# MEDIEVAL ISLAMIC ACHIEVEMENTS IN OPTICS

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The United Nations have declared 2015 as the International Year of Light and Light-based Technologies. The yearlong celebrations are aimed at stimulating worldwide interest in light and related sciences and technologies. The year 2015 marks the 1000th anniversary since the appearance of the remarkable seven-volume treatise on optics written by the great Arabic scientist Ibn al-Haytham. This article covers the medieval Arab and Islamic contributions to optics and related sciences. The impact of the Medieval Arab sciences on the European renaissance is also covered briefly.

## 1 Introduction

The pursuit to understand the mechanism of vision and the nature of light date back to antiquity. On the very basic level it provides us vision. On the most fundamental level through photosynthesis (mostly in the green leaves of the plants), light is necessary to the existence of life itself. In human skins, the sunlight induces the synthesis of the essential vitamin D. When harnessed, the light-based technologies can promote sustainable development and provide solutions to global challenges in energy, education, agriculture, health and well-being. Hence, the United Nations proclaimed 2015 as the International Year of Light and Light-based Technologies (IYL2015). In this article, we shall focus on the Medieval Arab achievements in optics during the Islamic Golden Age (eighth to thirteenth centuries). In order to comprehend the development of science in the aforementioned period, it is essential to have a brief review of the ancient Greek contributions to optics and their translations into the Arabic language. The remainder of this paper is organized as follows. Section 2 investigates the origins of optics in ancient Greece, which provided a lead to the medieval Arab scientists. Section 3 provides the history of translations notably from Greek to Arabic and then from Greek to Latin. Section 4 has a fairly detailed account of the Medieval Islamic Achievements in Optics. Section 5 has our concluding remarks.

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## 2 Greek optics

There is more to celebrate in the International Year of Light than meets the eye. Indeed the year marks the numerous anniversaries in optics from the last two centuries. The year 2015 marks the 1000th anniversary since the appearance of the remarkable seven volume treatise on optics Kitab al-Manazir (Book of Optics) written by the great Arab scientist Ibn al-Haytham. Ibn al-Haytham's influence on experiment and theory in optics is truly remarkable, and he is considered the father of modern optics, ophthalmology, experimental physics and scientific methodology. There were also other great works in optics by the Medieval Islamic scholars, during the Islam's magnificent Golden Age in the 8th-13th centuries. This period brought about major advances in medicine, mathematics and other sciences. The Arabic language held sway in an age that created Algebra, elucidated principles of optics, established the body's circulation of blood, named stars and created universities. The Arab legacy in sciences is


'1001 Inventions and the World of Ibn Al-Haytham' is a global educational campaign launched as part of the UNESCO's led 'International Year of Light 2015' that celebrates the 11th century scientist Ibn Al-Haytham. Image courtesy of 1001 Inventions.

best understood by going back further in time and examining the Greek contributions to sciences.

Light and vision have fascinated humans from time immemorial. The earliest known lenses were made from polished crystal, often quartz, and have been dated as early as 700 BC for Assyrian lenses such as the Layard Nimrud lens. There are many similar lenses from ancient Egypt, Greece and Babylon. The ancient Romans and Greeks filled glass spheres with water to make lenses. The Greek works on optics can be classified into three distinct traditions: extramission, intromission and a combination of the two. The third had to do with the anatomy of the eye [1]. The extramission theories required some sort of illuminating particles to be emitted by the eye. Intromission theories required the object being viewed to continuously emit the particles that travel to the eye of the observer. Aristotle and his followers were strong advocates of the intromission theories. The mathematician Euclid is associated with the extramission theory. Euclid developed the theory of geometric perspective based on the supposition that a cone of rays emanates from the eye of an observer in the direction of the visible object. Although there are obvious flaws in the basis of the extramission theory, it gives the right geometry with one-to-one correspondence between point on the object and points on the eye. Intromission theories though correct could not explain all the optical phenomena known at that time. Plato was a proponent of a hybrid theory, which combined both the intromission and extramission theories. Euclid analyzed mirrors and stated the equal-angles law of reflection. What is remarkable is that Euclid laid down the rules of locating the images formed by reflection. The mathematical aspects of optics developed by Euclid were later used by the astronomer Claudius Ptolemy in his studies of refraction.

While the intromission theory of light was concerned with the nature of light and the extramission theory was concerned with the mathematical aspects, the anatomy of the eye was addressed by the physician and surgeon Galen from the second century CE (Common Era). Galen had provided a very detailed description of the eye and the optic pathways. Galen paid particular attention to the crystalline humor (or lens). He described the crystalline humor as a round lens in the middle of the eye, which was the sensitive or photoreceptive portion of the eye. He had concluded that the crystalline lens is the principal instrument of vision. Galen subscribed to the intromission view.

