



Medieval Islamic Achievement in Optics

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Scholars in medieval Islam held optical knowledge superior to that of any other culture of the time. It was not an indigenous body of knowledge that had grown out of Islamic culture but an import that had originally been derived from ancient sources and was significantly advanced by Islamic practitioners.

If we are to understand Islamic achievement in optics, we must begin by investigating its origins in ancient Greece.

(Above) Hunayn ibn Ishāq's conception of the anatomy of the eye, from a 13th-century copy of his *Book of the Ten Treatises of the Eye*, Cairo, National Library. [Reproduced from David C. Lindberg, *The Beginnings of Western Science*, University of Chicago Press, 1992, p. 170.]

The surviving evidence for Greek optical thought is a collection of texts written over a period of some 600 years by Aristotle (384–322 B.C.), Euclid (fl. 300 B.C.), Ptolemy (fl. A.D. 125–150), Galen (d. after A.D. 210), and others.¹ These texts, which run from a few dozen pages to book length, fall into approximately three traditions. Aristotle and his followers sought to understand the physical process involved in vision, a process that Aristotle was convinced occurred through transmission from the visible object to the observer’s eye. Let us call this an intromission theory. Aristotle focused on the transparent medium between a visible object and the eye of the observer, the means by which a visible form was transmitted through this medium and what happened in the eye to produce visual sensation.

The mathematician Euclid, by contrast, directed his attention to the geometry of vision, ignoring physical considerations (with a few exceptions) in favor of ray tracing. The product of his study was a theory of geometric perspective based on the supposition that a cone of rays emanates from the eye of an observer in the direction of a visible object. The presence of visual rays entitles us to designate this as an extramission theory. Objects that intercept rays are perceived, and their apparent location in space is determined, by the position (within the cone) of the intercepted rays. Euclid also analyzed mirror images,

By approximately A.D. 900, good Arabic versions existed of all the classics of Greek science, including the important optical works.

clearly stating the equal-angles law of reflection and the geometric rules (which are still being taught today) for locating the image of an object seen by reflection. The mathematical tradition was extended in the second century by the great astronomer Claudius Ptolemy, who added studies of refraction (including an important experimental investigation) to the body of optical knowledge.




Finally, the great physician Galen investigated the anatomy of the eye and optic nerves in detail and with great skill and defended a theory of vision derived, with modifications, from Stoic sources. Antiquity thus saw three more-or-less distinct optical traditions competing for acceptance, each approaching the phenomena with different questions and answering to different criteria of success: the physical theory developed by Aristotle and kept alive by his followers was concerned with the physical realities of light

and its transmission and reception; Euclid and Ptolemy’s geometric analysis of light and vision, which was to be judged by mathematical criteria; and Galen’s anatomical and physiological analysis, answerable to the anatomical and medical concerns of a physician.

Transmission and recovery

This Greek optical literature experienced a twofold transmission: spatial and linguistic. By the beginning of the 10th century, Greek optical literature in translation was available in Baghdad and other cities in the Islamic world in Arabic versions. How did this come about? I offer an extremely short sketch of a long and complex process.

Beginning in approximately 325 B.C. with the Asian campaign of Alexander the Great and continuing for 900 years, Greek culture experienced a slow eastward diffusion—a process by which western and central Asia became Hellenized. Although conquest, colonization and commerce all contributed to the process, the most important mechanisms appear to have been religious developments within Greek Christianity. Early missionary activity led to the establishment of Christian churches in western Asia. Beginning in the fourth century, reinforcements came in the form of Christian heretics (the losers in theological battles fought out in various church councils) who fled eastward, bringing with them Greek language and culture, including books and schools. By the time Islam

400 B.C.	300 B.C.	A.D. 100	A.D. 200
<p>384–322 B.C. Aristotle attributed vision to the transmission of a “form” from the visible object to the observer’s eye.</p>  <p style="text-align: center;">Aristotle</p>	<p>300 B.C. Euclid proposed that geometrical rays pass from the observer to the visible object.</p>  <p style="text-align: center;">Euclid</p>	<p>A.D. 125–150 The great astronomer Ptolemy performed experiments on refraction.</p>  <p style="text-align: center;">Ptolemy</p>	<p>A. D. 210 The physician Galen explored ocular anatomy and physiology.</p>

(founded in 622) conquered these regions in the seventh century, Greek learning had become widespread, not only among Greek immigrants but also among the elites who represented the indigenous, host population. This process of Hellenization was repeated in the new Islamic empire (of which Baghdad was the major early center), as wealthy, educated Muslims found Greek learning both attractive and of practical value. Greek medicine was obviously desirable, but natural philosophy and mathematical science also had their proponents. In the long run, members of the Islamic elite patronized translation, so that by approximately the year 900, good Arabic versions existed of all the classics of Greek science, including all the important optical works. The next 300 years saw a flowering of optical thought among Islamic scholars who built on this foundation.

