What is the History of Medieval Optics Really About?[1]

A. MARK SMITH
Professor of History, University of Missouri at Columbia

SINCE ITS PUBLICATION IN 1975, David Lindberg's *Theories of Vision from Al-Kindī to Kepler*[2] has become the canonical source for our understanding of medieval optics and its place in the development of modern optics. Lindberg's ulterior purpose in writing this book was to show that, contrary to prevailing opinion, Johan Kepler's account of sight, which is based on the casting of point-by-point images through the lens at the front of the eye onto the retina at the back, represented a continuation of, rather than a break with, the medieval optical tradition, whose foundations were laid by the Arab Ibn al-Haytham, or Alhacen as he came to be known in the Latin West.[3] To be sure, Lindberg concluded, "Kepler attacked the problem of vision with greater skill than had theretofore been applied to it, but he did so without departing from the basic aims and criteria of visual theory established by Alhazen in the eleventh century."[4] So, even if we credit Kepler with opening the way toward the development of modern optics, neither the opening itself nor what came out of it during the seventeenth century marked a fundamental departure from the past. The transition from medieval to modern optics was evolutionary, not revolutionary.

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[1] Read 10 November 2001.

[2] Chicago: University of Chicago Press, 1975.

[3] *Theories of Vision*, 205–07. Lindberg's argument is directed primarily at Steven S. Straker, "Kepler's Optics: A Study in the Development of Seventeenth-Century Natural Philosophy" (Ph.D. diss., Indiana University, 1970) and A. C. Crombie, "Early Concepts of the Senses and the Mind," *Scientific American* 210.5 (1964): 108–16 and "The Mechanistic Hypothesis and the Scientific Study of Vision: Some Optical Ideas as a Background to the Invention of the Microscope," in *Historical Aspects of Microscopy*, ed. S. Bradbury and G. L'E. Turner (Cambridge: Heffer, 1967), 3–112. Until recently, it was commonly assumed that "Alhazen" was the proper Latin form of Ibn al-Haytham's proper name ("al-Haṣan"), but recent scholarship makes it clear that "Alhacen" was the preferred form during the Middle Ages.

[4] *Theories of Vision*, 207.

Lindberg's case rests on the fact, which he demonstrated in meticulous fashion, that Alhacen and Kepler based their accounts of vision on similar theoretical and methodological grounds. Both, that is, used the same basic model of punctiform light-radiation, and both relied upon the same ray-analytic procedure in tracing out the logical implications of that model. That the two reached markedly different conclusions is beside the point. The path that led to them was the same; Kepler simply followed it more rigorously. It would therefore seem reasonable to conclude with Lindberg that, in sharing the same analytic principles, Alhacen and Kepler operated within the same conceptual framework.

But this conclusion is grounded in a problematic assumption: namely, that, like Kepler and his seventeenth-century successors, Alhacen and his Latin medieval followers were primarily concerned with the physics of light and issues more or less directly relating to it.[5] As we shall see in due course, this assumption applies to the first group, but not to the second. For, unlike Kepler and his seventeenth-century successors, Alhacen and his medieval Latin followers were far more concerned with making sense of sight than with understanding light. Thus, while there is an undeniable link between Alhacen's and Kepler's accounts at the procedural level, the two are worlds apart at the conceptual level.

Before examining Alhacen's account of vision in detail, let us briefly set the background. The primary source for that account is the *Kitāb al-Manāẓir*, or "Book of Optics." Written in the 1030s, this work comprises seven books, the first three of which are devoted to a close analysis of visual perception, the second three to an equally close analysis of reflection, and the last to a study of refraction.[6] Alhacen seems to have intended the *Kitāb al-Manāẓir* as a critical response to Ptolemy's *Optics*, which predated it by nearly nine centuries. In particular, Alhacen challenged the central supposition of Ptolemaic optics that the eye emits visual flux, which passes outward from its centerpoint through the pupil in a radial bundle that forms a cone, as illustrated in figure 1.

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[5] See ibid., x–xi. Compared to his predecessors, in fact, Lindberg took a fairly broad view of pre-Keplerian optics to include not just the physics of light but also the mathematics and physiology of vision. Yet he drew the line at psychology and epistemology, claiming that "this limitation is not only expedient but also legitimate, since psychological and epistemological issues, though raised within the context of visual theory, were never its central concerns." By thus precluding psychology and epistemology, Lindberg effectively dismissed the perceptual aspects of vision to focus on its physical aspects—i.e., how light and color are radiated into and through the eye.

[6] For a critical Arabic edition and English translation of the first three of these seven books, see A. I. Sabra, ed., *Ibn al-Haytham*, al-Manāẓir I-II-III = Kitāb al-Manāẓir. *Books I-II-III: On Direct Vision* (Kuwait: National Council for Culture, Arts, and Letters, 1983) and *The Optics of Ibn al-Haytham: Books I-III on Direct Vision*, 2 vols. (London: Warburg, 1989).

