Ibn Al-Haytham On Optics and the Human Eye

The man who discovered how we see

– *Written by Thomas Leisten, Qatar*

When UNESCO declared 2015 the 'International Year of Light and Light-Based Technologies', across the world a calendar filled with symposia and high-profile educational campaigns was inaugurated on the the history of light-based discoveries, the ways in which our contemporary societies use it as a resource and will employ it in the future. UNESCO, however, chose the year 2015 as it supposedly marks the 1000th anniversary of the publication of a book, which like no other work of the medieval period, impacted for many centuries to come how pre-modern societies in the Middle East and Europe would think of the medium of light and vision. In the centre of the celebrations connected to the International Year of Light stood the medieval Muslim polymath Abu al-Hasan ibn al-Hasan ibn al-Haytham al-Basri al-Misri – known as Alhacen or Alhazen (a transliteration of 'al-Hasan') in the West – and his best known work, the *Kitab al-Manazir*, usually translated as the '*The Book on Optics*'.

Ibn al-Haytham appears to have written an autobiography towards the end of his life, which unfortunately, as with so many sources from this period, is lost to us. What we know of it has been discovered only in the form of brief quotations and anecdotes, embedded in a number of mostly late-medieval biographical dictionaries. None of these sources makes the effort to draw a detailed picture of one of the most remarkable thinkers and scientists of the early medieval Islamic world. From these scraps, however, it is possible to reconstruct the main events of Ibn al-Haytham's life, which took him from al-Basra in Iraq where he was born in 965 CE, eventually to Cairo in Egypt, where he died around the year 1040 CE.

At times, conflicting reports provided to us by later biographical authors such as Ibn al-Qifti (d. 1248 CE) and Ibn Abi Usaybi'a

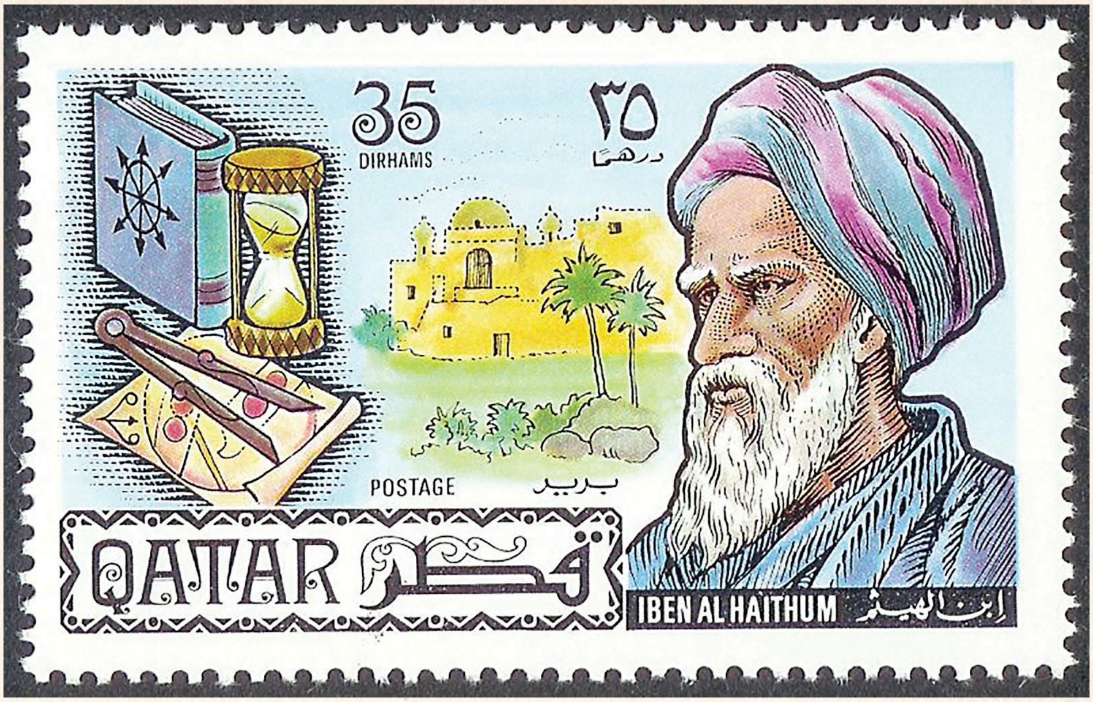

Image: Stamp with the idealised portrait of Ibn al-Haytham (Qatar, 1971).