Early Islamic contributions

The Islamic contribution to the science of optics within the medieval Islamic world should be measured not by the number of practitioners, which was small, but by the quality of the contributions, which was great. Setting aside writers on ophthalmology, who were numerous, Islamic optics was the work of approximately a dozen scholars who made important contributions to the classical optical tradition. We can grasp the basic contours of the Islamic contribution by examining the theoretical efforts of the three most prominent of these.

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As far as we know, the first Islamic scholar to master portions of the Greek optical tradition was Abū Yūsuf Ya‘qūb ibn Ishāq al-Kindī (d. ca. 866), a member of a prominent Arab family, who pursued his philosophical career principally in Baghdad. Al-Kindī's interest in optical matters stemmed at least in part from his belief that the world was a vast network of radiations, of which light was the easiest to study because of its visibility. He was familiar with Euclid's *Optics*, about which he wrote a short piece that was simultaneously a defense and a critique, entitled *On the Correction of Errors and Difficulties in Euclid's Optics*. Here al-Kindī defended with cogent argu-

ments Euclid's assumption that radiation issues from the observer's eye and that this radiation is rectilinear. But he objected to Euclid's notion that the visual rays were discrete and separated by spaces, insisting that the cone of radiation was not only physically real (a point on which Euclid had been ambiguous), but also continuous.²

These represent corrections and clarifications of Euclid's theory of visual radiation. But al-Kindī made an extraordinarily important original contribution to the theory of radiation from a luminous object when he challenged the ancient assumption that light emanates from luminous objects as a single, holistic unit, maintaining instead (and he was the first to do so) that light issues in all directions from each point on the surface of the object, independently of all other points. Although his notion that the process of radiation is thus incoherent rather than coherent might seem obvious to us, it was a fundamentally new claim at the time and one that would prove to have revolutionary implications for al-Kindī's successors.

While al-Kindī was dealing with the mathematics of radiation, his contemporary, Hunayn ibn Ishāq, also living in Baghdad, was working through the anatomy and physiology of the visual apparatus with the help of writings by the Greek physician Galen. Hunayn was a trilingual (Arabic, Syriac and Greek) descendant of Arab Christians and a prolific translator of medical works into

A.D. 800

A.D. 800

Al-Kindī argued that light radiates in all directions from every point of a luminous or illuminated object.

A.D. 900

Hunayn ibn Ishāq described the anatomy and physiology of the eye to an Arabic-speaking audience.



Al-Haytham

A.D. 1000

A.D. 1000

The brilliant mathematical scientist Ibn al-Haytham constructed a synthesis of Greek optical thought, which (in translation) would dominate European optics until the 17th century.

A.D. 1200

A.D. 1200

Roger Bacon popularized Ibn al-Haytham's ideas for a European audience.



Johannes Kepler

A.D. 1600

1600s

Kepler, the culminating figure in the optical tradition that began with the Greeks, devised the theory of the retinal image.

Arabic. He also wrote *Ten Treatises on the Eye*, a work in which he presented to Arabic readers a faithful account of the anatomy and physiology of the eye, drawn principally from Galen's *On the Usefulness of the Parts of the Body*. The most important piece of content for the future history of optics was Hunayn's claim (following Galen) that the sensitive organ of the eye is the crystalline lens, situated in the center of the eye. Hunayn thus made available Greek anatomical and physiological knowledge that would prove to be of crucial importance for Ibn al-Haytham, who would write on the topic 150 years later.³

The maturity of Medieval Islamic optics

Abū Alī al-Hasan ibn al-Haytham (known in medieval Europe as Alhacen) is the central figure in the history of Islamic optics. Born in Basra in approximately 965, he pursued a career as scholar and teacher in Cairo, where he died in approximately 1040.⁴ Al-Haytham mastered the whole of the Greek scientific tradition (insofar as it was available in Arabic) and wrote prolifically on all manner of topics, including mathematics and mathematical science, Aristotelian natural philosophy and Galenic anatomy and physiology. But al-Haytham's highest achievements were in the mathematical sciences, of which he was one of the truly great practitioners in the whole of the history of science.

