Optics and Optical Theories

The term *al-manāẓir* (plural of *manẓar* or *manẓara*), from the root *n-ẓ-r*, "to look at," was used by the Arabic translators of Greek works as equivalent to optics. In the Arabic medical literature deriving from Galen, the word *manāẓir* can also be used to indicate visual rays as used by Ḥunayn ibn Isḥāq (d. 977 ce) in *The Book of the Ten Treatises of the Eye (al-'Ashr maqālāt fī al-'ayn)*. However, the more common way to refer to visual rays (rays emanating from the eye) is *shuʿah*,[this needs to be a short u in transliteration] which is a term also employed for referring to the rays emanating from the sun.

Optics was recognized as a distinct discipline within the Islamic scholarly tradition by the middle of the tenth century. Al-Fārābī (d. 950 ce) includes a section on *ʿilm al-manāẓir*, "the science of optics," in his *Iḥṣāʾ al-ʿulūm* (Catalogue of the Sciences). This catalogue is representative of what subject matter was included in the discipline of optics by the middle of the tenth century in Islamic intellectual circles. The principal subject matter was the study of vision, as had been the case with the Greek tradition. However, the catalogue includes other subjects—surveying (determination of heights, widths, and lengths of objects ranging from trees, walls, valleys, and rivers to mountains and the heavenly bodies), measurements (*masāḥah*), and catoptrics, or the study of reflection from mirrors (*marāyah*). The latter section on *marāyah* in the Fārābī's catalogue is rather confused, which may indicate the state of scholarship at the time of writing or, more probably, the author's lack of expertise in this field of study. The majority of al-Fārābī's chapter on *ʿilm al-manāẓir* in his catalogue, however, is devoted to the study of vision.

The Arabic tradition of the study of vision reflects the Greek tripartite approach to the subject, as does the Latin tradition: a medical tradition, concerned primarily with the anatomy and physiology of the eye and the treatment of eye disease; a natural philosophical or physical tradition devoted to questions of physical causation; and a mathematical tradition directed toward a geometrical explanation. It is therefore necessary to have some knowledge of the Greek theories of vision in order to understand the framework within which all discussions on this subject within the Islamic world took place. Greek theories of vision—as is the case for the Arabic and Latin traditions on vision —are often classified using the “intromission vs. extromission (or emission)” division, where the former refers to emanations (of whatever kind) coming from the object and the latter to emanations coming from the eye. However, casting Greek theories of vision in this “either/or” way is misleading. It is perhaps better to think of classifying Greek theories within particular schools of thought: pre-Aristotelian, Aristotelian, Galenic, and that of the mathematicians. As we shall see below, those writing on vision in Arabic fell into one of the latter three categories.

Aristotle gives the first systematic account of vision. Prior to this only fragmentary accounts exist: one proposed by the “atomists” and the other by Plato. These are important, as they provided the conceptual starting point for Aristotle.

The atomists proposed that vision was the result of material contact between the object and the eye. Although there were differences in the detailed descriptions of how this happened, these theories shared the concept of how the “image” of the object—the term used most commonly for this was *eidola* (occasionally *simulacra*)—entered the eye and was thus perceived as the object. Vision then becomes an extension of touch. Material replicas, composed of atoms, emanate from the object (the material content of the object is not reduced, as other material replaces what is emanated). These *eidola*, it was proposed, either enter the eye to be perceived as the seen object or “activate” the air between the eye and object in such a way so that the “activated air” is perceived as the seen object. Plato proposed a theory based on a “visual fire” emanating from the eye, which then coalesces with daylight to form a “single homogenous body” stretching from the eye to the visible object. This coalescence of the visual fire and daylight forms the material substance between the eye and the object that allows communication, which culminates in the visible perception of the object. However, like the atomists, Plato too proposed emanation from the object—emanations composed of particles—as *eidola* that participate in the communication between the eye and the object. Vision thus results from the contact between this emanation from the object and the material substance formed by the coalescence of the visual fire and daylight.

Aristotle, although rejecting the idea of a visual fire, or “ray of vision,” emanating from the eye as Plato proposed as well as the notion of *eidola* emanating from the object, agrees with his predecessors about the necessity for a material intermediary between the eye and the object. Aristotle proposes that the medium between the object and the eye that gives rise to visual perception of the object is due to the property of transparency—a property found in air, water, and some solid substances. However, this property of transparency can only be “triggered” in the presence of light—without light, substances only have the potential to be transparent—they need light to actualize this potentiality. In the presence of light, therefore, a medium between object and observer, which has the potential to be transparent, becomes so, thus making the object visible to the observer.

