Descartes' Optics

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Descartes' work on optics spanned his entire career and represents a fascinating area of inquiry. His interest in the study of light is already on display in an intriguing study of refraction from his early notebook, known as the *Cogitationes privatae*, dating from 1619 to 1621 (AT X 242-3). Optics figures centrally in Descartes' *The World, or Treatise on Light*, written between 1629 and 1633, as well as, of course, in his *Dioptrics* published in 1637. It also, however, plays important roles in the three essays published together with the *Dioptrics*, namely, the *Discourse on Method*, the *Geometry*, and the *Meteorology*, and many of Descartes' conclusions concerning light from these earlier works persist with little substantive modification into the *Principles of Philosophy* published in 1644. In what follows, we will look in a brief and general way at Descartes' understanding of light, his derivations of the two central laws of geometrical optics, and a sampling of the optical phenomena he sought to explain. We will conclude by noting a few of the many ways in which Descartes' efforts in optics prompted – both through agreement and dissent – further developments in the history of optics.

Descartes was a famously systematic philosopher and his thinking about optics is deeply enmeshed with his more general mechanistic physics and cosmology. In the sixth chapter of *The Treatise on Light*, he asks his readers to imagine a new world "very easy to know, but nevertheless similar to ours" consisting of an indefinite space filled everywhere with "real, perfectly solid" matter, divisible "into as many parts and shapes as we can imagine" (AT XI ix; G 21, fn 40) (AT XI 33-34; G 22-23). Of this world he postulates that "from the first instant of creation," God "causes some [parts] to start moving in one direction and others in another, some faster and others slower" and that subsequently "He causes them to continue moving thereafter in accordance with the ordinary laws of nature" (AT XI 34; G 23). The laws of nature, Descartes suggests, in turn sort the world into three elements: a maximally fine element of fire, a coarser yet still "very subtle" element of air, and a relatively gross element of earth "whose parts have little or no motion" relative to one another (AT XI 24-25; G 17-18). The sun, fixed stars, and fire are constituted primarily by the first element

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and are responsible for the production of light. The earth, planets and comets are constituted by the third element and are responsible for the reflection and refraction of light. Finally, the heavens are constituted by the second element of matter and make possible the transmission of light from illuminated bodies such as the sun and stars to terrestrial bodies such as the earth and human perceivers.

Against this mechanistic background, Descartes identifies light with a tendency to motion caused by luminous bodies (AT VIIIi 108; CSM I, 259). In explicating this suggestion, he repeatedly invokes an analogy with the supposed tendency or *conatus* of a stone in a sling to recede from the center point around which it is rotated (AT XI 43-44; G 29). Importantly, for Descartes, this centrifugal conatus is not to be confused with any actual motion away from a center point. Indeed, just as the felt outward tension in a rotating sling is possible only as long as the stone is not released, so too the centrifugal conatus that Descartes identifies with light is possible only as long as the bodies of the relevant transparent medium are constrained in the radial direction in a state of static equilibrium (Shapiro 1974, 248). In explaining the nature of light, Descartes further insists that light must be propagated *instantaneously*. In support of this assumption – embraced prior to him by the likes of Roger Bacon, Grosseteste, Witelo, and Kepler – Descartes famously argues that "the action of light" may "pass from the heavens to the earth in the same way" as "the movement or resistance of the bodies encountered by a blind man passes to his hand by means of his stick," adding (rashly in hindsight) that "if this could be proved false, I should be ready to confess that I know absolutely nothing in philosophy" (AT VI 84;CSM I, 153) (AT I 308; CSM(K) III, 46). Finally, Descartes adds that light itself is propagated along straight lines, even if, as is likely the case, "the parts of the second element that serve to transmit this action – that is, light – can almost never be placed so directly one on the other that they make exactly straight lines" themselves (AT XI 100; G 64). In defense of this suggestion, Descartes once again makes adroit use of mechanistic analogies. In one such analogy, he argues that light may be transmitted linearly through a disordered plenum in much the same way as a person might transmit a perpendicular force by pushing downward on a convoluted stick. In another analogy, he defends the same point by noting that the weight of a ball may act perpendicularly even if it rests on top of a jumbled collection of balls in a vase (AT XI 100-101; G 64-65).