On the subject of optics, al-Haytham wrote a lengthy book entitled *Kitāb al-Manāẓir*, or *Book of Optics*, which was translated into Latin around the year 1200 as *De aspectibus*. This book, the 1572 printed edition of which occupied 282 folio pages, was influential in Europe as late as the 17th century. Al-Haytham's purpose in writing the book was to take the entire optical tradition as it had come down to him, separate truth from error and blend the truth into a single, successful account of the phenomena of light and vision. To achieve his aims, he would have to reconcile the mathematical preoccupations of the Euclidean tradition with Aristotle's exclusive concern for physical process and with the Galenic concentration on anatomical and physiological issues. The resulting theory would

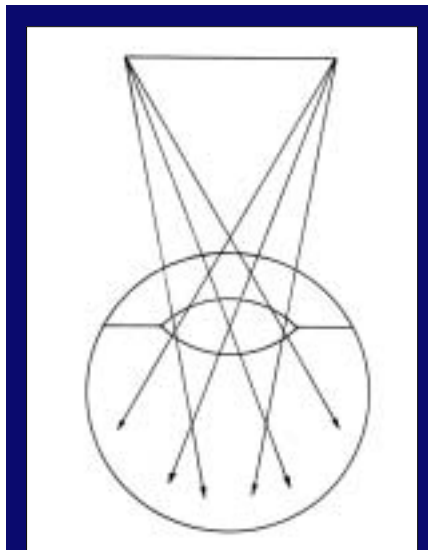


Figure 1. Rays emanating from two points on an object mix within the sensitive organ of the eye, the crystalline humor. For simplicity, refraction of obliquely incident rays on the various interfaces has not been shown. [Reproduced from David C. Lindberg, *The Beginnings of Western Science*, University of Chicago Press, 1992, p. 311.]

have to be comprehensive enough to answer the questions and satisfy the criteria of all three of the ancient traditions, as well as respond to the teaching of experience and experiment.⁵ This would be no simple task, for the ancient theories disagreed with one another fundamentally on such central issues as the nature of light and the geometry and direction of its radiation. Let us cut a narrow swath through these issues as we follow al-Haytham's theoretical trail.

Al-Haytham was adamantly opposed to the extramission theory of vision. Experience of such phenomena as the afterimage, he was certain, proved that rays passed from the observed object to the observer. However, he found the intromissionist theory of the atomists totally implausible. It was Aristotle, he believed, who had settled on the truth, namely, that visible objects send their qualities (forms, al-Haytham called them) through a transparent medium to the eye of an observer, which is to acknowledge that Aristotle was right about the physics of light and vision.

But the Aristotelian theory was devoid of mathematical content. It was the extramissionists, with their theory of the cone of rectilinear rays, who developed a theory of geometric perspective: an object that intercepts rays situated in the upper parts of the visual cone is perceived to be in the upper part of the visual field and so forth. To combine the mathematical achievements of the Euclidean tradition with Aristotle's understanding of the physics of radiation, al-Haytham had to find a way of appropriating the Euclidean visual cone for the intromission theory.

The obvious solution would be simply to reverse the direction of the rays that make up the visual cone, one ray from each point on the surface of a visible object. But al-Kindī's punctiform analysis of radiating objects had demonstrated to al-Haytham's satisfaction that rays emanate in all directions from each point on a visible object. It follows that each point in the sensitive organ of an observer's eye, the crystalline lens or humor, receives radiation from each point in the visual field (Fig. 1). If, for example, the visual field contains several objects, all of different colors, radiation from each point of each object would be received at each point in the crystalline humor, leading to mixing and total confusion. How is it, then, that we perceive a mosque in the center of our visual field, a palm tree to the right and a camel over there on the left, and that each object is perceived by sight with its parts correctly ordered? Visual perception, as we experience it, calls for a one-to-one correspondence between points in the visual field and points in the observer's eye—something that Euclid's visual cone provided but that al-Kindī's theory of radiation, when incorporated into an intromission theory, appeared to disallow.

Al-Haytham found the answer to this serious objection in the phenomenon of refraction, of which he made a thorough study. Although rays infinite in number emanate from each point on a visible object, he argued, only one ray from each point is incident perpendicularly on the cornea and again on the front surface of the crystalline lens (which is concentric with the surface of the cornea); and only this one ray from that point of the object

enters the lens without refraction and therefore at full strength. All other rays are weakened through refraction and, in ordinary vision (peripheral vision proved to be the exception), only the perpendicular (and therefore rectilinear) ray has the strength to stimulate the visual organ. But, of course, there is one such perpendicular ray from each point on the surface of the object, and the collection of such rays forms a visual cone, with the base on the visible object and the apex at the center of the eye (Fig. 2). Al-Haytham had his visual cone and therefore the needed one-to-one correspondence within an intromissionist framework. And with the visual cone came all the mathematical capabilities of the Euclidean tradition.