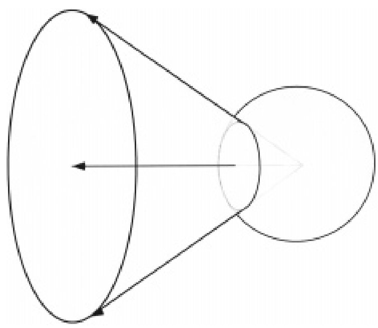

FIGURE 1

The rays within this cone are to be thought of by analogy to fingers that reach out to external objects and put us into visual touch with them. The information garnered from this visual contact is conveyed back through the cone of flux in the form of color-impressions. These color-impressions are subject to visual scrutiny after reaching the anterior surface of the eye, and from them we eventually get an internal "picture" of the objects they represent.[7] But why posit such visual radiation, Alhacen demanded, when it is perfectly sufficient to assume that objects are seen by means solely of what they radiate to the eye? In thus rejecting Ptolemy's extramissionism, Alhacen set himself the task of reformulating visual theory on an intromissionist basis.

Sometime around 1200 the *Kitāb al-Manāẓir* was rendered from Arabic into Latin under the title *De aspectibus*.[8] All indications are that this Latin version of the *Kitāb al-Manāẓir* lay fallow for the next fifty years or so until it began to be studied in earnest by a succession of Latin thinkers, starting with Roger Bacon. Out of this renewed interest developed the science of *perspectiva*, which found its core in the optical writings of Roger Bacon, Witelo, and John Pecham, all of which were composed between roughly 1262 and 1280.

The core itself consists of four basic treatises, the earliest of which, Roger Bacon's *De multiplicatione specierum*, was probably composed in the early 1260s. A few years later Bacon produced his *Perspectiva*, which was originally included as part of the *Opus majus* but was soon disseminated as an independent work.[9] By the mid-1270s the third of

[7] For a detailed account of Ptolemy's model of visual perception, see A. Mark Smith, *Ptolemy's Theory of Visual Perception*, Transactions of the American Philosophical Society, 86.2 (Philadelphia: American Philosophical Society, 1996), 19–35. Cf., however, Gérard Simon, *Archéologie de la vision: L'optique, le corps, la peinture* (Paris: Seuil, 2003), 131–64.

[8] For a critical edition, English translation, and study of the first three books of the *De aspectibus*, see A. Mark Smith, *Alhacen's Theory of Visual Perception*, Transactions of the American Philosophical Society, 91.4 and 91.5 (Philadelphia: American Philosophical Society, 2001). The subsequent discussion of Alhacen's visual theory will be based on this edition and translation.

[9] For Bacon's *De multiplicatione specierum*, see David C. Lindberg, *Roger Bacon's Philosophy of Nature* (Oxford, 1983); for Bacon's *Perspectiva*, see David C. Lindberg, *Roger Bacon and the Origins of* Perspectiva *in the Middle Ages* (Oxford: Clarendon Press, 1996).

the core works, Witelo's *Perspectiva*, was completed,[10] only to be followed within five years or so by the last and most popular of the Perspectivist treatises, John Pecham's *Perspectiva communis*.[11] With certain theoretical elaborations provided by these three key Latin thinkers, the Alhacenian model of light and vision represented the *ne plus ultra* in optics from roughly 1300 to 1600.[12]

To make proper sense of that model requires, first, understanding Alhacen's theory of light and color.[13] Start by thinking of light as a real and inherent quality in any self-luminous or illuminated object. Think of the object's surface as a composite of infinite point-sources from which light propagates in all directions. Think of the propagation itself in terms of replication, each point-source creating formal representations of itself in any continuous transparent medium, such as air. Think of the overall result as a sphere of propagation. And think of each radius within that sphere as a rectilinear trajectory along which point-forms of light are transmitted outward from the center.

Transparency, for its part, is what enables light-forms to penetrate certain objects without hindrance. Opacity balks such penetration and, in doing so, lets certain objects capture the light-forms reaching them.[14] This capture is manifested on their surfaces as illumination, and, once illuminated, they become sources of light-radiation in their own right. But all opaque objects are inherently colored, and light is naturally apt to mingle with color. So what actually radiates from the surfaces of visible objects is luminous color, not pure light. Pure light, in fact, is a mere theoretical abstraction for Alhacen and his Latin disciples. Its proper function is not to be seen—i.e., it is not really *per se* visible—but rather to render color visible.

How we see things by means of the luminous color they radiate to the eye depends on how the optic system is designed to apprehend it.[15] As conceived by Alhacen, whose account derives from Galen, the eye

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[10] See Sabetai Unguru, *Witelonis* Perspectivae *liber primus*, Studia Copernicana 15 (Warsaw: Polish Academy of Sciences, 1977) and *Witelonis* Perspectivae *liber secundus et liber tertius*, Studia Copernicana 28 (Warsaw: Polish Academy of Sciences, 1991). See also A. Mark Smith, *Witelonis* Perspectivae *liber quintus*, Studia Copernicana 23 (Warsaw: Polish Academy of Sciences, 1983).

