Medieval Optics, Scholasticism and Neutrality

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Abstract: If value judgments are a known source of scientific error, there are cases where the error comes from an *indirect lack of neutrality*, i.e. by simple adherence to a way of thinking, be it based on a thinking routine, an analogy (Bachelard), a presupposition (Holton), a model (Granger) or a paradigm (Kuhn). This article proposes to study the influence of scholasticism on medieval optics, and to show how it hindered the development of optics. By adhering to the idea of the primacy of argumentation over demonstration, Roger Bacon and John Pecham obtained poor results in optics, because, paradoxically enough, they aimed at reconstructing geometric optics without geometry.

Keywords: medieval optics, anatomy, geometry, scholasticism, value judgments.

In a narrow sense, scientific neutrality means that a theory does not make value judgments about its object of investigation: a scientific theory is concerned with 'being' and not with 'should be'[1]. The problem of neutrality is approached differently in philosophy of science, epistemology and history of science. In philosophy of science, the classical approach to the problem of neutrality is to find chains of arguments as to why science should be value-free or value-laden. Broadly speaking, this question divides the proponents of objectivity, scientific materialism and scientific realism[2], for whom scientific statements conform to the structure of reality, and their opponents who claim that reality is unknowable and that truth and objectivity are not

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[1] Max Weber, *Die „Objektivität" sozialwissenschaftlicher und sozialpolitischer Erkenntnis*, "Archiv für Sozia wissenschaft und Sozialpolitik", 19, 1904, pp. 22-87. Id., *Der Sinn der „Wertfreiheit" der soziologischen und ökonomischen Wissenschaften*, "Logos", 7, 1917, pp. 40-88.

[2] Karl R. Popper, *Objective Knowledge: An Evolutionary Approach*, Oxford 1972, Oxford University Press; Mario Bunge, *Scientific Materialism*, Dordrecht 1981, D. Reidel Publishing Co., French translation: *Matérialisme scientifique*, Paris: Syllepse, 2008; Rom Harré, *Varieties of Realism: A Rationale for the Natural Sciences*, Oxford 1986, B. Blackwell.

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universal notions. For instance, the proponents of historicist theories of rationality assert that a scientific theory has no validity outside a limited space-time[3]. Anti-realists consider that the purpose of science is to produce, not true descriptions of reality, but only models that fit empirical reality[4]. Social constructivists claim that the natural world plays a limited, in any, role in the production of scientific knowledge[5]. The division between the first group (say, the realists) and the second (the anti-realists) is reflected in the issue of values and neutrality. Realists have little choice but to affirm that science is value-free or to emphasize the epistemic values of science, such as objectivity[6]. In comparison, anti-realists can argue that science is value-laden at all stages of its production. This thesis, inaugurated by Richard Ruder[7], has now become the prevalent view of science[8]. It has even led to attempts to demonstrate that there is no gap between facts and values[9]. Other positions exist. For example, it has been argued that objectivity and neutrality do not operate at the same level, so that scientific objectivity can be maintained even in non-neutral contexts[10].

The debate is reflected differently in the history of science. By its very orientation, the history of science is not in a position to say whether science is value-based or not. Indeed, it is quite likely that many historians of science would reject the format of this philosophical question, resorting to abstract notions that are empirically unstable: Which science? Is it sure that all sciences react to values in the same way? Which values? Is it sure that all values produce the same effects? The history of science can nevertheless contribute to the debate on scientific neutrality by documenting historical episodes in which a given science has established a particular relationship with values. In the context of history of science, realism and anti-realism lead to different solutions. For realists, error is always a transient state in the pursuit of truth.

[3] Thomas S. Kuhn, *The Structure of Scientific Revolutions*, Chicago 1962, University Press, tr. it della II ed. *La struttura delle rivoluzioni scientifiche*, Torino 1979, Einaudi.

[4] Bas Van Fraassen, *The Scientific Image*, Oxford 1980, Oxford University Press.

[5] Harry M. Collins, *Stages in the Empirical Program of Relativism*, "Social Studies of Science", 11, 1981, pp. 3-10.

[6] Evandro Agazzi, *Scientific Objectivity and its Contexts*, Cham 2014, Springer International, pp. 419-421, 430-436.

[7] Richard Rudner, *The scientist qua scientist makes value judgments*, "Philosophy of Science", 20, 1953, pp. 1-6.

[8] Robert Proctor, *Value-Free Science? Purity and Power in Modern Knowledge*, Cambridge 1991, Harvard University Press; Harold Kincaid, John Dupré, Alison Wylie, *Value-Free Science? Ideals and Illusions*, Oxford 2007, Oxford University Press.

[9] Hilary Putnam, *The Collapse of the Fact/Value Dichotomy and Other Essays*, Cambridge 2002, Harvard University Press.

[10] Sandra Harding, *After the neutrality ideal: science, politics, and "strong objectivity"*, "Social Research", 59, 1992, pp. 567-587.

For anti-realists, the very notion of truth is irrelevant, and there is no point in invoking any boundary between truth and error. These very common solutions are not the only ones possible in the approach to scientific values and neutrality. An analysis of neutrality is indeed possible within the framework of realism, if one studies the influence exerted by any kind of values on scientific errors.

Insofar as values can induce scientific errors, it is necessary to specify in what sense the term error should be used. The history of errors is not necessarily overhanging and anachronistic. There is a more constructive way of appreciating errors. The historian of science can very well, by placing himself in a given space-time, determine what an author knew, what knowledge was available to him, and whether he could arrive at some result. What bears the name of error is then the *error relative to the situation in which the author was operating*. These errors are then referred to the cognitive, instrumental and material resources available to the author[11]. This way of proceeding has nothing to do with the sterile and anachronistic exercise of detecting errors in the absolute. When an error is detected, its origin and its consequences must be studied.