## 3 History of translations

By the sixth century CE, the scientific traditions of Ancient Greece had largely petered out, but the Greeks left behind important scientific and philosophical texts. We shall examine some of these texts later. In the seventh century the Arabs conquered Asia Minor, Persia, North Africa and Spain. By the ninth century the Arab civilization was dominant in the Mediterranean region. Cities such as Cordoba, Baghdad, Damascus and Samarkand became centres of lucrative trade and learning. These cities also boasted of amenities which did not become available in other parts of the world for centuries to come. For instance, the streets of Cordoba were paved and lit by lamps!

The real glory of Baghdad was not in her wealth but her intellectual creativity. The royal court attracted numerous scholars of the highest caliber. Science and arts were patronized by the caliphs to the extent that they built hospitals, observatories, universities, libraries and notably the bureaus of translation. The bureaus accomplished the task of translating every major scientific work into Arabic from Greek, Sanskrit, Pahlavi, Syriac and other languages. This mammoth effort of translation was supported by the Abbasid dynasty, centred in Baghdad for about two centuries from 750 to 950. The enlightened caliphs filled their courts in Baghdad with visiting scholars from near and far. The caliphs understood the crucial importance of scholarship to their ambitions of expanding the empire. Such an expertise was essential in order to derive both practical and intellectual benefits from the knowledge acquired through translations. A generally tolerant and pluralistic Islamic culture allowed Muslims, Christians and Jews to create new works of science together. It should be emphasized that the translations into Arabic were done by the subject experts and not by the linguistics alone. The need of high-quality translations was stimulated by the ongoing research of that time. This also resulted in the creation of new technical vocabulary in Arabic to express new thoughts and ideas and concepts acquired from Greek and other sources. Arabic translations of scientific works of those and earlier times gave the Arabs the sources to develop sciences to an admirably high degree. The era of translation lasted for about two centuries and paved the way for composition and innovation. This period from eight to thirteenth centuries was the most creative period in the history of Arab science and learning. The Arabs made tremendous original contributions to all the sciences then known.

Hunayn Ibn Ishaq (809-873) was an outstanding translator who rendered into Arabic the complete medical and philosophical works of Galen as well as of Aristotle. His many students completed the translation of Plato, Hippocrates, Ptolemy, Euclid, and Pythagoras into Arabic, and also made great original discoveries in mathematics, particularly in the integral calculus and spherical astronomy. Ibn Ishaq also wrote "Ten Treatises on the Eye", giving a detailed account based on Galen's "On the Usefulness of the Parts of the Body" [1]. The Greek works spanning six centuries, Aristotle (384-322 BC), Euclid (fl. 300 BC), Ptolemy (fl. 125-150 CE) and Galen (129-216 CE) were available to the Medieval Arabs [1].

The Arabic reservoir of knowledge created with both translations into Arabic and original contributions covered virtually all of science — medicine, chemistry, astronomy, mathematics and physics. The "western" science of the latter centuries originated from the study of these Arabic texts into Latin. In Western Europe, the work of translation from Arabic to Latin started in the 12th century. Spain, then under the Muslim rule, played the leading role in transmitting the Arabic reservoir of knowledge to Western Europe. Toledo served as the cultural capital. The impact of this activity was decisive. Many universities were created in Europe during this period, such as Bologna (founded 1088), Salamanca (1218), Padova (1222), Paris (1150), Montpellier (1289), Oxford (1096) and Cambridge (1209). These universities were structurally very similar to the Arab institutions. The universities in the European libraries stocked the books in Arabic along with their Latin translations. The curricula were directly influenced by the Arab science. For instance, the Arab medical textbooks were used in Padua, Parma and Oxford.

Ancient science and philosophy preserved in the Greek, Sanskrit, Pahlavi and Syriac languages would have been lost forever had the scholars centred around Baghdad during the 8th-12th centuries not translated them into Arabic. A comprehensive and a very detailed account of the history of translations into Arabic and then into the European languages is provided by Zakaria Virk in [2]. The contributions of the Arab world to science during the above centuries are to be understood in this background.

