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650 Years of Optics: From Alhazen to Fermat and Rømer

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ABSTRACT: Under house arrest in Cairo from 1010 to 1021, Alhazen wrote his Book of Optics in seven volumes. (The kaliph al-Hakim had condemned him for madness.) Some parts of the book came to Europe about 1200, were translated into Latin, and had great impact on the development of European science in the following centuries. Alhazen's book was considered the most important book on optics until Johannes Kepler's "Astronomiae Pars Optica" from 1604. Alhazen's idea about a finite speed of light led to "Fermat's principle" in 1657, the foundation of geometrical optics.

Keywords: History of optics; history of astronomy; history of astrometry

Ibn al-Haytham

The opinions in the Antique about light and how we see the objects around us followed Platon who understood light as rays emitted from the eye towards the surrounding. Since we see remote objects immediately upon opening our eyes the rays must propagate with infinite speed. Euklid said a hundred years later, around 280 BC, that light moves along a straight line, and he formulated the laws about reflection in a mirror. Heron from Alexandria proposed about 60 AD the general hypothesis that light takes the shortest path between two points, and on this basis he was able to reach the same results as Euklid.

In the Middle Ages the centre of natural sciences moved to the Arabic world where Alhazen formulated views about light which made great impact in Europe. Therefore his work and the effect on science in Europe should be mentioned at the present celebration of 400 years of telescopes. Alhazen's Book of Optics in a printed version from 1572 is found in the Leiden University Library in the Latin translation from the Kitab al-Manazir (Book of Optics). The ideas of light by Alhazen and the European "perspectivists" are explained and some pages from the book in Leiden are shown in the Figures 1 and 2.

Alhazen realized that light has its origin outside the observer, that the rays on their way hits the objects and we see an object when the rays from the object enter our eyes, an idea already proposed by Aristotle. Alhazen described the eye and its functioning, and he made mathematical descriptions of the properties of light. He proposed that light moves with finite speed, and that it moves more slowly in dense media. His astronomy was a theoretical attempt to fit the spheres of the celestial bodies into each other, a task he criticized his predecessors, especially Ptolemy, for not having solved.

Alhazen with the full Arabic name Abu 'Ali al-Hasan ibn al-Hasan ibn al-Haytham, or just Ibn al-Haytham, was born in Basra about 965 and travelled to Egypt and Spain. He worked in Cairo and died there in the year 1040. According to Steffens (2007) and Wikipedia (2008), he conducted research in optics, mathematics, physics, medicine and development of scientific methods. His main work, The Book of Optics, was written while under house arrest in Cairo during eleven years 1010-1021. According to Wikipedia, in his over-confidence about the practical application of his mathematical knowledge, he had assumed that he could regulate the floods caused by the overflow of the Nile. Ordered by the sixth Fatimid caliph, al-Hakim, to carry out this operation, he quickly perceived the insanity of what he was attempting to do, and retired in disgrace. Fearing for his life, he feigned madness and was placed under house arrest until al-Hakim died. During and after the arrest he devoted himself to his scientific work until his death.

According to medieval biographers, Ibn al-Haytham wrote more than 200 works on a wide range of subjects of which at least 96 of his scientific works are known. Most of his works are now lost, but more than 50 of them have survived to some extent. Nearly half of his surviving works are on mathematics, 23 of them are on astronomy, and 14 of them are on optics, with a few on other subjects. Not all of his surviving works have yet been studied.

Alhazen in Europe

Some parts of the Book of Optics came to Europe about 1200, were translated into Latin, and had great impact on the development of European science in the following centuries. Alhazen's book was considered the most important book on optics until Johannes Kepler's "Astronomiae Pars Optica" from 1604. Surprisingly, Alhazens’s book was almost unknown in the Islamic world until the 1320s, according to Denery (2005) from whom I am quoting in the following.

The Latin translation of the Book of Optics exerted a great influence, for example, on the work of Roger Bacon, who cites him by name, and on Kepler and Fermat. It brought about a great progress in experimental methods. His research in catoptrics centred on spherical and parabolic mirrors and spherical aberration. He made the important observation that the ratio between the angle of incidence and refraction does not remain constant, and investigated the magnifying power of a lens. His work on catoptrics also contains the important problem known as Alhazen's problem. Alhazen has sometimes been called the "father of optics" and "the first scientist".

