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Ibn al-Haytham (d. ca. 432/1040) on Vision

Jan Hogendijk and Abdelhamid I. Sabra (†)

1 Introduction

Al-Ḥasan Ibn al-Haytham (b. ca. 354/965 or later, d. ca. 432/1040) was born in Basra and spent the first half of his life in Iraq. He then moved to Egypt where he met the Fatimid caliph al-Ḥākim (r. 386–411/996–1021) and seems to have done most of his scientific research. Not much is known about his life and his scientific network. His most important work was the *Optics* (*K. al-Manāẓir*), which is organized in seven books and which he may have written in the period 410–20/1020–30. The purpose of this work was “to examine afresh, and in a systematic manner, the entire science of vision and to place it on new foundations” (Sabra, “Introduction,” liv).

Different and incompatible theories of vision existed at the time. According to the extramission theory, vision occurs when the eye emits visual rays and senses the visible objects. The visual rays were supposed to be straight lines or very thin cones with the apex in the center of the eye. This extramission theory was held by most mathematicians, following the ancient Greek tradition of Euclid and Ptolemy of Alexandria. The intromission theory, held by most natural philosophers following Aristotle, assumes that vision happens because visible objects emit perceptible “forms” which are transmitted to the eye through a transparent medium.

We have selected for the reader, in the translation of Abdelhamid Sabra, the introduction to the *Optics*, where Ibn al-Haytham explains the main problem, and two characteristic passages in Books I and II where he presents his own theory of vision. Ibn al-Haytham’s theory is based on three basic ideas. The first idea is the notion of primary and secondary light. In the words of Sabra (“Form,” 118),

[l]ight is a form ... in virtue of which material bodies shine forth into the surrounding medium. Either it naturally inheres in the body, in which case it is considered an “essential” form ... or it is temporarily “fixed” in the body’s surface, and in this case it is said to be an “accidental” form ... The light that shines from naturally inherent or essential light ... is called “primary” ... that which shines from accidental light is called “secondary.”

As Sabra has noted (Sabra, “Introduction,” lv) the word “form” may seem redundant to a modern reader and might as well be omitted for clarity. Primary light travels along straight lines.

The second idea is the behavior of the secondary light. If an object, such as an apple, is exposed to the sun, every point on the surface of the object which is hit by the primary light will emit secondary light rays in straight lines in all directions. We see the object because each point on the surface of the object emits one secondary light ray entering our eye. In addition, the object emits many other secondary rays which cannot enter our eye. These secondary rays can meet new objects, and each point on the surface of such a new object will then emit new rays in all directions, which one might call tertiary rays, although Ibn al-Haytham mostly subsumes them under secondary rays. Such rays may also enter our eye, and so on.

The third idea is the way in which vision occurs. Assume again that the object is an apple. According to Ibn al-Haytham, each point on the visible part of the surface of the apple emits exactly one secondary light ray which enters the eye, namely, the ray perpendicular to the spherical parts of the eye. Ibn al-Haytham then distinguishes two different ways of seeing: in “seeing at a glance,” one sees only the shapes and the colors of the apple, without interpreting what one sees as “apple.” In “seeing after contemplation,” the faculty of judgment interprets the rays as an image of an “apple,” after comparing it to images of apples which had previously been committed to memory.

Ibn al-Haytham proves many of his statements by meticulous experiments. For example, he verifies the travel of secondary light along straight lines even for the light of dawn before sunrise (which he considers to be secondary light emitted by the atmosphere). The descriptions are so detailed that there is little doubt that Ibn al-Haytham actually performed his experiments.

The seven books of the *Optics* deal with direct vision (Books I–III), reflection in mirrors (IV), image-formation in mirrors (v), errors of sight by reflection (VI), and refraction (VII). In the quoted passages below, the reader will notice Ibn al-Haytham’s precise style of argumentation. The later Books IV–VII of the *Optics* contain many pages of lengthy geometrical arguments, explained in a precise but unbearably lengthy style, and are therefore difficult to understand. Thus it is no surprise that the circulation and also the fame of the *Optics* in the first century after its composition was limited.