Descartes' mechanistic approach to optics was crucially extended by his derivations of the two central laws of geometrical optics. In his *Dioptrics*, Descartes proposes to derive the law of reflection by attending to the behavior of a tennis ball rebounding at an angle off of a hard surface. In reference to Figure 1 below, he postulates that "a ball propelled by a tennis racquet from A to B meets at some point B the surface of the ground CBE, which stops its further passage and causes it to be deflected" (AT VI 93; CSM I, 156).

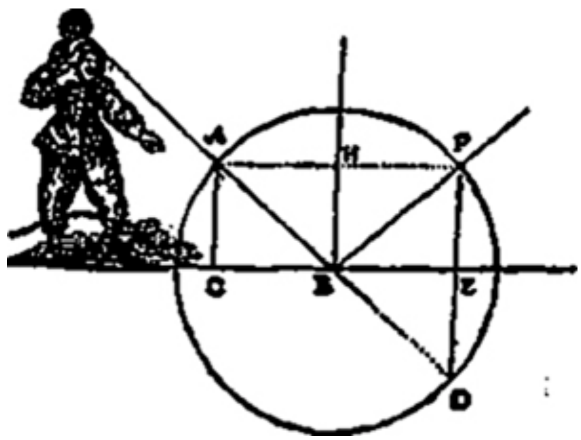

Figure 1

In order to determine the angle of the ball's reflection, Descartes suggests that "we can easily imagine that the determination of the ball to move from A towards B is composed of two others, one making it descend from line AF towards line CE and the other making it at the same time go from the left AC towards the right FE" (AT VI 95; CSM I, 157-158). Arguing that the ray's "encounter with the ground can prevent only one of these two determinations, leaving the other quite unaffected," Descartes maintains that the horizontal determination of the tennis ball from A to H will remain constant in spite of the ball's being reflected and thus will be equal to the horizontal determination from H to F (AT VI 95; CSM I, 158). Assuming further that the total speed of the ball is unaffected by reflection, Descartes is able to deduce that the tennis ball must pass through the point F, and that the angle of incidence ABC must be equal to the angle of reflection FBE, in agreement with the accepted law of reflection known since at least the time of the ancient Greeks.

In the *Dioptrics*, Descartes next derives the law of refraction in a similar fashion by replacing the hard ground of the previous demonstration with "a linen sheet … which is so thin and finely woven that the ball has enough force to puncture it and pass right through, losing only some of its speed … in doing so" as depicted in Figure 2 (AT VI 97; CSM 1, 158). Descartes further assumes that the total speed of the ball is determined by the resistance of the mediums through which it travels, and that its horizontal speed must remain constant since in passing from the first medium to the second, "it loses none of its former determination to advance to the right" (AT VI 98; CSM I, 158).

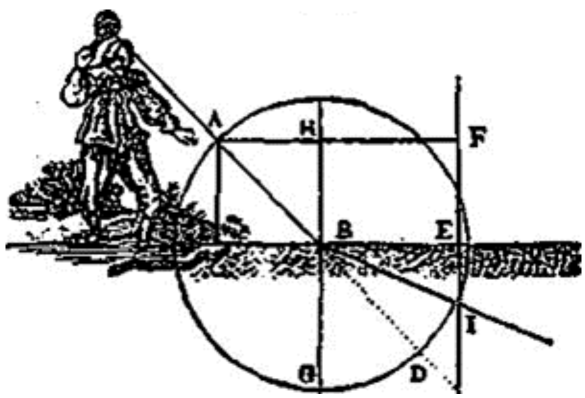

Figure 2

Letting HF be twice the length of AH and supposing that the ball travels twice as fast in the incident medium as in the refractive medium, Descartes argues that the ball must reach a point on the circumference of the circle at the same time that it reaches some point on the line FE (since by the first assumption, if the ball travels from A to B in one unit of time, it will travel from B to the circumference in two units of time, and by the second assumption, if the ball travels from A to H in one unit of time, it will travel from H to F in two units of time). Given these assumptions, Descartes concludes that it must be the case that the ball goes "towards I, as this is the only point below the sheet CBE where the circle AFD and the straight line FE intersect," and therefore that the ratio of the sine of the angle of incidence (BC) to the sine of the angle of refraction (BE) is a constant determined by the ratio of the resistance of the incident medium to the resistance of the refractive medium (AT VI 98; CSM I, 159). To put the same point in more familiar terms, Descartes' derivation thus purports to establish the law of refraction – published for the very first time in the *Dioptrics* – that the ratio of the sine of the angle of incidence to the sine of the angle of refraction is equal to a constant determined by the resistances of the mediums involved.

