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The light of the Moon: Ibn al-Haytham (Alhazen) and Galileo

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Almost at the turn of the 10^{th} century, Ibn al-Haytham (Alhazen) demonstrated that, contrary to the view held by all the scientists of that time, the light received on Earth from the Moon is not the light of the Sun reflected on the surface of the Moon. In the 17^{th} century, Galileo took up the same problem and arrived at almost the same result. This paper discusses the arguments of these two scientists as well as the context in which they are presented and tries to specify both their similarities and their differences.

Keywords: Moon, Sun, Earth, Alhazen, Galileo, reflection, secondary light

Introduction

This paper aims at a comparative study of the methods employed by two great scientists to prove that the Moon is not a polished body, i.e., it does not reflect solar rays in the way a convex spherical mirror does. The scientists in question are Ibn al-Haytham – or, in its latinized form, Alhazen or Alhacen – and Galileo. A great time interval separates these two. Alhazen lived in the 10^{th}–11^{th} and Galileo in the 16^{th}–17^{th} centuries. Living on two sides of the Mediterranean Sea, they were also largely separated in space; Alhazen spent most of his active life in Cairo in Egypt, whereas Galileo lived in Italy. At first sight, it would seem that they lived in two different intellectual worlds. Alhazen is mostly known for his renovation of the science of optics, while the name of Galileo is always associated with the emergence of the new physics. Nevertheless, a certain rapprochement between these two could be seen on the frontispiece of an astronomical book published in the first half of the 17^{th} century. The author of this book was Johannes Hevelius (1611–1687) and his book is called *Selenographia sive lunae descriptio*.

Hevelius was an astronomer mostly known in our days for his discovery of some new constellations invisible to the naked eye. He made his observations by a telescope installed on the roof of his house in Danzig (Gdansk in the present-day Poland). The results of his observations of the Moon are represented in a book entitled *Selenographia*

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sive lunae descriptio (*Selenography or the Description of the Moon*), published in 1647, five years after the death of Galileo and almost six centuries after the death of Ibn al-Haytham. His aim was to complete and to rectify Galileo's description of the Moon as reported in the latter's *The Starry Messenger*. Figure 1 shows the frontispiece of Hevelius' *Selenographia*.

Let us dwell a little while on this beautiful drawing. The man standing on the left is Alhazen, holding in his hand a piece of paper on which are drawn some geometrical figures. The man on the right is Galileo, holding in his hand his sighting tube or telescope. Beneath the figure of Alhazen (Alhasen) we see a schematic drawing of a brain and under it the word "ratione" (reason), beneath the figure of Galileo we see a drawing of an eye and under it the word "sensv" (sense).

Like many such illustrations in the books in that period, this drawing has allegorical connotations: it seems to indicate that astronomy can progress only by a combination of reasoning and observation. The underlying idea is genial and true, nevertheless, although the book is directly linked with Galileo's description of the Moon, we would search it in vain for any reference to Alhazen's contribution to this subject. The author mentions him only on a few occasions for his work on optics alone (especially for his findings on the refraction of light).



Figure 1 The frontispiece of Hevelius' *Selenographia*.

Alhazen's *Optics* and its reception in Europe

No wonder that Hevelius knew Alhazen and held him in great esteem. In fact, throughout a large part of the Middle Ages and the Renaissance period, Alhazen's optical *magnum opus*, *The Book of Optics*, was the main source of inspiration for almost all European scientists having something to do with this subject. This could be seen through a short review of the reception of this work in Europe. In the description below, some other landmarks in the history of optics are also indicated.

Alhazen, a great mathematician[1], wrote his main work, *The Book of Optics*, in about 1000 CE. *Circa* 1200 the book was translated into Latin in Spain. In about 1270, the Polish monk Witelo published his *Perspectiva* which is a kind of commentary on Alhazen's *Optics*. In the 14$^{\text{th}}$ century Alhazen's *Optics* was translated into Italian; this was a significant event, because translating scientific books in a vernacular language was not common practice at that period. In 1572, Risner printed the Latin translation of Alhazen's *Optics* together with Witelo's *Perspectiva*. In 1604 Kepler publishes his *Ad Vitellionem paralipomena*, which is considered as one of the founding texts of modern optics. The title of the book shows its links with Vitelo's *Perspectiva* and, through it, to Alhazen's *Optics*. In 1632, Galileo published his *Dialogue Concerning the Two Chief World Systems*. This book, which brought its author before the Inquisition, contained a defense of the Copernican astronomy against the Aristotelian–Ptolemaic world-view, although, because of the close relation which had always existed between astronomy and optics, it was not devoid of optical discussions. In 1637 Descartes published his *Dioptrique*, another important text of modern optics. In 1647, Hevelius published his *Selenographia sive lunae descriptio*.