In the east, Ibn al-Haytham’s *Optics* became known through the revision by Kamāl al-Dīn al-Fārisī (ca. 700/1300), who shortened the text and thus made the work more palatable (Sabra, “Commentary”). Kamāl al-Dīn added four appendices, including the first correct explanation of the rainbow in history by refraction in raindrops which are considered as small spheres.

One Arabic manuscript of the *Optics* ended up in al-Andalus before 1080, and the work was translated into Latin around 1200; Ibn al-Haytham’s first

name, al-Ḥasan, was Latinized as Alhacen and later as Alhazen. Just like Kamāl al-Dīn, the anonymous Latin translator (or translators) abbreviated the work, and the translation was often easier to understand than the original. The Latin translation influenced European scholars of optics, and a version of it was printed (Risner). More recently, the seven books have been edited by Mark Smith from the Latin manuscript tradition. Unfortunately, the first quoted passage is missing in the Latin translation, probably because the beginning of the *Optics* was missing in the Arabic archetype manuscript, but English translations of the Latin versions of the second and third passage can be found in Smith (2:372–4, 516–19).

After Ibn al-Haytham, further progress in the theory of vision was made when Johannes Kepler worked out the focusing properties of eye lens and the image-formation on the retina in 1604. But Ibn al-Haytham was “undoubtedly the most significant figure in the history of optics between antiquity and the seventeenth century” (Lindberg, 58). Today he is one of the most celebrated exact scientists of the Arabic-Islamic tradition.

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2 Translation

Al-Ḥasan Ibn al-Haytham, *K. al-Manāẓir: al-Maqālāt 1, 2, 3 fī l-ibṣār ‘alā l-istiqāma*, ed. Abdelhamid Sabra, Kuwait: al-Majlis al-Waṭanī li-l-Thaqāfa wa-l-Funūn

wa-l-Ādāb, 1983, pp. 59–62, 158–60, 322–6, trans. Abdelhamid I. Sabra, *The Optics of Ibn al-Haytham: Books I–III; On Direct Vision*, 2 vols., London: The Warburg Institute, 1989, vol. 1, pp. 3–6, 80–2, 211–14 (numbering of paragraphs follows Sabra's translation).

[p. 3] [*From the Preface to Book 1*]

[§ 1.1.1] Early investigators diligently pursued the inquiry into the manner of visual sensation and applied their thoughts and effort to it, eventually reaching the limit to which their investigation had led, and gaining as much knowledge of this matter as their inquiry and judgment had yielded. Nevertheless, their views on the nature of vision are divergent and their doctrines regarding the manner of sensation not concordant. Thus, perplexity prevails, certainty is hard to come by, and there is no assurance of attaining the object of inquiry. How strong, in addition to all this, is the excuse for the truth to be confused, and how manifest is the proof that certainty is difficult to achieve! For the truths are obscure, the ends hidden, the doubts manifold, the minds turbid, the reasonings various; the premises are gleaned from the senses, and the senses (which are our tools) are not immune from error. The path of investigation is therefore obliterated and the inquirer, however diligent, is not infallible. Consequently, when inquiry concerns subtle matters, perplexity [p. 4] grows, views diverge, opinions vary, conclusions differ, and certainty becomes difficult to obtain.

[§ 1.1.2] Our subject is obscure and the way leading to knowledge of its nature difficult; moreover, our inquiry requires a combination of the natural and the mathematical sciences. It is dependent on the natural sciences because vision is one of the senses and these belong to natural things. It is dependent on the mathematical sciences because sight perceives shape, position, magnitude, movement, and rest, in addition to its being characterized by straight lines; and since it is the mathematical sciences that investigate these things, the inquiry into our subject truly combines the natural and the mathematical sciences.

[§ 1.1.3] Natural scientists have inquired into the nature of this subject according to their art, and exerted themselves in it as much as they could. The learned among them settled upon the opinion that vision is effected by a form which comes from the visible object to the eye and through which sight perceives the form of the object. Mathematicians, for their part, have paid more attention to this science than others. They have pursued its investigation, paying attention to its details and divisions. They have distinguished objects of vision, assigning causes to their particular properties and stating reasons for each of them. All the same, they have continued throughout the ages to disagree about the principles of this subject, with the result that the opinions of

the various groups among the practitioners of this art have gone different ways. But for all the disparity in their ranks, their different epochs, and the divergence of their views, in general they agree that vision is effected by a ray which issues from the eye to the visible object and by means of which sight perceives the object; that this ray extends in straight lines whose extremities meet at the center of the eye; and that each ray through which a visible object is perceived has as a whole the shape of a cone the vertex of which is the center of the eye and the base is the surface of the visible object. These two notions, I mean the opinion of the physicists and that of the mathematicians, appear to diverge and contradict one another if taken at their face value.