The legitimacy and provenance of Descartes' mechanistic derivations of the laws of optics have long been the subject of controversy (Sabra 1967, 69-135). One natural worry about their explanatory power concerns Descartes' use of moving balls to model what he takes to be an instantaneous phenomenon. His response to this concern appears to rest on the thought that since light is a tendency to motion, it must obey the same laws as moving bodies themselves (AT I 450-1; CSM I, 73-74). Another worry concerns the basis for Descartes' decomposition of the determination of incident rays into two orthogonal determinations capable of being analyzed independently of one another. In responding to the charge that his analysis is ultimately arbitrary, Descartes insists that the decompositions he invokes are not merely heuristic or conceptual, but are in some sense real and determined by nature (AT I 452). Yet another worry focuses on the ability of Descartes' mechanical models to explain cases of refraction towards the perpendicular. For even granting that a refractive medium could, as it were, retard a ray of light in the vertical direction, one might wonder what mechanical cause could explain the, as it were, acceleration of a ray of light in the vertical direction (see AT VI 100; O 79). Worries such as these encouraged the suspicion that Descartes had plagiarized the law of refraction from Willebrord Snell when they were both living in Holland – a charge first made publicly by Isaac Vossius in 1662, but intimated earlier by both Huygens and Leibniz. Although suspicions of plagiarism have persisted to the present day (and, indeed, the law of refraction is now known alternatively as Snell's Law, Descartes' Law, and the Descartes-Snell law) there appears to be no decisive evidence supporting the charge, and leading scholars have concluded that Descartes most likely arrived at his results independently of Snell's work (Sabra 1967, 102-103; Schuster 2000, fn 3).

Although Descartes is perhaps most famous today, with respect to the history of optics, for his role in the discovery of the law of refraction, his derivations of the laws of optics are but one element of an even more ambitious project. Having discussed the nature and laws of light in the first two discourses of the *Dioptrics*, Descartes devotes its next four discourses to the topic of vision. Following closely Kepler's "two-cone" theory of the formation of retinal images, Descartes begins by explaining how "the objects we look at do imprint very perfect images on the back of our eyes" (AT VI 114; O 91). In reference to Figure 3 below, he holds that rays of light emitted from the visible bodies V, X, Y fan out in all directions, and are subsequently refracted by "the three surfaces of [the eye] BCD, 123, and

456 … in the way that is required for them to reconverge at a single point," as for example, T, S, or R (AT VI 117; O 93).