In all the above-mentioned texts Alhazen's *Optics* is somehow present. All the authors mentioned knew this book through its translations, commentaries or recensions. As we cannot enter into the details of Alhazen's contribution to the science of optics and the influence it exerted on Medieval and Renaissance science, we confine

[1]Alhazen lived in the second half of the 10$^{\text{th}}$ and the first half of the 11$^{\text{th}}$ century. Many of his works have been edited, translated and commented upon by modern scholars. Of the host of studies, I mention only a few which seem to me to be the most important. Mustaf Nazif's seminal work (*Alhazen, His Researches and Discoveries in Optics*, 2 Vols., 1942–1943), written in Arabic, is still an indispensable source for any study of Alhazen's optical works. There is no complete edition of the entire text of *The Book of Optics*, but there exists a critical edition of its first three books, with an English translation and notes by A.I. Sabra (*The Optics of Ibn al-Haytham, Books I–III: On Direct Vision*, London, 1989). The first three books of the Latin translation of Alhazen's *Optics* have been translated into English as A. Mark Smith, *Alhacen's Theory of Visual Perception* (American Philosophical Society, 2001). Almost all of the mathematical works of Alhazen, together with some of his philosophical and astronomical writings, have been edited, translated into French and commented upon by Roshdi Rashed in volumes 2–5 of his colossal work: Roshdi Rashed, *Les mathématiques infinitésimale du IX^{e} au XI^{e} siècle* (5 vols., London, 1993–2006). Rashed's *Geometry and Dioptrics in Classical Islam* (London, 2005) sheds a new light on the history of optics before Alhazen and elucidates the part of his work dealing with the refraction of light. The Arabic text of Alhazen's treatise *On the Light of the Moon* has been published in a non-critical and truncated form in a collection of his treatises (Hayderabad). The first translation of *On the Light of the Moon* is the German translation of Karl Kohl: "Über das Licht des Mondes. Eine Untersuchung von Ibn al-Haitham", in *Sitzungsberichten der Physikalisch-medizinishchen Sozietät in Erlangen*, 56–57 (1924–1925), pp. 305–398. A critical edition of the text of this treatise with a French translation and a detailed commentary is part of my *L'optique et la physique celeste: L'œuvre optico-cosmologique d'Ibn al-Haytham* (forthcoming). All the references to this treatise in the body of the paper are to this edition.

ourselves to a short discussion of his main achievements in his book, because all these authors knew Alhazen by this book alone and also because some of the concepts and theses of Alhazen are used in both Alhazen's and Galileo's discussion of the Moon.

Alhazen's main achievements in his *Optics*

- *Doing away with the concepts of visual ray and visual flux*

Before Alhazen[2], the science of geometrical optics was based on the concept of visual flux. Vision was supposed to produce by rays which emanated from the eye, under the form of discrete lines or a continuous cone, and, on touching the surface of the objects "saw" them. Even the philosophers who opposed this conception, accepted and used the results obtained through its use, because it seemed that this theory was the only one that could explain the direct vision, as well as the vision produced via reflection and refraction.

By a mixture of reasoning and experimentation, Alhazen shows that all the phenomena already explained by the use of visual rays could be explained by a theory based upon light rays emanating from the objects and arriving into the eye. Visual rays were at least superfluous, because the new theory could preserve all the advantages of the visual ray theory, without committing itself to its basic assumption with its absurd consequences. This was not a simple reversal of the direction of vision; it rather changed the subject-matter of the optics: from now on, this science had for its object "the light" and all the phenomena related to its propagation. Vision was only one of the manifestations of the propagation of light. Moreover, this new theory led to the introduction of new concepts, the most important of which was the new concept of the secondary light.

- *Discovery of the secondary light*

Before Alhazen, optics treated vision under three headings: 1) direct vision; 2) vision produced by reflected visual rays (the main part of which was vision by mirrors); and 3) vision produced by refracted visual rays (when visual rays passed from a transparent medium into another one). To this tripartite division corresponded a tripartite division of objects, which is based on their behavior when encountering visual rays: 1) transparent bodies (i.e., those which let the direct propagation or the refraction of visual rays); 2) polished bodies (i.e., those which caused the reflection of visual rays); and 3) opaque bodies (i.e., those which stopped the visual rays and, by consequence, were seen by them). As for the sources of light (because the presence of light was one of the "conditions" of vision), they were restricted to earthly objects such as lamps and chandelles and, of course, heavenly bodies the Sun and the Moon. Alhazen adds a fourth category to this classification. Through a detailed study of

[2]Until recently, by this expression one often understood the optics of Euclid and Ptolemy which had passed to the Muslim world, so that Alhazen was considered as the direct heir of these two mathematicians. The work of Roshdi Rashed draws our attention to the great importance of the optical activity done in the Islamic world itself before Alhazen and the role it has played in the constitution of the new optics of Alhazen. For a review of the work by Rashed in its relation to the history of optics, see Hossein Masoumi Hamedani, *Roshdi Rashed: Initiation à sa pensée et son œuvre*, Institut du Monde arabe, Paris–Casablanca, 2021, pp. 130–158.

some natural phenomena and several carefully designed experiments, he shows that every opaque body, illuminated by the light emanating from a source, becomes a "secondary source of light". That is to say, the light emanates from every point of its surface in every possible direction. The secondary light obeys the same laws of transmission, reflection and refraction. By the same method, Alhazen shows the existence of tertiary sources of light, and so on, *ad infinitum*, so that almost every terrestrial object actually becomes a source of light.

