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Dominique Raynaud

A Critical Edition of Ibn al-Haytham's *On the Shape of the Eclipse*

The First Experimental Study of the Camera Obscura

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Acknowledgments

I have benefited from much advice during the course of this long research on Ibn al-Haytham's *On the Shape of the Eclipse*.

This work was initiated several years ago when I first got Naẓīf's book in my hands and suspected some discrepancies between Naẓīf and Wiedemann's readings of *On the Shape of the Eclipse*. I first collated and transcribed the manuscripts. At this stage, I benefited from the linguistic support of Fatma Fersi (University of Grenoble), Hamdi Mlika (University of Kairouan) and Elaheh Kheirandish (Harvard University). I also express gratitude to Ken Saito (Osaka Prefecture University), Gregg de Young (American University in Cairo), and A. Mark Smith (University of Missouri) for insightful comments on a previous article of mine, published in the *Archive for History of Exact Sciences*, that contributed much to the present work in establishing the stemma codicum of Ibn al-Haytham's treatise.

I am especially indebted to J. Lennart Berggren (Simon Fraser University), Sylvia E. Hunt (Laurentian University), Gaute Hareide (Volda High School), and Zheran Wang (Beijing University), who made valuable suggestions to improve my translation and commentary, and Hassan Tahiri (University of Lisbon), who kindly revised my transcription of the whole Arabic text, paying particular attention to its grammatical accuracy. He also helped decipher two barely legible marginalia in MS B. I thank him for his patience and dedication.

St. Pierre, May 2015

Introduction

This book aims at providing the first critical edition with translation and commentary of Ibn al-Haytham's *On the Shape of the Eclipse*, which is the first experimental study of the camera obscura.

The motivation to undertake this edition results from the very significance of Ibn al-Haytham's treatise in the history of optics:

1. *On the Shape of the Eclipse* strictly adheres to the experimental method—an extremely rare occurrence in the middle of the Middle Ages—that allowed Ibn al-Haytham to resolve two outstanding issues from at least Late Antiquity: "Why does the Sun penetrating through quadrilaterals form, not rectilinear shapes, but circles?" (*Problemata Physica* XV, 6) and "Why is it that during eclipses of the Sun, if one views them through a sieve or a leaf the rays are crescent-shaped in the direction of the Earth?" (XV, 11). As Ibn al-Haytham's solution is closely dependent on the use of the experimental method that inspires the whole treatise, I defer this discussion to a more suitable place (see Chapter 3, pp. 95–7);

2. *On the Shape of the Eclipse* provides the first successful attempt to merge the two branches of Ancient optics, which finally resulted in the abandonment of the extramission theory. This bestows historical significance on Ibn al-Haytham's work, since there is no prior history of this approach. In this regard, the treatise represents a key milestone in the history of optics (Section 1).

3. *On the Shape of the Eclipse* also includes pioneering research on the conditions of formation of images—in a time deemed to be committed to aniconism. However, it is an open question whether Ibn al-Haytham's work laid the basis for future investigation on the camera obscura (Section 2).

1. A Key Milestone in the History of Optics

Ancient and Medieval optics were divided into two special branches: *optics* proper (*optica, 'ilm al-manāẓir, de aspectibus*), centered on the study of sight and visual perception; *burning mirrors* (*catoptrica, 'ilm al-marāyā, de speculis comburentibus*), which focused on the geometric analysis of light, thereby laying the foundations of modern physical optics. One was the science of visual rays; the other was the science of luminous rays. Both parts have Greek roots. The first is found in Euclid's *Optics* and the second in Diocles' *Burning Mirrors*. Both works were acquired by scientists in medieval Islam.[1]

Ibn al-Haytham is generally credited with being the instigator of the unification of the two branches of optics (Sabra 1989, II: liv; Smith 2001: cxvi). More specifically, his intromission theory would have allowed him to break through the barrier between the science of visual perception (the direct vision, studied in Books I-III) and the science of light (the reflexion, studied in Books IV-VI). This unification was possible because of the symmetry of the laws of optics: the law of reflection is the same, whether the ray of light is emitted by the eye to the visible objects (extramission) or is communicated by the objects to the eye (intromission).

There are strong signs that *On the Shape of the Eclipse* was an early work by Ibn al-Haytham, which he composed when he began his optical masterpiece—probably soon after *Optics* I, 3, which is quoted in it—and that it already aimed at integrating the science of vision (physio-psychological optics) and the science of light (physical optics). In this work, indeed, Ibn al-Haytham does more than just apply geometrical optics to explain what causes an image to form in the camera obscura; he mostly questions the conditions of visibility of the image of the Sun and the Moon cast in

1. This division was perpetuated for another several centuries in the West. At the time of considering the problem of pinhole images, Roger Bacon chose to develop the subject in full in his *De speculis comburentibus*, which seems a strange choice. Regardless, it is worth noting that, while the projection of images through a screen does not require any mirror, the phenomenon involves radiations of light—not sight. This explains quite well why Bacon attributed this discussion to the science of burning mirrors, i.e., the science of light.

the darkroom. This approach is notably reflected by the phrases “perceived by the sense,” “perceptible” and “imperceptible” frequently recurring in his work.

If one accepts that *On the Shape of the Eclipse* was one of the early works by Ibn al-Haytham—a fact supported by both astronomical dating (Appendix, pp. 161–86) and the rudimentary reference to Apollonius’ *Conics*, of which he was soon to become a connoisseur—this treatise should be seen as the first accomplished work in which the two branches of Ancient optics were unified in one synthesis.