The scientists discussing optics in Europe at those times are called "perspectivists" after Roger Bacon's book "Perspectiva" from about 1270, but the word perspective has here a very different meaning from that in the Renaissance art of painting. Perspective meant the science itself about seeing, and the perspectivists thought that optics gave a deep insight into how we get to know anything about the world. It begins with the emission of light and colours from the objects through air to the eyes and then to the brain. This view is based on Alhazen's book.

Roger Bacon, a Franciscan theologian, describes emission of light and colours as a “multiplication of species”, which is in fact the title of one of his books, and an idea going back to Aristotle. The word species is explained as force or likeness, and species are considered as the source of all natural action and causation. The species is the real source to our sensing and intellectual understanding of the world. Through the species the surrounding medium is assimilated to the object. For example, a flame creates species in the surrounding air. These species heat the air and assimilate therefore the air to the nature of fire, but the air does not become fire, etc. etc., according to Denery (2005) pp.86-96. Bacon says that the visible object in its true nature and essence enters the eye and reproduces itself inside the eye.

A great hurdle for the understanding of how we see the objects was, with our words: the image formation in the eye. Light comes to our eyes from all directions, according to Alhazen, but how can the eye distinguish the directions to the various objects? Alhazen gave an answer which we know is wrong, but which Bacon adopted: the species multiply themselves in all directions, but only the species arriving perpendicularly to the surface of the eye are really sensed. The other species are refracted in the lens of the eye and neutralize each other. Clearly, the species must be understood in their remote historical context, and not as an “anticipation” of the modern photons.

Alhazen's ideas were not bettered until the time of Kepler and Snell; Willebrod Snell van Royen and René Descartes formulated the law of refraction mathematically in respectively 1621 and 1637. Pierre de Fermat, however, could not accept Descartes’ justification or demonstration of Snell's law which was based on an analogy with mechanical phenomena. Based on Heron’s ideas about the shortest path and Alhazen’s assumptions about a finite speed of light, smaller in dense media, he formulated in 1657 “Fermat’s principle” which expresses that light follows the path which takes the shortest time. Fermat then derived the law about light moving on straight lines, as well as the laws of reflection and refraction, thus perfecting the geometrical optics.

The legacy of Ibn al-Haytham in the Book of Optics about the different finite speeds of light spanned six centuries culminating with “Fermat’s principle” in 1657 and, finally, the measurement of the finite speed in cosmic space by Ole Rømer in 1676.