To this main achievement, we can add other contributions of Alhazen which fall outside the scope of this paper, but somehow intervene in our discussion of the problem of the light of the Moon:

- *The first explicit formulation of the laws of direct propagation and reflection of light,*[3] *and,*
- *Basing these laws on experiment;*
- *A full study of the phenomena of reflection and refraction including the formation of images in all kinds of mirrors (plane, concave and convex);*
- *Putting forward a theory of perception based on the visual perception;*
- *Presenting a more exhaustive theory of visual errors;*

And, last but not least,

- *Extending the application of optics to problems which were hitherto thought to be outside the reach of scientific examination and which are treated by Alhazen in separate treatises (On the Light of the Moon, On the Face We See on the Moon, . . .).*

This paper deals with one of these extensions of the domain of application of optics, put forward by Alhazen in his treatise *On the Light of the Moon*.

The problem of the light of the Moon

As the nearest celestial object to the Earth, the Moon has always attracted the attention of astronomers and philosophers alike. As for the light we receive from this object, there were two problems: where does this light come from? And how do we receive this light? From the Antiquity, these problems had received two answers which were accepted by everyone:

- *The origin of the light of the Moon.* The Moon has no light of itself, rather it receives its light from the Sun. This thesis was accepted by everybody at least since the 5^{th} century B.C. We call this thesis "the reception thesis".
- *The way the light of the Moon reaches us.* The unanimous thesis was that the Moon is a polished body which reflects the light of the Sun. In other words, the Moon was supposed to behave like a huge convex spherical mirror. This thesis will be called "the reflection thesis".

[3]These laws had already been formulated by Ptolemy in his *Optics*, but only for the case of vision. Moreover, the authors who wrote on burning mirrors employed these laws, albeit in a special case, without ever explicitly formulating them.

At the very beginning of his treatise, Alhazen explains how and why these two problems have come about, and why such unanimous theses are held about them. He writes:

> The body of the Moon differs from any other luminous celestial body: it changes its aspect, the figures that the luminous part of its surface presents to the eye are modified, and the light propagates from it in all directions. That is why the most rigorous researchers believe that its body is not luminous, and that the light which it presents to the eye is in fact that which it receives from the Sun. For, they have found that any part of the Moon's surface is always limited, by the extremity of the visible surface of its body, by an arc of a circle whose convexity is turned towards the Sun and whose widest part is facing the very body of the Sun; and they found that the more the Moon approaches the Sun, the more this part becomes smaller. They also found that when the Moon is full and light covers its visible surface, its uncovered luminous surface always faces the Sun.
>
> Moreover, the ancients did not bequeath a detailed discourse on how this body sends back its light after receiving it from the Sun. As for mathematicians, they seem to believe that the body of the Moon has no light of itself; that its light which radiates on the Earth is in fact the solar ray which, after having illuminated the Moon, is reflected on its surface towards the Earth; that the Moon is a spherical, dense, smooth and polished body; that when the Sun is opposite it, and that its ray reaches the surface of the latter, the solar ray is reflected from it and is prolonged, and that this ray, falling on a dense body, illuminates it, in the same way as reflection occurs in mirrors and in all polished bodies; and that the luminous color that we see on the Moon, at the moment when the latter is far from the Sun, is only the light of the Sun which has illuminated it. However, none of them left us a verified discourse on this subject, neither on the reception of the light by the Moon nor on the reflection of the light on the latter, a verified discourse. Apart from mathematicians, other researchers who also study the nature of celestial bodies believe that the Moon receives its light from the Sun. Indeed, this is found among their words, although in a discursive and not demonstrative way. Also, they are silent about how this light radiates towards the Earth.

In the text quoted, Alhazen expresses his discontent with the situation in which the problem of the light of the Moon is found. None of the two groups of researchers he mentions – the "mathematicians" and the others "who also study the nature of celestial bodies" (by which, he means the natural philosophers) – has presented a convincing proof for the two theses to which he refers. The natural philosophers have been content with the reception thesis, without venturing into the reflection problem. The mathematicians have treated both aspects of the problem, but their theses seem to Alhazen to be "non-demonstrative". Thus, he tries to put forward demonstrative solutions for the two problems.

The first problem: the figure of the Moon

The "proof" proposed by Alhazen covers all the aspects mentioned in the text cited above. He doesn't even take for granted the idea that the Moon is a sphere; rather he proves it. Of the two groups of researchers mentioned by him, the natural philosophers and the mathematicians, the first believed that the Moon is spherical because it is a simple body and every simple body should be spherical. The second group, the mathematicians, invoked observational evidence, i.e., the phases of the Moon. All the phases of the Moon are bounded with two arcs of a circle and this by itself shows that the Moon is spherical. Drawing upon this idea, Alhazen demonstrates that the Moon could not have any other shape, because all other shapes which we can envisage for it (a flat Moon, a hemi-spherical concave Moon, etc.)[4] have consequences which are in contradiction with observation. So far, we have highlighted a main characteristic of Alhazen's method: what he means by the "proof" is observational proof, not a proof of the kind proposed by the philosophers for the spherical shape of the Moon[5].