[11] See David C. Lindberg, *John Pecham and the Science of Optics* (Madison, Wis.: University of Wisconsin Press, 1970).

[12] Friedrich Risner's landmark tandem edition of Alhacen's *De aspectibus* and Witelo's *Perspectiva* in 1572 under the title *Opticae Thesaurus* represents the final stage in the dissemination of this model.

[13] For Alhacen on light and color, see Smith, *Alhacen's Theory*, liii–liv.

[14] For Alhacen on opacity and transparency, see Smith, *Alhacen's Theory*, liv–lv.

[15] For Alhacen on the optic system, which includes not just the eye but its connection to the brain via the optic nerve, see Smith, *Alhacen's Theory*, lvii–lx.

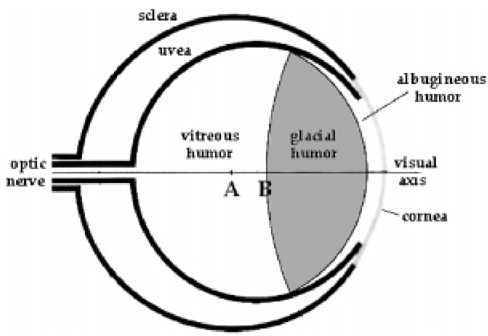

FIGURE 2

consists of two nesting, but eccentric, spheres. As illustrated in figure 2, the outer sphere, centered on A, is contained by the scleral tunic. The cornea at the front forms a transparent continuation of this tunic. The inner sphere, centered on B, is enclosed by the uveal tunic. At its front lies the round aperture that forms the pupil. The uveal sphere contains three transparent fluids, or humors, of differing optical density. The rearmost, and most optically dense, of the three is the vitreous humor. Ahead of it lies the glacial humor, and ahead of this lies the albugineous humor. The interface between albugineous and glacial humors forms a convex spherical section concentric with the eye as a whole and therefore with the cornea. The interface between glacial and vitreous humors forms a concave spherical section. Together, these interfaces, which are defined by a gossamer membrane called the *aranea* (i.e., spider web), mold the glacial humor into the shape of a double convex lens.

Both the scleral and uveal spheres have a small opening at the rear through which visual axis AB passes. Extending back from their respective openings, the tunics enveloping these spheres form the inner and outer sheaths of the hollow optic nerve. The optic nerves of both eyes continue through the eyesockets to join at the optic chiasma, and, after parting, wend their way to the forefront of the brain, as represented in figure 3. There each nerve feeds into the frontmost of three successive cells, or ventricles, that are replete with animal spirit, which is a distillate of pneumatized—or "aerated"—blood that passes from the left ventricle of the heart through the carotid arteries into the base of the brain. Serving as the medium for all sensitive, perceptual, and intellectual functions, animal spirit perfuses the entire optic complex from the front of the brain to the anterior surface of the glacial humor. There it takes specific form as visual spirit, which is peculiarly sensitive to visible stimuli. Thus sensitized, the glacial

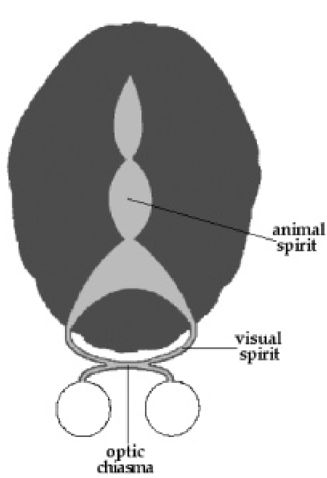

FIGURE 3

humor is prepared to accept physical light- and color-impressions in a visual way.[16]

Now, let us place a luminous object, such as BCD in figure 4, directly in front of the eye. According to the Alhacenian account, each point on the object's surface will radiate its form through every facing point on the cornea to the anterior surface of the glacial humor. Thus, point D on the luminous object's surface radiates its form through the cornea to distinct and separate points, such as E, F, and G, on the anterior surface of the glacial humor. Likewise, *every* point on the object's surface will radiate its form through the cornea to *each* point on the anterior surface of the glacial humor. For instance, points B, C, and D on the luminous object's surface all radiate their forms through the cornea to the same point E on the anterior surface of the glacial humor.