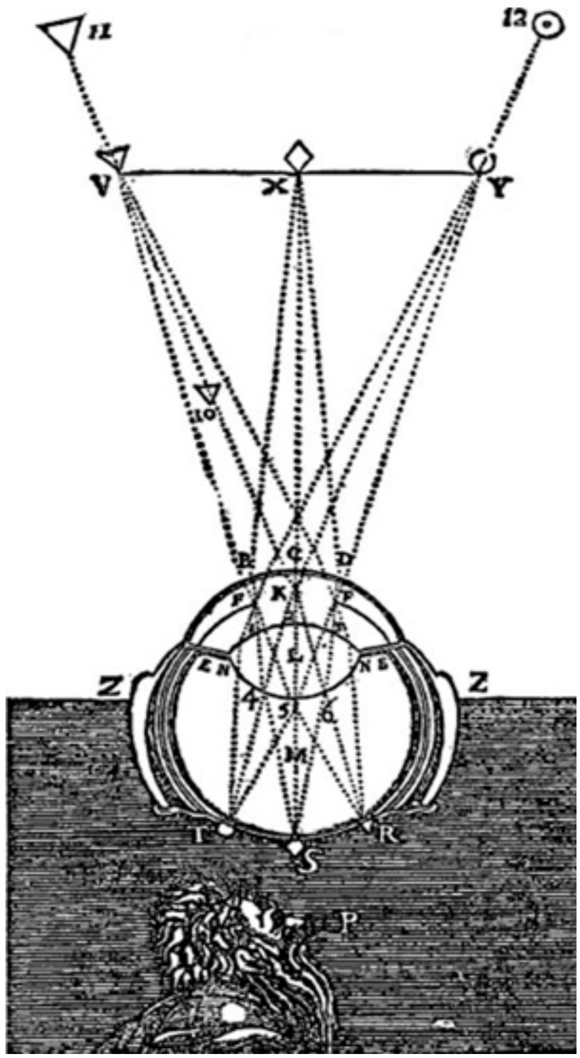

Figure 3

Having clarified how "the images of objects form thus on the back of the eye," Descartes proceeds to explain how "they also pass beyond to the brain," suggesting that rays striking the back of the eye stimulate individual fibers of the optic nerve so that a picture "which is quite similar to the objects V, X, Y is formed once more on the interior surface of the brain," and is in turn transported to "a certain small gland … which is the seat of the common sense" (AT VI 129; O 100). Although the physiological side of Descartes' account of vision might seem to imply that the process of vision is exhausted by a point-by-point transmission of images, he explicitly rejects just such a view, emphasizing that "we must not hold that it is by means of this resemblance that the picture causes us to perceive the objects, as if there were yet other eyes in our brain with which we could apprehend it" (AT VI 130; O 101). Descartes' positive view is that rays of light mechanically stimulate our eyes, that those stimulations are then mechanically passed to the interiors of our brains, but that once there they "act immediately on our mind in as much as it is united to our body," and give rise, under the right circumstances, to our familiar perceptual experiences (AT VI 130; O 101). As a blow to the eye that results in the perception of a colored flashes attests, the cause of a visual perception and the visual perception itself needn't resemble one another in any significant way (AT VI 131; O 101-2).

In the *Dioptrics*, Descartes' treatment of vision sets the stage for an extended discussion of its natural limitations and the means available for improving it. It is in this context that Descartes introduces his theoretical explanation of the telescope by means of a three part thought experiment (Ribe 1997, 54). First, Descartes proposes that "inasmuch as the first of the three liquids that fill the eye causes nearly the same refraction as common water," we may imagine an eye being extended by placing "right against it a tube full of water, such as EF," capped by a lens of roughly the same shape as the outer surface of the eye itself, as in Figure 4 below. Second, Descartes notes that "inasmuch as it would be very inconvenient to join water against the eye in the manner that I have just explained," the same effect might be obtained by placing a solid tube filled with a single lens or lenses or "other transparent bodies" just in front of the eye as in Figure 5.

Figure 4

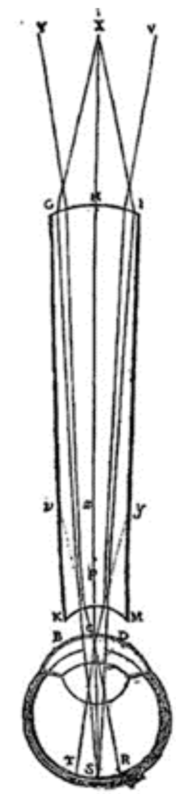

Figure 5

Descartes next notes, however, that since “there would again be some inconvenience in finding lenses or other such bodies sufficiently thick to fill the entire tube HF, and sufficiently clear and transparent so that they would not impede the passage of light … we will be able to leave the whole inside of this tube empty, and merely place, at its two ends, two lenses which have the same effect” (AT VI 159; O 122). He proudly concludes, “on this alone is founded the entire invention of these telescopes composed of two lenses placed in the two ends of a tube, which gave me occasion to write this *Treatise*” (AT VI 159; O 122). Descartes goes on to develop this initial explanatory sketch, applying results from his *Geometry* to explain the refractive properties of lenses used individually and in combination (discourse 8), provide guidance on the construction of magnifying glasses, telescopes and microscopes (discourse 9), and even outlining procedures for grinding hyperbolic lenses (discourse 10) (Ribe 1997, 56).