2. Ibn al-Haytham’s Legacy

In a famous lecture to the French Academy of Sciences, François Arago (1839: 250–1) credited Giambattista della Porta with being the inventor of the camera obscura (*Magia Naturalis*, 1558). Two years later, Guglielmo Libri (1841, 4: 303–314) corrected Arago’s error from excavating three texts prior to that of Della Porta: Girolamo Cardano (*De Subtilitate*, 1550); Don Papnutio (*Di Lucio Vitruvio de Architectura Libri X*, transl. Cesariano, 1521); Da Vinci, e.g., *Codex A*, fol. 20v (ca. 1490). Subsequently, Curtze (1901) drew attention to the camera obscura by Levi ben Gerson, around 1329/42. Later Pierre Duhem (1913: 505) discovered another text on the camera obscura by the astronomer Roger of Hereford, dated 1178. Then Wiedemann (1914) published his German translation of Ibn al-Haytham’s work on the eclipse. In the late sixties, Lindberg (1968, 1970*ab*) reconstructed the centuries-long history of pinhole images (a tradition that only differs from the study of the camera obscura in that the device is not necessarily equipped with a screen). Since then other texts have been discovered, such as that of Guillaume de Saint-Cloud, around 1290. We now know that the result—not the operation—of the camera obscura was already described by the Chinese philosopher Mo Zi before 391 CE (Graham 1978: 375–9).

As a consequence, the question is no longer to decide who, among Della Porta, Maurolico or Da Vinci, invented the camera obscura, but to put each person in the right place in the long course of this history, and to precisely determine what followers owed to predecessors. As the camera obscura gained some kind of popularity in

16th-century Europe—to cite but a few: Reinhold (1542), Gemma Frisius (1545), Cardano (1550), Della Porta (1558), Barbaro (1568), Danti (1573), Benedetti (1585), Kepler (1604), Scheiner (1612), Schwenter (1636), Kircher (1646)—the question is also to know if the interest of the early modern scientists for the operation of this instrument owed something to the acquaintance of scholars with the medieval tradition of the camera obscura and, in particular, if some of them benefited Ibn al-Haytham's pioneering research on the subject.

In this respect, it is worth noting that some science historians consider such legacy unlikely (e.g., Lindberg 1968: 156) whereas others are inclined to believe it possible (e.g., Goldstein 1985: 141).

One major argument in favor of such legacy is that at least seven treatises by Ibn al-Haytham were available to subsequent scholars:

1. Apart from Latin and Italian translations, the *Optics* (*Kitāb al-Manāẓir*) was referred to ca. 1085 in the *Istikmāl* by al-Mu'taman Ibn Hūd, King of Saragossa, who cites the lemmas for solving Alhazen's problem discussed in Book 5 (Hogendijk 1986: 49), ca. 1230 by Jordanus de Nemore (*De triangulis* IV.20), who quotes "19 quinti perspective" (Clagett 1964: 668–9; 1984: 297–301), ca. 1250 by Bartholomaeus Anglicus (*De proprietatibus rerum* III.17) who cites the "auctor pespective" (Long 1979: 39–45).
2. *On the Rainbow and the Halo* (*Maqāla fī al-hāla wa-qaws quzah*) was referred to ca. 1170 by Averroes in his *Middle Commentary on Aristotle's Meteorology* where there is a mention of "Avenatan in tractatus famoso" (Sabra 1989, II: lxiv).
3. *On Parabolic Burning Mirrors* (*Maqāla fī al-marāya al-muḥriqa bi al-qutū*), translated in Latin by Gerard of Cremona, was known to Bacon (*De speculis comburentibus*), Witelo (*Perspectiva* IX, 39–44), the 13th-century *Speculi almukefi compositio*, Jean Fusoris (*De sectione mukefi*) and Regiomontanus (*Speculi almukefi compositio*).
4. *Book on the Completion of the Conics* (*Maqāla fī tamām kitāb al-makhruṭat*) was known to Maimonides who partly translated it around 1231 in his *Notes on Some of the Propositions of the Book of Conics* (Langermann 1984).
5. *Commentary on the Almagest* (*Maqāla fī ḥall shukūk fī kitāb al-Majisṭī*) was available to Judah ben Solomon ha-Cohen of Toledo, at the time when he composed his encyclopedia *Midrash ha-Ḥokhmah* in 1247 (Langermann 2000: 377).

6. *Commentary on the Premises of Euclid's Elements* (*Sharh muṣādarāt kitāb Uqlīdis*) whose Books V–VII, X and XI were translated into Hebrew by Moses ibn Tibbon of Marseilles, and Book X was given a another translation by Qalonymos b. Qalonymos of Arles (Lévy 1997: 434). This work was subsequently available to Levi ben Gerson when he wrote his *Commentary to Books I–V of the Elements* (Lévy 1992: 87, 90).
7. *Epistle on the Quadrature of the Circle* (*Risāla fī tarbi‘ al-dā'ira*) was quoted before 1350 by Meyashsher ‘Aqov, alias Abner de Burgos (Langermann 1996: 50).[2]

It must be noted that none of these subsequent texts were known to us before special research was done to establish the facts. So the possibility that other tracts by Ibn al-Haytham were known to scholars—especially Hebrew savants who had some mastery of Arabic—should not be precluded *a priori*.