The Galenic view (derived from the Stoics) has some resonance with the Platonic one. It rests on the emanation from the eye of the "pneuma"—an active agent composed of a mixture of air and fire. The optic or visual pneuma is sent from the brain through the hollow optic nerves to the eye. Pneuma emerges from the eyes and "alters the air" around the eye so it becomes endowed with the sensory power to detect the change in the medium induced by the presence of the object. Thus, it is not the pneuma that extends to the object, and thus it cannot act as the intermediary between object and observer. Rather, the pneuma causes a change in the medium between the object and the observer—this changed medium acts, according to Galen, like a "nerve in the body," meaning a transmitter of sensation—in this case visible sensation. Among the Greeks, Galen gives an anatomical and physiological context in which vision occurs: he proposes that the main organs involved in vision are the crystalline lens, retina, cornea, iris, uvea, vitreous and aqueous humors, eyelids, and optical nerves. The optic nerves are hollow in order to carry the optical pneuma from the brain (the seat of consciousness) to the eye, and the crystalline lens is the principal organ of vision.

The two principal proponents of the mathematical approach to the study of vision are Euclid and Ptolemy—both of whose works were widely circulated in Islamic intellectual circles. According to Euclid, vision results from visual rays issuing from the observer's eye that fall on the object, which is then perceived. These visual rays, one can deduce from Euclid's scheme, are physical agents of sight. What distinguishes Euclid's scheme from other Greek ideas advocating emanation *from* the eye is the geometrical analysis imposed on how visual rays interact with the perceived object. Euclid proposes that the visual rays are rectilinear—that is, they proceed in straight lines. Also, a collection of visual rays forms a cone. These two assumptions allow Euclid to use straight lines and angles to represent visual rays in a geometrical diagram. Thus, optical problems are rendered into geometrical ones—the physical three-dimensional reality of visual rays into two-dimensional geometrical lines and angles. Most of Euclid’s work on vision focuses on geometry and ignores the inevitable physical questions that arise regarding the nature of the visual rays, the material contact between the visual rays and the object, and matters concerning the anatomy, physiology, and psychology of the visual process.

Ptolemy extended Euclid’s mathematical treatment of vision as well as providing a scheme incorporating physical, physiological, and psychological features. Ptolemy, like Euclid, the Galenists, and Platonists, attributes sight to the action of visual rays emanating *from* the eye. He agrees with Euclid that these rays are rectilinear and conical and can thus be subject to geometrical analysis. Ptolemy assigns a physical character to the visual ray and proposes that it has the same essence as light—within the scheme of “essences” in antiquity—quintessence. This light—whether external as in that produced by a luminous body such as the sun or in the case of visual rays issued by the observer—is endowed with an energy, which decreases on impact with any physical surface.

In terms of the nature of the cone in which the visual rays emerge from the eye, Ptolemy, unlike Euclid who had proposed that the rays emerging are discrete and spatially separated from each other, posits that the rays must form a continuous bundle shaped as a cone. Color forms an important function in Ptolemy’s scheme of vision—it is the interaction—it is not explained how—between visual rays from the observer’s eye, the color of the object and external radiation—in most cases the radiation from a luminous body such as the sun—which makes vision possible.

The first significant work on optics within the Islamic world was by al-Kindī and is extant only in its Latin translation from the Arabic, titled *De Aspectibus*. Al-Kindī, like all scholars writing on optics within the Islamic world, uses Greek ideas as his starting point. *De Aspectibus* is composed as a response to Euclid's *Optica*. Al-Kindī makes clear that he broadly sides with Euclid and Ptolemy in how the process of vision should be understood. He thus falls into the category of mathematicians. Al-Kindī considers the study of vision a part of optics and considers it a mathematical science—*ʿilm al-taʿlimī*. Al-Kindī's analysis of vision is therefore geometrical. He accepts Euclid's proposition that vision is based on visual rays and that these rays are rectilinear. However, he goes further than Euclid in proposing that the rays from any luminous body, such as the sun, are also rectilinear and gives an account of how shadows are formed in this section of *De Aspectibus.*

Al-Kindī's principal concern in his work on vision is to defend the theory of visual rays as proposed by Euclid and Ptolemy: that visual rays proceed *from* the eye to the object. In terms of the nature of the visual ray itself, al-Kindī agrees with Euclid that the visual ray, along with being rectilinear, forms a cone with its vertex at the eye and its base at the object being perceived. In terms of the nature of the cone, al-Kindī sides with Ptolemy in proposing that the cone must be composed of continuous (visual) radiation rather than the discrete visual rays that Euclid had proposed.