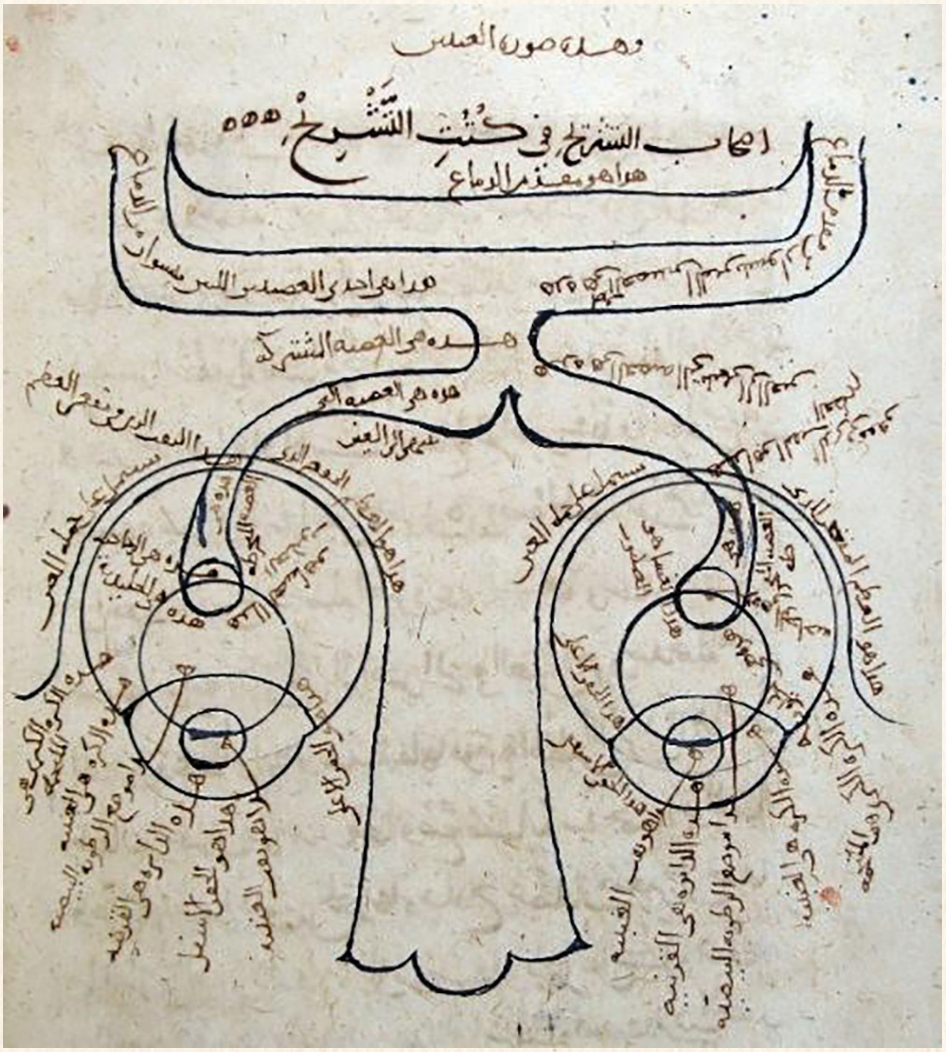

Image: The structure of the human eye according to Ibn al-Haytham, late 11th century CE of copy of the *Kitab al-Manazir* (MS Fatih 3212, vol. 1, fol. 81b, Süleimaniye Mosque Library, Istanbul).