The second problem: the reception thesis

He follows the same strategy in case of the reception thesis. In this case, the main evidence always invoked, by both the natural philosophers and the mathematicians, was the lunar eclipse, in which the Earth prevents the Sun rays from reaching to the surface of the Moon and, as a consequence, the Moon is not seen. According to Alhazen, this sole evidence does not show by itself that Moon receives its light from the Sun, unless we show that no other phenomenon could cause the lunar eclipse. So, in a part of the treatise, he demonstrates that no other mechanism could produce the lunar eclipse and the lunar eclipse could be explained only by the reception thesis, i.e., only by assuming that the Moon has no light of itself, and that it receives its light from the Sun.

As for the reflection thesis, it is denied, for the first time in history, by Alhazen. He shows that the Moon emits the light received from the Sun like an opaque earthly body. It does not *reflect the light*; it does not behave like a spherical mirror. Rather, it is a *secondary source of light*.

Alhazen's argument is divided into two parts. In the first part, he proves that the light we receive from the Moon emanates from each and every point of its surface. This thesis is verified by the use of the experimental device shown in Figure 2.

This device consists of two parallel plates ($ABCD$ and $UVXY$) vertically installed on a support. The plate $ABCD$ is equipped with a rectangular opening (KL) and the plate $UVXY$ is equipped with a semi-spherical cavity with a small orifice (O) which let the light rays pass through. By pointing the apparatus toward different parts

[4] A part of his section of Alhazen's treatise is lost. I have tried (see Masoumi Hamedani, *L'optique et la physique celeste:...*) to reconstruct this missing part based on the remaining parts and the citations of this text in some later astronomical and philosophical works.

[5] For these two kinds of proof, and the difference between a "mathematical" and a "physical" proof, see Hossein Masoumi Hamedani, "Physics and the Mathematical Sciences in Classical Islam: A Conceptual and Historical Survey", in Giovanna Lelli (ed.), *Mathematics and Physics in Classical Islam*, Leiden, Brill, 2022, pp. 22-40.

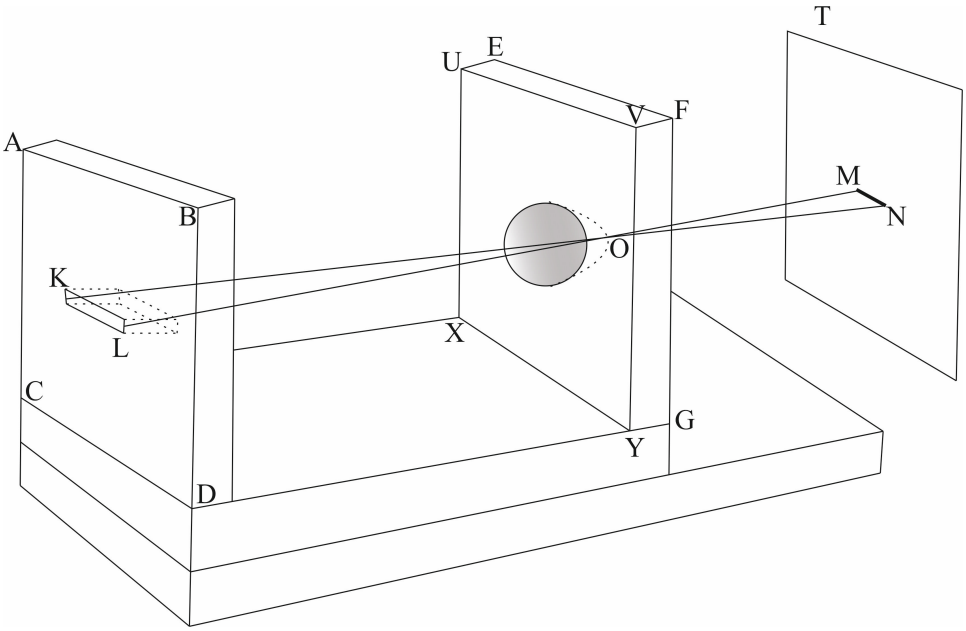


Figure 2 Alhazen's apparatus for the verification of the emanation of light from every point of the surface of the Moon.

of the Moon, we always see a bright line (MN) on the screen T placed behind the apparatus. MN is in fact the image of the part of the Moon which faces the opening KL. The length of the line MN depends on the part of the Moon which is in front of KL, so that if we cover a part of KL, MN becomes smaller. This experiment is in fact one of the many uses Alhazen makes of *camera obscura*, a device conceived and invented by him to experimentally study the propagation of light.