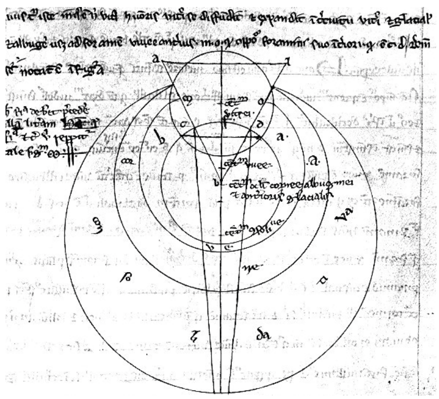
The scientific error can come from direct value judgments. It can also result from an *indirect lack of neutrality*, by adherence to a way of thinking, be it based on a thinking routine, an analogy (Bachelard), a presupposition (Holton), a model (Granger) or a paradigm (Kuhn). This article aims at studying an indirect lack of neutrality in the case of medieval optics, a field combining medicine (ocular anatomy) and physics (geometrical optics). It will document the influence of scholasticism on it, and will show how this method hindered the development of optics. Incidentally, this article will report on how some historians of science have hidden, or minimized, this influence, which also raises the question of the non-neutrality of historians vis-à-vis their subject of study. This article will not attempt to document the well-known problem that the use of the *Arguitur quod… In oppositum… Respondeo dicendum…* can lead to unnecessary raciocinations. For example, Biagio da Parma wrote fifteen pages to state a rule of refraction which was already known in antiquity (*Questiones super perspectiva communi* I, 9)[12]. Besides this problem, the scholastic method seems to have induced the following problems, which will be detailed in the article:

11 Example: In the *Epistle on the light of the stars*, Ibn al-Haytham claims that the fixed stars and planets have their own light (Ibn Al-Haytham, Walīd ‘Arafat and Henry J.J. Winter, The Light of the Stars: A Short Discourse by Ibn Al-Haytham, “The British Journal for the History of Science”, 5(3), 1971, p. 284). This thesis is not a contextual error, because the phases of Venus only became observable with the telescope in 1609. Galileo then drew the conclusion that the planets reflected the light of the sun (Galileo Galilei, *Il saggiatore, nel quale con bilancia esquisita e giusta si ponderano le cose contenute nella libra astronomica e filosofica di Lotario Sarsi Sigensano*, Roma 1623, G. Mascardi, p. 217).

12 Biagio da Parma/Blaise de Parme, *Questiones super perspectiva communi*, (ed. Graziella Federici Vescovini et al.), Paris 2009, J. Vrin, pp. 143-152.

1. The reference to Aristotle incites to multiply the couples of opposites (*Categories* VIII), which can lead to dichotomize what cannot be. This problem is at work in the study of ocular anatomy and pinhole images (Sections 1 and 2).
2. The belief in the power of the scholastic method can induce the rejection of competing methods, including geometric methods that are essential to solve optical problems. This issue arises in the study of pinhole and specular images (Sections 2 and 3).
3. The commentary of texts can lead to an abusive retention of old, false or contrary to experience arguments. This is particularly evident in the passages dealing with the burning spherical mirror (Section 4).

1. *Ocular Anatomy*



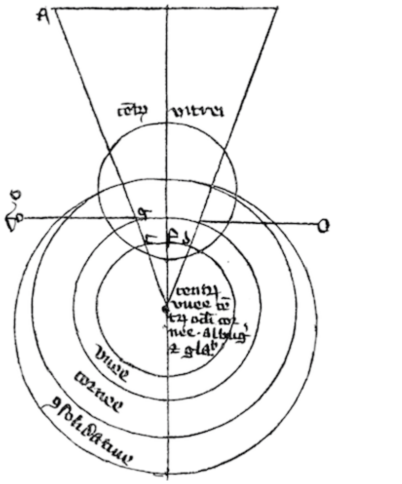


Fig. 1a-b: Bacon's diagram of the eye: London, BL, MS Royal 7 F VIII, fol. 54v (left); Prague, Univerzita Karlova, MS 1552 (right) (from Dominique Raynaud, *Eye Representation and Ocular Terminology from Antiquity to Helmholtz* (Hirschberg History of Ophthalmology, Vol. 16), Amsterdam 2020 Kugler/Wayenborgh, pp. 52-53. Bacon, *Perspectiva* I, 2-3.

Roger Bacon's description of ocular anatomy[13] is drawn from three sources: the *Canon* of Avicenna, al-Majūsī's *Pantegni* translated by Constantine the African, and Alhacen's *Optics*. According to Bacon, the eye has seven

[13] David C. Lindberg, *Roger Bacon and the Origins of Perspectiva in the Middle Ages. A Critical Edition and English Translation, with Introduction and Notes*, Oxford 1996, Oxford University Press, pp. 26-32; Id., *On the applicability of mathematics to nature: Roger Bacon and his predecessors*, "British Journal for the History of Science", 15, 1982, pp. 3-25.

parts: “The eye has therefore three tunics, or tissues, three humours, and a membrane which resembles a spider’s web” (*Oculus igitur habet tres tunicas seu panniculos et tres humores et unam telam ad modum tele aranee*). The tunics are detailed in chapter 2. The first is the retina (*rete vel retina*), the second is twofold: the choroid behind, the cornea in front (*secundina… cornea*), the third is also twofold: the sclera behind, the conjunctiva in front (*sclyros… conjunctiva*). The humours are described in Chapter 3. Apart from the arachnoid, which is connected to the humours by convenience, the three humours of the eye are the aqueous humour (*humor albugineus*), the crystalline humour and the vitreous humour. Instead of using the usual terms for the crystalline (*humor crystallinus*) and the vitreous (*humor vitreus*), Bacon introduces a new terminology, which is not used by any of his sources:

> Inside [the arachnoid] there is a body which is called glacialis… But it has two parts. The inner part, located at the end of the [optic] nerve, resembles molten glass, which is why it is called vitreous humor. As for the anterior part, it is similar to ice, hail and crystal […] and, not having received a particular name from the author of the *Perspectiva*, it is called anterior humor glacialis. Others call it the crystalline, glacialis or hail humor, because it resembles these substances [*Et in hac [telam aranee] continetur corpus quod vocatur glaciale… Sed habet duas partes; una est interior apud extremitatem nervi, et est simile vitro liquato, propter quod vocatur humor vitreus; altera pars anterior est similis glaciei et grandini et cristallo… et vocatur anterius glacialis, non habens aliud nomen proprium apud auctorem Perspective. Sed vocatur apud alios humor cristallinus vel glacialis vel grandinosus, quia est similis eis*][14].

The diagram of the excellent manuscript London, British Library, MS Royal 7 F VIII, fol. 54v (Figure 1A) shows the pyramid of rays ABL entering the eye without undergoing refraction on the cornea (while crossing the cornea the ray is strongly deviated, passing from a medium of index $n = 1$ to a medium of index $n = 1.376$). The pyramid of rays is refracted only at the interface of the lens and the vitreous (while the ray is less deviated, passing from a medium of index $n = 1.376$ to a medium of index $n = 1.386$). The Prague manuscript, Univerzita Karlova, MS 1552, presents a more primitive figure, which omits this refraction (Figure 1B). The most noticeable deviation from the previous terminology is the introduction of two terms: *glacialis anterior* to designate the lens and *glacialis interior* to designate the vitreous (*al-ruṭūba al-jalīdiyya = humor glacialis*, *al-ruṭūba al-zujājiyya = humor vitreus*, used by Galen, Ḥunayn ibn Isḥāq, al-Majūsī, Avicenna and Alhacen). The homophony between *interior* and *anterior* and the propensity to reconstruct *interior/exterior* and *anterior/posterior* pairs would be a source of confusion for

[14] D.C. Lindberg, *Roger Bacon* cit., p. 30. See also Adam Bednarski, *Die anatomischen Augenbilder in den Handschriften des Roger Bacon, Johann Peckham und Witelo*, “Sudhoffs Archiv für Geschichte der Medizin”, 24, 1931, pp. 60-78; D. Raynaud, *Eye Representation* cit., pp. 51-53.

later commentators, such as Henry of Langenstein, ca. 1375[15]. It is possible that this terminology was influenced by scholasticism. The medieval enumeration of the parts of the eye was already dependent on a search for symmetry between anterior and posterior parts. This is the origin of the couples: *uvea/retina, cornea/secundina, coniunctiva/sclirotica*. The replacement of the lens and the vitreous by the couple *anterior/interior glacialis* results from the same process being applied to the inner part of the eye.