(d. 1270 CE) suggest that Ibn al-Haytham originally occupied a high-ranking government position in the province of Basra. While he carried out his duties without a great passion for administration, his real interest, initially devoted to theology, soon encompassed vast fields such as philosophy, ethics, politics, poetry and music. While the works and treatises he produced or with which he has been credited over his lifetime, form a list of over 200 titles (of which only a few have survived to the present day), his reputation as one of the most important thinkers and influential figures in the history of science is based on his surviving work on mathematics, physics, astronomy and optics.

As a young man he moved from Iraq to Egypt to seek employment, apparently on invitation, at the splendid court of the Fatimid caliph al-Hakim bi-amr Allah (r. 996 to 1021 CE). There, he was involved in an engineering project that proposed new ways of regulating the annual flood of the river Nile, on which Egypt's economy depended in its entirety during this period. As a number of prominent seasonal celebrations and rituals took place around the annual flood and distribution of Nile water to the fields – and the caliph himself took part in these – one may sense that this project (for which Ibn al-Haythem possibly may have recommended himself to the Fatimid) had an extremely public high-profile. When it became obvious that the desired outcome could not be achieved and the project failed, Ibn al-Haytham may have feigned temporary insanity, some sources say, to evade punishment by the notoriously suspicious and erratic ruler. In any case, after this short stint at government work in Egypt, Ibn al-Haytham chose the life of a private scholar instead and took up residence (possibly even in a tent) in front of the al-Azhar mosque and university in the centre of Fatimid Cairo, where he must have lived for the following decades. For the rest of his life, he supported himself by copying scientific manuscripts and teaching, which gave him the leisure time to carry out his extensive research and exchanges with other scholars and scientists.

To judge from some of the autobiographical information that has been preserved, we can assume that Ibn al-Haytham's inquisitive nature was sparked early on by his observation of the fragmentation of religious communities into sects and schools.

He states:

"Having gained an insight into the intellectual bases of these sects, I decided to dedicate myself to the search for truth so as to tear away the veil of superstitions and doubts which an illusive vision has cast on people, and so that the doubting and skeptical people may lift their gaze freed from the membrane of spell and skepticism".

Advocating – in true scholarly fashion – an unbiased and a comparative approach, he reached the conclusion that truth is one and that it can be detected by observing, testing and asking objective questions. But while this approach pertained initially only to the realm of Ibn al-Haytham's own faith and his coming to terms with the complicated religious landscape of his time, his basic effort of gaining favour with God by seeking and detecting knowledge and truth, lies at the foundation of some of Ibn al-Haytham's most important scientific works.

While Ibn al-Haytham appears to have been a prolific writer in many fields during his earlier years, his work originating from the last decade of his life, written approximately between 1028 and 1038 CE, focused almost exclusively on optics and related fields. In the list of works that he published during this period and which can be securely attributed to his authorship, we find treatises on burning mirrors, assumptions on the light of the stars and the moon, suggestions on the nature of the 'marks' of the moon, treatises on rainbows, halos, eclipses and the quality of shadows, all of which culminate in his *Kitab al-Manazir*, '*The Book of Optics*'.

Written over a period of several years during the 1030s, this seminal work consists

Image: The structure of the human eye according to Ibn al-Haytham in Kamal al-Din al-Farisi's *Tanqih al-Manazir*, a comment on the *Kitab al-Manazir* (MS III. A3340, fol. 25b, Topkapi Palace Museum, Istanbul. The copy is dated to 1316 CE.

> *Ibn al-Haytham came to the conclusion that the eye does not send out rays of light, but that the eye receives light to arrive at visual perception*

of seven books, of which the first two volumes in particular became milestones for understanding the processes that the human eye undergoes when it sees and views an object. For this reason, Ibn al-Haytham begins the volumes by expounding his theories on the nature of light and, related to it, vision; the ability of the eye to discern the quality of the object it contemplates and how this process is carried out. He includes in his discussion the role of colours and the varying surface structure of an object in the process of viewing them. Two volumes of the series (Books III and VI) study problems of reflection and discuss optical illusions and errors that occur in the process of seeing, while two more books (IV and V) represent a collection of experiments through which Ibn al-Haytham sought to prove his points made earlier in his work. Finally, Book VII focuses on issues of refraction, discussing light as it passes through media of various density and the consequences involved for the process of seeing.

