has moved Dr. Stocking to condescension and disdain; ignoring many important matters, he reaches into the Acknowledgements to remark sourly upon my wife's finding Rivers's grave. No wonder I was "posing somberly" beside it. Foreboding, perhaps.

Apart from natural objections to various comments by the reviewer, I should like to make a couple of specific corrections. Rivers did not die in his rooms; nor am I an American student of the Inuit. I am a Canadian who has worked among Northern Athapaskans. Mere details, but perhaps suggesting, along with other considerations, that *W. H. R. Rivers* was "skimmed" rather than read carefully by the reviewer.

David Lindberg. *Theories of Vision from Al-Kindi to Kepler.* Chicago: University of Chicago Press, 1976. 324 pp. (Reviewed by ROBERT J. RICHARDS)

The early history of visual perception is labyrinthian, but its many turns should be of considerable interest to the historian of science. That history, in one of its aspects, exhibits a heritage of mathematical and physical inquiry only a little less endowed than astronomy in refinement of its technical concepts; indeed, many associated with important advances in mathematics and astronomy also made significant contributions to optics: for example, Euclid, Archimedes, Ptolemy, Alhazen, Kepler. Anatomical and physiological investigations of vision by ancient, medieval, and Renaissance physicians constitute another distinguishable tradition in the early history of perception. The natural philosophers—the Atomists, Platonists, Aristotelians, Stoics, along with their descendants—make up a third group proposing theories of light propagation, sensory operation, and cognitive interpretation of visual images. These three approaches to the scientific analysis of vision are conceptually isolable (by reason of the primary intent and achievement of their practitioners) into fairly distinct intellectual traditions. Their histories, nonetheless, evince integration at every turn. Thus, historians who wish to pursue internal scientific development, as well as those interested in modes of external influence, will be rewarded if they patiently search the early history of visual perception.

Yet this is a topic which relatively few historians of science have taken up, and fewer still with sure hand. Recent efforts in English to give broad coverage to this history (excepting Alistair Crombie's monograph, "The Mechanistic Hypothesis and the Scientific Study of Vision," in *Historical Aspects of Microscopy*, ed. S. Bradbury and G. Turner [Cambridge: W. Heffer, 1967]) have been either too sketchy to be useful or very unreliable—usually both. This cannot be said of David Lindberg's *Theories of Vision from Al-Kindi to Kepler.*

Lindberg has produced a history of the best kind: it offers detailed analysis of an extensive range of visual theories and a complementary appreciation of their diverse intellectual traditions and interplay. He has examined the primary documents carefully and made critical use of the secondary literature. His bibliography is comprehensive.

The introductory chapter briefly describes the perceptual theories of the Atomists, Plato, Aristotle, the Stoics, Galen, and the mathematicians—Euclid, Hero, and Ptolemy. Emerging from these ancient views were two rival conceptions of vision. The Atomists and Aristotle argued that seeing occurred through reception of an image into the eye. But Galen demurred: How could an atomic configuration or an immaterial species shed by a mountain enter the small pupil of the eye? The Greek physician countered with a theory derived in essentials from Plato and the Stoics and cast into the ready optical geometry of the mathematicians: the eye was not a receptor but an effector; it emitted a perceptive power to form a cone of optical sensitivity, with vertex in the eye and base at the object seen.

Lindberg's next three chapters detail both the development of emission theories by Arab scientists and the revolution in optical theory prepared by the Aristotelian commentators Avicenna and Averroes and brought off by Alhazen. In the ninth century al-Kindi, for example, rehearsed arguments, borrowed from Theon of Alexander (fourth century), against visual intromission: if the eye received representative images, then distant objects should be seen as clearly as those nearby, small objects as easily as large, and objects on the periphery as distinctly as those opposite; if a coherent form of the object were admitted to the eye, then a ring viewed along its edge should be still seen as circular, not as a straight line, as in fact we see it. Al-Kindi proffered instead the theory of the visual ray. His version employed the Ptolemaic mathematical model and thus opposed, in intermural struggle, the Euclidean, which assumed an emitted cone of diverging rays rather than the radially repleat cone of Ptolemy. Al-Kindi also adopted the important Galenic refinement of visual ray theory: that nothing is actually transmitted from the eye, but that the visual power transforms the intervening medium into a sensitive cone continuous with the sensitive elements of the eye. Yet al-Kindi was not merely an imitator, but also an originator. He advanced the simple but suggestive thesis that every point on a luminous body emitted an infinite number of rays; it was an idea which Alhazen would later cultivate in explaining the intromission of point-forms of light and color.