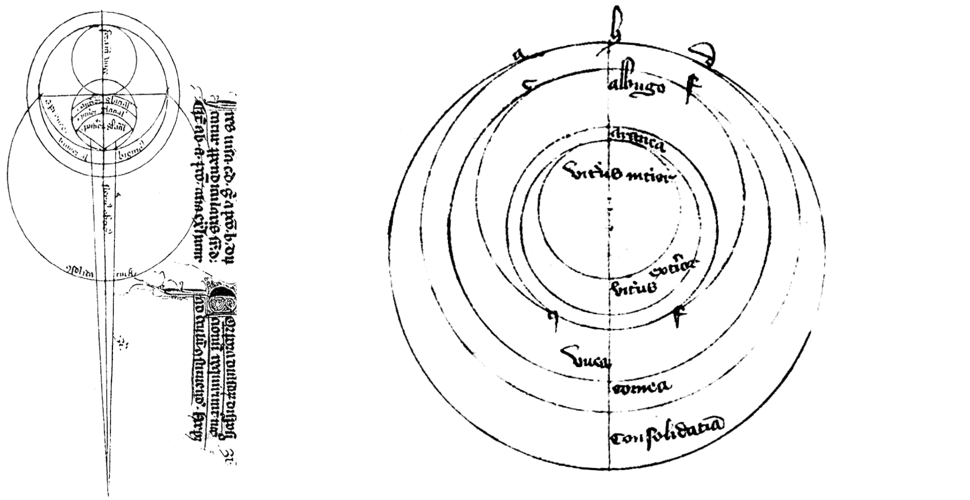


Fig. 2a-b: Pecham's diagram of the eye: Oxford, Bodleian, MS Ashmole 1522, fol. 153v (left); Paris, BnF, MS Latin 7368, fol. 90v (right) (from D. Raynaud, *Eye Representation*, pp. 57-58).

1.1. *Pecham,* Perspectiva communis *I, 31*

John Pecham gives two descriptions of the eye. The first one lists three humors and four tunics, according to an author whose name is not quoted: "And thus, according to the Physicist, the eye has three humors and four tunics" (*Et ita secundum istum Physicum oculus habet tres humores et 4 tunicas)*[16]. It could be Alhacen. The second description lists three humours and seven tunics, according to an unidentified *De elementis*, which is neither Galen's nor Isaac Israeli's[17]. In the first of the two descriptions, Pecham lists

15 D. Raynaud, *Eye Representation and Ocular Terminology from Antiquity to Helmholtz* (Hirschberg History of Ophthalmology, Vol. 16), Amsterdam: Kugler/Wayenborgh, p. 66.

16 D.C. Lindberg, *John Pecham and the Science of Optics: Perspectiva communis*, Madison 1970, University of Wisconsin Press, p. 114.

17 Ivi, p. 249, nn. 91-92.

the parts of the eye starting with the outermost consolidative (*consolidativa*). Then come the cornea (*cornea*) and the uvea (*uvea*). Similarly, the outermost humor is the albuginous humor (*humor albugineus*). The most interior is the humor glacialis (*humor glacialis*) and includes, as in Bacon, the crystalline lens and the vitreous:

> This humor is divided into two, because its anterior part cuts out a larger portion of the sphere, and the globe of the eye is concentric and equidistant from this anterior part of the eye; it also has a posterior part which is called the vitreous […] these two are surrounded by a kind of delicate web which is called the spider [*Et hic humor dividitur un duos, habet enim anteriorem partem maioris spere portionem et toti oculo concentricam et equidistantem anterior parti visus; habet et posteriorem que vitrea dicitur… et hec due circumdantur tela quadam subtili que aranea appellatur*][18].

The distinction between *glacialis anterior* (lens) and *glacialis interior* (vitreous) does not follow any classical source on the anatomy of the eye: it is inherited from Bacon. One of the best manuscripts, Oxford, Bodleian Library, MS Ashmole 1522, fol. 153v, shows a carefully drawn but inaccurate figure of the eye (Figure 2A). The *glacialis* is divided into three parts: *anterior glacialis* (lens), *interior glacialis* (?) and *posterior glacialis* (vitreous). It is possible that this third part was introduced to respect the anterior/posterior symmetry. In other manuscripts, the diagram of the eye is degenerated, both graphically and terminologically. In the Paris manuscript, Latin 7368, fol. 90v (Figure 2B), it is the vitreous that is divided into two parts: *vitreus interior* (the lens) and *vitreus exterior* (the vitreous). These errors, which are common throughout the manuscript tradition[19], highlight a pitfall of the scholastic method. Bacon and Pecham never practiced dissection. Their knowledge of the eye is purely bookish, which explains why the linguistic division of parts of the eye does not coincide at all with the anatomical structures. This defect also guides the lack of realism in the representation of the eye. The crystalline lens is a convergent meniscus *or* a sphere; the vitreous is a biconvex lens *or* a meniscus; the optic nerve is a canal crossing the tunics of the eye until the glacialis, when it is not simply omitted (Figure 2AB). These errors have pervaded all subsequent literature. Traces of them can be found not only in Lorenzo Ghiberti, *Commentario terzo*, fol. 18v, who uses the expression "glacialis sphere" *spera gratialis!* following Bacon's *Perspectiva* I, 4, 2[20], but also in Leonardo da Vinci, who is reputed to have performed dissections of the eye. Leonardo does however draw a spherical lens in the center of the eye-

[18] D.C. Lindberg, *John Pecham and the Science of Optics* cit., p. 114.

[19] Adam Bednarski, *Die anatomischen Augenbilder in den Handschriften des Roger Bacon, Johann Peckham und Witelo*, "Sudhoffs Archiv für Geschichte der Medizin", 24, 1931, pp. 60-78; D. Raynaud, *Eye Representation* cit, pp. 57-60.

[20] Ed. Bergdolt 1988: 90; D. Raynaud, *Eye Representation* cit, p. 486.

ball, and refers to it under the old name of “glacialis humor” *omore graciale!* (Codex Atlanticus, fol. 599v)[21].