The most persuasive counter-argument against the survival of this work in later periods is the length of time that elapsed before the solution was rediscovered by Kepler. Notably, why did major perspectivists such as Bacon, Pecham and Witelo fail to understand the formation of images? Only two medieval authors, Egidius de Baisiu (Mancha 1989: 14) and Levi ben Gerson (Goldstein 1985: 48–49) approched the correct solution without, however, offering a fully satisfactory answer. After further intuitions by Da Vinci, the true explanation for the formation of the image was provided in Kepler's *Ad Vitellionem Paralipomena* (Kepler 1604: 48–56).[3]

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2. This list sidesteps *On the Configuration of the World* (*Maqāla fī hay'at al-‘ālam*), a work translated into Latin as *De configuratione mundi* under the auspices of Alfonso X el Sabio (*versión alfonsí,* before 1284), into Hebrew by Jacob ben Makhir ibn Tibbon of Montpellier as *Ma'amar bi-Tekunah* in 1275 and again by Solomon ibn Pater of Burgos in 1332. The work was subsequently known to Levi ben Gerson, who cited it in *The Wars of the Lord* (Lévy 1992: 86). The reason for leaving it aside is that the authorship of this work has been disputed by Rashed (1993: 490–1) who, on the basis of internal analysis, argues that this work is most certainly a work by Muḥammad the philosopher rather than by al-Ḥasan ibn al-Ḥasan the mathematician (see Chapter 1.2, pp. 14–5).
3. Kepler undertook this research to solve the problem posed by Tycho Brahe, who noted that the apparent diameter of the Moon seems to be reduced by about one-fifth during a partial eclipse of the Sun. Shortly after his meeting with Tycho, Kepler returned to Graz, where he observed a partial solar eclipse on July 10, 1600 by using a camera obscura. He then realized that the anomalous image was due solely to the size of the aperture of the camera obscura. He recorded his observation in his Eclipse Notebook for the year 1600, and expanded his correct explanation four years later, in *Ad Vitellionem Paralipomena* (Kepler 1600: 399–401; Kepler 1604: 48–56; Straker 1970, 1981; Plate 3.2).

Are those points enough for deciding for or against the acquaintance of medieval scholars with of Ibn al-Haytham's work? My position is that all the guesses that have been made so far—both pro and con—are pointless due to methodological weaknesses. Historical borrowings can be established with confidence only through textual parallels (Raynaud 2009, 2012*ab*). Textual parallels can be discovered only when one has at his disposal an accurate source-text. It is hard to take a strong view about Ibn al-Haytham's legacy until a reliable critical edition is made. A major aim of the present critical edition is to prepare future research on the putative legacy of *On the Shape of the Eclipse* in Latin Europe.

Chapter 1
This Edition

1. The Need for a Critical Edition

Ibn al-Haytham, born in Baṣra in the mid-tenth century and died in Cairo after A.H. 432/1040 (Sabra 1989, II: xix-xxiv; Rashed 1993: 1–19), is the author of over one hundred treatises dedicated to the mathematical sciences, among which is the *Epistle on the Shape of the Eclipse* (*Maqāla fī ṣūrat al-kusūf*). Even though Ibn al-Haytham's work was written around the first millenium, the work only benefited three studies. These are: a free abridged translation by the German physicist Eilhard Wiedemann (1914), an extensive commentary by the Egyptian engineer Muṣṭafā Naẓīf (1942), and a short comment by the Egyptian-American historian of science Abdelhamid I. Sabra (1989).

Let us review them one by one.

1. Wiedemann's Translation

Ibn al-Haytham's *On the Shape of the Eclipse* was freely translated into German by Eilhard Wiedemann (1914: 155–169). As this translation was the only testimony on Ibn al-Haytham's work until that date, Wiedemann provided a valuable service to the history of optics. Wiedemann's transalation was made from MSS O and L. He was unaware of the existence of MS P, which is the more faithful manuscript. None of MSS O and L is complete. Both lack 14 words at lines 247–8 (time 0.344),[4] 56 words at lines 562–6 (time 0.789) and 83 words at lines 569–77 (time 0.795).

4. 0 denotes the beginning of the text, 1 the end of the text. See Section 2.1, p. 17.

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Wiedemann's work is an abridgement. His edition consists of 7,000 words, representing half of the original Arabic text, which is 14,000 words long. Such abridgment is not due to the "verbosity of Arabic" (Sabra 1989, II: lxxxv-lxxxvi). Even if we use the same vocabulary in order to not exaggerate the differences (e.g., " wall" instead of "plane opposite to the plane of the aperture"), it appears that Wiedemann made deep cuts into the text (underlined):

"Eine ähnliche Erscheinung beobachtet man nicht am Mond, weder zur Zeit der Finsternis, noch am Anfang oder Ende des Monates, wenn er sichelförmig ist, trotzdem seine Gestalt der der Sonne im obigen Fall entspricht.	"No such thing happens with the eclipse of the Moon, nor in the early or last days of the month when the moon is crescent-shaped, and even though the remaining part of the Sun, when the eclipse is not a total one, resembles the shape of the Moon at the beginning or at the end of the month. Whenever a substantial part of the Sun remains, it looks like a crescent, when the Moon is seen on clear nights. And if, in the early or last days of the month, the Moon is facing a body with an aperture similar to that which produces a crescent-shaped image when the Sun is facing that aperture at the time of its eclipse, and [if] the moonligth appears on the
Er erscheint stets rund, auch, wenn die Bedingungen, unter denen die Beobachtung angestellt wird, in beiden Fällen genau gleich sind." (Wiedemann 1914: 156).	[wall], its light will always be circular. It will never be like the image of the sunlight, even if the two apertures facing the Sun and the Moon are equal."