Hunain ibn Ishaq (ninth century) so successfully portrayed Galen's theory of vision in his *Book of the Ten Treatises on the Eye* that Western readers for centuries believed it to be the work of his master. Avicenna (eleventh century), on the other hand, would have none of emission theory. In *De anima* he emptied an ocean of arguments, in the best medieval fashion, to submerge completely all versions of visual ray theory. For example, if, as the Galenists held, the medium between an object and one's eye were altered by the power of the psychic pneuma, then others of debilitated sight should be able to take advantage of the transformed medium; of course, they could not. Alhazen, however, was the one who administered the death blow to visual ray theory. This contemporary of Avicenna dispatched theories of visual emission, not by collecting more arguments against them, but by producing an alternative mathematical theory. Alhazen's *De aspectibus* was, as Lindberg justly regards it, a revolutionary event in the history of visual perception. In that optical thesaurus, so called by its sixteenth-century editor, he constructed an intromission theory of vision using the resources of Aristotelian physics and the instruments of Ptolemaic-al-Kindian mathematics. He maintained that punctiforms of light and color radiated in all directions from every point on an illuminated body and that at every point in the intervening medium the vertex of a cone was formed, available to the receptive eye, with the base of the cone on the radiant body. The eye became thereby impressed with complex images which the critical faculty could interpret. Alhazen was familiar with Galenic ocular anatomy; but he geometrically standardized the received model to meet, in his estimation, the necessary mathematical, physical, and psychological requirements—for example, a lens forward of the center of the eye to refract ingressing rays and thus deliver an upright image through the optic nerve. And with insight sharpened on extensive studies in dioptrics, he perceived the need, which Kepler would finally satisfy, to include rays oblique to the surface of the eye in a theory of ocular refraction and image formation.

Lindberg's next three chapters describe the reception and elaboration of visual theory by medieval thinkers in the West. Grosseteste, Bacon, Pecham, Witelo, and Henry of Langenstein among the perspectivists receive special attention, though Albert the Great, John Buridan, Nicole Oresme, and Blasius of Parma, as well as other

Aristotelian commentators, are not neglected. The story here is of the influence of Alhazen and the gradual elimination of all vestiges (as were still present, for instance, in Grosseteste, Bacon, and Pecham) of visual ray theory.

In chapter eight Lindberg introduces the discussion of Renaissance ocular anatomy with some preliminary but instructive remarks concerning the use of perspective theory by the Italian painters. This quite naturally leads him to Leonardo, whose imaginative genius for optical construction sometimes overpowered his observing eye. Leonardo had some acquaintance with the optics of Pecham and Witelo (Alhazen's expositors) and defended intromission theory, though by the fifteenth century there were few attackers. His ocular anatomy was fairly unusual, even primitive, certainly several grades below even the standard descriptions of Avicenna and much inferior to Galen's. I suspect Leonardo took as actual anatomical representations what earlier perspectivists, such as Pecham, offered only as geometrical models. Nonetheless, he made two important innovations, which, however, remained buried in his notebooks for several hundred years: he noted that the pupil dilated as light grew dim; and he likened the eye to a *camera obscura*, in which light rays decussated as they entered the aperture. Fabricius (whom Lindberg mentions only in passing) at the beginning of the seventeenth century and Porta at the end of the sixteenth would, respectively, give these two optical ideas currency. The remainder of the chapter briefly surveys ocular anatomy from Mondino (fourteenth century) to Plater (sixteenth century).