The experiment, repeated on different nights and in different places, leads Alhazen to the conclusion that light is emitted in every direction from every point on the external surface of the Moon.

Refutation of the reflection thesis

It seems that by showing that the light of the Moon is emitted from every point of its surface, Alhazen has achieved his main goal. As everybody knew that the Moon has no light of itself and that it received its light from the Sun, the result obtained could convince everyone that the Moon is a secondary source of light. Nevertheless, the idea that the Moon is a polished body and that it "reflects" the light received from the Sun was so deep-rooted that Alhazen feels obliged to refute it in the second part of the treatise. His refutation is based on the one hand, on his theory of image formation in mirrors and, on the other hand, on the distances between the Sun, the Moon and the Earth. Moreover, Alhazen's argument is based on another premise: for an object to be seen, it is not sufficient that it emits a light, rather it is necessary that

the light emitted reaches the observer's eye. The problem of the formation of images in all kinds of mirror (plane, convex and concave) is fully explained by Alhazen in his *Optics*. Figure 3 shows the result of his research for the case of a convex spherical mirror.

In this figure, C is the center of the spherical mirror, O is a point-object and E is the eye of the observer. O', the image of O in the mirror, is on the intersection of two light rays: 1) the ray OC emanating from O perpendicular to the surface of the mirror, and 2) the ray OIE which emanates from O and, after being reflected at point I on the mirror, reaches the eye of the observer. The ray OC intersects the continuation of the ray IE, i.e., the reflected ray.

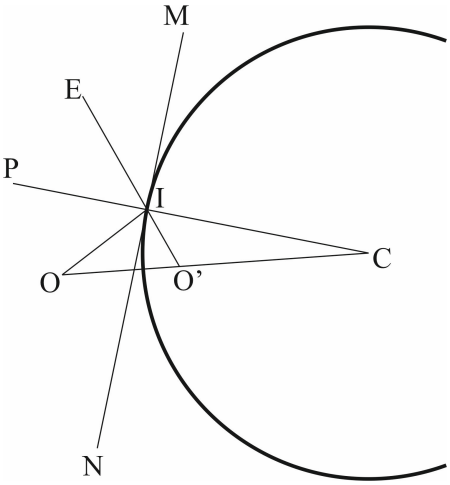


Figure 3 Image formation in a convex spherical mirror.

Two features of this theory of image formation are important to Alhazen's refutation of the reflection thesis:

The angles of incidence (OIP) and of reflection (EIP) are equal;

The incident and reflected rays (OI and IE) and the normal to the surface of the mirror (IP, or the tangent to the surface of the plane, MN) are in the same plane.

Apart from the laws of reflection, Alhazen's refutation of the reflection thesis is based on the distances between the Earth, the Sun, and the Moon.

In Figure 4, S is the Sun, M the Moon and E the Earth. Alhazen takes the distances between these bodies to be

$ME \cong 50D$[6]

$ES \cong 1200D$ (D is the diameter of the Earth).

These values have been known since the age of Antiquity. They were first obtained by Aristarchus of Samos and then, by another method, by Ptolemy. The value of ME is relatively good (the real distance between the Earth and the Moon is about $60D$), but the value of ES is too small. In fact, it is only 1/400 of the real value.

[6]In Ptolemaic models, the distance between the Earth and the Moon varies considerably. The value we have chosen is approximately the mean value.

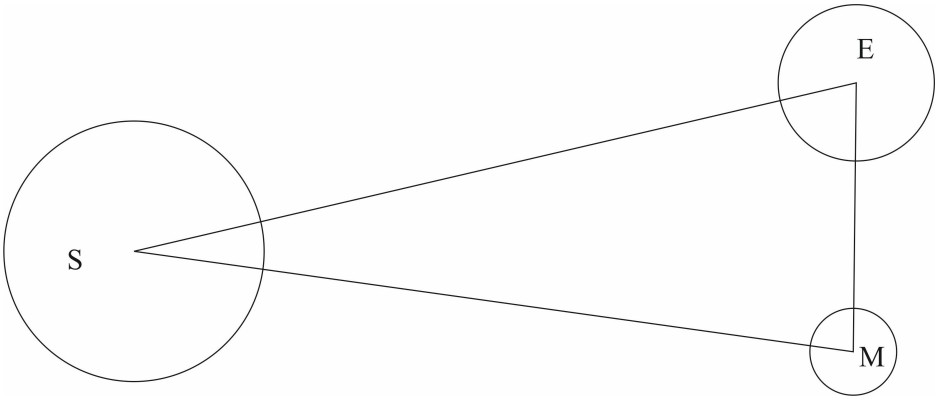


Figure 4 The distances between the Sun, the Moon and the Earth.

With these two principles, Alhazen proceeds to prove that the Moon does not reflect the light it receives from the Sun.