Although Wiedemann successfully caught the overall content of the work, whole passages were left untranslated. Some other minor problems affect his résumé.

As the manuscripts are not punctuated, his translation does not always keep pace with the Arabic phrasing. Some sentences are cut into two, while clauses of separate sentences are put together. In the following example, the words left untranslated by Wiedemann are underlined (points and commas added):

والسطح المقعر مماس لكُرة القمر على قوس من دائرة محيطة بكُرة القمر. ثم يمتد هذا السطح المخروط المقعر حتّى ينتهي إلى كُرة الشمس. فيقطع كُرة الشمس على قوس من دائرة مساوية للدائرة التي هي قاعدة السطح المحدب، وذلك أن المخروط الذي يحيط بكرة الشمس مساو للمخروط الذي يحيط بكرة القمر، وقد تبين ذلك أصحاب التعاليم. فالسطحان المخروطان المحدب والمقعر قاعدتاهما قوسان من دائرتين متساويتين. (lines 118–25)

"Die konkave Fläche berührt die Mondkugel in einem Kreisbogen, dann schreitet sie bis zur Sonne fort und schneidet sie in einem Kreis, der gleich dem entsprechenden Kreis des konvexen Kegels ist.
Nach den Mathematikern ist der die Sonnenkugel begrenzende Kegel gleich dem die Mondkugel begrenzenden.

Die Sichel ist also von zwei Bögen von zwei gleichen Kreisen begrenzt." (Wiedemann 1914: 157).

"The concave surface is tangent to the Moon sphere, along an arc of circle ... it extends up to the Sun sphere. The Sun sphere is cut off along an arc of a circle, which is the base of the convex surface, because the cones bounding the Sun and the Moon sphere are equal, as was found by the mathematicians. The bases of the two surfaces of the cone, the convex and concave, are two arcs of two equal circles. If we examine the intersection of the convex and concave surfaces of the cone, this makes a crescent-shaped figure bounded by two arcs of two equal circles."

In this passage, Ibn al-Haytham introduces the result of the mathematicians (i.e., the astronomers) to account for the equality of the two [envelope] surfaces of the cones. As the two heavenly bodies have the same angular size, their cones are equal. However, because of the punctuation used by Wiedemann, the causal relationship between the two clauses of this sentence is not rendered (Arabic has وذلك أن…).

In a limited number of cases, we also find accidental misinterpretations of Ibn al-Haytham's intentions. See for example this edition, lines 89–93 (note 24).

The shortcomings that affect this abridged version in no way diminish the value of Wiedemann's work, which has yet to be praised for giving Western scholars access to the content of Ibn al-Haytham's work. I have consulted it on many occasions.

2. Naẓīf's Study

Ibn al-Haytham's *On the Shape of the Eclipse* has been independently studied by Muṣṭafā Naẓīf on the eve of World War II. As an engineer well versed in the history of Arabic science, Naẓīf wrote a penetrating analysis of Ibn al-Haytham's optical research. The work is discussed in the first of his two-volume set (Naẓīf 1942: 182–204; reed. 2008: 276–298).

Which manuscripts did Naẓīf use? His book contains only five passages between quotes (pages 182, 197, 199, 200 and 202), none of which conform exactly to the original. Here is, for instance, a first quotation to the very beginning of the text:

قد يوجد ضوء الشمس وقت كسوفها، اذا نفذ من ثقب ضيق مستدير، وانتهى الى سطح مقابل الثقب هلاليا، اذا كان الجزء الباقى من جرم الشمس هلاليا ولم يستغرق الكسوف جميعها. ولا يوجد مثل ذلك عند خسوف القمر، اذا كان الجزء الباقى منه هلاليا، ولا في أوائل الشهور وأواخرها، بل يوجد ضوؤه أبدا مستديرا اذا كان الثقب مستدير ... الخ (Naẓīf 1942: 182/276)	قد يوجد صورة ضوء الشمس في وقت كسُوفها، إذا خرج ضوءها من ثقب ضيق مستدير وانتهى إلى سطح مقابل الثقب على مثل شكل الهلال، إذا لم يستغرق الكسُوف جميعَها وكان شكل ما بقي منها هلاليًا. وليس يظهر مثل هذه الحال في كسوف القمر ولا في أوائل الشهور وأواخرها إذا كان القمر هلالا وشكل ما تبقى من الشمس. (this edition, Naẓīf's omissions overlined)

The second quotation refers to a passage at the end of the treatise, around time 0.838, just before the beginning of MS P, fol 45v:

ان كل هلال تحيط به قوسان من دائرتين متساويتين فان القوس المقعرة منهما أقل من نصف دائرة، لأن كل دائرتين متساويتين تتقاطعان فان الواصل بين تقاطعهما هو وتر في كل منهما وليس بقطر... (Naẓīf 1942: 197/291)	أن كل هلال يحيط به قوسان من دائرتين متساويتين. فإن القوس المقعرة منهما يكون أقل من نصف دائرة، لأن كل دائرتين متساويتين يتقاطعان، فإن الخط الذي يتصل بين تقاطعهما هو وتر في كل واحد منهما. فهو أصغر من قطر... (this edition)

Although Naẓīf's left-hand excerpts are put in quotation marks, all of them are altered and do not match the handwritten readings. This holds true for all five quotations in his book.