Although al-Kindī's treatment of vision is essentially geometrical and similar to that of Euclid and Ptolemy, he explicitly addresses the issue of the physical nature of the visual ray, unlike his Greek predecessors. It is clear that al-Kindī does not envisage the visual ray as a material substance emanating from the eye and extending to the object. Rather, he proposes that the visual power of the eye transforms the medium—air—between the eye and the object, and it is this "transformed medium" that allows the object to be perceived by the eye. In this line of reasoning, al-Kindī comes close to what the Galenists had proposed in their optical theory.

Ḥunayn ibn Isḥāq was a contemporary of al-Kindī's and a trained physician. He agreed with al-Kindī that vision was the result of emanation from the eye. His principal work on vision is titled *Ten Treatises on the Eye* and is closely based on the Galenic corpus on vision. In fact, it is through the Latin translation of Ḥunayn's work that Galenic ideas on vision became familiar to the Latin world. In his work on vision, Ḥunayn rearticulates the Galenic view of how an object is perceived: the visual spirit emanating from the eye transforms the air between the eye and the object so that the air becomes an instrument for perceiving the object. Thus, although al-Kindī's treatment of vision is geometrical and Ḥunayn's based on anatomy, in terms of the physical process of how vision occurs, the two share the common position that vision must be accounted for by an emanation *from* the eye. The ideas of both were highly influential in the Islamic and Latin worlds: al-Kindī on al-Fārābī, Ibn Ḥazm, Naṣīr al-Dīn al-Ṭūsī, al- Qarāfī, and Aḥmad ibn Abī Yaʿqūb Yaʿqūbī, and Ḥunayn on al-Rāzī, al-Jurjānī and ʿAlī ibn ʿĪsā in Arabic; in Latin, both their works were translated by at least the middle of the thirteenth century and were widely circulated.

Al-Kindī and Ḥunayn therefore represent the commitment to the idea of an emanation *from* the eye in early writings on optics in the Islamic world. There was, however, concomitantly considerable support for the alternative Aristotelian view that rejects the possibility of any emanation from the eye. These ideas are espoused by Muḥammad ibn Zakarīyā al-Rāzī according to his biographies (none of his works on vision survive) and al-Fārābī, who, although faithful to the Euclidean model in an early work such as the mentioned *Iḥṣāʾ al-ʿulūm*, appears to have shifted position in his later works. In the works of Ibn Sīnā and Ibn Rushd one witnesses an extensive and detailed defense of the Aristotelian position on vision and a rejection of the idea that vision is based on an emanation from the eye.

Ibn Sīnā deals with vision in a number of his works: *Kitāb al-shīfāʿ*, *Kitāb al-najāh*, *Maqālah fī al-nafs*, *Danishnāmah*, and *Kitāb al-qānūn fī al-ṭibb*. His main concern is to demonstrate that vision cannot occur via an emanation from the eye. The mathematical school represented by Euclid, Ptolemy, and al-Kindī had based their arguments primarily on geometry with some physical content—implicit in the case of Euclid and explicit in the cases of Ptolemy and al-Kindī. Ibn Sīnā ignores geometry and focuses on physics. These theories had been based on the assumption that there was contact between the emanation from the eye (either directly or via the medium of a transformed air) and the object. Ibn Sīnā posits that this is not possible, as this would require continuous contact between the object and the eye. If the contact were not continuous, then the impression of the object being observed would be broken, which, he says, is an observational falsehood. Ibn Sīnā also refutes the Galenic view on physical grounds by suggesting that it is not feasible for the air to act as an instrument for sight—the example he brings forth to counter this Galenic notion is that an individual’s perception is not effected when the wind is blowing. Ibn Sīnā therefore concludes that the only viable alternative remaining is the Aristotelian notion of vision, although he situates the Aristotelian theory within a Galenic anatomical and physiological framework. He applies this methodology as well in his work on reproduction, where he situates Aristotelian theories on reproduction in a Galenic anatomy in the chapter titled “Hayawān” in the *Kitāb al-shīfāʿ.*