2. *Formation of pinhole images*

2.1. *Bacon,* De speculis comburentibus

This treatise on the burning mirror incorporates a side discussion of the shape of light passing through a polygonal aperture. The question has aroused some interest because the shape of the light spot may differ from that of the light source. Bacon begins by defining the shape of the beam of light by comparing the size of the aperture to that of the source:

> I say that, from the sun to the opening, the light can multiply only in three ways: according to straight parallel lines […] according to lines that intersect in the luminous body […] according to lines that intersect in the direction of the opening [*Dico ergo quod cum lux no possit multiplicari a sole ad foramen super lineas rectas nisi tribus modis, scilicet super rectas et equedistantes… super rectas quod concurrant in lumino-so… super lineas concurrentes versus partem foraminis*][22].

This development is nothing but the transposition of the three types of shadows defined by ancient optics to the form that light takes behind the aperture.

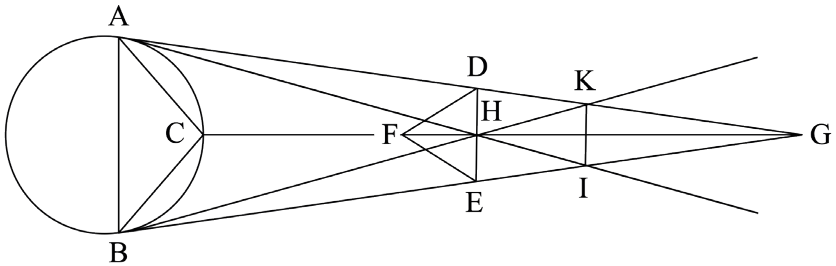


Fig. 3: Light passing through a triangular aperture according to Bacon (redrawn after Lindberg Roger Bacon’s *Philosophy of Nature*, cit.).

Let ABC be the solar disk in which is drawn the triangle ABC. Let AD, BE, CF be straight lines by which light propagates to the triangular aperture

[21] D. Raynaud, *Leonardo, Optics, and Ophthalmology*, in F. Fiorani, A. Nova, eds., *Leonardo da Vinci and Optics*, Venezia 2013, Marsilio Editore, pp. 255-276.

[22] David C. Lindberg, *Roger Bacon’s Philosophy of Nature. A critical edition of the ‘De multiplication specierum’ and ‘De speculis comburentibus’*, South Bend 1983, St. Augustine’s Press, pp. 304-308.

DEF. Straight lines AD, BE, CF intersect at point G behind the opening. In addition, let AH, CH and BH be straight lines passing through H, the center of the aperture (represented, by license, on the side DE). The rays AH and BH will cut BE and AD at points I and K (Figure 3). Bacon concludes:

It is thus evident, according to this figure, that the light of the round pyramid is occulted inside the triangle until IK, and that after IK, it occults the triangle, and that the triangular light gradually narrows from the opening until IK, preserving a triangular shape; it is manifest to the sight that there the maximum narrowing occurs and that then [the light] extends continuously in a round figure. [*Patet igitur secundum dictam figurationem quod lux pyramidis rotunde usque ad IK intra triangulam occultatur, et post sectionem IK triangulam occultat, et quod lux triangula a foramine usque ad IK continue angustatur in figura triangulari; et ibi est maxima angustatione visui manifesta, et continue ultra dilatatur in figura rotunda*][23].

A first failure of Bacon's reasoning is to consider that a qualitative change occurs in IK, IK separating the HK domain where the light is triangular from the KG domain where the light is circular. Bacon employs a dichotomy between the straight and the curved, the rectilinear propagation of light and the rotundity of the observed image; a dichotomy between the HK domain where light is supposed to be triangular and the KG domain where light is supposed to be circular. However, as Alhacen has shown in the *On the Shape of the Eclipse*, the shape of the light spot goes insensitively from angular to circular (ed. Raynaud 2016: 63-66). It is a continuous change, which is, for a given size of the aperture, a function of the focal distance to the screen. Any dichotomous reasoning is therefore an obstacle on the way to the solution. Only a continuous reasoning allows to solve the problem of pinhole images[24].

A second failure is that, although Bacon develops his argument by refer-

[23] Ivi, p. 312.

[24] Comments on Bacon's study of pinhole images are sometimes confusing: "[1] It should be noted, first of all, that Bacon does not associate the problem of pinhole images with the camera obscura… Bacon's work appeared several centuries before such applicability was first suggested. [2] Nor does Bacon relate the theory of pinhole images to observation of eclipses, as did Pseudo-Aristotle and Pseudo-Euclid before him, and John Pecham, William of St. Cloud, and John Kepler after him. [3] Bacon is simply interested in the geometrical modes in which light is propagated" (D.C. Lindberg, *John Pecham and the Science of Optics* cit., p. 220). The sentences are numbered for discussion. To point 1, it must be answered that Bacon's study does not enjoy any primacy: the first mathematical-experimental study of the darkroom was carried out by Alhacen, who gave the solution sought by Bacon (ed. Raynaud 2016). To point 2, it must be said that Roger Bacon explicitly associates the study of light passing through a narrow aperture with solar eclipses. A passage of *De speculis comburentibus* states that "the spherical part of the sun is totally luminous at all times, except during an eclipse, since it is then crescent-shaped [lit. razor-shaped]" (*portio solis sperica totaliter illuminta omni tempore preterquam in eclipsi, quoniam tunc novaculatur*) (ed. Lindberg 1983: 310). To point 3, it should be said that Bacon's exclusive interest in the geometry of the multiplication of light through the aperture is balanced by his poor abilities in geometry (see below).

ring to the letters of a geometric figure, he does not produce any geometric demonstration. The figure and the lettering illustrate a simple observation. The defect seems to result from Bacon's too strong dependence on the regime of sensible evidence (*secundum dictam figurationem… visui manifesta… sic videmus ad sensum…*). Having formulated the problem in unclear terms, Bacon will not find any solution, which he honestly admits: they are "problems which seem to me very difficult and of which I do not know the solutions […] I do not know at all what to say" (*rationes michi multum difficiles et quarum solutiones ignoro… Quid igitur sit hic dicendum penitus ignore)*[25]. This closes the argument.

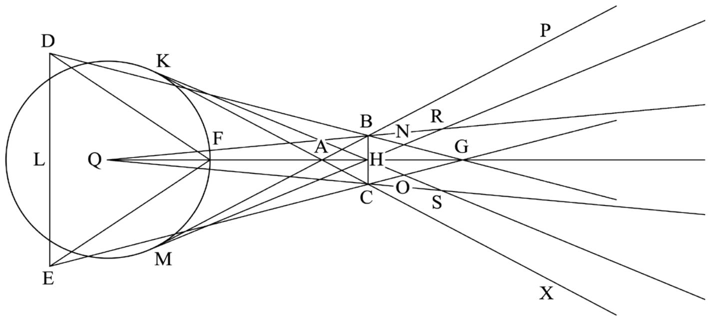


Figure 4: Light passing through a triangular aperture according to Pecham (redrawn after Lindberg, *John Pecham and the Science of Optics*, cit.).