This situation is rather intriguing, given that the right-hand passages agree with each other in all extant manuscripts. There is only one omission in MS L located after the text of the first citation. We also find two minor errors in MSS O and B, before and after the text of the second citation. These readings have no consequences whatsoever on how we are to interpret these passages.

The same applies to diagrams. The diagram that most resembles that of the genuine work is Fig. 10 (Naẓīf 1942: 190). Setting aside the lines of the drawing, only 4 letters out of 14 match that of the Ibn al-Haytham's diagram: these are the letters L N Y T on the vertical axis (Figs. 1.1–1.2).

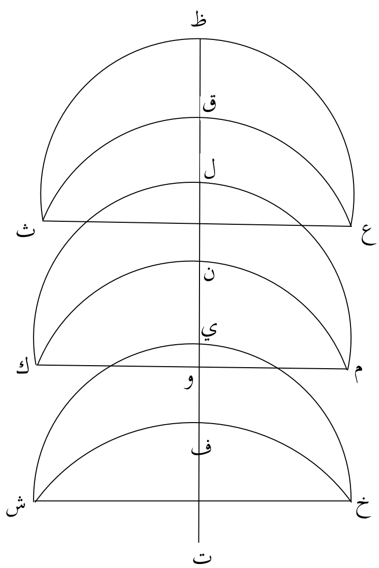

Fig. 1.1. MS P Crescents

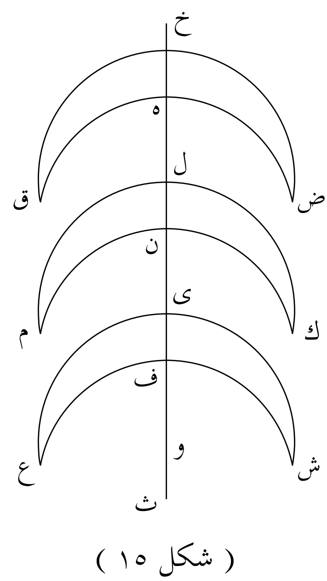

Fig. 1.2. Naẓīf's Crescents

The solution to the puzzle is given at the end of Naẓīf's book. The first thing to note is that Naẓīf had no knowledge of the German translation: he only cites Wiedemann's "Zu Ibn al-Haiṭams Optik" (1910) not "Über der Camera obscura bei Ibn al-

Haiṭam" (1914). Therefore the deviation from Ibn al-Haytham's text is unrelated to that of Wiedemann. Now we note that Naẓīf used Kamāl al-Dīn's *Tanqīḥ al-manāẓir li-dhawi al-abṣār wa al-basā'ir*, a text that perfectly matches his version:

قد يوجد ضوء الشمس وقت كسوفها، اذا نفذ من ثقب ضيق مستدير وانتهى الى سطح مقابل الثقب هلاليا اذا كان الجزء الباقى (١) من جرم الشمس هلالياً ولم يستغرق الكسوف جميعها ولا يوجد مثل ذلك عند خسوف القمر اذا كان الجزء الباقى منه هلالياً ولا في أوائل الشهور وأواخرها (٢) بل يوجد ضوؤه ابدا مستديرا اذا كان الثقب مستدير [٣٨٢] ... الخ (Fārisī 1929: 381–2)

قد يوجد ضوء الشمس وقت كسوفها، اذا نفذ من ثقب ضيق مستدير، وانتهى الى سطح مقابل الثقب هلاليا، اذا كان الجزء الباقى من جرم الشمس هلاليا ولم يستغرق الكسوف جميعها. ولا يوجد مثل ذلك عند خسوف القمر، اذا كان الجزء الباقى منه هلاليا، ولا في أوائل الشهور وأواخرها، بل يوجد ضوؤه أبدا مستديرا اذا كان الثقب مستدير ... الخ (Naẓīf 1942: 182/276)

The only minor differences between the two texts are: 1. the punctuation added by Naẓīf and 2. his removal of the tags introduced by Muṣṭafā Ḥijāzī, when editing Kamāl al-Dīn's text in 1929.

It thus appears that Naẓīf had a second-hand knowledge of *On the Shape of the Eclipse*. He commented on Ibn al-Haytham's work exclusively from the 1929 edition of Kamāl al-Dīn's commentary. This is further confirmed by the list of manuscripts at the end of the book: among the three manuscripts consulted by Naẓīf, none is a witness of *On the Shape of the Eclipse*.[5]

Kamāl al-Dīn al-Fārisī's recension of Ibn al-Haytham's work is not without interest from a scientific point of view. However, the two texts are different: 1. Kamāl al-Dīn produced an original work that went farther than his predecessor's on a number of optical issues; 2. Even when Kamāl al-Dīn cites Ibn al-Haytham, he speaks in his own words: he does not fully and accurately reflect Ibn al-Haytham's thought; 3.