If Descartes' treatment of the telescope serves as the crown jewel of his *Dioptrics*, his brilliant analysis of the rainbow serves the same function in his *Meteorology*. In the beginning of the eighth discourse of that essay, he announces that "The rainbow is such a remarkable phenomenon of nature, and its cause has been so meticulously sought after by inquiring minds throughout the ages, that I could not choose a more appropriate subject for demonstrating how … we can arrive at knowledge not possessed at all by those whose writings are available to us" (AT VI 325; O 332). Making experimental use of "a perfectly round and transparent large flask [filled] with water" as a convenient substitute for actual raindrops, and making reference to Figure 6 below, Descartes draws three especially noteworthy conclusions.

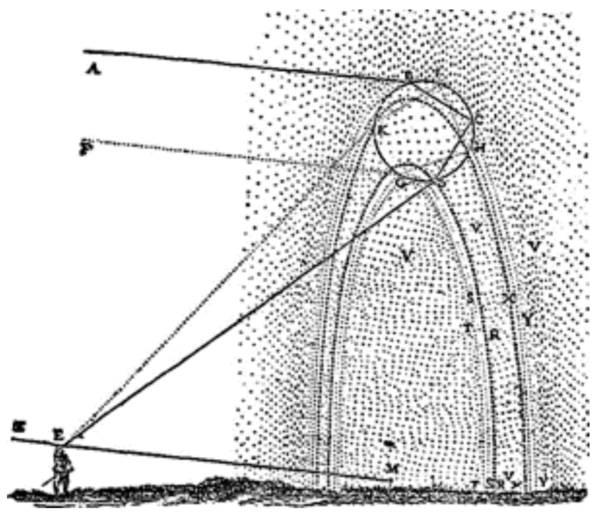

Figure 6

First, tracing the rays of light from "the section of the sky marked AFZ," Descartes observes that the height of the primary rainbow, as measured by the angle DEM, is approximately 42 degrees, and the height of the secondary rainbow, as measured by the angle KEM, is approximately 52 degrees (AT VI 326-327; O 332-333). Second, Descartes concludes that "the primary rainbow is caused by the rays which reach the eye after two refractions and one reflection [as, for example, at B, C, and D], and the secondary by the other rays which reach it only after two refractions and two reflections," as for example at G, H, I, and K (AT VI 329; O 334). Third, and most significantly with respect to the development of the history of optics, Descartes shows through a series of systematic calculations that the once reflected and twice refracted rays should cluster around a maximal observational angle of approximately 42 degrees – roughly the observed angle of the primary rainbow – while twice reflected and twice refracted rays should cluster around a minimal observational angle of 52 degrees – roughly the observed angle of the secondary rainbow (AT VI 336-40; O 339-342). This important result allows Descartes to offer novel explanations of an important range of phenomena that had long puzzled investigators of the rainbow such as, for example, why primary rainbows are most brightly and sharply defined at their upper extremes, while secondary rainbows are most brightly and sharply defined at their lower extremes (Boyer 1987, 211-215; Buchwald 2007).

Descartes' influence on the subsequent history of optics is difficult to overestimate. Many of his published results – including the law of refraction, his descriptions of anaclastic curves, and his explanation of the rainbow – represent clear advancements, and served as solid foundations for subsequent natural philosophers and scientists to build upon. Such was the nature of Descartes' genius, however, that he managed to make equally great contributions to the history of optics even where he was taken to have gone most wrong. Dissatisfied with Descartes' derivations of the law of refraction, Fermat showed how essentially the same results could be obtained from an easiest path principle. Opposing Descartes' view that light is merely a tendency to motion and is propagated instantaneously, Huygens developed his wave theory of light and used it to successfully explain a range of recalcitrant phenomena including, most famously, the refractive properties of Iceland Spar. Likewise, Newton's famous experiments with prisms and his novel theory of colors were instigated by his acquaintance with Descartes' published views. Few in the history of science, it is safe to say, have been so successful, in both success and failure, as Descartes in his work on optics.

For Further Reading

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Related Entries

Color; *Discourse on Method*; Experiment; Explanation; Force; *Geometry*; Hydrostatics; Laws of Nature; Light; *Meteorology*; Method; Motion; *Optics*; Perception; Physics; Rainbow; *Treatise on Light*; Fermat, Pierre de; Galilei, Galileo; Huygens, Constantijn and Christiaan; Kepler, Johannes; Leibniz, Gottfried Wilhelm; Mydorge, Claude; Newton, Isaac

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