From a historical perspective, it is relevant to have a closer look at the Arabic manuscripts from the Golden Age of Islamic contributions. This has been done by the contemporary science historians including Abdelhamid Ibrahim Sabra and Roshdi Hifni Rashed. Sabra carried out a long and very arduous work for the critical edition of most of Ibn al-Haytham's seven volumes of Kitab al-Manazir (Book of Optics), and provided an English translation and commentary [3-5]. Roshdi Rashed edited, commented and translated into French all the Arabic translations of the ancient Greek works in mathematics. He also translated the works of several unknown Muslim mathematicians from medieval times. He discovered four Arabic translations of Diophantus' Arithmetica (also lost in Greek) written in the third century CE. The analysis of these has shed new light into the works of later mathematicians both in the Arab world and in Europe. This enabled Roshdi Rashed to reconstruct the history of the theory of numbers leading to major conclusions. For instance, the work on elementary arithmetic functions was done prior to 1320 CE and that Ibn al-Haytham had attempted to prove the perfect number theorem now known after Leonhard Euler (1707-1783). He also edited, translated and commented on the works of several Arab mathematicians including Nasir al-Din al-Tusi (1201-1274) and Omar Khayyam (1048-1131). He also studied the role of mathematics in the optics of the Medieval Arab scholars. In the process, he discovered the book, "On the Burning Instruments", by Abu Said al-Ala Ibn Sahl, which we shall see in fair detail in this article. These findings of Roshdi Rashed have provided new insights into the Medieval Arab contributions to optics, particularly the works of Ibn Sahl, Ibn al-Haytham and Kamal al-Din al-Farisi. For his insightful studies, Roshdi Rashed was awarded the 2007 King Faisal International Prize [6]. Contemporary translations of the Arabic manuscripts from antiquity into English and French have shed new light on the Arab contributions to sciences and optics in particular.

## 4 Medieval Islamic achievements in optics

The medieval Arab contributions to optics need to be revisited in the light of the historical discoveries made in the 1990's by R. Roshed. Otherwise, one has an account with fewer names such as Al-Kindi (801-873), Ibn al-Haytham (965-1040), Al-Farisi (1267-1319) and wide gaps, as is customary [1]. During the first two centuries of the Islamic Golden Age (eighth to thirteenth centuries) the intellectual activity in the Arab world went through two stages in tandem: translations accompanied with original contributions. Both the stages enjoyed an official patronage. The phenomenon of reflection of light was understood by the Greeks prior to Archimedes who had tried to burn the Roman fleet approaching Syracuse using reflection of light. Among the vast literature translated into Arabic were Ptolemy's Optics and the Conic Sections of Apollonius. Applications of parabolic mirrors for burning instruments, first described by Anthemius of Tralles (about 474- before 558 CE), were also known to the Arabs in Iraq. In 1990, Roshdi Rashed brought to light the historical discovery that the geometric study of the refraction, hitherto attributed to Snell, Descartes, and/or Fermat in its sine law form, was known and written upon by Abu Said al-Ala Ibn Sahl (940-1000) working in the Abbasid court in Baghdad [7-14].

Ibn Sahl had translated Greek books on optics including Ptolemy's Optics. Ibn Sahl succeeded in stating the law of refraction of light with a diagram. The explanation of the Ibn Sahl diagram, the related geometric constructions with the conserved quantity and its equivalence with the familiar sine law form are available in [7, 9, 11]. It had long been known that Ibn Sahl wrote on burning mirrors; it is cited in the works of Ibn Haytham among others. Libraries in Damascus and Tehran contain antique manuscripts bearing this title. Based on the catalogue information, these were perceived to be copies of the same book till 1990, when Roshdi Rashed took the task

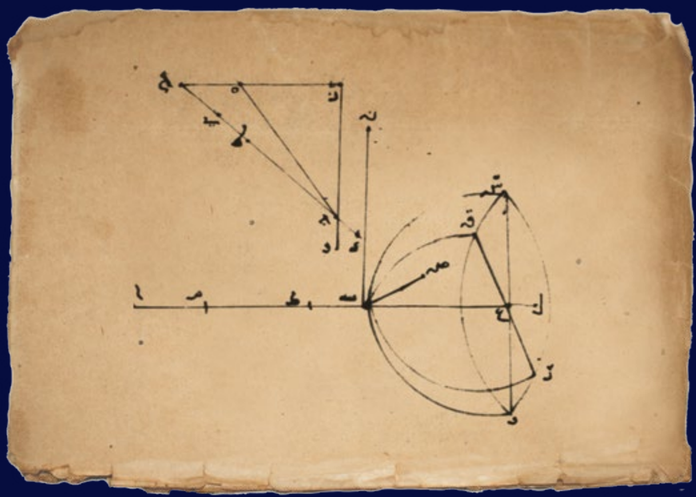

Fig. 1 Ibn Sahl's diagrams for refraction and the plano-convex lens from Ibn Sahl's treatise, "On the Burning Instruments", written in 984 CE. From Milli MS 867, folio 7r; Milli Library Tehran, Iran.