5. Istanbul, Ahmet III, MS 3329, fols. 1v–125r: *Commentary on the Almagest* (*Fī Sharḥ al-Majisṭī*); London, India Office, MS 1270, fols. 116v–118r: *On the Compass of Great Circles* (*Maqāla fī birkār al dawāir al-'iẓām*); Lahore, Private Collection 71, fols. 36v–42v: *On Seeing the Stars* (*Maqāla fī ru'ya al-kawākib*). The other two manuscripts appearing in the 2008 reprint are those quoted by Rashed in his introduction: Bursa, Hüseyin Çelebi MS 323, fols. 23v–52r: al-Baghdādī's *On Place* (*Fī al-makān*); Tehran, Majlis-i Shūrā, MS 827: al-Rāzī's *Summary* (*al-Mulakhkhaṣ*).

Muṣṭafā Naẓīf used the Hyderabad edition at a time when the autograph of Kamāl al-Dīn's *Tanqīḥ* was unknown (this is now the Adilnor MS, Malmö). We now know that the Hyderabad edition is not faithful to the autograph manuscript, which has been discovered in the meantime (Sabra 1989, II: lxxii).

Despite this substitution—most likely determined by the troubled times in which this research was done—Naẓīf perfectly rendered the optical and mathematical ideas embedded in this work (1942: 196–8).

3. Sabra's Comment

Another comment on Ibn al-Haytham's *On the Shape of the Eclipse* appeared in the introduction to the English translation of Ibn al-Haytham's *Optics*, Books I-III. When reviewing Ibn al-Haytham's optical works, Abdelhamid I. Sabra devoted three pages to this work (Sabra 1989, I: xlix-li). He gave a good summary of the work with helpful notes on several concepts, such as the word image, to be found in Ibn al-Haytham's treatise. Sabra also used a wider range of sources. According to his own words, he consulted three manuscripts: Istanbul, Fātiḥ 3439, Leningrad B 1030 and India Office 1270, along with commentaries, namely those by Kamāl al-Dīn (1929, II: 381–401), Wiedemann (1914) and Naẓīf (1942). Though short, Sabra's commentary is reliable and well informed. Several problems remain nonetheless:

1. A comment is not a critical edition of the text;

2. All of the manuscripts were not consulted. In particular, Oxford, Bodleian, MS Arch. Seld. A32 (which is the only manuscript that makes extensive use of diacritical marks) and London, India Office, MS 461 (which is one of the rare manuscripts to have the diagrams carefully drawn) were not available to him;

3. Sabra did not inform us how he decided between the different versions he used, that is, firstly, between the three manuscripts he consulted, and secondly, between those manuscripts and the scholarly literature. He simply warns us that:

> Throughout his commentary, Kamāl al-Dīn distinguished the statements which he derived from the *Optics* by introducing them with 'he said', while introducing his own comment with 'I say'. This has sometimes given the impression that he was quoting I.H.'s actual words when in fact he was summarizing or re-phrasing the text (Sabra 1989, II: lxxii).

The same holds for *On the Shape of the Eclipse*. So Sabra probably diverged from Kamāl al-Dīn's version and Naẓīf's commentary on a number of issues, but we do not know exactly on what points he differed.

This survey reaches a simple conclusion: there is so far no reliable edition of Ibn al-Haytham's *On the Shape of the Eclipse*. Thus a critical edition is needed.

2. Codicological and Stemmatological Notes

1. Authorship and Date

Little is known about Ibn a-Haytham's life. He was born in Baṣra in the mid-tenth century—note that the date A.H. 354/965, frequently reported in the literature, refers to Muḥammad ibn al-Ḥasan ibn al-Haytham's birth. Ibn a-Haytham went to Egypt with a plan to control the flow of the Nile that he proposed to the caliph al-Ḥākim.[6] Ibn al-Haytham realized his project was unworkable and admitted failure. According to certain bio-bibliographers, as he feared revenge of the caliph, he preferred to retire by feigning madness. After the ruler's death, most sources agree that he settled next to the Azhar mosque-university in Cairo, earning his living from copying mathematical texts. Ibn al-Haytham died on or after A.H. 432 (11 September 1040–30 August 1041) for Ibn al-Qifṭī stated that "he had in his possession a volum (*juz'*) of geometry written by Ibn al-Haytham's hand and dated A.H. 432" (ed. Lippert 1903: 167; Sabra 1998; Rashed 1993). Historical sources are inconsistent on many other facets of his life.

As is well known, there has been a twenty-year long controversy between Abdelhamid I. Sabra and Roshdi Rashed on whether we should or should not identify Abū ʻAlī ibn al-Ḥasan ibn al-Ḥasan ibn al-Haytham (the mathematician) with Muḥammad ibn al-Ḥasan ibn al-Haytham (the philosopher). This controversy casts a shadow over some major episodes of Ibn al-Haytham's life and works. The two scholars have

6. Abū ʻAlī Abū Manṣūr Tāriq al-Ḥākim (called al-Ḥākim bi Amr Allāh) reigned from 29 Ramaḍān A.H. 386/15 October 996 to 27 Shawwāl A.H. 411/13 February 1021 (Canard 1975: 79–84). Ibn al-Qifṭī constantly refers to him as "ruler" (*al-ḥākim*) without explicitly mentioning his identity, which is inferred only on the basis of his "cruelty and versatility."

used different methods: Sabra supports the identity of the two persons on the basis of biographical interpolation (Sabra 1972: 189–96; 1989, II: xix–xxxii; 1998: 1–50; 2002/3: 95–108); Rashed supports his view on the basis of internal analysis of Ibn al-Haytham's works (Rashed 1993: 1–19, 490–491, 511–538; 2000, 937–941; 2002: 957–959; 2007: 47–63). Altogether, over 160 pages are devoted to the debate. This knotty controversy looks like a dilemma: either we know with certainty only a few facts about Ibn al-Haytham's life and works, or we know a larger amount of facts which are uncertain in nature. Neither position is comfortable according to the standards of history of science.

