ARABIC SCIENCE OF LIGHT: THE BIRTH OF MODERN OPTICS AND OF THE EXPERIMENTAL METHOD

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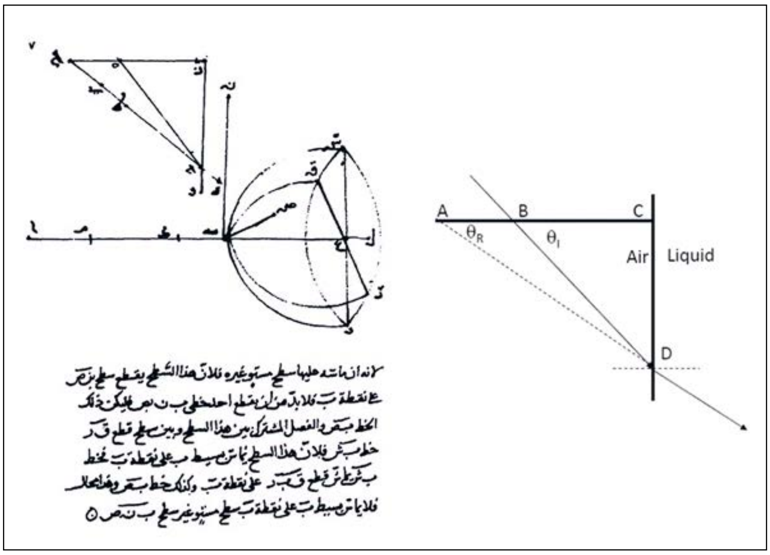
A millenium ago, the world witnessed a major revolution via the field of Optics. The study of Light, freed from postulates and axiomatic approaches, by the Arab Scholar Ibn-Al-Haytham marked the birth of the experimental method with its observational and analytical protocols, and the use of mathematics in formalising them. This revolution lead to the awakening of Sciences in Europe throughout the middle ages till the Renaissance.

▲ The eye according to Hunayn Ibn Ishaq. From a manuscript dated ca. 1200.

A millennium ago, the works of the Arab scholar Al Hassan Ibn Al Haytham represented a revolution in Optics that would gradually propagate through medieval Europe, but most importantly, they represent the birth of the experimental method as scientists practice it ever since.

The ancient Greeks were more interested in the phenomenon of Vision rather than the nature of Light. Their theories can broadly be classified into: Extramission theories, specifically attributed to Euclid (325 - 265, BC) and the mathematical School of Alexandria, in particular Claudius Ptolemy (c. AD 100 – c. 170), which required that visual rays or illuminating particles be emitted by the eye. Euclid established the laws of reflection and his Optics is mainly based on the concept of visual rays that propagate linearly, the visual cone, with the eye as its origin and the contours of the observed object as its base and the visual angle formed by the rays reaching its edges.



▲ **FIG. 1:** (Left) Ibn Sahl and the law of refraction: the planar convex lens from Ibn Sahl's treatise "On the Burning Instruments" (Public Domain, courtesy of Milli Library, Tehran). (Right) a reproduction of the upper diagramme of the left panel showing a decomposition of the ray trajectories (see text).

Intromission theories, whose most prominent advocate was Aristotle (384-322, BC), postulated that objects continuously send-off microscopic replicas of themselves that travel to the eye. They avoid some obvious problems of the extramission theory, *e.g.* that near and far objects are simultaneously visible the moment the eye is opened. A third approach, defended by Plato and Galen, and to a certain degree also by Aristotle, proposed that light emitted by the eye engages in some way with the intervening air and the aforementioned replicas. All these theories, which prevailed till the end of the first millennium AC, shared the fundamental premise that physical contact between eye and object is needed for vision.

The fall of Rome in 476 and the advent of Islam (570-632) represented major social and political events that would profoundly transform Knowledge and Thought. Islam's rapid expansion, first under the Omayyad dynasty with Damascus as its capital, then from 750 till 1250 under the Abbasid dynasty with Baghdad as its capital, would lead to profound changes in the development of ideas. In 786, Haroun Al Rashid became caliph in Baghdad and initiated an intense intellectual activity marked by the translation of Greek texts. His son, Al Mamun (813-833) created in Baghdad one of the first centres of scientific research in History, the famous Beit al-Hikma (House of Wisdom). A frenzied intellectual activity prevailed with the translation, study and commentary of the texts by the Greeks, Persians, Indians, *etc.*, in an atmosphere of openness to and respect of all religions (Muslims, Christians, Jews, Zoroastrians, Sabeans, etc) and origins (Arabs, Persians, Greeks, etc). This is exemplified by Hunayn Ibn Ishaq (808-873), a Nestorian Christian, trilingual (Arabic, Syriac and Greek) who was an authority in the translation of Greek works and a great Scholar. He wrote ten treatises on the eye and among other findings, he determined that the sensitive organ of the eye lens is located at its centre. During this time, three key scholars emerged in the development of Optics as a science: Yaqub Ibn Ishaq Ibn Sabah Al Kindi (801-873), Al-Alla Ibn Sahl (940-1000), and Abu Ali al-Hassan ibn al-Hassan Ibn al Haytham (died after 1040).