2.2. *Pecham,* Perspectiva communis *I, 5*

Here is how Pecham describes the passage of sunlight through a small triangular aperture:

> The incidences of rays[26] passing through polygonal apertures of moderate size appear rounded on bodies placed in front [of the aperture], and are always wider the further [from the aperture, *NdA*] they are" [*Incidentias radiosas per angularia foramina transeuntes mediocris magnitudinis in obiectis corporalibus rotundari semperque fieri eo maiores quo remotiores*][27].

Let KLM be the solar disk, whose rays pass through the triangular opening ABC (Figure 4). The shape of the light spot that is seen just behind the aperture is not due to the source (which is the KLM circle). The rays reach

[25] Ed. Lindberg 1983: 312-316.

[26] *Incidentias radiosas*: "incidences of rays". I diverge from the English translation "incident rays". Pecham refers to the part of the ray in contact with the screen, not the whole ray.

[27] D.C. Lindberg, *John Pecham and the Science of Optics* cit., pp. 66-82.

the point H, but not the point G, intersection of DB and EC. The rays coming from the center of the sun QB and QC intersect the marginal rays KC and MB at points R and S. Pecham claims that line RS is the limit from which the light spot is no longer triangular but circular, even if "the light acquires circularity gradually" (*Videmus lumen ipsum paulatim rotunditatem acquirere)*[28]. The shape of the light passing through a polygonal aperture would result from two causes: 1° the mixing of the rays passing through the aperture; 2° the spontaneous acquisition of circularity by the light. Pecham thus brings in a final cause: the Platonic idea that the sphere is a perfect form (*sperica figura… perfectissima… nobilissima*), which is taken from *Tractatus*: "As the light is very active, it acquires by itself the circular shape" *Quia igitur lux est maxime activa, acquirit sibi figuram circularem*[29]. Pecham has only two positive pieces of knowledge: 1. The size of the image depends on the focal length; 2. The image is inverted[30]. But his explanation is flawed, because it replaces the geometrical analysis with the finalistic argument that light naturally tends to a circular form (*habet naturalem inclinationem ad figuram circularem*). It is worth noting that Pecham does not vary the shape or size of the opening, which could lead to the solution. He only considers "triangular openings of moderate size" (*per angularia foramina mediocris magnitudinis*).

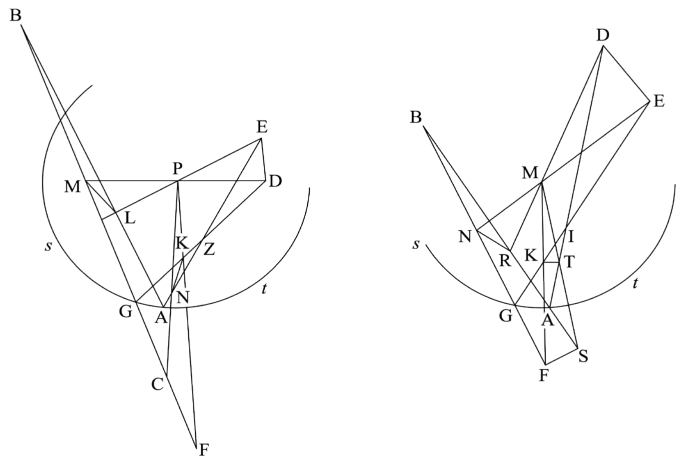


Figure 5a-b: Image location in a concave spherical mirror according to Bacon (left) and Euclid (right)[31].

[28] Ivi, p. 70.

[29] Id., *John Pecham. Tractatus de Perspectiva*, St. Bonaventure 1972, The Franciscan Institute, p. 34.

[30] Id., *John Pecham and the Science of Optics* cit., pp. 66, 70.

[31] Takahashi Ken'ichi, *The Medieval Latin Traditions of Euclid's Catoptrica*, A Critical Edition of *De speculis*, Fukuoka: Kyushu University Press; D.C. Lindberg, *Roger Bacon and the Origins of Perspectiva* cit.

3. *Image Formation in Concave Mirrors*

3.1. *Bacon,* Perspectiva III*, 1.4*

Here is how Bacon determines the location of the image reflected by the concave spherical mirror:

> [1] For the visible object, ED, falls to the mirror by the rays intersecting at Z, for although reflection is made from every point, yet only those intersecting each other meet at such a distance in the eye. For the visible object KN, which is within the confluence of the rays, appears otherwise than it is; [2] because, in general, height and depth that are within the confluence of the rays appear inverted; but objects outside of the confluence appear erect, as they are *[1] Visibile enim ED cadit in speculum per radios concurrentes in Z, licet enim ab omni puncto fiat reflexio, tamen soli se intersecantes concurrunt a tanta distantia in oculo. Visibile enim KN, quo est intra radiorum confluentiam, apparet aliter quam est, [2] quia universaliter altitudo et profunditas, que sunt intra radiorum confluentiam, apparent everse; que autem extra apparent erecte, sicut sunt*[32].

Let GA be the concave spherical mirror of center P, two objects ED and KN, the eye being at point B. The two visual rays BAE and BGD intersect at point Z. Bacon claims that if the object ED is beyond (*extra*) the intersection Z, its image is straight (*apparet sicut est*); whereas if the object KN is within (*intra*) the intersection Z, its image is inverted (*KN… apparet aliter quam est*). Compared to the available knowledge, there are many errors:

1. The conclusion is wrong. While in Euclid's figure (Figure 5B) the object KN is seen straight, and the object ED is seen inverted; Bacon change the figure: *et ideo hoc pono figurationem*[33] (Figure 5AB) and draws the opposite conclusion. The geometric analysis reveals the error: the image is inverted (KN) when the rays intersect (EL, DM); it is straight (ED) when the rays do not intersect (KF, NC).
2. The proposition derives from Euclid's *Catoptrics*, which is known in three Latin versions. The comparison shows that Bacon used version II[34]. While the text refers to *Catoptrics* 11, the passage actually combines propositions 12 [passage 1] and 11 [passage 2][35]. As the two propositions study different situations, the combination is wrong.
3. The proposition is void of demonstration. Bacon describes the visual rays

[32] D.C. Lindberg, *Roger Bacon and the Origins of Perspectiva* cit., pp. 276-278.

[33] Ivi, p. 278.

[34] A witness of which is the Oxford manuscript, Bodleian Library, MS Auct. F.5.28, fols. 24r-29r. Cfr. T. Ken'ichi, *The Medieval Latin* cit., p. 241, fig. 12.