[§ 1.1.4] Mathematicians, moreover, differ about the structure of this ray and about the manner of its production. Some take the view that the radial cone is a solid body, continuous and compact. Others think that the ray consists of straight lines which are fine bodies the extremities of which meet at the center of the eye and divergently extend until they reach the visible object; and that sight perceives those parts of the surface of the object which the extremities of these lines encounter, whereas the parts of the object's surface that fall between those extremities are not perceived. Thus it comes about that the extremely small parts and minute pores in the surfaces of visible objects are invisible. Again, a group among those who believe the radial cone to be solid [p. 5] and compact thinks that the ray issues from the eye in one straight line until it reaches the object, after which it moves extremely quickly over the length and breadth of the surface of the object—so quickly in fact that the movement is imperceptible—and through this movement the solid cone is produced. Another group believes the matter to be different and that when the eyelids open in front of an object, the cone is immediately produced, all at once, in no sensible time. A group from among all of these thinks the vision-producing ray to be a luminous power which issues forth from the eye to the visible object, and that sensation is brought about by that power. Another group is of the opinion that when the air comes into contact with the eye it receives from the eye only a certain quality which immediately turns the air into a ray through which sight perceives the visible objects.

[§ 1.1.5] Each of those groups was led to its belief by reasonings, arguments, methods, and evidence of its own. But the settled view of all those who have inquired into the manner of visual sensation divides on the whole into the two contrary doctrines which we mentioned earlier. Now, for any two different doctrines, it is either the case that one of them is true and the other false; or they are both false, the truth being other than either of them; or they both lead to one thing which is the truth. [In the latter case] each of the groups holding those two doctrines would have failed to complete its inquiry and, unable to

reach the end, has stopped short of it. Alternatively, one of them may have reached the end but the other has stopped short of it, thus giving rise to the apparent difference between the two doctrines, although the end would have been the same had the investigation been pushed further. Disagreement may also arise in regard to the subject of an inquiry as a result of a difference in methods of research, but when the inquiry is rightly conducted and the investigation intensified, agreement will emerge and the difference will be settled.

[§ 1.1.6] That being the case, and the nature of our subject being confused, in addition to the continued disagreement through the ages among investigators who have undertaken to examine it, and because the manner of vision has not been ascertained, we have thought it appropriate that we direct our attention to this subject as much as we can, and seriously apply ourselves to it, and examine it, and diligently inquire into its nature. We should, that is, recommence the inquiry into its principles and premises, beginning our investigation with an inspection of the things that exist and a survey of the conditions of visible objects. We should distinguish the properties of particulars, and gather by induction what pertains to the eye when vision takes place and what is found in the manner of sensation to be uniform, unchanging, manifest, and not subject to doubt. After which we should ascend in our inquiry and reasonings, gradually and orderly, criticizing premises and exercising caution in regard [p. 6] to conclusions—our aim in all that we make subject to inspection and review being to employ justice, not to follow prejudice, and to take care in all that we judge and criticize that we seek the truth and not to be swayed by opinion. We may in this way eventually come to the truth that gratifies the heart and gradually and carefully reach the end at which certainty appears; while through criticism and caution we may seize the truth that dispels disagreement and resolves doubtful matters. For all that, we are not free from that human turbidity which is in the nature of man; but we must do our best with what we possess of human power. From God we derive support in all things. [...]

[p. 80] [*From Book 1, Chapter 6: on the Manner of Vision*]

[§ 1.6.56] Now that we have shown this, it remains for us to expose the opinion of those who hold the doctrine of the ray and show what is unsound and what is sound in it. We say: If vision occurs only through something that issues forth from the eye to the visible object, then that thing is either a body or not. If it is, then, when we look at the sky and see it and the stars in it and discern and contemplate them, there will issue at that moment from our eyes a body which will fill [the space] between the sky and the earth without the eye losing anything of itself. But this is quite impossible and quite absurd. Vision

does not, therefore, occur by means of a body that goes out of the eye. If, on the other hand, the thing that issues forth from the eye is not a body, then it will not sense the visible object, for sensation belongs only to animate bodies. Therefore, nothing issues from the eye that senses the visible object.