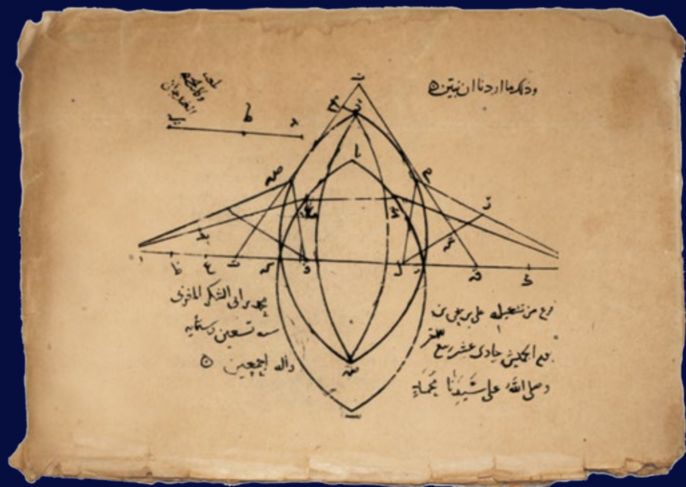

Fig. 2 Ibn Sahl diagram for a biconvex hyperbolic lens from Ibn Sahl's treatise, "On the Burning Instruments", written in 984 CE. From Milli MS 867, folio 26r; Milli Library Tehran, Iran.

to organize and study them. The pages turned out to be parts of the same dishevelled manuscript, pages mixed and some lost, unnumbered, but providentially containing the key results and revealing the overall structure of the work. This is the Ibn Sahl's book, "On the Burning Instruments", written in 984. Roshdi Rashed reassembled it, translated it, and published it [7]. Ibn Sahl's book is both experimental and theoretical. He provides the mechanical means to draw the conic sections. In this book, he describes the law of refraction with a diagram (fig. 1).

In his book Ibn Sahl analyzed burning mirrors, both parabolic and ellipsoidal; he considered hyperbolic plano-convex lenses and hyperbolic biconvex lenses. He develops the geometry of refraction as the Greeks did for reflection. His expertise is evident in the abstract lines in his diagram of the biconvex hyperbolic lens that concentrates the light of a near source at a point (fig. 2). He succeeded in stating the law of refraction of light (commonly known as the Snell's law after the Dutch scientist, Willebrord Snellius, 1580-1626) long before Snellius himself [7, 9, 11]. This treatise, "On the Burning Instruments", makes Ibn Sahl the first mathematician known to have studied lenses and further shows that in the first half of the tenth century catoptricians were actively working on refraction [7]. (For a detailed explanation of fig. 1 and 2 see the Insert by A. Bettini.)

Ibn Sahl was well known among his colleagues and students. His most famous student was Abu Ali al-Hasan Ibn al-Haytham (965-1040), known as Alhacen Alhazen, the Latin transliteration of his first name al-Hasan. Ibn al-Haytham wrote several books on optics acknowledging his mentor Ibn Sahl [7, 8, 11, 15]. Ibn al-Haytham was born in Bassorah (Basra), Iraq in 965. He started his carrier in Bassorah which was the chief centre of translations and scientific activities then. Later he migrated to Egypt, and worked in Cairo, which was under the reign of the Fatimid Caliph al-Hakim, a patron of sciences. Ibn al-Haytham had proposed to the Caliph a hydraulic project to control the flow of the river Nile, which was refused by the Caliph! Ibn al-Haytham continued to live in Cairo in the neighbourhood of the famous al-Azhar University, until his death after 1040. Al-Azhar University was then the epicentre of academic enquiry. Ibn al-Haytham wrote prolifically on subjects as diverse as poetry and politics. He made experimental contributions of the highest order [1, 15]. The "1001 Inventions" is an award-winning, British-based organisation that creates international educational campaigns and engaging transmedia productions aiming to raise awareness of the contributions to science, technology and culture from the Golden Age of Muslim Civilisation. This organization is one of the founding partners of the International Year of Light and is playing a key role during IYL2015 to promote and celebrate the tenth century pioneer Ibn al-Haytham [16]. On this occasion a bust of Ibn al-Haytham was commissioned by "1001 Inventions" (fig. 3).

**Insert: Explanation of the Ibn Sahl figures**

This insert gives an explanation of figs. 1 and 2, which are the diagrams of Ibn Sahl for the lens limited by a plane and a hyperboloid, and two hyperboloids, respectively. As his interest is burning, the source is on the axis, at infinite and finite distance, respectively.