Al-Haytham proceeded to discuss the nature of the radiation of light and color along Aristotelian lines. He introduced the anatomy of the visual organs into his visual theory, tracing radiation through the eye and optic nerves to the optic chiasma, where the nerves from the two eyes meet. He also moved beyond visual theory to an analysis of reflecting surfaces and refracting interfaces, offering here a massive exploration of reflection and refraction, as well as image formation by either means in reflecting and refracting surfaces of spherical, paraboloidal, conical and cylindrical shape. His analysis was geometric (without quantitative data or law of refraction), but it displayed consummate geometric skill that would not be surpassed in European optics until the 17th century.

This discussion does not exhaust al-Haytham's optical achievements. Much more is to be found in his *Book of Optics* and more than a dozen other optical writings, all highly nuanced, argued with precision and heavy with mathematical demonstrations and empirical observations. My attempt in this short article has been merely to follow the central thread of al-Haytham's achievement.

The influence of Islamic optics

Most of the Islamic achievement in optics was translated into Latin in the 12th and 13th centuries, along with the Greek sources upon which Islamic thinking on this subject had been built. Most important of the translations from Arabic were

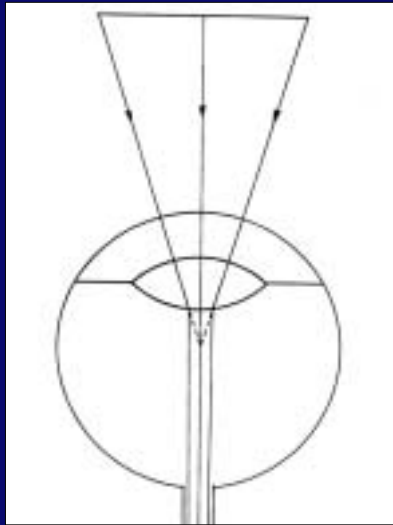


Figure 2. Visual cone (and the resulting one-to-one correspondence between points in the visual field and points in the eye) in the intromission theory of Ibn al-Haytham. Rays obliquely incident on the cornea and crystalline lens, which are not visually efficacious, are not shown. [Reproduced from David C. Lindberg, *The Beginnings of Western Science*, University of Chicago Press, 1992, p. 312.]

the optical works of al-Kindī, Hunayn ibn Ishāq and Ibn al-Haytham. Once they became available in medieval Europe, these works began to exercise a broad and continuing influence. To offer but one example, Roger Bacon (d. ca. 1292), who has become famous for his alleged authorship of original scientific works, was, within the realm of optics, a student of the Islamic tradition and a faithful disciple of Ibn al-Haytham.

In conclusion, I cannot resist leaping momentarily to the 17th century and Johannes Kepler. I do not believe that Kepler, who presented his theory of the retinal image in 1604, came to this new theory by breaking with the past optical tradition and undertaking investigations with the camera obscura, as has often been claimed. On the contrary, Kepler gained a thorough mastery of the medieval optical tradition spawned by al-Haytham's *Book of Optics* by reading the primary sources and accepting their central assumptions and almost all their content. But he was troubled by the claim that radiation that entered the eye

obliquely and, therefore, refracted, is visually irrelevant. It seemed clear to him that radiation that was only slightly refracted would be only slightly weakened and must, therefore, be brought back into the story. It followed that there could be no one-to-one correspondence (required for clear vision) between the visual field and the crystalline lens, because if all the radiation that fell on the eye was judged visually efficacious, the lens would be the place where all the rays mixed. The only reasonable alternative was a one-to-one correspondence between points in the visual field and points on the retina. Kepler thus came to his new theory of vision by working within the framework of the medieval optical tradition, which was to accept all its basic theoretical principles, while correcting a small, but crucial, error.⁶

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References

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2. For a short account of al-Kindī's optical achievements, see Lindberg, *Theories of Vision*, pp. 18-32. For an exhaustive analysis, see Roshdi Rashed, *Oeuvres philosophiques et scientifiques d'al-Kindī*, vol. 1: *L'optique et la catoptrique* (Leiden: Brill, 1997).
3. See the superb treatment of Hunayn's career, as both translator and author of scientific treatises, by G. C. Anawati and Albert Z. Iskandar, "Hunayn ibn Ishāq," *Dictionary of Scientific Biography*, XV, pp. 230-49. Also Lindberg, *Theories of Vision*, pp. 33-42.
4. The definitive account of al-Haytham's life and works is found in A. I. Sabra, *The Optics of Ibn al-Haytham, Books I-III on Direct Vision*, 2 vols. (London: Warburg Institute, 1989), vol. 2, pp. xix-liii.
5. See Lindberg, *Theories of Vision*, pp. 58-86; Sabra, *Optics of al-Haytham*, vol. 2, pp. liii-lixii.
6. For more on Kepler, see Lindberg, *Theories of Vision*, pp. 86, 185-208.

Additional Reading on the Early History of Optics

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