[§ 1.6.57] Now it is evident that vision occurs through the eye. If that is so, and if the eye perceives the visible object only through something that issues from [p. 81] it to the object, and if that issuing entity cannot sense the object, then what issues from the eye does not [itself] sense the object but rather conveys to the eye something of the object through which the latter is perceived by the eye. However, what is said to issue from the eye is not something perceptible by the senses but conjectured. But it is not permissible to conjecture anything unless there is a reason that calls for this conjecture. Now the reason that led those who hold the doctrine of the ray to maintain their doctrine is that they found that the eye perceives the visible object when an interval exists between them; and it was generally recognized that sensation occurred only through touch; so they also thought that vision occurred through something issuing from the eye to the visible object so that this entity may either sense the object in its own place or take something of the object back to the eye where it is sensed.

[§ 1.6.58] But if it is not possible that a body should issue from the eye and sense the visible object, and if nothing can sense the visible object other than an animate body, it only remains to conjecture that what issues from the eye to the object receives from the latter something which it conveys to the eye. And since it has been shown that the air and the transparent bodies receive the form of the visible object and convey it to the eye and to every body opposite the object, then that which is thought to convey to the eye something of the visible object is the air and the transparent bodies placed between the eye and the object. But if the air and the transparent bodies convey to the eye something of the visible object at all times and in any event (provided that the eye faces the object) without the need for something that issues forth from the eye, then the reason that led those who hold the doctrine of the ray to maintain their doctrine ceases to exist. For they were led to assert that doctrine by their belief that vision is effected only through something that extends between the eye and the object for the purpose of conveying something of the object to the eye. But if the air and the transparent bodies placed between the eye and the object convey to the eye something of the object without the need for anything to issue from the eye, and, moreover, if these bodies extend between the eye and the object, then the need to affirm the existence of anything else through which something is conveyed to the eye no longer exists, and there no longer exists a reason for their saying that a conjectural entity conveys to

the eye something of the object. And if no reason remains for maintaining the doctrine of the ray, then this doctrine is invalidated.

[§ 1.6.59] Moreover, all that mathematicians who hold the doctrine of the ray have used in their reasonings and demonstrations are imaginary lines which they call “lines of the ray.” And we have shown that the eye cannot perceive any visible object except through these lines alone. Thus the view of those who take the radial lines to be imaginary lines is correct, and we have shown [p. 82] that vision is not effected without them. But the view of those who think that something issues from the eye other than the imaginary lines is impossible and we have shown its impossibility by the fact that it is not warranted by anything that exists, nor is there a reason for it or an argument that supports it.

[§ 1.6.60] It is therefore evident from all that we have shown that the eye senses the light and color that are in the surface of a visible object only through the form of that light and color, which [form] extends from the object to the eye in the intermediate transparent body; and that the eye does not perceive any of the forms reaching it except through the straight lines which are imagined to extend between the visible object and the center of the eye and which are perpendicular to all surfaces of the coats of the eye. And that is what we wished to prove.

[§ 1.6.61] That, then, is the manner of vision in general. For that which sight perceives of a visible object by pure sensation is only the light and color in that object. As for the other properties that sight perceives of a visible object, such as shape, position, size, movement, and the like, these sight cannot perceive by pure sensation, but only by inference and signs. We shall afterwards explain this thoroughly in the second book when we enumerate the properties perceptible by sight. But that which we have shown, I mean the manner of vision, accords with the view of the learned among physicists and with the generally accepted view of mathematicians. It is now clear from [what we have shown] that the two groups are right and the two doctrines correct, mutually compatible and not contradictory. But neither [doctrine] is complete without the other, for sensation cannot be effected by virtue of one [of these two doctrines] without the other, nor can vision take place without their combination.