Following R. Rashed [7] the explanation of fig. 1 is the following. It contains two parts. The upper one is used to establish the tools for the following analysis, including the law of refraction. Figure 1a is redrawn from fig. 1, labelling the points as in [7].

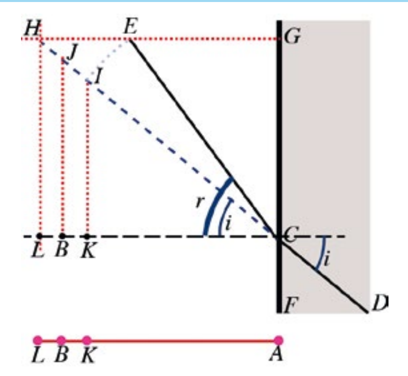


Fig. 1a

The plane *FG* is the interface between a crystal on the right and air on the left. In modern language be n the refractive index of the crystal. The incident ray, in the crystal, is *DC*, the refracted ray is *CE*, while *CH* is the continuation of the incident ray in the air. The angles of both rays with the normal *CG*, *i* and *r*, are also shown. The normal to the interface in an arbitrary point *G* cuts the refracted ray and the continuation of the incident one in *E* and *H* respectively. Consequently, the ratio *CE/CH* is

$$\frac{CE}{CH} = \frac{\operatorname{cosec} r}{\operatorname{cosec} i} = \frac{\sin i}{\sin r} = \frac{1}{n}$$

Ibn Sahl does not define the refraction index nor uses the trigonometric functions. However, he considers the ratio *CE/CH* as independent of the incident angle. This is implicitly equivalent to the Snell law.

As the next step, let *I* be the point on the line *CH* such as *CI=CE*. Then also

$$\frac{CI}{CH} = \frac{1}{n}$$

is a constant. Finally, be *J* the point on the same line such that *HJ=JI*, a definition needed for the following study. In conclusion, the relative distances of the points *C, I, J, H* on the same line characterise the refraction properties of the crystal. Finally, Ibn Sahl projects these points and *C* on the line *LBKA* to gain independence from the incident angle. The constant ratio, which will be used in the calculations, is now

$$\frac{AK}{AL} = \text{const}$$

The second part of fig. 1 is the diagram used to prove that the plano-hyperbolic lens converges rays from the infinite parallel to the axis in its focus. Once more, it is redrawn with the labels of ref. [7] in fig. 1b.

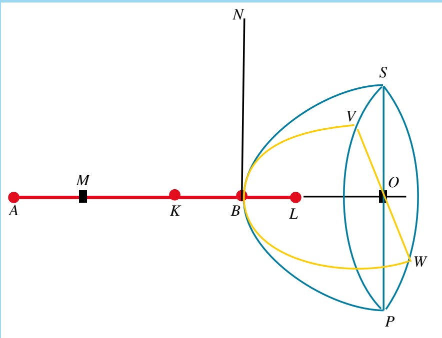


Fig. 1b

We start from the basic line *LBKA* (in red, from right to left). Then let *M* be between *A* and *K* such that *AM* = *BK*. We take the normal to the line in B and consider the point *N* on it such that *BN*×*BM* = 4 *BL*×*LM*. The curve *SBP* is the hyperbola of vertex *B*, axis *BM*, and latus rectum *BN*. We now rotate the arc *BS* about the axis *AB* generating a hyperbolic surface, which is the concave surface of the lens. In the rotation, the point *S* describes a circle with centre *O* in a plane which is the other surface of the lens. It is drawn in perspective in fig. 1b.

Ibn Sahl goes on with his geometric demonstration of the proposition: "Solar rays parallel to *OB* and passing through this solid are refracted at the hyperbolic surface, and the refracted rays converge at *A*". One finds the full development in ref. [7]. To do that one needs to consider also the section labelled as *VBWO* obtained by rotating *SBPO*, drawn in yellow in perspective in fig. 1b.