Ibn Rushd, a dedicated Aristotelian like Ibn Sīnā, also makes a case for the Aristotelian view on vision in at least two of his works, *Kitāb al-ḥiss wa-al-maḥsūs* (*De sensu et sensato* in the *Epitome* of the *Parva naturalia*) and *Kitāb al-kullīyāt*

(*Colliget*). In his work on vision, like Ibn Sīnā, Ibn Rushd situates the Aristotelian view on vision within Galenic anatomy and physiology.

The study of vision, which as described by al-Fārābī in his catalogue constituted the major part of optics up to the mid-tenth century, can be thought of as a trichotomy consisting of the mathematicians and followers of Euclid and Ptolemy such as al-Kindī; the physicians and followers of Galen such as Ḥunayn; and the natural philosophers and followers of Aristotle such as Ibn Sīnā and Ibn Rushd. This trichotomy was of course not absolute and interests overlapped: Ibn Sīnā follows a natural philosophical(Aristotelian) enquiry with regard to the study of vision but sets this within the inherited medical corpus of Galen. Within this trichotomy, it is important to note that the natural philosophers and physicians pay no attention to geometry in their analysis—one finds the barest hint of an interest in, or relevance of, geometry—only the concession that visual radiation is rectilinear. There is no study of catoptrics (reflection) or dioptrics (refraction).

It is in the work of Ibn al-Haytham (Alhazen or Alhacen in Latin) that one sees this trichotomy being unified: his work brings together the anatomical, the natural philosophical (or physical), and the mathematical in his transformative study of vision in his magnum opus *Kitāb al-manāẓir*, translated into Latin by the end of the twelfth century with the titles *De Aspectibus* or *Perspectiva*. Its subsequent translation into other languages such as Italian and the fact that it was printed as an edition (Latin) in 1572 (Basel) is testimony as to its wide circulation and influence in the Latin West. Knowledge of its contents is evident in the works Roger Bacon, John Pecham,[David Lindberg who is an authority uses this version of the name - perhaps give both versions?] and Witelo, among others, and it provided the conceptual starting point for Johannes Kepler.

Ibn al-Haytham postulates a theory of vision based on the emanation *from* the object to the eye. However, unlike others who posited this theory based on the complete form of the object somehow being perceived by the eye, Ibn al-Haytham suggests what can be termed a “correspondence” process whereby each point on the surface of the object radiates in all directions—the coherent form or image perceived by the eye thus corresponds to each point on the surface of the perceived object. The key mechanism by which Ibn al-Haytham suggests that the rays radiating from the object enter the eye is *refraction*. All who had worked on the study of vision had acknowledged the need for the presence of light for vision to occur. However, they had either not considered the specific role of external light radiation in the visual process or had suggested that the visual rays interacted with external light radiation (in some way) to elicit visual perception without proposing how. Ibn al-Haytham, in contrast, offers a theory of vision where light radiation is an *independent* contributor to the visual process. He rejects the visual ray of the Euclidean school and replaces it with light radiation while holding to the Euclidean notion that radiation responsible for vision is rectilinear. It can therefore be mathematically analyzed by using the rules of reflection and refraction. In Ibn al-Haytham’s scheme of vision, therefore, light is an independent physical property whose nature operates by rectilinear propagation, reflection, and refraction. It is therefore subject to experimentally verifiable rules. Its physical effect on the physiological systems embedded in the ocular anatomy of the eye initiates *specific processes* leading to the visual perception of external objects and their qualities (such as color) through mental interpretive processes. In the last stage in the visual process—that of interpretation – that Ibn al-Haytham mentions, he introduces another disciplinary approach to vision—that of psychology—hitherto ignored in the study of vision.