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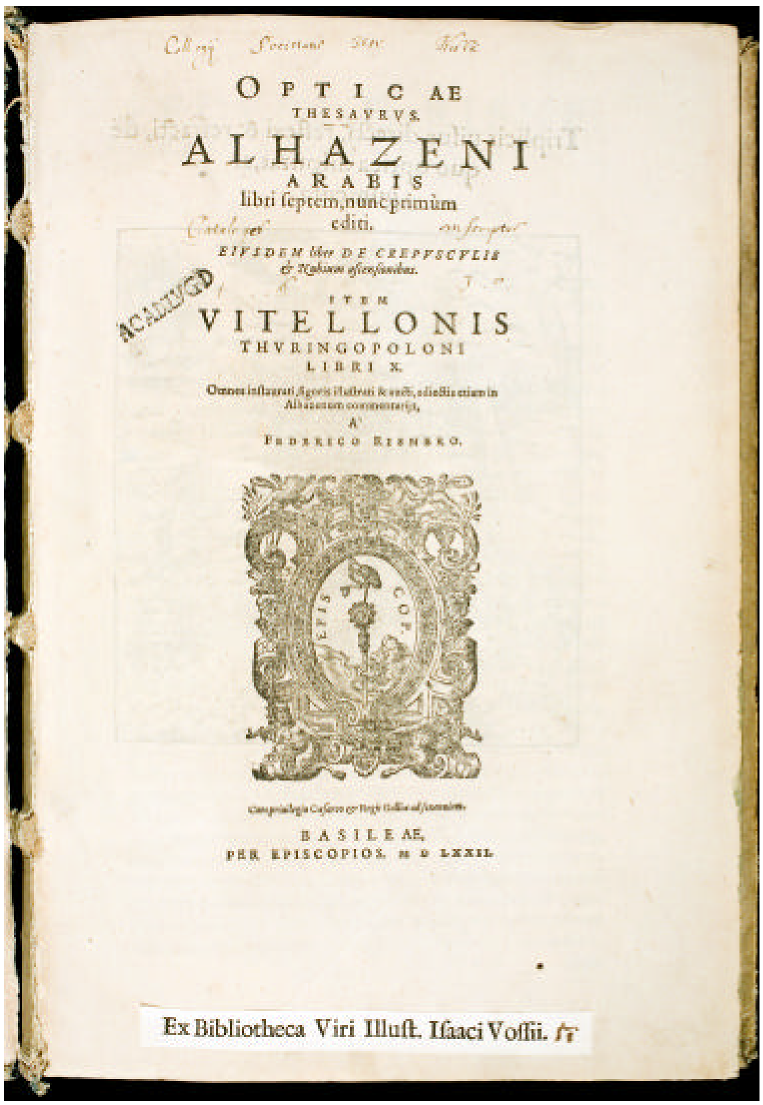
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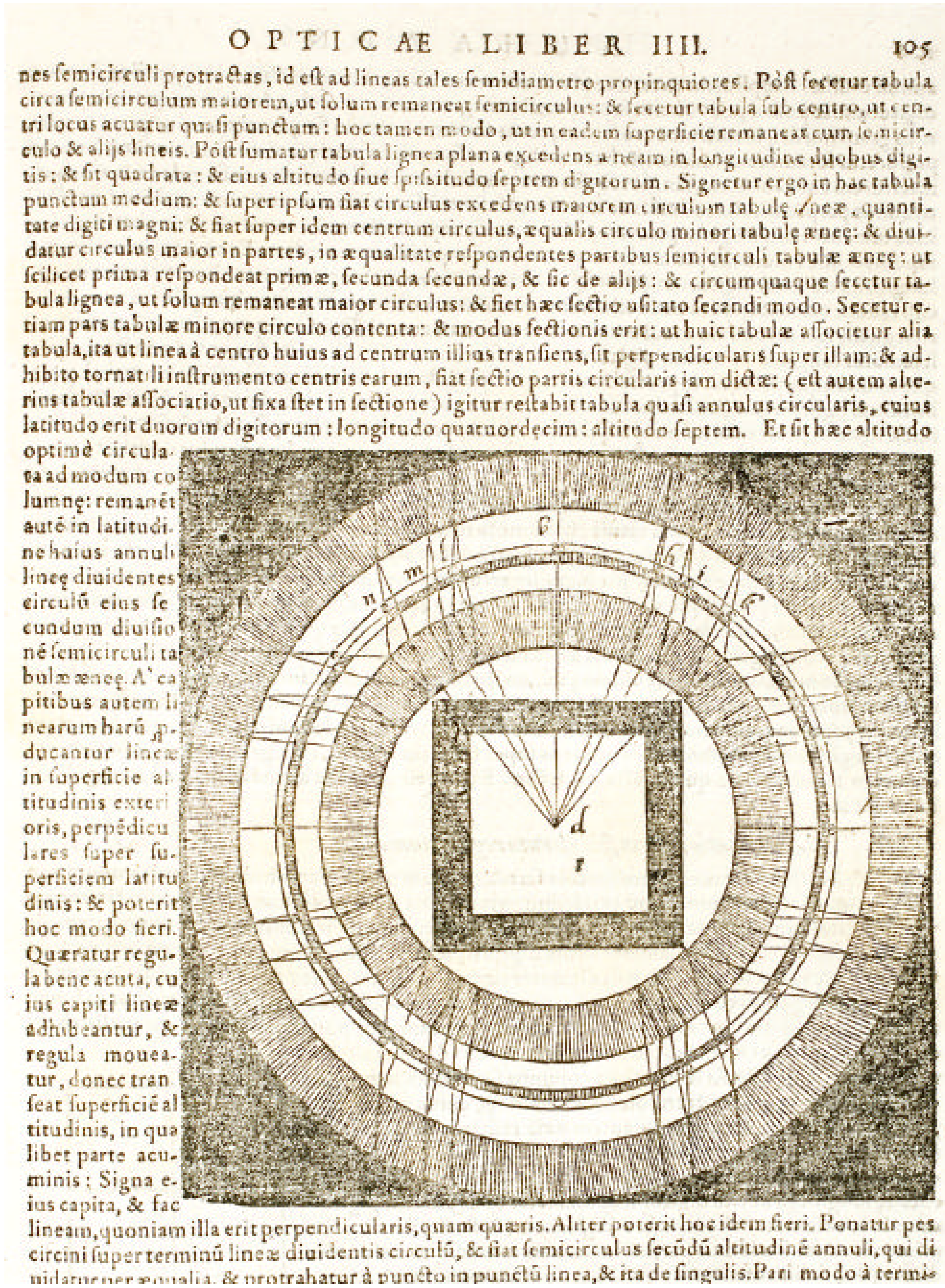
Fig. 1 The title page of Kitab al-Manazir (Book of Optics) in Latin translation, a version printed in 1572 and found in the Leiden University Library