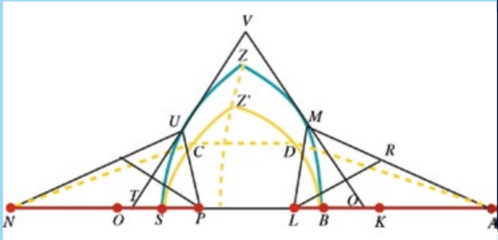


Fig. 2a

Figure 2 of the paper shows the geometry for the lens limited by two hyperboloids. In fig. 2a we redraw it, only its upper half for simplicity. Ibn Sahl uses the *LBKA* structure associated with the arc *BMZ* of the hyperbola with vertex *B* and focuses *A* and *L*, and the analogous *PSON* with associated arc *SUZ* of the hyperbola of vertex *S* and focuses *P* and *N*. The two hyperbolas are the traces of the surfaces of the lens. He proves that rays from a source in the focus *N* of one hyperbola converge in the focus *A* of the other hyperbola. In doing so he uses twice the refraction law as

$$\frac{NO}{NP} = \frac{AK}{AL} = \text{const}$$

In fig. 2a the yellow arcs *SCZ'* and *BDZ'* are shown in perspective, being obtained by rotating *SUZ* and *BMZ,* respectively, out of the plane of the rest of the figure. It is used to study the geometry of a generic ray entering in *D* and exiting in *C*. The demonstration [7] needs also the segments shown in fig. 2a.

A. Bettini

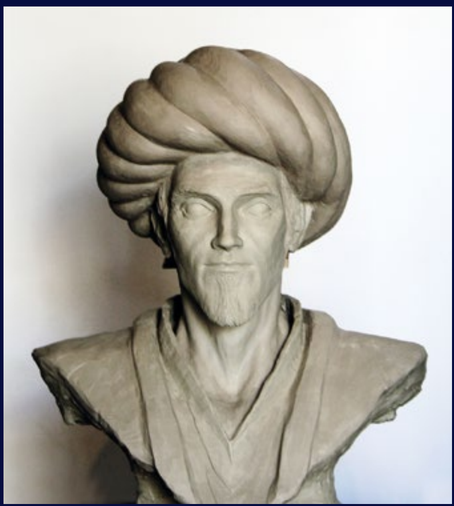

Fig. 3 Creative representation bust of Ibn al-Haytham made by artist Ali Amro and commissioned by 1001 Inventions for the UNESCO International Year of Light 2015. Courtesy of 1001 Inventions (www.1001inventions.com, www.ibnalhaytham.com)

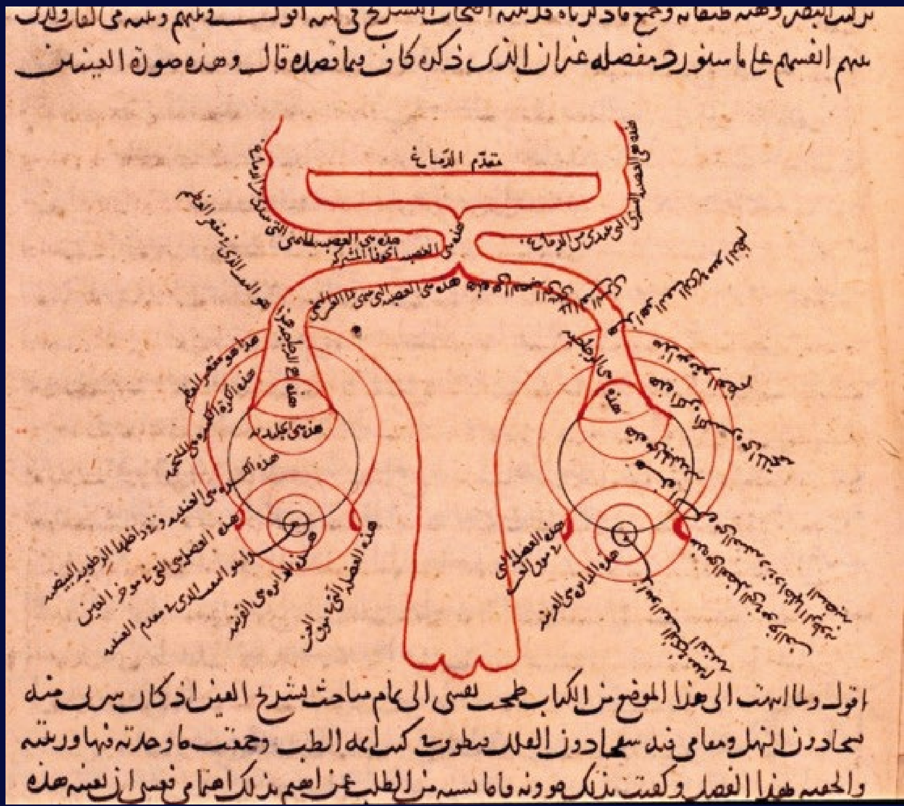

Fig. 4 Ibn al-Haytham's description of the human visual system from Kitab al-Manazir From MS 3340, folio 16a; Topkapi Palace Museum Library, Ahmed III, Istanbul, Turkey.