Before Ibn al-Haytham embarked on his own studies on optics, a series of eminent Muslim scholars had worked on this subject. Al-Kindi (801 to 873 CE), Hunayn ibn Ishaq (809 to 873 CE) and others had based their own research on texts of ancient Greek and Roman authors such as Aristotle (384 to 322 BCE), Euclid (ca. 300 BCE), Galenus (born 130 CE) and Ptolemy (90 to 168 CE). These texts had just become available through the immense translation projects of the Bait al-Hikma, the 'House of Wisdom' in early 9th century Baghdad, sponsored by the Abbasid caliph al-Ma'mun. These former approaches offered widely disparate views on how the human eye interacted with light to perform vision. Euclid and Ptolemy, for instance, favoured the extramission theory, according to which, the eye emits light rays to illuminate the viewed object. In their theory, Euclid and Ptolemy both postulated the geometrical correspondence between points in the eye and points on the object that are targeted by those presumed rays of light. Aristotle, on the other hand and with him Galenus, were known to have been proponents of the intromission theory. According to this version, colourful objects create a qualitative change in the nature of a transparent medium between object and observer and these changes are transmitted to the observer and finally cause vision. Aristotle's idea was basically the development of a theory that had been argued before him by the Greek atomists. According to them, objects constantly emitted atoms in all directions, which could be compared to the scales of a snake, which are actually minuscule images of the original object. The benefit of the intromission theory is that it removed some of the obvious drawbacks of the extramission approach, for instance the fact that objects situated both near and far could be seen the very moment one opened their eye, without suffering a delay in seeing the further removed object through 'wandering' little images of the object further away.

Building on the optical theories of Euclid and Ptolemy, Ibn al-Haytham set out to refute the extramission theory using a systematic series of experiments and observations. He offers for instance the example of the painful process of looking into a bright light – even the sun – and also describes the phenomenon of the afterimage as arguments that in the process of vision the eye is the recipient of an action from the outside. Likewise, he argues that man cannot see at night and in darkness. If the eye were able to send out rays of light on its own, objects would be illuminated in the dark so that one would be able to see at any time of the day.

Thus, Ibn al-Haytham came to the conclusion that the eye does not send out rays of light, but that the eye receives light to arrive at visual perception.

From a scientific point of view, the *Kitab al-Manazir* presents a new approach to the studies and theories about vision in the Middle Ages by integrating Aristotelian intromission theories into the analysis of vision, with a thorough analysis of its physiological components: "Sight, says Ibn al-Haytham, is composed of various layers, coats and bodies, its principle and origin being situated in the frontal part of the brain. [And] vision perceives light and colour existing on the surface of the object one is looking at through an intermediary diaphanous body located between vision and its object. Vision necessarily perceives all objects through supposed straight lines (of perspective) that stretch between the object and the central point of sight."

One of the great merits of Ibn al-Haytham's theories of vision is that it did not only aim at rejecting and replacing the ancient extramission or intromission theories, but also integrated in his studies the new and essential observations in the field of ocular anatomy and physiology. He freely admits that he bases some of his description of ocular anatomy on the works of others and he shows in his description of the eye a close familiarity with the tradition of the eye's anatomy that can be traced back to Galenus. Ibn al-Haytham thus begins by describing the optic nerves that issue from the anterior portion of the brain. They meet and unite into the common nerve, before they separate again and extend into the eyes. These are, according to Ibn al-Haytham, constructed of four tunics: iris, retina, cornea and what he describes as "white fat". In addition, he describes three vitreous bodies, pupil, lens (which he calls "glacial humor") and the vitreous gel that fills out most of the eye's interior. While this description is admittedly not very much different from the way some of his predecessors, for instance Galenus, Hunayn ibn Ishaq or Ali ibn 'Isa had described the various elements of the eye, Ibn al-Haytham introduces a new thought in as far he attempts to introduce a geometric model into ocular anatomy. He argues that all parts of the eye are distinguished by a spherical surface and that all ocular surfaces have their centres on the single line that passes through the centre of the pupil and terminates at the centre of the optic nerve where it joins the brain. This is, of course, a highly idealised anatomical scheme, the origin of which was certainly not the result of a dissection, but forced by the necessities of Ibn al-Haytham's intromission doctrine.