To explain how a coherent visual impression is sifted from this chaos of overlapping forms, Alhacen appealed to the refractive and sensitive properties of the glacial humor.[17] First, the impinging color-form must radiate through the refractive interface between albugineous and glacial humors. Among all such forms, only those that reach this interface orthogonally, that is, along perpendiculars BE, CA, and DF in figure 5, will pass unrefracted. The rest, whose radial paths are represented by DE and CF, will be deflected out of the account. Second, by analogy to a projectile, forms of luminous color impinge most forcefully when they strike the interface directly along the orthogonal. The more obliquely they strike, the more glancing the impingement. Being most forceful and, therefore, most acutely felt by the glacial humor, the orthogonal impingements are the only ones that make a sensible impression on it. The rest are simply ignored. So it is on the basis of its sensitivity that the glacial humor abstracts a coherent visual representation, or "image," B′C′ in figure 6, that is in proper point-to-point correspondence with its generating object BC. On the basis of its refractivity, meanwhile, the glacial humor allows each point on the abstracted image to radiate straight through toward the center of the eye. The field of effective vision is therefore defined by a cone of visibility with its base in the visible object BC and its vertex at centerpoint A of the eye. Defining the center of sight, this vertex serves as the

[16] This anatomical and physiological model is Galenic in origin, and many of the details, such as the ventricular structure of the brain and the manufacture of animal spirit, are not explicitly mentioned by Alhacen. Roger Bacon, however, was explicit in tying the Galenic model of the brain, in all its details, to the Alhacenian account of vision. See Smith, *Alhacen's Theory*, xxxvii–xlix and lxxxiv–xc.

[17] For Alhacen on the refractive and sensitive selection of visual images by the crystalline lens, which is formed of glacial humor, see Smith, *Alhacen's Theory*, lx–lxii.

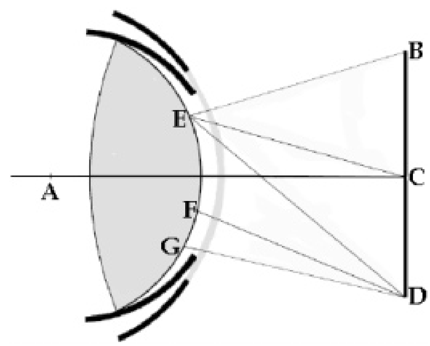

Figure 4

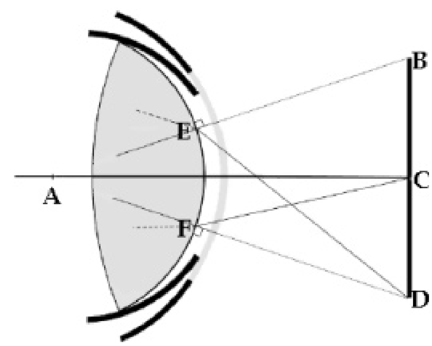

Figure 5

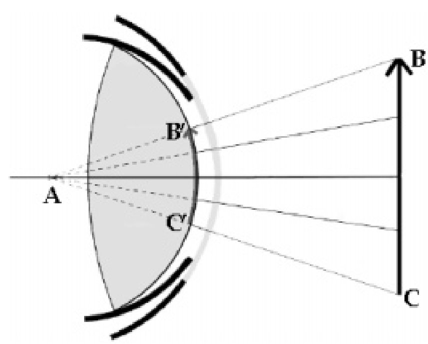

Figure 6

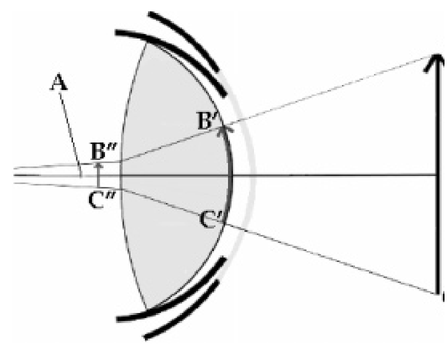

Figure 7

ultimate reference-point for the geometrical analysis of sight within the cone of visibility. On that basis, we gauge the distance of objects according to how far they lie from the center of sight, whereas we gauge their size according to a correlation of their perceived distance and the visual angle they subtend at the center of sight.[18]

If every point-form on the image abstracted by the glacial humor passed straight through the eye, then the rays along which they are transmitted would cross at centerpoint A and continue on in inverted order. The resulting image would therefore be upside down. But in meeting the refractive interface between glacial and vitreous humors before centerpoint A, these rays are deflected outward by being bent toward the normal as they pass from the optically rarer glacial humor into the optically denser vitreous humor. In this way, image B″C″ in figure 7, which is transmitted along these refracted rays, is channeled in proper, upright order into the hollow optic nerve at the back of the eye.

[18] For Alhacen on spatial perception, see Smith, *Alhacen's Theory*, lxiv–lxvi.

At that point it will have shrunk enough to fit into the narrow opening so as to be conveyed in proper, upright order through the visual spirit pervading the nerve. And when it finally reaches the optic chiasma, it will be fused with its mate from the other eye. Such fused images are what we normally see in binocular vision, although in abnormal circumstances, when the two images fail to fuse properly, we see double.[19]

Let us go back for a moment to the object represented in this process. According to the Alhacenian account, particularly as it was interpreted by his Latin followers, all physical objects present themselves to us in various ways and at various levels. This brings us to the notion of intentionality.[20] Take, for example, Georges Seurat's well-known *Sunday Afternoon on the Island of la Grande Jatte*. At the very lowest level, it represents a mere composite of colored dots. As such, it can be likened to the pointillist representation formed at the anterior surface of the glacial humor. At a somewhat higher level, though, it represents a number of bodies in space. At a higher level yet, it represents a group of men and women distributed in various positions and poses on a tree-shaded lawn by water's edge. And at an even higher level, it represents a social event occurring in Paris during the summer of 1884. Nevertheless, although we may "see" all of these things portrayed in the painting, they are not actually there. They are merely implied, or intended, by the peculiar juxtaposition of colors on the painting's surface, and they remain implicit until they are subjectively realized through perception.

