Who really discovered Snell's law?

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Open any physics textbook and you'll soon come across what English-speaking physicists refer to as "Snell's law". The principle of refraction – familiar to anyone who has dabbled in optics – is named after the Dutch scientist Willebrørd Snell (1591–1626), who first stated the law in a manuscript in 1621. In French, however, the same law is often called "la loi de Descartes" because it was René Descartes (1596–1650) who first put the law into widespread circulation in his *Discourse on Method*, published in 1637.

Indeed, Descartes not only stated the law, but also explained and derived it by considering how light would behave if it were made of particles. He even used the law to derive the hyperbolic form of perfect lenses that can focus incoming parallel rays to a single point. With this calculation, Descartes fulfilled what had been a 2000-year search for a perfectly focusing lens or "burning glass" – otherwise known as an "anaclastic".

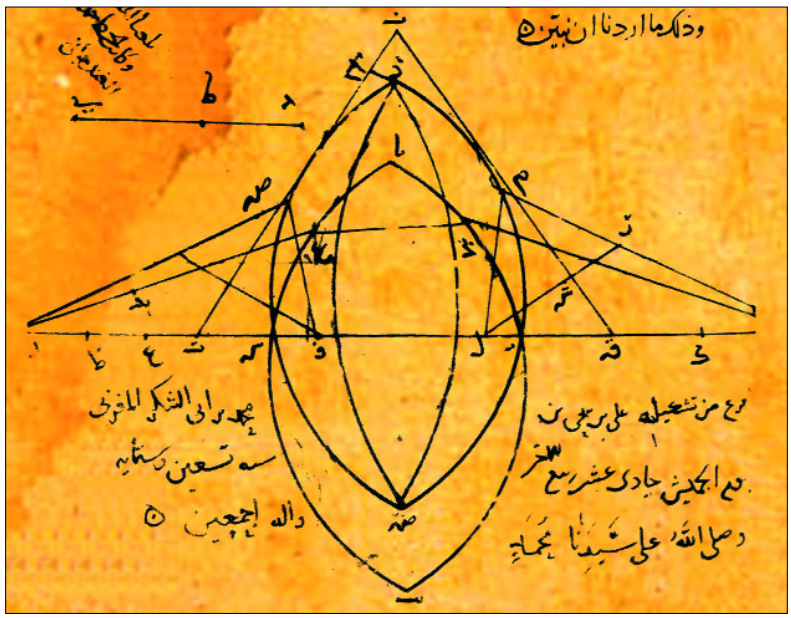
But the origin of this search can be traced back to the ancient Greeks, who were among the first to use lenses to light fires. In *The Clouds*, for example, Aristophanes suggests that solar rays can be focused by a lens to erase the records of financial debts recorded on wax tablets. Rome's vestal virgins, meanwhile, would use burning glasses to ceremonially re-kindle their sacred fire with a pure flame drawn from the Sun, untainted by Earthly dross. The Sun's rays can also be focused with concave mirrors, which came to be known as *speculi ustori* – cremators' mirrors – for their ability to light funeral pyres. They could even be used to light pyres for the living, as Archimedes (c287–212 BC) is said to have demonstrated to Roman soldiers besieging the Greek colony at Syracuse.

Surprisingly, however, the point where the reflected rays converge and burn was not named by the Romans – even though they must surely have noticed it. We owe our name for this "burning point" to Johannes Kepler (1571–1630), who carried out extensive research into reflecting and refracting surfaces a few decades before Snell and Descartes. Kepler named the burning point a "fireplace", which, in Latin, gives us the word "focus".

Kepler's work on burning glasses, however, was only moderately successful, lacking as he did the required sine law of refraction to determine the shape of refracting surfaces. Kepler certainly tried to obtain the law, after the English mathematician and astronomer Thomas Harriot (1560–1621) let it slip that he knew it. Indeed, Harriot knew the law as early as 1602, long before either Snell or Descartes. But when Kepler asked for the law, Harriot merely sent him some precisely computed tables of data, lamenting that ill health prevented him from putting it explicitly into a form suitable for publication.

As Harriot's health ebbed, so did Kepler's patience. Waiting no more, Kepler improvised. He observed that when light rays are close to the axis of a lens, the angles of incidence and refraction (rather than the sines of the angles) are proportional to one another, with the multiplier depending on the medium between which the light passes. Applying this approximation first to lenses and then to lens-based instruments, Kepler produced a theoretical approach so effective that his method and diagrams are reproduced, almost unchanged, in optics textbooks today.

Although Kepler's treatment succeeded in describing the refraction of rays close to the optical axis, it was still an approximation – and could thus never have led him to the elusive anaclastics that science had long sought. What



ROSHDI RASHED

There is no doubt that Ibn Sahl understood the sine law of refraction

is interesting, however, is that Kepler had previously written a text on astronomical optics, expanding on a book written by the Polish scholar Witelo (1250–1275) some four centuries earlier. Witelo's text was bound in with a printed edition of the *Opticae Thesaurus* – his translation of an optics textbook by the Islamic scholar Abu Ali al-Hasan Ibn al-Haytham (965–1040), who is more commonly known by his Latinized name of Alhazen.

Ibn al-Haytham was influential in Europe for several centuries, with virtually all European optics from the Middle Ages to the Renaissance building on his work. One work that he translated was *Optics* by Ptolemy of Alexandria (c150), which contains Ptolemy's studies of refraction at air–glass and air–water boundaries. However, Ptolemy's results were obtained not by measurement – as he presented them – but by calculation, using an incorrect quadratic "law" of refraction.

But because Ibn al-Haytham accepted this part of the book, Ptolemy's error was perpetuated for a further 600 years. Worse still is the fact that Ibn al-Haytham had actually seen the correct sine law of refraction when he translated *On the Burning Instruments*, written in about 984 by the mathematician Abu Said al-Ala Ibn Sahl. The latter makes clear reference to Ptolemy's *Optics*, rejects the erroneous law of refraction found therein, states the current law (in much the same terms as Harriot) and then goes on to compute, with purely theoretical interests, the anaclastics that Descartes thought were his own.

Based on a recent analysis of Ibn Sahl's work by the French scholar Roshdi Rashed, there is no doubt that Ibn Sahl correctly understood the sine law of refraction and that he should be acknowledged as its originator. From the viewpoint of modern physics, it is regrettable that his contributions were lost for so long, but this is certainly not the only historical triumph of falsity over perfectly correct theory. Perhaps the next question to ask is why science sometimes makes such regressive choices.

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