As the sensitive ocular organ, he identifies the 'glacial humor' of the crystalline lens, because he argues, in an experiment, sight can be prevented by the insertion of an opaque body in the pupil on a direct line between the pupil and the glacial humor of the lens, but sight returns, if this opaque body is removed again. On the question of *how* the lens and its glacial humor perceive the forms of light that are entering the eye, he continues that the transparent substance of the eye can assume the quality of the object in front of it. The transparency of the eye's vitreous bodies allows it to 'receive forms', and yet, because it possesses a certain density, these forms cannot simply pass through it. As a result, 'forms are fixed in its surface and body, albeit only weakly'. More distinctly, he describes the effect of light on the eye as a sort of physical reaction and uses, once more, the comparison with the sensation of pain:

"When light reaches the surface of the glacial humor (lens), it acts on it and the glacial humor 'suffers', since it is a property of light to act on the eye and a property of the eye. And the glacial humor perceives on account of this action and suffering, because of the forms of visible things that are on its surface and pass through its whole body; and it perceives through the ordering of the parts of the form on its surface and throughout its body."

These are indeed two novel elements in comparison to ancient Greek or earlier Islamic theories of vision: first, vision is a physical sensation not unlike pain. Second, and more central to Ibn al-Haytham's theory of vision, the parts of the perceived form must be properly arranged on the surface of, and within the lens, in exactly the same order as the parts of the visible object from which the form originated.

We know little about Islamic optics after Ibn al-Haytham, although the comment on his *Kitab al-Manazir* by Kamal al-Din al-Farisi (d. ca. 1320) is proof that his works were still widely read and disseminated. It was in the West, however, where Ibn al-Haytham, now called Alhazen, had its most immediate and long lasting influence:

It was in the middle of the 12th century, when Ibn al-Haytham's *Kitab al-Manazir* was finally introduced to Europe by being translated into Latin under the title *De Aspectibus* 'On Vision', presumably in either Spain or Italy. Based on this text, the Polish-German friar and scientist Witelo wrote in Italy between 1270 and 1278, in Italy, his only major surviving work, *Perspectiva.* Witelo's *Perspectiva* later became a source of major influence on the work of scholars and artists who worked on diverse subjects related to the theories of vision, optics and perspective such as the 13th century English friar Roger Bacon, the Florentine Renaissance artist Lorenzo Ghiberti or the early Baroque mathematician and astronomer Johannes Kepler, to name just a few. Interestingly enough, both works, the *De Aspectibus* (*Optics/Kitab al-Manazir*) of Ibn al-Haytham and Witelo's *Perspectiva* were made available to larger audiences when they were jointly printed in 1572 in Basel, Switzerland for the first time by Friedrich Risner, a German mathematician, who became the first chair of mathematics at the Collège de France.

