Did Kepler's *Supplement to Witelo* Inspire Descartes' Theory of the Rainbow?

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In 1604, Johannes Kepler published the *Supplement to Witelo* (*Paralipomena ad Vitellionem*). In this seminal work, which helped establish the basis of geometric optics and which quickly won widespread acceptance, Kepler demonstrated some fundamental discoveries regarding the optics of the human eye (see Ronchi 1957, 1970). The purpose of this historical note is to point out strong parallels between Kepler's treatment of the optics of the eye and Descartes' explanation of the rainbow, and to suggest that Kepler's work provided Descartes with some crucial keys for solving the rainbow problem.

Descartes published his theory of the rainbow in "Les Meteores," one of three appendices to the "Discourse on Method," (1637). He proudly announced that, using his new "method," he had solved a problem that people had worked on with little result for 2000 yr.

"The rainbow," "Descartes wrote in "Les Meteores," "is such a remarkable natural wonder and its cause has been sought so zealously by able men and is so little understood, that I thought that there was nothing I could choose which is better suited to show how, by the method which I employ, we can arrive at knowledge which those whose writings we possess have not had" (See Boyer 1959.) Descartes wrote in a style characteristic of his age. Scientists then were wont to magnify the importance of any discovery by pointing out that the ancients had failed in their attempts to find a solution, and by overlooking or inadequately acknowledging the crucial advances made by their predecessors or contemporaries. The lack of proper referencing makes it more difficult to trace the origin of some of the ideas that led to Descartes' momentous discovery.

Boyer, in his excellent book *The Rainbow From Myth to Mathematics* (1959) showed that renewed attention devoted to the rainbow problem in the early years of the seventeenth century had paved the way in many respects for Descartes' work. To be sure, there were still many conflicting theories regarding the cause of the rainbow, some of which were ridiculous, but the idea that the bow was caused by sunlight striking spherical drops and could be simulated by aiming a beam of light at a spherical globe filled with water was well known. By this time, the primary rainbow had also been attributed to light refracting into the drop, reflecting off its concave interior surface, and refracting once again on leaving the drop. The idea that the secondary bow was produced by two internal reflections had also been proposed.

By themselves, these ideas are inadequate to explain why the rainbow appears about 42° from the antisolar point, since rays undergoing two refractions and one or two reflections emerge from the drop at a variety of angles. Descartes' achievement is best stated in his own words.

> The principal difficulty still remained, which was to determine why, since there are many other rays which can reach the eye after two refractions and one or two reflections when the globe is in some other position, it is only those of which I have spoken which exhibit the colors. . . . I took my pen and made an accurate calculation of the paths of the rays which fall on the different points of a globe of water to determine at what angles, after two refractions and one or two reflections they will come to the eye, and then I found that after one reflection and two refractions there are many more rays which can be seen at an angle of from forty-one to forty-two degrees than at any smaller angle; and that there are none which can be seen at any larger angle. I found also that, after two reflections and two refractions there are many more rays which come to the eye at an angle of from fifty-one to fifty-two degrees than at any larger angle, and none which come at a smaller angle. ("Les Meteores." See Boyer 1959.)

Now note the parallels with Kepler's earlier work on the eye in the *Supplement to Witelo*. Kepler began by treating the eye as a spherical globe of water through which light is transmitted. Although he failed to obtain the proper law of refraction, he did have access to a table of angles of incidence and refraction. Using this table, he showed for the first time that the image of an observed object is recorded on the eye's back surface, the retina. Kepler calculated the paths of a large number of rays from a distant object incident at various points along the entire front of the spherical eyeball and refracting into it. These calculations showed that the various rays do not even approximately converge at a point on the back surface. He then showed that the only way to obtain a reasonably convergent image on the eye's back surface is to restrict the rays' entry to a narrow aperture. He concluded by announcing that the pupil performs this function, serving as a diaphragm that allows only a narrow bundle of light rays to enter the eye. Kepler confirmed all of these findings by (or possibly based on) careful experiments with water-filled globes.

In his theory of the rainbow, Descartes used three crucial ideas first developed by Kepler which apply to transmission of light through a spherical eyeball: (1) the calculation of the optical paths of a large number of almost parallel rays incident on the sphere; (2) the recognition that only rays from a small part of the sphere contribute to the construction of the visual image; and (3) the fact that this narrow bundle of rays is focused.

Kepler's contributions to optics and theory of vision as described in the *Supplement to Witelo* were almost universally known and accepted. Descartes was certainly aware of the work, and did privately acknowledge his debt to Kepler, for in a letter to Marin Mersenne on 31 March 1638 (Descartes 1939), he stated that, "Kepler was my principal teacher in optics, and I think that he knew more about this subject than all those who preceded him." Furthermore, in Appendix I to the *Discourse on Method,* entitled "La Dioptrique," Descartes treated the optics of the eye in much the same manner as had Kepler (again without public acknowledgment), although Descartes did include the influence of the lens. In sum, it is quite tempting to think that Descartes' manner of addressing the rainbow problem owed more to Kepler's approach than to his own method.

The link between Kepler and Descartes imparts a new sense of historical continuity to Descartes' theory of the rainbow and shows how it fits within the context of the optics of their time. Kepler's *Supplement to Witelo* was itself a direct outgrowth of G. B. Della Porta's *De Refractione* (1593), a work treating the optics of the eye, the camera obscura, and lenses (see Ronchi 1970). But even with the sense of continuity provided by Kepler's discoveries, it still took profound insight for Descartes to realize that raindrops would not require apertures similar to the pupil in order to focus rays from limited portions of their surfaces and so produce a rainbow. Kepler himself failed to apply his own techniques to the rainbow and hence failed miserably in his published attempts to explain it. (Boyer points out that Kepler revealed far more insight concerning the nature of the rainbow in his correspondence.) Even if we acknowledge a possible debt to Kepler, Descartes' solution of the rainbow problem remains a scientific achievement of the first order.

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