Figure 5 illustrates in a synthetic way the method employed by Alhazen to show that the light we receive from the Moon is not due to the reflection of solar rays on the surface of the Moon. The circle to the center S is a cross section of the Sun, the sphere to the center O is the Moon and Z is an earthly observer. Suppose that the Moon is a polished body. The ray XK emitted from the point X hits the surface of the Moon at point K and after being reflected reaches the point Z. The same thing occurs to the ray emanating from Y and reflecting toward Z. Note that, according to the laws of reflection, the incident ray XL and the reflected ray LZ are in the plane of the circle RLT, also the incident ray YK and the reflected ray KZ are in the plane of the circle RKU. Moreover, the angles formed by XL and LZ and the tangent to

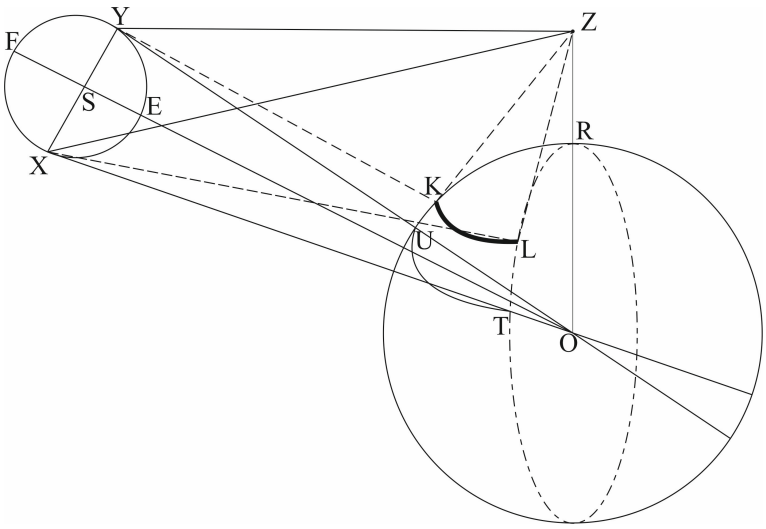


Figure 5 Alhazen's refutation of the theses of reflection.

the circle RLT at point L are equal and the angles formed between YK and KZ and the tangent at point K to the circle RKU are also equal.

The remaining part of Alhazen's argument is purely geometrical. Given that

$$YZ \cong XZ \cong YK \cong XL \cong 1200D$$

and

$$ZL \cong ZK \cong ZO \cong 50D,$$

he calculates first the arc UT and, based on one of the theorems he has already proved, concludes that $KL \ll UT$. The arc KL gives the "length of the place of reflection", i.e., the length of the part of the Moon on which the solar ray could be reflected (and reach the eye of a terrestrial observer) if the Moon were a polished body. By similar calculations, he calculates the "width of the place of reflection" in the direction perpendicular to KL. These two values give the dimensions of the patch on the surface of the Moon on which solar rays could be reflected and reach the eyes of terrestrial observers. As both values are too small compared to the apparent diameter of the Moon, Alhazen concludes that if the Moon reflected the light it receives from the Sun in the same way that a convex spherical mirror does, it would have been invisible.

The origin of the reflection problem

In a remark, he tries to locate the origin of this idea in a misunderstanding concerning the light and its reflection. He writes:

> Yet an intransigent adversary can always jump on the idea that light is reflected from the surface of the body of the Moon, but not in the way it is reflected from the surfaces of the spheres. For the body of the Moon, although spherical, is perceptibly flat, so it will necessarily be flat with respect to the light emanating towards it from the body of the Sun. Therefore, the spherical part of its surface towards which the light of the Sun emanates will not be distinguishable from a flat surface, as is the case with natural bodies when the difference between convexity and flatness is not perceptible. But this is certainly impossible, because the light, falling on a polished surface, is not reflected from it according to the requirements of the distance from the luminous body from which the light emanates towards the polished body, but according to the requirements of the surface of the body it encounters. However, to give more weight to our argument and to answer the specious argument of our adversary, we are going to demonstrate that light cannot in any way be reflected on the surface of the Moon, even if the reflection occurred there from the same way it occurs on flat bodies.

The way Alhazen explains this misconception and tries to refute it, depends on his theory of image formation in mirrors. The misconception to which Alhazen refers was based on a confusion between the reflection in plane and spherical mirrors. It was because, on the one hand, the Moon is a huge body and in many geometrical problems one could treat an arc of a huge circle as a straight line, or a part of a huge spherical body as a plane surface. On the other hand, the solar rays which fall upon the surface of the Moon could be considered as being parallel (due to the great