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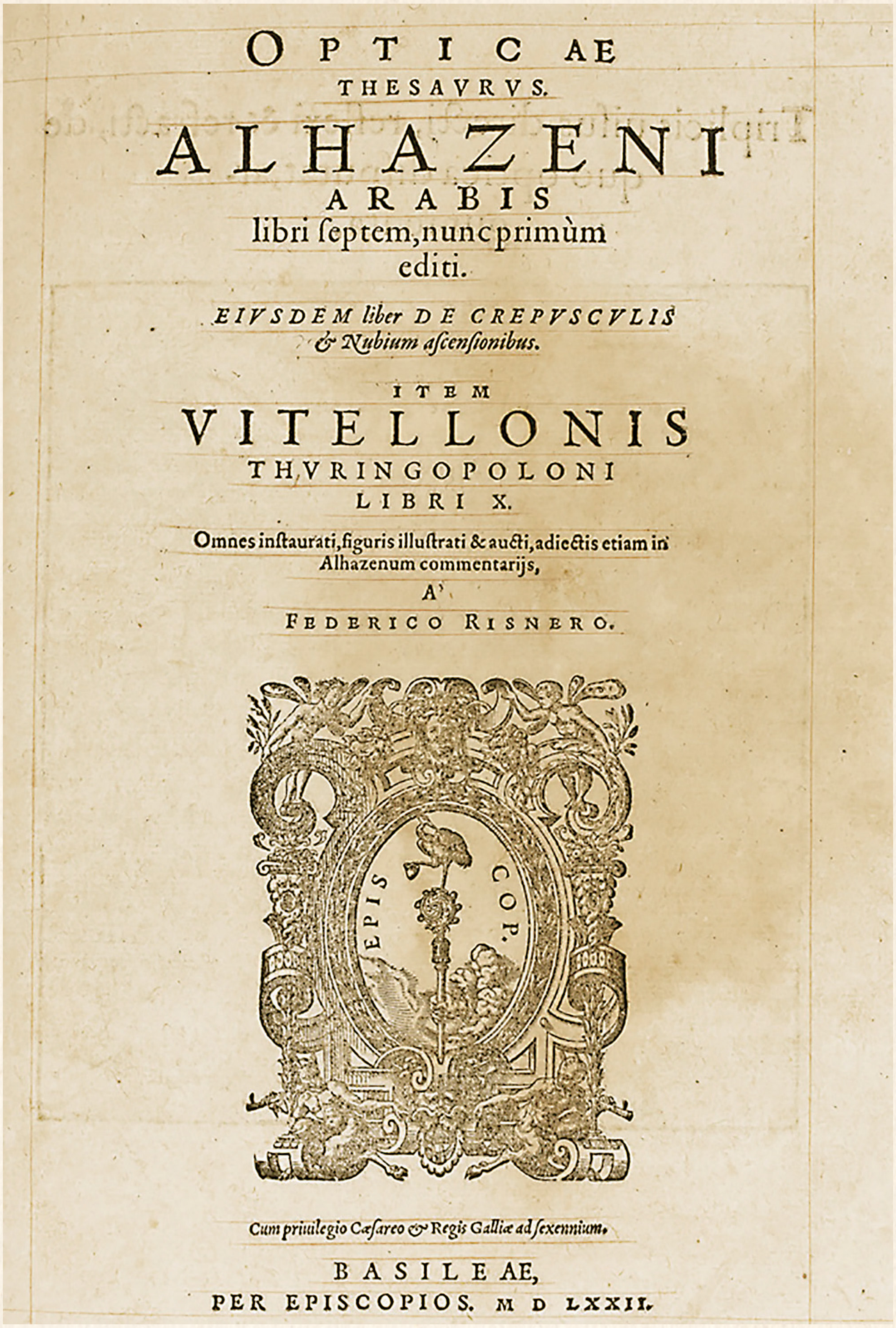
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EIVSDEM liber DE CREPVSCVLIS
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PER EPISCOPIOS. M D LXXII.

Image: Title page of the Friedrich Risner's print of the seven books of Ibn al-Haytham's *Kitab al-Manazir* (Optics) and Witelo's *Perspectiva*, Basel 1572 (private collection).

But even long before it appeared in print, Ibn al-Haytham's discussion on how convex lenses could be used to create enlarged images of objects may have been instrumental in the invention of such useful things as eyeglasses, which in Italy during the 13th century quickly replaced so-called 'reading stones' – hemispherical lenses made of glass or rock crystal that enlarged letters when put on top of a manuscript. It is also possible that the basic conceptual framework that finally led to Johannes Kepler's (1571 to 1630) theory of the retinal image and the beginning of a modern theory of vision, was, to no small measure, provided by Ibn al-Haytham's earlier achievement.

Thomas Leisten M.A., Ph.D.
Chief Officer Archeology, Education and Conservation
Qatar Museums Authority
Doha, Qatar

Professor
Princeton University
Princeton, USA