Because of this controversy, the authorship of *On the Shape of the Eclipse* needs to be established. A first response is given by the way all manuscripts are titled: "al-Ḥasan ibn al-Ḥasan ibn al-Haytham's *Epistle on the Shape of the Eclipse*." The text provides additional information. In the course of the treatise, the author says that he has dealt with the rectilinear propagation of light in his *Optics*: "From every point of every self-luminous body, light radiates in every straight line ... We have explained that, with due proof and experimentation, in the first book of our work on *Optics*" (lines 47–8). We also read in the subsequent text: "This has been shown in the first chapter of the book of *Conics*" (line 56), a mention that fits well within the focus of interest of Ibn al-Haytham, who attempted a reconstruction of Apollonius' *Conics* lost Book VIII (for editions of this work, see Hogendijk 1985; Rashed 2000).

These facts indicate with no doubt whatsoever that the author of *On the Shape of the Eclipse* was Abū ʿAlī al-Ḥasan ibn al-Ḥasan ibn al-Haytham, the mathematician and astronomer.

The date of composition of *On the Shape of the Eclipse* is unavailable using common historical methods. None of the extant five manuscripts bears a date of composition and, to my knowledge, there is no historical document usable for dating. However, it appears that the date of composition of this work can be determined through astronomical methods. As the demonstration is too long to fit into the main text, I will content myself with referring the reader to the *Appendix: A Tentative Astronomical Dating for the Epistle*. The result of this research is that Ibn al-Haytham may have recorded in his treatise the partial solar eclipse visible on 28 Rajab A.H. 380/21

October 990 CE from Baṣra. Should this dating be confirmed by future research, *On the Shape of the Eclipse* would definitely be an early work by Ibn al-Haytham—a fact that fits well with the case that the author of the work is “al-Ḥasan ibn al-Ḥasan ibn al-Haytham,” with no mention of his future *kunya* Abū ‘Alī.

Since the *Optics*, Book I, is referred to in *On the Shape of the Eclipse*, the above dating would mean that Ibn al-Haytham started composing *Optics* in his youth, before leaving the Būyid ‘Irāq around the turn of the millenium. Thus his optical research presumably took shape under the reign of the emir Bahā’ al-Dawla (wa-Diyā’ al-Milla), who ruled over ‘Irāq from 989 to 1012 after his brother Ṣamṣām al-Dawla (Shams al-Milla), who reigned from 983 to 986 (for more details on the Būyid dynasty, see Bosworth 1975; Kraemer 1992; Donohue 2003).

2. The Manuscripts

Ibn al-Haytham’s *On the Shape of the Eclipse* is extant in five manuscripts:

F Istanbul, Süleymaniye, Fātiḥ, MS 3439, fols. 117r–123v. Size 190 × 130 mm. Incomplete. The manuscript, written in poor *naskh*, was completed by Ibrāhīm ar-Rūjānī al-Bakrī in Mosul, in the night of ‘Ashūrā’ AH. 587/7 February 1191 (Krause 1936: 458). The text is unfaithful up to time 0.061 and ends at time 0.922. The diagrams are legible enough, but often distorted. Diagram 4 is missing.

B Oxford, Bodleian Library, MS Arch. Seld. A.32, fols. 81v–100v. Size 180 × 115 mm. The copy, written in a careless *naskh*, “was transcribed before A.H. 633 (A.D. 1235–6), being contained in a volume which came into the possession of Yaḥyā ibn Muḥammad ibn al-Labūdī [of Damascus] in that year. In the colophon we are informed that the copyist transcribed the text from a copy claiming to have been transcribed from the prototype” (Sabra and Shehaby 1971, ix). The diagrams often impinge on the text. They are distorted by a lack of parallelism and squareness. The intersection points are rough.

P St. Petersburg, Institute of Oriental Manuscripts, MS B 1030, fols. 21r–47v. Size 170 × 92 mm. MS P predates the mid-fourteenth century. We know that this manuscript was copied and checked against Ibn al-Haytham’s autograph in A.H. 750/1349. “This collection, written in mediocre *nasta‘līq*, is of great scientific quality” (Rashed 2005: 15). The text ends at time 0.926. All of the diagrams are geometrically clear and accurate.

O London, India Office, MS 1270 (Loth 734), fols. 79r–86v.[7] Size 279 × 114 mm. The manuscript is in good *naskh*, evidently from the sixteenth century. As stated by Loth, this copy is "well written in a small hand, with numerous neatly drawn diagrams" (Loth 1877: 214). MS O was initially part of the library of Richard Johnson (1753–1807), who came back to England in 1799. MS O was purchased by the India Office at the nabob's death in 1807. The text ends at time 0.998, seven words before the end.