Al-Kindi amended Euclid's extramission theory by considering visual rays as three-dimensional prints produced by the observed object. Two important theoretical and experimental manuscripts authored by the Bagdad mathematician **Ibn Sahl** were discovered three decades ago in Damascus and Tehran by the historian of Science Roshdi Rashed, who analysed them in great detail [1-3]. They report, among others, mechanical methods of continuous drawing of conics. Ibn-Sahl not only considered burning (curved) mirrors, but lenses. He contributed the first mathematical description of burning lenses, including plane-convex and biconvex lenses. This brought him to consider the problem of the refraction of light, which he treated for a flat surface separating two media (see figure 1 left), leading to the formulation of the law of refraction five centuries before Willebord Snell and René Descartes.

The upper left inset of his drawing in figure 1 is reproduced in the right panel. Ibn Sahl refers to the ratio of the lengths: DB/DA, which he states is a constant for the crystal, and recognizes it as the ratio of the sines of the refracted (θ_R) and incident (θ_I) angles, and therefore the ratio of refractive indexes.

The above works paved the way to the major scientific revolution initiated by **Ibn al-Haytham** (known as Alhazen or Alhacen in medieval Europe). Born in Basra (Iraq), he spent most of his time in Cairo, under the reign of Fatimid Caliph al-Hakim, who showed strong interest in science and philosophy [4]. Alhazen worked at the famous Al-Azhar University, then a major centre of academic inquiry [5]. He left nearly 100 titles, in mathematics, Optics, Astronomy, Philosophy, Astrology, Statics and Hydrostatics and various other subjects. His main achievement is the *Kitab Al Manazir* (*Book of Optics*), which represents a revolution in science. Indeed, for the first time, the conditions of light propagation and those of vision are separated. Light becomes a physical object and Optics is no longer a "geometry of perception" [6]. Underpinning this development is the link he established for the first time, between mathematics and natural phenomena: *"Our subject is obscure and the way leading to knowledge of its nature difficult; moreover our inquiry requires a combination of the natural and mathematical sciences"* [7]. This approach goes well beyond optics and aims at *"inventing the means and the procedures to apply mathematics on the ideas of natural phenomena"* [6].

Ibn-Al-Haytham introduced novel concepts, such as: light rays and light bundles as a set of straight lines propagating independently from each other, at a very high but finite velocity, or the incidence of light on matter creates reflection. He explained refraction by the velocity of light being affected by the density of the medium. He also introduced the vectorial description of light propagation.

Kitab Al Manazir is the first real science textbook, combining experiments with mathematical validation. It is a series of Books dealing with specific subjects regarding light [8]. The historian of Science, Abdelhamid I. Sabra, edited the first critical Arabic version of the first 3 books and their translation into English, and Roshdi Rashed the critical edition of parts of the 7^{th} book [7,9]. Books I to III are devoted to the theory of vision, the physiology of the eye and the psychology of perception. The correct model of vision is presented: a passive reception by the eye of rays reflected from objects, but also physiological explanations of visual perception and optical illusions [10]. Books IV to VII contain a complete formulation of the laws of reflection and a detailed investigation of refraction, including experiments involving angles of incidence and deviation. They also contain "Alhazen's problem", which consists in determining the point of reflection from a plane or curved surface, given the centre of the eye and the observed point, and is solved by means of conic sections. Other optical works include *Daw'al-qamar* ("On the Light of the Moon"), *al-Hāla wa-qaws quzah* ("On the Halo and the Rainbow"), *Sūrat al-kusūf* ("On the Shape of the Eclipse"), and *al-Daw'* ("A Discourse on Light"). The latter presents a discussion of optical illusions, visual perception, rainbows, atmospheric density, various celestial phenomena (the eclipse, twilight and moonlight), refraction, catoptrics, the dioptre, spherical and parabolic mirrors, *etc.*

By giving ascendance to observations rather than to postulates, by dissociating the physical object from the perception and by the mathematical formalization of observations, Ibn-Al-Haytham introduced the mathematical language (and its intrinsic logic) as a structuring element of science.

Kitab Al Manazir had a profound influence on the work of most scholars till the Renaissance. The first translation into Latin was by Gerard of Cremona (1114-1187) under the title Perspectiva. The Silesian monk Erazmus Ciolek Witelo (1230 - 1275) will actively advocate Ibn-Al-Haytham's works and ideas in Europe. John Peckham (c. 1230 – 1292) wrote a manual for teaching optics, inspired from *Kitab Al Manazir.* Fourteen translations of the latter are identified in Europe, six of them in Great Britain. The last version will be published in 1572 by Friedrich Risner in Basel, over five centuries after Ibn Al Haytham's death. The experimental method will only later be fully formalised by Roger Bacon (1561-1626) with the *Novum Organum* and René Descartes (1596-1650) with *Le discours de la Méthode*. Finally, Ibn-Al-Haytham's works in optics will also influence artistic activity till the $XVII^{th}$ century, as he remained a reference in painting thanks to his works on perspective [11-13]. His discoveries are also invoked in the most celebrated medieval novels: *Le Roman de la Rose* (Guillaume de Lorris and Jean de Meun) and *The Canterbury Tales* (Geoffroy Chaucer).

Knowledge has never been the product of a single group, civilization or country. It is a transformative process characterised by a continuous flow of ideas, explanations, experiments and rationalizations that move over time and through space. The rise of science in Europe since the renaissance is part of this flow and cannot be disjointed from what preceded it during the eight centuries of the Arabic civilization. ■

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