[35] T. Ken'ichi, *The Medieval Latin* cit., p. 240, 238.

by letters, but he does not invoke either the law of reflection or the rule according to which the image lies at the intersection of the extended visual ray and the cathetus. Bacon *describes* the figure, but does not determine geometrically the position of the image.

This last observation shows that the use of geometric figures has not been properly assessed: "These figures are not purely decorative; they all support a serious and sustained geometric argument"[36]. In the spectrum of possible relations between text and figure, one can distinguish: a *decorative relation*, when the text is decorrelated from the figure; *illustrative*, when the text refers globally to a figure that serves as an example; *descriptive*, when the text describes parts of the figure without justifying them; and *demonstrative*, when the text refers to a figure whose features are justified by optic-geometric principles. With these definitions in mind, it is clear that Bacon's figures respond to descriptive, not demonstrative relationships. We can again read this feature as a preference of the author for scholastic argumentation over geometric demonstration.

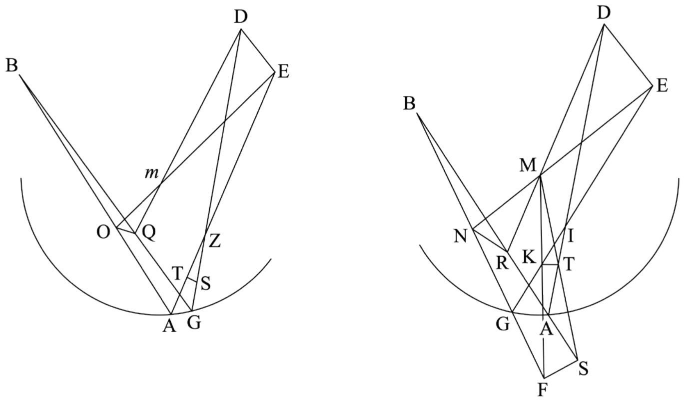


Fig. 6a-b: Image location in a concave spherical mirror according to Pecham (left) and Euclid (right) (redrawn after Lindberg, *John Pecham*, cit. and Takahashi, *The Medieval Latin*, cit.).

3.2. *Pecham,* Perspectiva communis II, 50

"In concave [spherical] mirrors, the object appears sometimes inverted and sometimes upside down" (*In speculis concavis res nunc conversas nunc eversas apparere)*[37] (Figure 6A). This statement is a copy of *Tractatus* 13,

[36] D.C. Lindberg, *Roger Bacon and the Origins of Perspectiva* cit., p. xliv.

[37] D.C. Lindberg, *John Pecham and the Science of Optics* cit., p. 204.

which itself was a verbatim copy of Bacon's *Perspectiva* III, 1.4: *Notandum quod diversimode reflectuntur a speculis concavis… sub humilioribus humiliora*[38], except a "saut du même au même" *BG, qui est… sed BG*. But Bacon's text being a paraphrase of Euclid, *Catoptrics* 11-12 (ed. Heiberg 1895: 304-306; Takahashi 1992: 240), the passage is, strictly speaking, a quotation of a quotation of a quotation. In spite of the rhetorical formula: "It is easily demonstrated from the *De speculis*… " (*Hoc ex libro De speculis faciliter demonstratur*…), the proposition is not demonstrated at all, and shows no facility. The difficulties are multiple:

1. The statement is misleading. Pecham distinguishes *conversas* and *eversas*, which are synonyms. This difficulty was perhaps already present in the Latin version.
2. The body of the text does not reproduce the difference between *conversas* and *eversas*, but joins the Euclidean text in separating objects that "appear inverted" (*apparent eversa*) and those that "appear as they are" (*apparent sicut sunt*). Unfortunately, Pecham is mistaken in his attribution: he claims that the magnitudes placed below the intersection (*intra confluentiam*) are inverted; that those placed beyond the intersection (*extra confluentiam*) are straight; Euclid says the opposite.
3. Based on Bacon, Pecham claims that Euclid is wrong (*credo quod erravit*). But it is Pecham who is wrong, as can be seen by comparing the texts and calculating the position of the images NR and FS of the segments DE and KT (Figure 6B).

The determination of the image involves the law of reflection, the cathetus (and thus the center of curvature of the mirror) and the extended visual ray. First anomaly: Pecham does not include either the cathetus or the center of curvature, which is not even represented on the figure: I add it to the point *m* (Figure 6A). Second anomaly: Pecham does not extend the visual rays BA, BG beyond the mirror surface. Since Pecham uses neither the center of curvature of the mirror, nor the cathetus, nor the extended visual rays, he cannot determine the images of DE and TS. Therefore, he cannot say anything at all about their relative position. This example points to the very limit of the process of trying to solve a question of geometrical optics without geometry. All these problems result from the fact that Pecham rejects the methods of geometrical optics – the very ones used by the authors he quotes – in favor of scholasticism, and that he gets confused by the pairs of opposites. I will elaborate further on Bacon and Pecham's relationship to geometry in the conclusion.

38 Ivi, pp. 63-64.

4. *Study of the Burning Mirror*

4.1. *Bacon,* De speculis comburentibus

Bacon raises the problem of the burning mirror starting from the last proposition of Euclid's *Catoptrics*: "By means of concave mirrors facing the sun, one can set fire" (*Ex concavis speculis ad solem positis ignis accenditur*)[39]. Bacon surveys the different types of mirrors. He notes that the concentration of rays occurs only in concave mirrors, in different ways depending on whether the mirror is spherical or parabolic. For the spherical mirror, Bacon refers exclusively to the geometrical analysis of Euclid, *Catoptrics* 30[40]. Let EDZ be the sun, ABG the concave spherical mirror whose center of curvature is the point T. From point D on the sun, we draw the axis DB of the mirror passing through point T. Let us draw the ray DG which is reflected at the point K of the axis DB (Figure 7A). The point K is necessarily between B and T. Bacon repeats Euclid's demonstration: GT being the normal of the mirror at point G, the incident ray GD being on one side of the normal GT, the law of reflection imposes that the reflected ray GK is on the other side, on BT. In the original Greek version, the Euclidean proposition had two difficulties:

1. A not very explicit wording suggested that the point K was the focus of all the rays, which is false in the case of the spherical mirror;
2. The second part of the proposition redoubled the error by confusing the focus and the center of curvature of the mirror T.

The Latin version tried to overcome these difficulties by substituting the word *periferia*, which is absent from the Greek text, but did not correct the figure showing the whole of the reflected rays ending at K. Bacon clarifies the meaning of the Latin version:

> Similarly, it can be shown that all rays incident on the surface of the mirror, and equally distant from point B, are reflected to the same point on the line TB [...] Similarly, it can be shown that the rays of no other circle compete at the same point [on the axis, *NdA*] [*Similiter potest ostendi quod omnes radii incidentes ad superficiem speculi et equaliter distantes a puncto B ad idem punctum in linea TB reflectuntur… Et eodem modo potest demonstrari quod nullius circulationis radii concurrunt ad eundem punctum ad quem concurrunt radii alterius*][41].