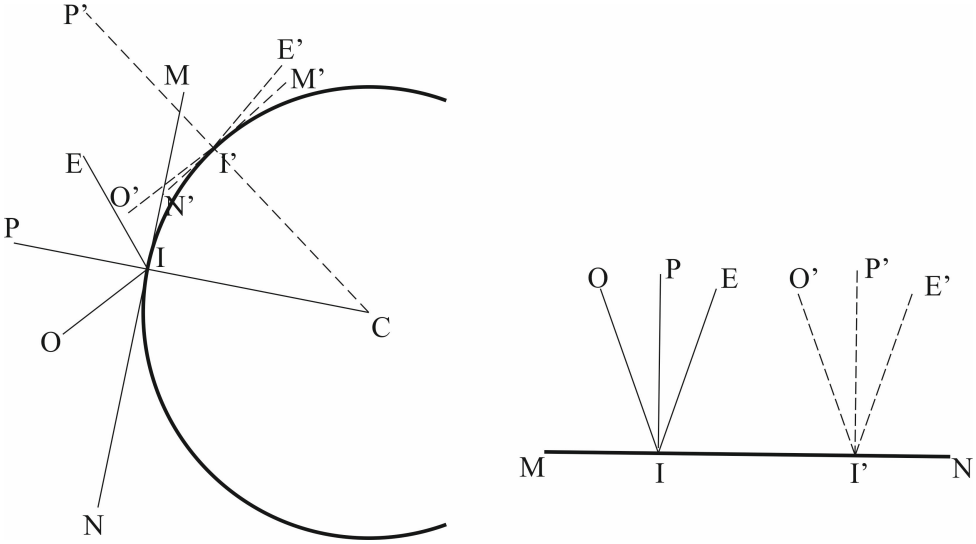


Figure 6 In a plane mirror (at the right), if the incident rays (OI and $O'I'$) are parallel, the rays (IE and $I'E'$) are also parallel, whereas in a spherical mirror the parallel rays (OI and $O'I'$) are reflected in different directions (IE and $I'E'$). The reason is that reflection takes place with respect to the normal (or tangent) to the surface of the mirror and not the surface of the mirror itself.

distance between these two bodies), so the reflected rays coming from the visible part of the Moon were thought to be all parallel. The gist of Alhazen's argument is shown in Figure 6. He shows that even in the case where the incident rays are parallel, in a spherical mirror the reflected rays will not be parallel. In this way, Alhazen shows that one cannot ignore the curvature of the Moon when dealing with the reflection of light rays on its surface.

After this remark, Alhazen proceeds to show that even if the Moon had a plane surface, the light we receive from it would not be the result of the reflection of the light of the Sun on its surface.

Galileo on the light of the Moon

Galileo discusses the problem of the light of the Moon in his *Dialogue Concerning the Two Chief World Systems – Copernican and Ptolemaic* (1632). This book, which was one of the main causes of Galileo's trial, is in the form of a dialogue taking place in three days between three persons: Salviati, a learned man who is in fact the mouthpiece of Galileo, he puts forward Galileo's arguments against the orthodox Aristotelian and Ptolemaic views expressed by his adversary Simplicio, a staunch Aristotelian who defends the Ptolemaic–Aristotelian world-view. The dialogue is mediated by a third *dramatis personae*, Sagredo, an intelligent man not contaminated by Aristotelian views and willing to accept the new facts and theories put forward by Salviati. His interventions are almost always in favor of Salviati.

The first problem: the figure of the Moon

The Moon is one of the main subjects of the first dialogue, because many of Galileo's new discoveries were related to the Moon. Drawing upon Galileo's telescopic observations of the surface of the Moon, Salviati argues that the Moon is an Earth-like body, with mountains and valleys, so it is not the perfect sphere which the philosophers believed. But, despite the fact of the existence of its mountains and valleys, the overall shape of the Moon is spherical. To demonstrate that the Moon is spherical, Salviati refutes only one rival thesis: the Moon is not a plane surface. Salviati's argument is based upon observable properties of the Moon. Although the details of his argument are different from those put forward by Alhazen in his treatise *On the Light of the Moon*, both authors are motivated by the same idea. For both of them, what can decide the shape of the Moon is the observable consequence it can have. Salviati refutes this alternative figure for the same reason that Alhazen has already done; it has some consequences which are against experience. The argument of Galileo is summarized in this sentence which is in agreement with what Alhazen shows in his much more detailed treatment:

> For if its surface were flat, it would all become covered with light at once, and likewise would all be deprived of light in an instant.[7]

The second problem: the light of the Moon

Like Alhazen, Galileo shows that light is not reflected on the surface of the Moon. His argument, put in the mouth of Salviati, is based on the difference between reflection on plane and spherical mirrors. In a plane mirror, all solar rays, which are considered to be parallel (because of the great distance between the Sun and the Earth), are reflected in one direction, while a spherical mirror reflects the incident solar rays in different directions. To show this difference he makes an experiment on a plane and a spherical mirror, both placed in a dark room. One sees a good part of the plane mirror illuminated by the Sun, while the spherical mirror seems to be not illuminated at all. In Galileo's own words:

> In a plane mirror all solar rays are reflected in the same direction but in a spherical mirror solar rays are reflected in different directions. The difference is due to the law of the equality of the angles of incidence and reflection.
>
> Let us consider this in regard to what would happen if the mirror had a spherical surface. Unquestionably we should find that of the whole reflection made by the illuminated surface, only a small part would reach the eyes of a particular observer, there being only the very least possible part of the entire surface which would have the correct slope to reflect the rays to the particular location of his eyes[8].