The works of Ibn al-Haytham have been extensively cited by later generations of Arab and European scholars. Based on the ancient bibliographies, it is found that there are at least 96 scientific titles under his name of which half of them have survived [15]. Half of them are on pure mathematics. Twenty-three titles are related to astronomy. He authored fourteen books on optics alone. His magnum opus, the seven-volume "Kitab al-Manazir" (Book of Optics) earned him the apt title of "father of optics". Volumes 1 to 3 are devoted to the physiology of the eye and the theory of perception (fig. 4). Volumes 4 to 7 cover geometrical and physical optics.

Ibn al-Haytham changed the course of optics by establishing experiments as the norm of the proof of the field. His optical theories rested on qualitative laws and quantitative rules derived from experiments, which he performed with an instrument that he designed and built himself. In order to settle the long-standing debate over how vision worked, Ibn al-Haytham pioneered an experimental set-up of surprising simplicity: the pinhole camera (*camera obscura*). The pinhole camera became a standard method for generations of physicists after Ibn al-Haytham. Isaac Newton, for example, used it to conduct his famous prism experiment in which he analysed the decomposition of white light into basic colours. The pinhole camera is the basic principle behind all photography from the earliest to modern-day digital cameras. Here, Ibn al-Haytham decisively distinguished the study of optics (both physical and geometric) from that of visual perception, experimentally establishing optics and more generally physics as an independent science. This was the first time that the vision was understood treating the eye as an instrument. Ibn al-Haytham's achievement was to come up with a theory which successfully combined parts of the mathematical ray arguments of Euclid, the medical tradition of Galen, and the intromission theories of Aristotle.

Ibn al-Haytham also discovered spherical aberration. He developed mathematical equations to explain the reflection of light from curved mirrors. He also examined the double refraction in a sphere and related problems (double refraction occurs in certain crystals in which the velocity of light rays is not the same in all directions). His expertise in experiments and mathematical modelling provided the right tools to tackle many optics-related problems. He could conclude that light travelled with different speed in different materials. Ibn al-Haytham enunciated that "a ray of light, in passing through a medium, takes the path which is the easier and quicker". In this he was anticipating Fermat's Principle of


Fig. 5 Two views of the frontispiece of the first edition of the Latin translation of Ibn al-Haytham's book "Kitab al-Manazir" (Book of Optics) as "Opticae Thesaurus Alhazeni"; Courtesy Posner Memorial Collection at Carnegie Mellon University, USA.

Least Time by many centuries [17, 18]. The beginning of the analogy between geometrical optics and mechanics, usually attributed to Descartes, can be traced back to Ibn al-Haytham [19]. In passing, we note that now Hamilton's opto-mechanical analogy has been extended into the wavelength-dependent regime [20-24]. He studied a variety of optical phenomena such as dispersion of light into constituent colours, rainbows, shadows and eclipses. He introduced the concept of atmospherics refraction, twilight and the Moon illusion (Moon appears bigger on the horizon than when it is higher in the sky). Ibn al-Haytham went against the accepted wisdom by arguing that light has a finite speed.

The voluminous "Kitab al-Manazir" was first translated into Latin as "De Aspectibus" sometime prior to the 1230s, and the proposals contained within it were used in the optics manuscripts "Perspectiva" by Roger Bacon (1265), "Perpectiva" by Witelo (1275) and "Perpectiva Communis" by John Pecham (1290). These scholars viewed optics in the context of vision motivated by religious beliefs and hence their approach was that of theologians [25-26]. It was translated again into Latin in 1270 as "Opticae Thesaurus Alhazeni" (fig. 5). The Latin translation is available online from [27]. The other book which was extensively translated was "On Parabolic Burning Mirror". Few mathematical and scientific writings in the Middle Ages have been as influential as those of Ibn al-Haytham, whose works were translated into Latin, Italian, and Hebrew. These two titles alone provided the basis of research in optics for centuries. His mathematical works influenced Roger Bacon (1214-1292), Frederick of Fribourg, Johannes Kepler (1571-1630), Snell (1580-1626), René Descartes (1596-1650), Christiaan Huygens (1629-1695) and many others. Ibn al-Haytham's work was republished in Latin in 1572, after the advent of the printing press, and is explicitly referenced in the writings on optics by Johannes Kepler, Snell, Fermat (1601-1665) and several others. Other scientists such as Leonardo da Vinci (1452-1519) and Isaac Newton (1643-1727) also benefited from his theories in optics and other fields [7-8, 10, 13-15, 25-26].