Just so, the visual image abstracted by the glacial humor and conveyed to the optic chiasma is an intentional, and therefore subjective, representation of its generating object. As such, the visual image expresses the visible nature of the object it represents. But more to the point, in expressing the visual realization of that nature, it represents the very seeing of the object. This representation, in turn, intends a host of things that are not actually in it, since it consists of nothing more than colors rendered visible by the sensitized glacial humor. By Alhacen's count, there are twenty such ulterior intentions, ranging from size, shape, and spatial disposition to corporeity, opacity, and even beauty or ugliness.[21] We realize these intentions by submitting the visual image at the optic chiasma to perceptual scrutiny and judgment. This process is carried out in the brain by the so-called Final Sensor (*ultimum sentiens*). Syllogistic in nature, the process itself entails

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[19] For Alhacen on the channeling of visual images into the hollow optic nerve, see Smith, *Alhacen's Theory*, lxi–lxii; for Alhacen on image-fusion, see ibid., lxxiii–lxxvi.

[20] On intentionality, see Smith, *Alhacen's Theory*, lxxxvii–lxxxix.

[21] For Alhacen on the visible intentions, see Smith, *Alhacen's Theory*, lxii–lxiii.

discrimination, as well as comparison and correlation of intentional features, the result being an intentional representation of the object according to the full array of its physical properties that can be visually perceived.[22] As has already been mentioned, spatial characteristics, such as distance and size, are perceptually determined by reference to the center of sight at the vertex of the cone of visibility. From the perceptual representation formed in this way, we abstract an even higher-level conceptual representation of the object as a specific or general type. That, in the end, is how we see something as a horse, or as an animal, rather than as a mere array of colors or as a certain object of a certain shape and size, lying at a certain distance.

From this account it should be clear that Alhacen and his medieval followers conceived of vision not as a simple act, but as a complex process unfolding in stages, from physical radiation, through brute sensation, to perception and, finally, conception. Each stage is marked by the formation of a particular intentional representation, which is a virtual likeness in much the same way that a painting is a virtual likeness of what it represents. This process is illustrated in figure 8. The luminous color-forms transmitted through air are intentional representations, or virtual likenesses, of the actual colors on the object's surface. Physically radiated to the eye, these color-forms generate a visual representation, or image, in the optic complex. This image is a virtual likeness of the object at the level of pure sensation. Transmitted through the spirit pervading the optic complex, the visual representation gives rise to a more abstract perceptual representation. This intentional representation is realized in the animal spirit of the brain. So too is the conceptual representation arising from it.

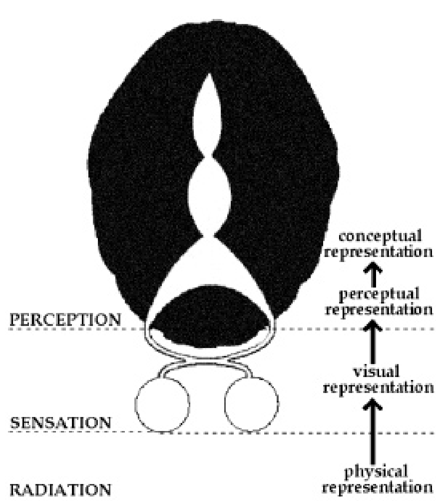

FIGURE 8

In figure 9 we have an actual late medieval illustration of the

[22] For Alhacen on this process of visual scrutiny and certification, see Smith, *Alhacen's Theory*, lxviii–lxxiii. See also A. I. Sabra, "Sensation and Inference in Alhacen's Theory of Visual Perception," in *Studies in Perception*, ed. Peter Machamer and Robert Turnbull (Columbus: Ohio State, 1978), 160–85.