Bacon interprets the word *periferia* not as the meridian arc of the spherical mirror, but as the circumference traced on the mirror by a movement

[39] Id., *Roger Bacon's Philosophy of Nature* cit., p. 272.

[40] Heiberg, *Euclidis Optica, Opticorum recensio Theonis, Catoptrica*, ed. J.L. Heiberg, Leipzig 1893, Teubner, p. 340.

[41] D.C. Lindberg, *Roger Bacon's Philosophy of Nature* cit., pp. 272-274.

of revolution around the axis DB. The points A, G of this circle reflect the incident rays DA, DG to point K; the incident rays falling on another circle of the concave mirror are reflected to another point on the axis.

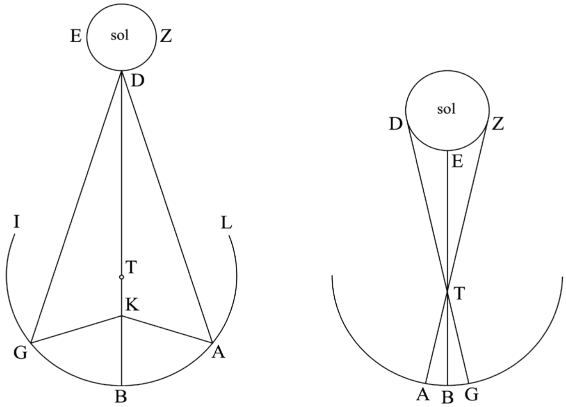


Fig. 7a-b: Focusing of the rays in the spherical burning mirror according to Bacon (redrawn after D.C. Lindberg, *Roger Bacon's Philosophy of Nature*, see footnote).

The second part of the proposition is illustrated by another figure (Figure 7B). Let DEZ be the sun, ABG the concave spherical mirror of center T. From point E let us draw the line ETB passing through T, which will be the axis of revolution of the mirror. From any point D of the sun, a ray DT passes through the center T and falls to the point G of the mirror surface.

And as all these rays fall at equal angles on the surface of the mirror… because they pass through the center, each one is reflected on itself. Therefore, all of them intersect at the center… That's why if oakum is placed at this point, it ignites. [*Et quia omnes isti radii cadunt ad angulos equales super superficiem speculi, quia… transeunt per centrum, ideo quilibet reflectetur in se ipsum. Omnes ergo concurrunt in centrum… quare in eis stupa posita accendetur*][42].

It is curious that after having cleared up the ambiguities of the first part of the proposition, Bacon reproduces the second part without any criticism. This part has two errors:

1. it makes the point T a focus, which does not exist in the case of the spherical mirror;
2. it equates the focus with the center of curvature of the mirror.

[42] D.C. Lindberg, *Roger Bacon's Philosophy of Nature. A Critical Edition, with English Translation, Introduction, and Notes, of De Multiplicatione specierum and De speculis comburentibus*. Oxford 1983, Clarendon Press, p. 274.

The reasons for this conservatism are obscure. They may result from the absence of experimentation as well as from the respect of classical authors. The last pages of *De speculis* are devoted to the study of the parabolic mirror, whose focal property has already been described by Diocles. Bacon's initial statement is promising:

But our effort must now be directed to the surface that reflects all the rays of the sun falling on the whole mirror at a single point, and this is the concave surface of a parabolic body, as demonstrated in the *Liber de speculis comburentibus* [*Sed presens intentio est de superficie que reflectit omnes axes solis incidentes ad eam totam in punctum unum, et hec est superficies concava corporis mukefi, secundum quod demonstratur in Libro de speculis comburentibus*][43].

The reference to Alhacen's *De speculis comburentibus* – which can be identified by the Arabic word *mukefi* "sufficient", designating the parabolic section – suggests that Bacon is about to expose the solution of the burning mirror by following this relevant source.

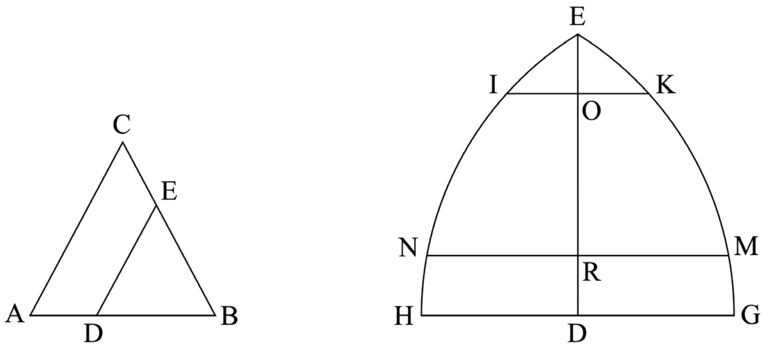


Fig. 8a-b: Side and front views of the parabolic mirror according to Bacon (redrawn after manuscripts)[44].

Let a cone be cut by the axial plane ABC. Suppose that the cone is rectangular at C, hence ∠ACB = ∟. From point D, the center of the base of the cone, draw DE a plane parallel to the generatrix CA perpendicular to the axial plane ABC (Figure 8A). The plane DE cuts the cone according to the desired shape:

43 D.C. Lindberg, *Roger Bacon's Philosophy of Nature* cit., p. 336.

44 The diagrams published by Lindberg (D.C. Lindberg, *Roger Bacon's Philosophy of Nature*, cit., p. 338) are not faithful to the handwritten figures. On the latter, the axial triangle ABC is not rectangular at C, and point D is not the center of the base AB as required by the text. The curve HNIEKMG is not a parabola. In accordance with medieval usage, the curve is rendered by two arcs of a circle EG and EH.

The common intersection of this plane surface and the cut half-pyramid is a parabolic section; it is contained by two straight lines and a sinuous line which is neither circular, nor straight, nor composed of segments. Thus, this section has approximately this shape [i.e. the curve HNIEKMG of axis ED, NdA]. [*Communis igitur sectio huius plane superficiei secantis et medietatis pyramidis secte es sectio mukefi; et continetur duabus lineis rectis et una tortuosa, que nec est circularis nec recta nec composita ex rectis. Et est huiusmodi sectio talis figure quasi*][45] (Figure 8B).

The most striking feature of this text is that Bacon does not provide any mathematical characterization of the parabola, neither by the abscissa-ordinate property (Apollonius of Perga), nor by any of the other known properties, such as the focus-direction property (Diocles), the focal property (Anthemius of Tralles), or the subtangent property (Alhacen). While Alhacen's *De speculis comburentibus* is a good mathematical text, all Bacon can say about the parabola is that it is "neither a circle, nor a straight line, nor a broken line". This shortcoming reflects the poor capacity of scholasticism to grapple with the problems of geometrical optics.