Ibn al-Haytham not only had direct influence on the development of European science, theology and literature, but also an indirect influence on art as revealed in recent discoveries [25-26]. To date, an asteroid has been named as asteroid 59239 Alhazen in his honour. As well as the crater Alhazen on the Moon, which lies near the eastern rim of the Moon's near side (Latitude: 15.9°N and Longitude: 71.8°E).

The medieval Islamic contributions to optics laid the foundation for the development of microscope and telescope. Based on the detailed descriptions in the Medieval Arab texts, it has been possible to reconstruct the numerous instruments such as astrolabes (instrument used for solving problems relating to time and the position of the Sun, Moon and stars in the sky), scalpels and clocks. A notable effort in this enterprise is that of the Turkish academic, Fuat Sezgin, who has displayed over a thousand instruments in the Institute for the History of Arabic-Islamic Science at the University of Frankfurt [28].

Three centuries after Ibn al-Haytham, the Persian physicist Kamal al-Din al-Farisi (1267-1319) wrote an important commentary on the Ibn al-Haytham's Book of Optics, in which he set out to explain many natural phenomena. For example, by modelling a water drop using Ibn al-Haytham's study of the two refractions in a sphere, he gave the first correct explanation of the rainbow. Al-Farisi also proposed the wave nature of light [29]. By contrast, Ibn al-Haytham had modelled light using solid balls in his experiments on reflection and refraction. Thus the question was proposed: is light wave-like or particle-like?

In our narration, we have mainly focused on Ibn Sahl and Ibn al-Haytham in fair detail. There are several other prominent scientists, who had worked on optics. The list includes: Yaqub Ibn Ishaq Ibn Sabah Al-Kindi (801-873); Hunayn ibn Ishaq (809–873); Abu Sahl Waijan Ibn Rustam Al-Quhi (940-1000); Qutb Al-Din Al-Shirazi (1236-1311); and Kamal Al-Din Al-Farisi (1267-1319). Fitting them in this short note would have been difficult. The reader is referred to the exhaustive works in [30-32].

## 5 Concluding remarks

We have briefly reviewed the ancient Greek contributions to optics. We have further seen how these historic works reached the Arab scholars during the 8th-10th centuries, through the route of translations. There are two aspects to be emphasized at this point. Firstly, there was a large-scale effort to gather Greek and other scholarly works and then translate them into Arabic. This gigantic endeavour was under a royal patronage of the enlightened caliphs spread over a period of more than two centuries. Such a sustained patronage is remarkable. This enabled the preservation of the scientific tradition, which is a shared heritage of the human race. This preservation alone would have provided the Medieval Arabs a special place in the history of science. Secondly, the exercise of translation and preservation enabled the scholars of that era to learn from diverse sources and prepare a fertile atmosphere for original contributions.

The original contributions of the Medieval Islamic scholars were of the highest calibre. Their achievements had a profound influence on the renaissance of science in Europe. European scholars also took very similar footsteps and translated the encyclopaedic knowledge of the Islamic scholars from Arabic to Latin and other European languages.

It is high time to recognize the Medieval Islamic achievements in optics and other sciences and give the due credit, which they rightly deserve. There have been numerous conferences on Arab Contributions to Science [33-35]. But this era of golden history is yet to find a mentionable place in school textbooks. The International Year of Light with its numerous outreach programmes is an excellent platform to convey the history of optics and science in general to those who are not fully aware of it. At the same time it is time for the Arab and Islamic countries to reflect on the decline of science in their nations and look forward to turning a new leaf. These countries should seriously consider investing generously in research (both basic and applied).

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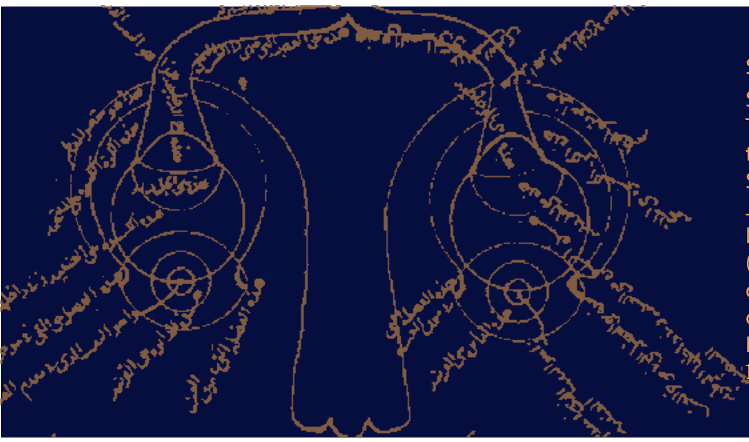


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