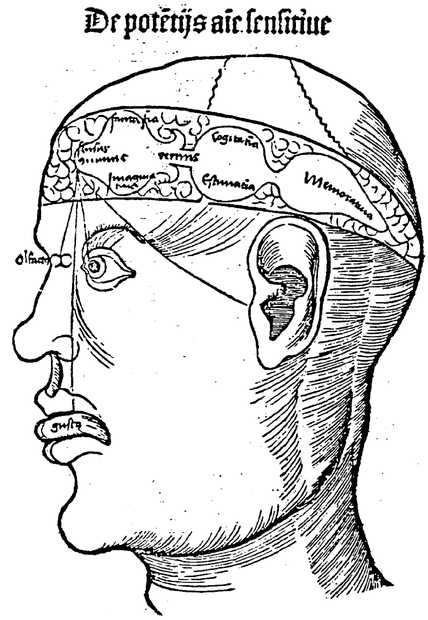

FIGURE 9

perceptual model just outlined.[23] The band toward the top of the head portrays the three ventricles of the brain in a sort of cutaway format. The various sense-links to the first ventricle are specifically represented by taste (*gustus*) and smell (*olfactus*). The visual and auditory links are drawn in but not labeled, and the tactile link is missing altogether. The anterior lobe of the first ventricle, where all the sense-links converge, is devoted to brute sensation, the responsible faculty being labeled *sensus communis*. The *sensus communis*, or "common sense," represents the clearing-house for all sense-data, including, of course, visual data. The posterior lobes of this same ventricle are devoted to perception, which is carried out by the faculty of perceptual representation (labeled *imaginativa*, or "imagination") and perceptual association (labeled *fantasia* or "phantasy"). Connected to the first ventricle by a passageway called the *vermis*, the second ventricle contains the conceptual—or cognitive—faculties, which include the *estimativa* and *cogitativa*. This latter faculty abstracts what I have called conceptual representations from the perceptual representations transmitted to the second ventricle through the *vermis*. And, finally, the posterior ventricle is where the conceptual representations abstracted by the *cogitativa* are transmitted for long-term storage by the memorative faculty, labeled *memorativa*. Stage by stage, from beginning to end, the visual process evolves in a continual succession of replications, each one representing the object at a more abstract intentional level. The physical, anatomical, and physiological structure of the visual system is expressly designed to support this succession. In every respect, therefore, the visual process is naturally disposed to give us a faithful subjective picture of objective reality.[24]

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[23] This figure is reproduced from Gregor Reisch, *Margarita philosophica* (Basel: Schottus [and M. Furterus], 1508).

[24] For a more detailed overview of the Alhacenian model of visual perception within the broader historical context of Perspectivist optics, see A. Mark Smith, "Getting the Big Picture in Perspectivist Optics," *Isis* 72 (1981): 568–89, and "Picturing the Mind: The Representation of Thought in the Middle Ages and Renaissance," *Philosophical Topics* 20 (1992): 149–70.

All of this is to say that Alhacenian optics is about appearances, about how things look to the perceiver from a particular point of view—that is, from the center of sight at the vertex of the cone of visibility. Ideally, when the light is right, the optic system sound, the object near enough to be properly viewed, and so on, appearance conforms to reality. But things are not always as they appear. This is especially evident in the case of reflection and refraction, where objects always appear dislocated, and often distorted. In plane mirrors things appear to lie behind the reflecting surface when they actually lie above it. In convex mirrors they appear behind the mirror and smaller and more bowed than they really are. In concave mirrors they are subject to a wide variety of distortions involving apparent place, size, and orientation. In a tub of water they appear higher and larger than they should. These are all instances of misperception or illusion. As such, they represent anomalies that demand rectification, and ray-analysis provides the means. It enables us to reconcile mere appearance, or illusion, with reality on the basis of key governing principles, such as the rectilinearity of the ray, the equal-angles law of reflection, the cathetus-rule of image-location, and so forth.

Just how complex the resulting analysis can be is illustrated by a theorem that occurs toward the end of book 5 of the *De aspectibus*. The point of this theorem is to demonstrate that, if A in figure 10 is an