L London, India Office, MS 461 (Loth 767), fols. 8v–34r. Size 229 × 140 mm. The manuscript is written in good *nastaʿlīq*. The date of the manuscript is deducible from the fact that the copy of al-Ṭūsī's *Treatise on Astrolabe* (*Risāla al-asṭurlābiyya*), appearing on fols. 1–7, was revised on 14th Shawwāl A.H. 1198/31 August 1784. The manuscript could have belonged to Governor-General Warren Hastings (1773–85), before it passed to the London Library (Loth 1877: 223). This manuscript has finely drawn diagrams, which all appear on a separate sheet.

Once acquired, the copies of the five extant manuscripts of *On the Shape of the Eclipse* were collated.

A first methodological novelty was to cut the digital copies into strips to lay the entire text on a single line. The five manuscripts were paralleled through a drawing software, whose baseline was calibrated by attributing the value 0.000 to the beginning of the text and the value 1.000 to its end. This turned out to be an effective device to compare the manuscripts and track the different readings, because any deviation in any manuscript can be identified easily and its point of occurrence in the edited work designated. This device facilitated the collation of the text and the tracking of handwritten variants.

The second methodological innovation was to apply the same editing rules to the text and diagrams—a suggestion that has been recently brought forward in view of the discrepancies that are often seen between the diagrams found in manuscripts and those depicted in scholarly editions of the same works: "The diagrams should be presented as they are found in the MSS, accompanied by a critical apparatus ... Where this is possible, we should seek to establish the text history of the diagrams and

7. O for Oblongus.

present this in a stemma" (Sidoli 2007: 546). In view of the advances made in diagram studies[8] and digital stemmatology,[9] a new method for the critical editing of geometric diagrams was devised—a method which, to my knowledge, has never been applied. As the stemma codicum of *On the Shape of the Eclipse* has been established elsewhere, I will limit myself to summing up the main results, while referring the reader to this publication for details (Raynaud 2014*c*).

3. The Stemma of the Text

As is well known to philologists, long omissions are of special interest for building the stemma codicum (Viré 1986; Woerther and Khonsari 2001). While a scribe can compensate for the omission of one word, he cannot restore a long passage without referring to the source. Thus all the descendants of a corrupted model will carry the same corruption. These omissions were detected across the manuscripts.

Then, I encoded all text accidents in a matrix of characters, which consists of six taxa (the five MSS and the out-group, that is, the text without errors) and of as many characters as there are omissions in the text from time 0.000 to time 0.922, a date that corresponds to the end of MS Fātiḥ. After comparing and examining the various programs available, I decided to use PHYLIP 3.69 (Felsenstein 2009), a program providing a whole package of algorithms.

The major cladistics techniques have recently been compared by estimating the similarity between the stemmata they provided on three independent data sets (Roos and Heikkilä 2009). This comparison showed the advantage of the Maximum Parsimony and RHM methods. In view of its wider diffusion, I have used the first one.

8. See Cambiano (1992), Decorps-Foulquier (1999), Netz (1999), De Young (2005), Mascellani et al. (2005), Crozet (2005), Saito (2005), Saito (2006), Sidoli (2007), Manders (2008), Sidoli and Saito (2009), Jardine and Jardine (2010), Saito et al. (2011), Sidoli and Li (2011), Saito and Sidoli (2012), Mumma et al. (2013).

9. The cladistic analysis is now being used in the critical editing of both literary and scientific texts. Key studies are: on the approach in general (Glenisson 1979; Reenen et al. 1996; Robinson 1996; Dees 1998; Huygens 2001; Woerther and Khonsari 2001; Macé et al. 2001; Reenen et al. 2004; Macé and Baret 2006; Cipolla et al. 2012); in literary texts (Robinson et al. 1996; Salemans 1996; Barbrook et al. 1998; Salemans 2000; Mooney et al. 2001; Windraw et al. 2008; Maas 2010); and in scientific texts (Brey 2009; Pietquin 2010; Cardelle de Hartmann et al. 2013).

When PHYLIP's Maximum Parsimony Algorithm is applied to the matrix of characters, a single most parsimonious tree is found (Fig. 1.3). The manuscripts connect to several ancestors by means of branches whose (horizontal) length is proportional to the number of transformed characters between the ancestor and the manuscript. A branch of zero length means that there is no difference between the manuscript (terminal node) and the progenitor (intermediary node).

```
+outG
|
1----Petersbg
|
|                      +--India1270
+----------------------2
                       |  +-------------Bodleian
                       +--3
                          |         +-------------------Fatih
                          +---------4
                                    +----------------------India461
```

Fig. 1.3. The Text Stemma

In this stemma codicum, MS Petersburg is directly connected to the ancestor [1]. MSS India Office 1270 and Bodleian connect to intermediate nodes [2] and [3]. MSS Fātiḥ and India Office 461 have a common intermediate ancestor [4]. The stemma helps us to decide which lectio should be followed when the manuscripts disagree. This recommends using preferably MSS Petersburg (the *lectio praeferenda*) and India Office 1270, for critically editing the text of *On the Shape of the Eclipse*.

4. The Stemma of Diagrams

The analysis of the handwritten diagrams follows in the same footsteps. The diagrammatic errors can be classified (a line drawn/missing; a geometric property true/false; a diagram oriented clockwise/counter-clockwise, etc.), and detected throughout the manuscripts by visual inspection.

Then a matrix of characters is made of six taxa (the five extant manuscripts of Ibn al-Haytham's work and the out-group, which simply consists of the list of common features) and of the 96 errors that we have detected in diagrams.