The final chapter of Lindberg's study is devoted to what he regards as the culmination of the medieval perspectivist tradition, Kepler's theory of the retinal image. Kepler, building on the views of Witelo, Pecham, and Porta, came to appreciate the refractive use of the lens in forming an image on the retina. He presumed with Plater that the sensitive instrument in the eye was the retina and not the lens, as all prior theorists had believed; and he abandoned, though with difficulty, the supposed requirement of an upright image. Kepler's optics offered "the first genuine instance in the history of visual theory of a real optical image within the eye—a picture, having an existence independent of the observer, formed by the focusing of all available rays on a surface" (p. 202).

Lindberg's study is admirable both for the exactness of its analyses and for its scope. With such breadth, however, it would be surprising not to find some lapses or questionable interpretations. I have found two which I believe important, though in the measure of the entire work they detract little.

The first concerns Galen's theory of vision. The theory asserts that in vision psychic pneuma issues from the eye to transform the illuminated medium (air) into an optically perceptive cone whose base is in contact with the visible body. Lindberg (pp. 40-41, 56) supposes that Galen must have also assumed a returning optical "radiation" which would leave its impress on the crystalline humor (lens) and thereafter be transmitted physiologically to the brain, the seat of conscious perception. But Galen, I think, was persuaded otherwise. In the discussion of vision in *De placitis Hippocratis et Platonis* he denied the return of any impression from the object to the eye or from the eye to the brain. In his view, the eye, that is, the retina, was already part of the brain and had resident a sensitive faculty, the psychic pneuma. The commerce between eye and brain upon which he insisted was the transmission of sensitive power (*aisthētikē dýnamis*) from the encephalic ventricles via the optic nerve and retinal processes to the crystalline humor. He thought there to be similar commerce between eye and intervening medium: when the pneuma issuing from the eye transformed the sun-illuminated air into something like itself, the cone of vision became virtually an extension of the optic nerve. For Galen vi-

sion was achieved, not in the brain by the reception of returning rays, but at the surface of contact of optical cone and distant object:

> Most think that the alteration caused by those things which impinge upon us is transferred through the nerve to the hegemonikon of the soul and thus gives rise to the perception of them; they do not consider that the sense of pain from a cut, crushed, or burned part of the body could not arise in the part unless that part had in it the power of sensing. The truth is other than they believe. For the nerve itself is part of the brain, just as a branch or shoot is part of a tree; and the part in which the nerve is implanted receives in itself the full power and discerns those things contacting it. Something similar happens to the air which surrounds us. For when it is illuminated by the sun it becomes for us an organ of vision, just as the pneuma which arrives from the brain. (Galen, *De placitis Hippocratis et Platonis*, in *Claudii Galeni Opera omnia*, vol. 5, ed. Carolus Kühn [Lipsiae, 1825], VII, 7, pp. 641-642.)

One of the sources of difficulty in Lindberg's interpretation is the assumption, an easy one for us, that sensation can take place really only in the brain. Galen, by contrast, understood sensation to occur in the initial alteration of the sensitive power, the pneuma, whether existing in the sense organ or as the modified medium. The precise nature of this sort of sensitive alteration (*alloiōsis*) is not completely clear in the texts. But Galen seems to have regarded it as akin to what Aristotle referred by his use of the same term: a transformation instantaneously effected throughout the entire substance. In the case of vision it would mean that the pneuma—which is stretched through the medium, eye, and brain—becomes immediately perceiving, without any transfer of impressions.

The second difficulty concerns an omission. Though Lindberg wishes to focus his attention on the development of visual theory during the Middle Ages and Renaissance, he knows the story cannot be told without due consideration of the ancient period. Unfortunately, he stops his background analysis with Ptolemy (second century), moving immediately then to the Arabs. But in the interim there were developments of singular importance for understanding the shape of later theories. Particularly significant were the Aristotelian commentators Alexander of Aphrodisias (third century) and John Philoponos (sixth century), both of whom Lindberg mentions but apparently has not examined firsthand. Alexander was the principal source of most of the arguments against visual ray theory which appeared in the later literature, especially in Avicenna's polemic. But, of equal moment, Alexander seems to have been the first to have proposed the adoption of the geometrical constructions of the mathematical emission theorists for use in reformulating Aristotelian intromission theory:

> But there is nothing emitted from the eye to the thing seen. . . . Rather colors appear in the intermediate diaphanous body, and just as it receives these forms it supplies them [to the eye]. . . . Magnitude is seen and judged by the angle of the cone which exists at the eye. Truly, things are seen through a cone which has a summit or vertex at the eye and a base, the boundary of which defines and delimits what is seen of the object from what is not seen. However, this cone is constituted, not by the emission of rays, but by the thing seen. . . . Through the cone of each thing seen the form of the visible object appears along straight lines. (Alexander of Aphrodisias, *Alexandri Aphrodisiensis, Peripatetici Doctissimi, Quaestiones naturales et morales et De fato: De anima libl ii*, Angelo Caninio Anglariensi interprete [Venetiis: apud Scotum, 1549], II, 38, p. 56 recto.)

John Philoponos made similar suggestions with added refinements (Philoponos, *Ioannis Alexandrie Philosophi in tres libros De anima Aristotelis* [Venetiis: apud Scotum, 1547], II, p. 55 verso). Hence, when Lindberg (p. 78) says of Alhazen's theory that "for the first time an intromission theory of vision has become a viable alternative,

adequate to compete on geometrical as well as physical and psychological terms with the theory of the visual ray," we must hesitate. Alhazen was not the first to recommend the bare idea of reformulating intromission theory in terms of emission geometry; nor the first to take some steps in this direction, although he was the first, as far as we know, to elaborate the idea at great length and with consummate brilliance. He was, perhaps, the first to make it viable.

Despite these flaws, small enough in this intelligent work, Lindberg's book will deservedly become the standard reference for the early history of visual perception.

The Author Replies:

I would like to thank Professor Richards for his sympathetic and generous review—especially gratifying in view of his own firm, firsthand knowledge of the sources on which my book was based. But Richards raises two objections. One of them—that I should have included Alexander of Aphrodisias and John Philoponos in the background chapter on ancient visual theory—I readily accept. I now realize that their inclusion (especially that of Alexander) would have shed important light on later developments.

The other objection pertains to my interpretation of Galen, and here I do not yield so easily. The issue is whether visual perceptions (which occur principally where the visual cone encounters visible objects) must be returned to the brain. I answer this question affirmatively, Richards negatively. Richards bases his analysis entirely on Galen's *De placitis Hippocratis et Platonis*, and I concur with his interpretation of this work. There is, however, another work, *De usu partium*, in which Galen presents a somewhat different view, arguing that "the crystalline humor . . . is the principal instrument of vision" and that the "principal and greatest usefulness [of the retina] . . . is to perceive the alterations of the crystalline humor." It is on the basis of these passages that I argue for transmission to the brain.

Now can we take one of these works as more representative of the "true" Galenic position? Richards apparently casts his lot with *De placitis*—no doubt the wise choice, if a choice is to be made, for here Galen presents by far the more systematic account of his visual theory. However, we must not forget the possibility that the two accounts can be merged or reconciled. But for my purpose, no decision on Galen's intentions need be made: my analysis of Galen was presented solely to elucidate the visual theories of two Islamic scholars, Hunain ibn Ishaq and Averroes, the former a disciple of Galen and the latter a borrower of certain Galenic doctrines; indeed, the analysis to which Richards takes exception is located wholly in the sections on Hunain and Averroes. Hunain drew on both *De placitis* and *De usu partium* and conflated their theories, and to reveal what he was getting at I found it useful to cite both *De placitis* and *De usu partium* without concern for distinguishing the separate strands; it seems to me that this is exactly the correct procedure. I did less well in the section on Averroes, where (under Hunain's influence) I carelessly conflated Galen's two accounts without discussing the legitimacy of such a step. Two things, then, are important. First, the visual theories of *De placitis* and *De usu partium* must be distinguished with more care than I exercised in my book. Second, we must keep in mind that, although Galen's fullest account of vision, in *De placitis*, makes no mention of transmission from the base of the visual cone to the brain, there are passages in *De usu partium* where such a process seems to be implied; and the latter is equally part of the Galenic tradition.