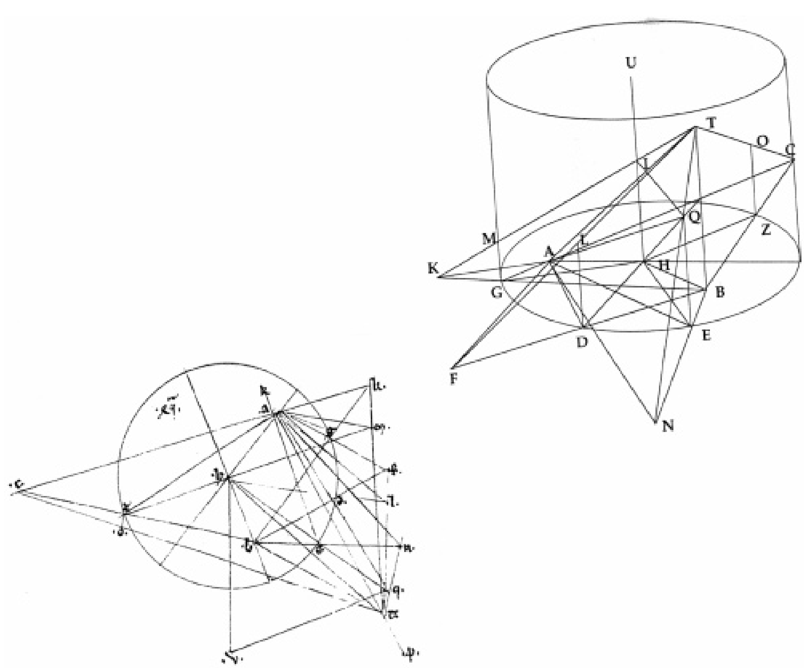

FIGURE 10

object-point placed inside a concave cylindrical mirror, defined by arc GDEZ, if T is a center of sight within that same cylinder, and if A and T are placed in an appropriate relationship to one another vis-à-vis axis HU of the cylinder, then the image of object-point A will reflect to center of sight T from as many as four points—i.e., M, L, Q, and O—on the cylindrical segment. Furthermore, each of those points will lie on a determinate elliptical section on the cylinder's surface.[25] Alhacen's ultimate purpose in demonstrating such things is to establish a basis for determining image-location and, from there, determining precisely how images appear distorted according to size, shape, location, or orientation, in spherical, cylindrical, and conical convex and concave mirrors. However "modern" Alhacen's ray-analysis may appear at a mathematical level, it is anything but modern at the conceptual level—at the level, that is, of analytic intent.

From this it should be evident that the ultimate reference-point for Alhacen's analysis of reflection is the center of sight—e.g., point T in the previous figure. And the same holds for his subsequent analysis of refraction. Furthermore, Alhacen and his Latin followers drew a clear and crucial distinction between the kind of image formed at the anterior surface of the glacial humor and the kind of image seen in a mirror. The former is invariably referred to by the Latin term *forma*, or "form," which connotes the sort of objective concreteness that an impression made in wax by a signet-ring would have.[26] The term *ymago*, or "image" properly speaking, is reserved for what is seen in a mirror, and it is etymologically related to the psychological faculty of "imagination."[27] In other words, the *ymago* is a subjective construct, pure and simple, whereas the *forma* is both subjective and objective. Or, to put it anachronistically, the image abstracted by the eye is at least partly real, whereas the image seen in the mirror is wholly virtual. Within such an analytic context, then, the science of optics is not about light-radiation, reflection, or refraction, as we understand them in the modern, objective sense, but about how we perceive things directly or by mediation of reflective or refractive surfaces. With these points made, let us turn, finally, to Kepler.

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[25] For the text of this theorem, see Risner, *Opticae thesaurus*, 184–85. The diagram to the lower left of the figure is reproduced from one of the manuscript-versions of the *De aspectibus* (Paris, Bibliothèque Nationale, MS Lat. 7319, f. 233r); the diagram to the upper right is my reconstruction of the figure to fit the specific parameters of the theorem.

[26] For a discussion of the Alhacenian concept of "form," see A. I. Sabra, "Form in Ibn al-Haytham's Theory of Vision," *Zeitschrift für Geschichte der Arabisch-Islamischen Wissenschaften* 5 (1989): 115–40.

[27] See Risner, *Opticae thesaurus*, 125: "Et forma comprehensa in corpore polito nominatur imago" [And a form perceived in a polished body is called an image].

Kepler presented his account of vision in the fifth chapter of *Ad Vitellionem paralipomena* (A Supplement to Witelo), which was published in 1604.[28] As noted earlier, Witelo was one of Alhacen's Perspectivist followers, and in this case he clearly stood proxy for him. Like Witelo, and thus Alhacen, Kepler assumed that light propagates spherically from point-sources. Like Witelo and Alhacen, he assumed that this propagation occurs within a continuous transparent medium. Like Witelo and Alhacen, he assumed that light and color intermingle naturally to radiate in tandem from the surfaces of visible objects. And, like Witelo and Alhacen, he assumed that the transmission of light and color can be resolved into individual rays within the sphere of propagation. Unlike Witelo and Alhacen, however, Kepler wondered what would happen if the lens formed by the glacial humor were treated as nothing more than a refractive body and if *all* the rays from a given point-source, not just the orthogonals, went into the formation of the visual image. Using a glass sphere containing water to represent the lens and tracing the passage of light through it, he determined that, if the incoming light is channeled through a small aperture directly in front of the sphere, all the rays passing through that aperture from a given point-source A in figure 11 will be focused by the sphere to a particular spot B on the opposite side. On this basis, he concluded that the eye, with its pupil and its lens, is designed for no other purpose than to focus the light emanating from specific points in the visual field to specific corresponding points on the retinal screen at the back, as is illustrated in figure 12. Altogether, these points form an inverted image of everything within the visual field, an image Kepler pointedly referred to as a *pictura*—a painting—to distinguish it from a mere *ens rationale*, or "mental entity," that has only intentional status.[29]

So far it looks as if, in transposing the visual image from the anterior surface of the lens at the front of the eye to the retinal screen at the back, Kepler simply followed the imperatives of Alhacenian ray-analysis to their logical conclusion and, in the process, resolved certain inconsistencies. This is essentially Lindberg's point. But let us take a closer look. For one thing, Kepler's retinal image is upside down. Yet we see things rightside up, a fact the Alhacenian account takes into full consideration.

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[28] For a recent English translation of this work, see William H. Donahue, *Johannes Kepler: Optics* (Santa Fe: Green Lion, 2000); for chap. 5 see 171–236.