[7] Galileo Galilei, *Dialogue Concerning the Two Chief World Systems – Ptolemaic and Copernican*, Translated by Stillman Drake, 2nd Edition, University of California Press, Berkeley and Los Angeles, 1967, p. 62. For Alhazen's method, see Masoumi Hamedani, *L'Optique et la ...* .

[8] Galileo, *op. cit.* p. 74.

Alhazen and Galileo: similarities

The similarity between the methods of the two authors is evident. Both of them show that the Moon has a spherical shape and their arguments are essentially the same. In their argument for the spherical shape of the Moon, both of them draw on the essential difference between reflection on a plane mirror and reflection on a concave mirror; and both arrive at the same conclusion: the light we receive from the Moon is not due to the reflection of solar rays on the surface of the Moon. In other words, the Moon does not behave like a convex spherical mirror.

Alhazen and Galileo: differences

The first difference which could be seen in the way of arguing of the two authors is due to the fact that Galileo had already seen the Moon with its mountains and valleys by his telescope, and firmly believed that the Moon is a body much like the Earth, whereas Alhazen could only demonstrate his thesis through terrestrial experiments and geometrical arguments. He could only rely upon his optical knowledge and on what was known at his time of the sizes and distances of the Sun, the Moon, and the Earth. For this reason, Galileo only shows that the Moon is not a flat body, but Alhazen is obliged to refute other figures that one could imagine for the shape of the Moon.

The second difference: The method of Alhazen is quantitative: he calculates the part of the Moon which can reflect solar rays so that the reflected rays would reach the eye of a terrestrial observer. He shows that this part is so small that it is actually invisible. The argument of Galileo is qualitative, instead of the Moon itself, he uses a spherical mirror, and then concludes, based on an analogy, that

> the surface of the Moon is not flat, it is spherical; and the rays incident upon such a surface are found to be reflected in all directions at angles equal to those of incidence, because of the infinity of slopes which make up a spherical surface. Therefore the Moon can send its reflections everywhere and need not send them all to a single place like those of a plane mirror[9].

The third difference: For Alhazen, the concept of "secondary light" is an irreducible concept. It is a property of every opaque object to receive light and to emit it in every direction. For Galileo, the light we receive from the Moon is the result of a great multitude of reflections produced on different parts of an opaque body. So, in final analysis, Galileo reduces the emission of light from the surface of the Moon to the concept of reflection, and in so doing he draws upon the fact that the Moon is not a smooth body. It is true that the Moon is no more a huge spherical mirror, but it is a collection of very many tiny mirrors. The body of the Moon is decomposed in a very great number of plane mirrors, each of them reflecting the light received from the Sun in a specific direction, many of these reflecting lights ending on the surface of the Earth. In other words, the fact that the Moon does not emit its light towards the Earth in the same way that does a convex spherical mirror provides an additional proof for what he has already seen by his telescope: the Moon is not a *smooth* body.

[9]Galileo, p. 62.

Conclusion

As far as we know, the treatise of Alhazen, *On The Light of the Moon*, was never translated into Latin or any other European Language before the 20th century.[10] So Galileo did not know the result already obtained by Alhazen. He reproduces this result, but in his reproduction he draws upon the optical principles already formulated by Alhazen. So we can conclude that the optics Galileo knew and employed was that of Alhazen. Of course, after Galileo this science underwent another transformation which achieved its culmination in 1704 in the publication of Newton's *Opticks*. Nevertheless, even if Newton's researches led to new discoveries, e.g., the diffraction of light, geometrical optics never abandoned the principles laid out by Alhazen.

Apart from the general influence of Alhazen's *Optics* which we witness in the work of Galileo, his *On the Light of the Moon* has another, more important, significance for the history of science. The main achievement of Galileo in his *Dialogue* is considered to be the idea that the Earth and the heavens are made of the same stuff. It was a great step toward the emancipation of physics and astronomy from the cosmological dualism which was dominant throughout the Antiquity and the middle ages. This dualism had two essential components: 1) the heavens and the Earth are made of different stuffs, and 2) they are subject to different laws of motion. I hope to have shown that Alhazen's research on the light of the Moon put into question this dualism at least in the case of the Moon. By showing that the Moon emits the light received from the Sun just like an opaque terrestrial body, he showed that the Moon is not totally different of the Earth. In another treatise, entitled *On the Figure We See on the Face of the Moon*, he showed that the existence of the spots on the Moon signifies the existence of a kind of composition in the body of the Moon. So the Moon was not the simple body that the cosmological dualism demanded. Of course Alhazen was neither the first person to put into question the cosmological dualism for philosophical or theological reasons, nor the first person to hold that there exists a difference between the Moon and other heavenly bodies (the Moon spots and the fact that Moon has no light of itself had always supported such ideas), he was, as far as we know, the first person to base such a thesis on mathematical and experimental foundations. And this is the principal point that establishes a link between his work and that of Galileo.

[10] Apart from his *Optics*, the only work of Alhazen translated into Latin in the Middle Ages was his treatise *On Paraboloid Burning Mirrors*.