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nes ſemicirculi protractas, id eſt ad lineas tales ſemidiametro propinquiores. Pòſt ſecetur tabula circa ſemicirculum maiorem, ut ſolum remaneat ſemicirculus: & ſecetur tabula ſub centro, ut centri locus acuatur quaſi punctum: hoc tamen modo, ut in eadem ſuperficie remaneat cum ſemicirculo & alijs lineis. Poſt ſumatur tabula lignea plana excedens æneam in longitudine duobus digitis: & ſit quadrata: & eius altitudo ſiue ſpiſsitudo ſeptem digitorum. Signetur ergo in hac tabula punctum medium: & ſuper ipſum fiat circulus excedens maiorem circulum tabulę æneæ, quantitate digiti magni: & fiat ſuper idem centrum circulus, æqualis circulo minori tabulę ænec: & diuidatur circulus maior in partes, in æqualitate reſpondentes partibus ſemicirculi tabulæ æneę: ut ſcilicet prima reſpondeat primæ, ſecunda ſecundæ, & ſic de alijs: & circumquaque ſecetur tabula lignea, ut ſolum remaneat maior circulus: & fiet hæc ſectio uſitato ſecandi modo. Secetur etiam pars tabulæ minore circulo contenta: & modus ſectionis erit: ut huic tabulæ aſſocietur alia tabula, ita ut linea à centro huius ad centrum illius tranſiens, ſit perpendicularis ſuper illam: & adhibito tornatili inſtrumento centris earum, fiat ſectio partis circularis iam dictæ: (eſt autem alterius tabulæ aſſociatio, ut fixa ſtet in ſectione) igitur reſtabit tabula quaſi annulus circularis, cuius latitudo erit duorum digitorum: longitudo quatuordecim: altitudo ſeptem. Et ſit hæc altitudo optimè circulata ad modum columnę: remanēt autē in latitudine huius annuli lineę diuidentes circulū eius ſecundum diuiſionē ſemicirculi tabulæ æneę. A' capitibus autem linearum harū ꝓducantur lineæ in ſuperficie altitudinis exterioris, perpēdiculares ſuper ſuperficiem latitudinis: & poterit hoc modo fieri. Quæratur regula bene acuta, cuius capiti lineæ adhibeantur, & regula moueatur, donec tranſeat ſuperficiē altitudinis, in qualibet parte acuminis: Signa eius capita, & fac lineam, quoniam illa erit perpendicularis, quam quæris. Aliter poterit hoc idem fieri. Ponatur pes circini ſuper terminū lineæ diuidentis circulū, & fiat ſemicirculus ſecūdū altitudinē annuli, qui diuidatur per æqualia, & protrahatur à puncto in punctū linea, & ita de ſingulis. Pari modo à termi-

Fig. 2 A page from the Book of Optics, selected mainly for its nice figure, the meaning of which, however, we do not understand. According to an expert in Latin, Dr. Christian Marinus Taisbak, the text speaks in great detail about a bronze plate and a wooden plate in which certain lines shall be drawn with great care, but for what purpose we could not deduce