[29] As Kepler puts it: "Cum hactenus Imago fuerit Ens rationale, iam figurae rerum verè in papyro existentes, seu alio pariete, picturae dicantur" [Since hitherto an Image has been a Being of the reason, now let the figures of objects that really exist on paper or upon another surface be called pictures]; for the Latin version of this quotation, see Franz Hammer, ed., *Johannes Keplers gesammelte Werke* (München: Verlag C. H. Beck, 1939), 2:174; for the English, see Donahue, *Johannes Kepler: Optics*, 210.

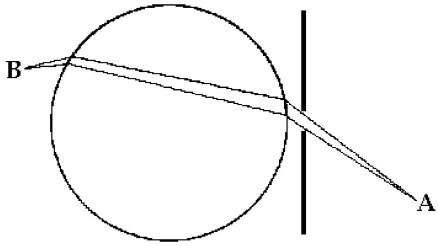

FIGURE 11

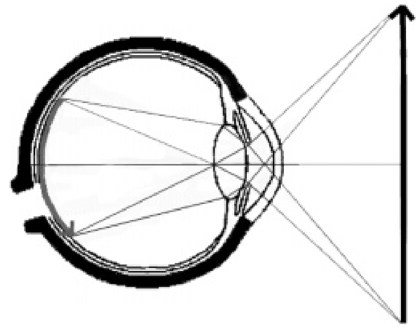

FIGURE 12

For another, Kepler's retinal image is real, not subjective or intentional. It exists *objectively*, there for anyone, not just the perceiver behind the eye, to see. This means that the image itself, not the object it represents, must be what is actually perceived. If so, then vision can never be veridical, because it is based on mistaking the physical, objective representation for what it represents. For yet another thing, the retinal image is too large to fit into the optic nerve, much less pass through it to the brain for perceptual scrutiny. Gone is the peculiar sensitivity of the glacial humor. Gone is the succession of intentional representations passing through the eye into and through the brain. Gone is the tight linkage between objective cause and subjective effect so critical to the medieval account. Gone, as well, is the cone of visibility, and with it the vertex to serve as a reference-point for spatial perception. All that remains is a sightless mechanism whose sole function is to focus incoming light in a specific pattern on the retina. As for what happens to this pattern afterward, how the visual faculty might actually apprehend it, or how it might eventually be judged at the subjective level, "This," Kepler asserted dismissively, "I leave to the natural philosophers to argue about. For the arsenal of the optical writers does not extend beyond [the] opaque wall [formed by the retina]."[30]

Implicit in this disclaimer is a recognition on Kepler's part that his account of retinal imaging is wholly incompatible with the Alhacenian model of visual perception. And implicit in his evident refusal to see this as a serious problem is a conception of optics, of its basic aims and criteria, that is diametrically opposed to that of his medieval predecessors. For them, as we have seen, optics is first and foremost about sight. Or, to borrow a useful, if somewhat pretentious, buzz-word from

[30] Donahue, *Johannes Kepler: Optics*, 180.

postmodernist criticism, it is oculocentric. The primary goal of medieval optics is therefore to explain how objective reality is subjectively manifested in the perceptual system through the mediation of light and color. Every part of that explanation, including the physical account of light and color, is bent toward the fulfillment of that goal. For Kepler, on the other hand, optics is first and foremost about light, about how it acts in its own right apart from any of its sensible or perceptual effects. In short, Keplerian optics is luminocentric rather than oculocentric. Its primary goal is therefore to explain light in terms of its objective, physical manifestations alone. If the physical theory designed to meet this goal conflicts with the prevailing model of visual perception, then so much the worse for that model.

Kepler thus posed a dilemma for subsequent thinkers. To adopt his theory of retinal imaging with all its entailments meant jettisoning the Alhacenian model of light and sight. In the long run, of course, that is precisely what happened, and by the end of the seventeenth century the science of optics had been radically transformed in accordance. Light was now understood in material rather than qualitative terms, not as a formal effect propagated through transparent media, but as a continual succession of tiny bodies shooting, or striving to shoot, through space and interacting dynamically with other bodies in the way of their passage. Visual images had been replaced by optical images, some real, some virtual. The center of sight had been replaced by focal points. And, perhaps most telling of all, luminosity and color had been transformed from real, objective qualities to mere psychological states bearing no resemblance whatever, intentional or otherwise, to their objective, physical causes.

At bottom, therefore, Kepler's account of retinal imaging represented not a continuation, but a repudiation of the medieval optical tradition. At issue was the relationship between objective cause, in the form of light and color, and subjective effect, in the form of perceptual impressions. Medieval optics was explicitly designed to bind the two as tightly as possible by means of intentional representations. Keplerian optics was implicitly designed to sever this bond by interposing the opaque wall of the retina between the perceiving subject and the perceived object. Out of the resulting disjunction arose not only the modern science of physical optics but also the mind-body dualism of Descartes and his philosophical successors.