir, edited by A. Mark Smith (2001), Transactions of the American Philosophical Society; *91*, 4 and 5, 14.

treatises entitled *Treatise on Spherical Burning Mirrors, Treatise on Parabolic Burning Mirrors and Treatise on the Burning Sphere*.

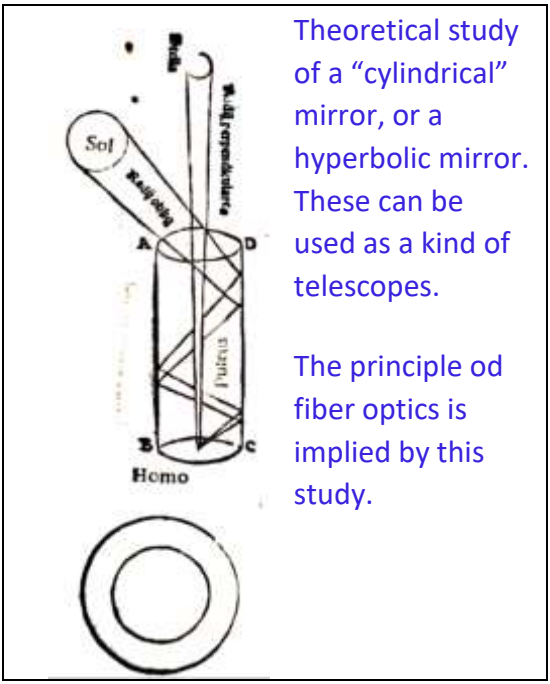
/These medieval scientific books on optics are very important and they show that based on Alexandrian philosophers works, most of them now lost, of Euclide, Diocles, Apollonius, Archimedes, Heron, Ptolemy and other, medieval, mainly Islamic Arabic scientific texts continue developing optics and that there is continuation in science. In some of these books optical systems of the pharos are mentioned and this proves that there were advanced optical systems at the Pharos, for observing the ships at see and to direct the light towards the Mediterranean.

The polymath Giambattista Della Porta[84] (1535 – 1615) in the book *Natural Magic* (1589) describes the telecope of the Pharos as reported by Reeves[85] in her book *Galileo's Glassworks: the Telescope and the Mirror* presents the possiblr

[84] Giambattista della Porta, Magiae naturalis libri XX in quibus scientiarum naturalium, divitiae et deliciae demonstrantur, Napoli: Horatium Salvianum, 1589; 1658 English version, Natural Magick by John Baptista Porta a neapolitane in twenty books, London; Della Porta, G. (1957) *Natural Magick*, Basic Books. See also Della Porta, G. (1999). De refractione optices parte: libri novem... Ex officina Horatii Salviani, apud Jo. Jacobum Carlinum, & Antonium Pacem.

[85] Reeves, E. A. (2009) *Galileo's Glassworks: the Telescope and the Mirror*, Harvard University Press.

use of a telescope at the top of the Pharos, perhaps made with the combination of a mirror and a lens. In an English version of Della Porta *Natural Magic* has a chapter on how to use lights at a very large distance using a parabolic mirror obliquelly (7th book, chapter XVI, On strange glasses).




Theoretical study of a "cylindrical" mirror, or a hyperbolic mirror. These can be used as a kind of telescopes.

The principle od fiber optics is implied by this study.

The "telescope" at the top of the Pharos could have been constructed by a mirror, a parabolic mirror, a hyperbolic cylindrical mirror, as there are scientific texts studying this

type of optical instruments. Another optical system has been in use probably to direct the light at the appropriate directions. A simple and effective system based on the theoretical knowledge of conical mirrors, parabolic and hyperbolic and experience they could construct two cylindrical mirrors, one parabolic and one hyperolic, with other possible variations. The reason to use cilindrical mirror is that the quality of reflection at very large reflection angles is better than at small angles, especially if the anomalies of the metallic mirror are large. This type of reflection is in use at space telescopes working at very small wavelengths, for X-rays. They have been used for the first time by ROSAT[86] to observe the Cosmos in X rays. A similar system of mirrors is suitable the Pharos to focus the light from the fire at the base to the top to be redirected with a system of mirrors perhaps conical like the one suggested by H. Thiersch in 1909 and ancilary mirrors for the direction of beams along the surface of the sea. In fact if the beams of light are directed towards the smoke above the Pharos or even better towards some nearby clouds then the lighthouse light becomes visible at much larger distances than the actual height of the building permits. This type of reflection of light at a height makes the lighthouse visible at very large distances, as much as 300 km that are mentioned by some authors that otherwise seems more as an exaggeration.

[86] Sumner, T. J., J. J. Quenby, R. Lieu, J. Daniels, R. Willingale, X. Moussas (1989), Susceptibility of soft X-ray grazing incidence telescopes to low energy electrons, Monthly Notices of the Royal Astronomical Society, 238, 1047–1054.

Multiple reflections in cylindrical mirrors, parabolic and hyperbolic, like the ones suggested in this study, have been in use in antiquity as the book by the Archbishop of Canterbury and important scholar proves. Johannes Peckham, who taught at Oxford, in his book, published two centuries after his death in Venice, entitled *Perspectiua communis* (Common Optics [*Perspectivness*]), contains the study of multiple reflections of light inside a cylinder, a precursor of fiber optics, in fact.

Hypothetical mirror system of the Pharos.

It consists of two sets of concentric mirrors. One set parabolic mirrors and one set of hyperbolic mirrors. The use of a quasi-cylindrical mirror (hyperbolic or parabolic) gives better reflection for a given quality of the mirror surface. The combination of a parabolic and a hyperbolic mirror gives better focusing. The fire is a the bottom. The light is guided to the top. A conical mirror can shed the light parallel to the sea. The conical mirror can be shaped so that it directs the light is some directions only, not 360 degrees around. An angle of some 200 degrees is sufficient to direct the light to the sea all around Alexandria, taking into account the shape of the coast of Egypt. If the light is sufficient it can be visible to 300 km, with appropriate conditions of temperature and humidity.

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