Snell's law or Harriot's?

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Physics has a fascinating history, and the use of historical and biographical material can enrich physics teaching by presenting a fuller portrayal of the subject. Indeed, many introductory textbooks often summarize important historical developments to supplement the main text.[1] In optics, one particularly interesting historical episode is the search for the law describing refraction—the bending of light at the boundary between two different transparent materials. Although Snell's sine law of refraction is now taught routinely in undergraduate courses, the quest for it spanned many centuries and involved many celebrated scientists. Perhaps most interesting is that the first discovery of the sine law, by sixteenth-century English scientist Thomas Harriot (1560–1621), has been almost completely overlooked by physicists and physics educators, despite much published material describing his contribution. In this note we review the history of the law of refraction, discuss Harriot's discoveries, and suggest that his life and work provide a rich source of historical material for educational use.[2]

The first studies of refraction were probably performed in the fourth century BC by Chinese philosophers who noted the apparent shallowness of pools of water. The best-known ancient study, however, is that of Ptolemy of Alexandria (ca. 150), who tabulated refraction angles across air-water and air-glass boundaries, but without giving an explicit law describing his results. Metaphysical attempts to formulate a law of refraction were made by the Greek Damianos (ca. 400), and much later by Robert Grosseteste (ca. 1168–1253) in England, but in both cases led only to an imperfect law where a ray passing from a rare to a dense medium has an angle of refraction equal to half the incident angle.

Little further progress was made until the sixteenth and seventeenth centuries, and the correct sine law of refraction was first published in 1637 by René Descartes (1596–1650). The Dutch astronomer Willebrørd Snell (1591–1626), however, had independently circulated the sine law in a 1621 manuscript, and Snell and Descartes are today given joint credit for the discovery. About twenty years before Snell's discovery Johannes Kepler (1571–1630) had also looked for the law of refraction, but using the early data of Ptolemy. Unfortunately, Ptolemy's data is in error, and Kepler could obtain only an approximation, which he published in 1604. Kepler later tried to obtain additional experimental results on refraction, and corresponded with Thomas Harriot of England from 1606 to 1609 since Kepler heard that Harriot had carried out some detailed experiments. In 1606, Harriot sent Kepler some tables of refraction data for different materials at a constant incident angle, but without providing enough detail for the data to be very useful. Kepler requested further information, but Harriot was not forthcoming, and it appears that Kepler eventually gave up the correspondence, frustrated with Harriot's reluctance.

Apart from the correspondence with Kepler, there is no evidence that Harriot ever published his detailed results on refraction. His personal notes, however, reveal extensive studies significantly predating those of Kepler, Snell, and Descartes. Harriot carried out many experiments on refraction in the 1590s, and from his notes it is clear that he had discovered the sine law at least as early as 1602.[3] Around 1606, he had studied dispersion in prisms (predating Newton by around 60 years), measured the refractive indices of different liquids placed in a hollow glass prism, studied refraction in crystal spheres, and correctly understood refraction in the rainbow before Descartes.

Exactly why Harriot kept his results unpublished is unclear. Harriot wrote to Kepler that poor health prevented him from providing more information, but it is also possible that he was afraid of the seventeenth-century English religious establishment, which was suspicious of the work carried out by mathematicians and scientists. After his death, most of Harriot's papers were mislaid, and it is only in the twentieth century that his true place in the history of science has become known. Although now celebrated by historians of science,[2,3] Harriot is not well known among physicists and physics educators, and we have not found his work on refraction mentioned at all in texts that discuss the history of optics.[4] This is surprising, since Harriot's research and his discovery of the sine law before Snell was clearly pointed out in a 1951 article in the *American Journal of Physics*.[5]

Besides studying refraction, Harriot was an innovative scientist who made contributions in many other areas. As a mathematician, he contributed to the development of algebra, and introduced

the symbols of > and < for *greater than* and *less than*. He studied navigation and astronomy, and made the first telescopic observations of sunspots. He was a friend of the English courtier and explorer Sir Walter Raleigh, and travelled to Virginia as a scientific observer on a colonizing expedition in 1585. Harriot was probably the first to study the indigenous Algonquian people, and it was he, not Raleigh, who introduced tobacco into England from Virginia (although Raleigh can be given "credit" for popularizing the smoking habit). Unfortunately, the discovery of tobacco boded ill for Harriot since he died as a result of nostril cancer, and he has the dubious honor of being the first person to have his smoking habit recorded by a physician during treatment.

As with his studies of refraction, Harriot's discoveries in other fields were largely unpublished during his lifetime; until this century Harriot was known only by an account of his travels in Virginia published in 1588 and by a treatise on algebra published posthumously in 1631. Nonetheless, recent research has revealed his wide range of interests and his genuinely original discoveries. Harriot's studies of refraction is but one example where his work overlapped with independent studies being carried out by others in Europe, but in any historical treatment of optics his contribution rightfully deserves to be acknowledged. In teaching, the story of Harriot provides a fascinating example illustrating parallel discoveries in physics, and his life and work provide a rich source of material illuminating the development of renaissance science.

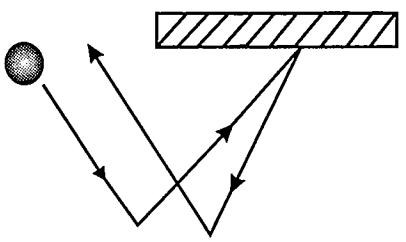
References

1. See, for example: P.A. Tipler, *Physics for Scientists and Engineers*, extended version (Worth, New York, 1991); P.G. Hewitt, *Conceptual Physics* (Harper Collins, New York, 1993).
2. The majority of the historical material in this note comes from J.W. Shirley, *Thomas Harriot: A Biography* (Oxford University Press, New York, 1983) and *Dictionary of Scientific Biography*, edited by C.C. Gillespie (Scribner's Sons, New York, 1970–1990).
3. J. Lohne, "Thomas Harriot: The Tycho Brahe of optics," *Centaurus* **6**, 113–121 (1959).
4. See, for example: D.J. Lovell, *Optical Anecdotes* (SPIE Press, Washington, 1984); E.F. Hecht, *Optics* (Addison-Wesley, MA, 1987).
5. J.W. Shirley, "An early experimental determination of Snell's law," *Am. J. Phys.* **19**, 507–508 (1951).

Physics Trick of the Month

Crazy Bounce

Super bouncing balls made of hard rubber are sold in many toy stores. The slightest spin on such a ball causes it to bounce in an erratic manner. For example, try this on a table that stands on a hard surface. Throw the ball as shown by the zigzag arrow. It will hit the table's underside, reverse direction, and bounce back to you!



Here's something to amuse your students. Tell them you have discovered a technique by which you can throw the ball in such a way that it will stop in midair, reverse direction, and come back to you. Students will be eager to see a demonstration.

How do you do it? Just toss the ball straight up in the air! Follow this by saying you are also able to drop the ball from a height of four feet, and it will not hit the floor. How? Drop it and catch it with the other hand.

Martin Gardner, *Hendersonville, NC 28792*