[p. 211] [*From Book 2, Chapter 4: on Distinguishing (the Ways in Which) Sight Perceives Visible Objects*]

[§ 2.4.12] We say also that when sight perceives an object whose form is then ascertained by the sentient, the form of that object will remain in the soul and take shape in the imagination. And the form of a repeatedly perceived object will be more firmly fixed in the soul than the form of one perceived only once or a few times. And when sight perceives an individual, then repeatedly and

continually perceives other individuals of the same species, the form of that species will be confirmed in the soul, and a universal form of that species will thus take shape in the imagination.

The proof that the forms of visible objects remain in the soul and in the imagination is [as follows]: when we remember a [p. 212] person whom we knew or saw or met before and whose form has been ascertained, and if we correctly remember that person and the place in which we met him, we will immediately imagine the individual features of that person, the outline of his face, his gait or posture at that time, and imagine the place in which we met him, and may also imagine at the same time other visible objects that were present in that place. But to imagine the form of that person and the form of the place in which we met him and the state he was in, without the presence of the person and the place, is clear evidence that the form of that person and place still exists in our soul and remains in our imagination. Similarly, when we remember a city which we have previously seen and from which we have been absent, we will imagine the form of the city and of the places and individuals we have come to know in it, if we remember all this in the absence of the city and of what we have seen in it. Again, when we remember objects previously seen, and correctly remember having seen them, we will imagine their forms as they were then seen. But to imagine the forms of objects previously seen, in the absence of these objects at the time of remembering them, is clear proof that the forms perceived by sight exist in the soul and are imprinted in the imagination. [...]

[§ 2.4.16] [p. 213] Now for the universal forms which are produced in the soul for the species of visible objects and which take shape in the imagination. To every species of visible objects belong an appearance and a shape which are the same for all individuals of that species, while the individuals differ in respect of particular properties which are also visible. Color [for example] may be the same in all individuals of one species. Now appearance, shape, color, and all properties which constitute the appearance of every individual of a certain species is a universal form of that species. And sight perceives that appearance and shape, and every property which is the same for the species' individuals, from all the individuals of that species which it has perceived; and it also perceives the particular properties in which those individuals differ while agreeing in the universal properties. And as the sight repeatedly perceives the individuals of one species, the universal form in that species will be repeatedly presented to it together with the difference between the particular forms of those individuals. And when the universal form has been repeatedly presented to the soul, it will be fixed and established in it. And from the difference between the particular forms that accompany the universal forms as they

are repeatedly presented, the soul will perceive that the form that is identical for all individuals of the species is a universal form of that species. In this way, [p. 214] then, the universal forms which sight perceives of the species of visible objects are produced in the soul and in the imagination.

[§ 2.4.17] The perceived forms of individual visible objects and the forms of their species therefore remain in the soul and are fixed in the imagination, and as they are repeatedly perceived by sight they become more firmly fixed in the soul and in the imagination; and visible objects are recognized by the sentient by means of the forms produced in the soul for the species of these objects and their individuals. It is on these forms that the sentient relies in perceiving what the visible objects are, because perception of what they are is due only to recognition, and recognition results from comparing the form presently perceived by sight with the form that has been fixed in the soul by the forms of objects already seen, and from likening the presently perceived form to one of the forms in the imagination. Perception of what the object is, therefore, is perception of the similarity between the object's form and one of the forms established in the soul and in the imagination for the species of visible objects. And it is on the universal forms produced in the soul for the species of visible objects that the sentient relies in perceiving what the visible objects are, whereas it is on the individuals' forms produced in the soul for each of the objects previously seen and imagined that it relies in recognizing individual objects. The faculty of judgment tends by nature to liken the forms of objects presently perceived to the form fixed in the imagination and acquired by the soul from the forms of visible objects. When, therefore, sight perceives an object, the faculty of judgment will look for a similar form in the imagination. If it finds such a form, it will recognize the object and perceive what it is; if not, then it will neither recognize the object nor perceive its quiddity. However, because of the speed with which the faculty of judgment assimilates the form of the object at the moment of vision, it may err by likening the object to another, different from it, if the object has a property which exists in the other. Then, when it later contemplates the object and ascertains its form, it will liken it to the form truly similar to it, thus realizing at the second time the error it made in the first assimilation. It is in these ways, then, that the sense of sight perceives what the visible objects are.