Interestingly, Ibn al-Haytham's *Kitāb al-manāẓir* was more circulated and influential in translation in the Latin West than in its original Arabic. There is only one known direct sustained study of the *Kitāb al-manāẓir* in Arabic, the *Tanqīh al-manāẓir* by Kamāl al-Dīn al-Fārisī—produced at the beginning of the fourteenth century in Tabrīz under Ilkhanid patronage. In the *Tanqīh al-manāẓir*, Kamāl al-Dīn devotes considerable space to his commentary on the *Kitāb al-manāẓir* but also to a number of other works by Ibn al-Haytham—those on the rainbow and halo, on light, on the burning sphere, on the shape of the eclipse, and on the formation of shadows. Kamāl al-Dīn thus significantly widens the scope of the nature of *manāẓir*—optics. The *Tanqīh al-manāẓir* survives in many more manuscript copies than the *Kitāb al-manāẓir*, indicating that it must have been widely circulated.

Ibn al-Haytham's *Kitāb al-manāẓir* also received some indirect attention within Arabic scholarship during the Ottoman period: a work based on Kamāl al-Dīn's work by Taqī al-Dīn ibn Maʿrūf, titled *Nūr hadīqat al-absār wa nūr hadīqat al-anzār* (The Gardens of Visions and the Gardens of Sights) was produced under the patronage of the Ottoman Sultan Murād III. In this work, however, Taqī al-Dīn restricts himself solely to the study of vision, indicative of a narrower scope of optics compared with that espoused by Kamāl al-Dīn.

Al-Kindī's "catalogue of the sciences" presents the scope of *al-manāẓir*—optics—as an established discipline within the mathematical sciences in Islamic scholarship. It is easy to assume that this simply reflects the Aristotelian view that optics is part of mathematics. However, this ignores the fact that Aristotle considered optics in the very narrow sense of the study of perspective and catoptrics (reflection); he did not include the study of vision or the nature of light in his category of optics. Consequently, his work on vision lacks any mathematical treatment. Al-Kindī therefore treats optics as a mathematical science in a much wider sense than Aristotle. In fact, in describing the scope of optics as “what appears to sight” (*mā yazhar fī al-baṣar*) al-Kindī shows great prescience and sets the stage for the ever-widening scope of optics as a category of study in Islamic scholarship. This scholarship culminates in the work of Kamāl al-Dīn al-Fārisī, who includes subject matter such as the study of the rainbow and halo in his magnum opus on optics—subject matter that hitherto had been subsumed under meteorology. Optics as a discipline therefore should be understood as a much wider and diverse category in the Islamic scholarly tradition compared with its Greek progenitor.

<R1>Bibliography</R1>

<REF>Ibn al-Haytham. *The Optics of Ibn al-Haytham*. Books 1–3, *On Direct Vision*. Translated by A. I. Sabra. London: Warburg Institute, 1989.

Kheirandish, Elaheh. “The Many Aspects of ‘Appearances’: Arabic Optics to 950 AD.” In *The Enterprise of Science in Islam: New Perspectives*, edited by Jan P. Hogendijk and Abdelhamid I. Sabra, pp. 55–83. Cambridge, Mass.: MIT Press, 2003.

Lindberg, David C. *Theories of Vision from al-Kindi to Kepler*. Chicago: University of Chicago Press, 1976.

Rashed, Roshdi. “Geometrical Optics.” In *Encyclopedia of the History of Arabic Science*, edited by Roshdi Rashed, vol. 2, *Mathematics and the Physical Sciences*, pp. 643–671. London: Routledge, 1996.

Sabra, A. I. “Ibn al-Haytham.” In *Dictionary of Scientific Biography*, edited by Noretta Koertge, vol. 4., 1-4 New York: Thomson Gale, 2008.

Sabra, A. I. “Ibn al-Haytham’s Revolutionary Project in Optics: The Achievement and the Obstacle.” In The *Enterprise of Science in Islam: New Perspectives*, edited by Jan P. Hogendijk and Abdelhamid I. Sabra, 85–118. Cambridge, Mass.: MIT Press, 2003.

Sabra, A. I. “Manazir.” In *The Encyclopaedia of Islam*, 2nd ed., edited by P. J. Bearman, Th. Bianquis, C. E. Bosworth, et al., vol. 6. Leiden, Netherlands: Brill, 1991. [online version?]

Sabra, A. I. *Optics, Astronomy and Logic: Studies in Arabic Science and Philosophy*. Aldershot, U.K.: Ashgate, 1994.

Sabra, A. I. “Optics, Islamic.” In *Dictionary of the Middle Ages*, edited by Joseph R. Strayer, vol. 9. , 240-247, New York: Charles Scribner’s Sons, 1987.</REF>

<EA>Saira Malik</EA>