Conclusion

This article proposed to study a case of *indirect lack of neutrality* in medieval optics. Bacon and Pecham, adhering to the idea of the primacy of scholastic argumentation over geometrical demonstration, obtained poor results in optics, because, paradoxically enough, they aimed at reconstructing geometric optics without the help of geometry. This judgment is not overhanging, since it is based on the definition of contextual errors given in the introduction: Bacon and Pecham quote classical authors who use geometry to solve optical problems, and yet do not follow their methods. This is an informed rejection. Roger Bacon is sometimes seen as a mathematician who aimed at extending mathematical analysis to all fields, because of the title of Book IV: *On the utility of mathematics for physics*. The judgment that he could be a precursor of the 17th century scientists[46] is abusive.

1. Bacon wrote extensively on the application of mathematics to nature, but instead of analysing the epistemological foundations that could justify the application of mathematics to physics, he *rhetorically* defends the utility of mathematics.

[45] D.C. Lindberg, *Roger Bacon's Philosophy of Nature* cit., p. 338.

[46] The history of these judgments is traced by David Eugene Smith (*The place of Roger Bacon in the history of mathematics*, in A.G. Little (ed.), *Roger Bacon Essays*, Oxford 1914, Clarendon Press), and Nicholas W. Fisher, Sabetai Unguru, *Experimental science and mathematics in Roger Bacon's thought*, "Traditio", 27, 1971, pp. 353-378.

2. Another difficult point is that mathematical proofs, when they exist, are always combined with other registers of proof (mainly empirical and metaphysical). This casts doubt on the very argument of Book IV: if mathematics is the only science that brings certainty, one does not see what benefit there is in combining it with metaphysical arguments. Bacon therefore promotes mathematisation only in form, not in substance. This attitude seems to result from a reluctance to obliterate the ontological difference between mathematics and physics.
3. Historians are divided on Roger Bacon's mathematical contribution; Lindberg and Hackett praise him much.

> Bacon perfectly understood and successfully conveyed the geometrical principles of reflection […] His geometrical analysis of refractive phenomena was similarly successful […] It is clear from these examples that Bacon achieved significant success in fulfilling his project of mathematizing nature[47].

In the same vein, Hackett writes: "Roger Bacon was The Philosopher and Scientist who taught the Latin West to think about light and vision […] Bacon opened the eyes of Western thinkers to the need to do serious mathematical and physical-experimental work on these topics"[48]. His success was in fact very limited. In any case, Bacon's contribution is less demonstrative than the optical sources he had at his disposal and which he cites (mainly Euclid, Alkindi and Alhacen). By refusing to engage in the geometric analysis of problems, Bacon was regularly condemned to failure. In optics, the errors detected concerning the shape of the light behind a narrow aperture, the location of reflected images, or the focus of the spherical mirror, lead to express reservations about his mathematics. The same is true in mathematics, where Bacon's *Geometria speculativa* is in fact a mathematical treatise for beginners[49]. This is why well-informed historians of science have voiced criticisms of Bacon's alleged mathematical skills. For instance, Fisher and Unguru write: "Not only does Bacon commit elementary mathematical errors, but he also demonstrates his inability to understand the fundamental mathematical concepts"[50]. Similar harsh judgments can be found in the literature[51]. These elements finally explain

47 D.C. Lindberg (ed.), *Roger Bacon and the Origins of Perspectiva* cit., pp. xlv, l.

48 Jeremiah Hackett (ed.) *Roger Bacon and the Sciences. Commemorative Essays*, Leiden 1997, E.J. Brill, p. 6.

49 A. George Molland, *Roger Bacon's Geometria Speculativa*, in M. Folkerts and J.P. Hogendijk (eds.), *Vestigia Mathematica. Studies in medieval and early modern mathematics in honour of H.L.L. Busard*, Amsterdam 1993, Rodopi, pp. 265-303.

50 N.W. Fisher, S. Unguru, *Experimental science* cit., p. 354.

51 D.E. Smith, *The place of Roger Bacon* cit, p. 182; A.G. Molland, *Roger Bacon's knowledge of mathematics*, in J. Hackett (ed.), *Roger Bacon and the Sciences. Commemorative Essays*, Leiden 1997, E.J. Brill, p. 168; A. Mark Smith, *From Sight to Light*, Chicago 2014, University of Chicago Press, p. 271.

how Bacon's scholastic project leads him to depart from the Greco-Arabic tradition in optics, by approaching the subject from an argumentative rather than a demonstrative angle. It is noteworthy that Bacon does not show the usefulness of mathematics by *mathematizing* natural phenomena, but by producing speculative arguments about the usefulness of mathematics, which is different.

John Pecham is playing in a slightly different configuration. The pedagogical orientation of the *Perspectiva communis* can explain a certain degree of simplification of knowledge – it has been called a *Perspectiva ad asinos*. However, this orientation cannot explain all the errors of the text – and for which Pecham's sources are not responsible. These errors stem from an orientation of thought that favors the scholastic method to the detriment of mathematics. As soon as he can, Pecham abandons geometrical demonstration for speculation. Occasionally, the same occurs in logic: he asserts the existence of causes, but does not establish causal relations, preferring to proceed by superposition of arguments. From this point of view, Pecham's treatise testifies to the difficulty of abandoning the axioms of thought of an intellectual tradition. Pecham discovered rather late Witelo's *Perspectiva*, whose model he wanted to copy. But he did not find a way to articulate these approaches. The project was doomed to failure: one cannot at the same time claim the Euclidean heritage and reject the use of mathematics. In the history of optics, Pecham's *Perspectiva communis* will probably remain the most striking example of a work that met with popularity (judging by the number of manuscripts and editions circulated) but whose intellectual project remains inscrutable, since the author is basically trying to develop a geometrical optics without the help of geometry. Bacon's and Pecham's optics have internal differences, but they share the same ambition: they want to apply to optics the scholastic argumentation based on pairs of opposites rather than mathematical reasoning. Finally, it should be noted that nothing in the historical analysis of these cases of *indirect lack of neutrality* requires abandoning realism. Indeed, all of Bacon and Pecham's shortcomings in optics concern knowledge that was accessible either to observation (neither the structure of the eye, nor the shape of light passing through a narrow aperture depends on social values) or to demonstration (the fact that the reflected image is straight or reversed, or that the rays do not focus at a single point in a spherical concave mirror is not conditioned by social values). These cases simply account for contextual errors that could have been avoided had Bacon and Pecham not departed from the geometric tradition that has nurtured optics since antiquity.