MILESTONES

GETTY

MILESTONE 1

Let there be light

In the beginning — or, at least, from around the sixth century BCE — the Vaisheshika school of Hindu philosophy held that the world was based on the 'atoms' of earth, air, fire and water. Rays of light were thought to be composed of fast-moving fire atoms or *tejas*, with the characteristics of the light depending on the speed and arrangement of the *tejas*. The nature of light — whether it indeed be some kind of particle or, instead, a wave propagating through a medium — was to become one of the greatest scientific debates of the succeeding centuries: one that was resolved barely a century ago.

Around 300 BCE, Euclid decided that light travelled in straight lines, and described the laws of reflection. In the second century, Ptolemy wrote about refraction. Laws of refraction were formulated by Ibn al-Haytham (also known as Alhazen), who wrote his *Kitab al-Manazir*, or *Book of Optics*, in 1021. Ibn al-Haytham was a prolific experimentalist, notably studying dispersion too. He also thought of light as a stream of minute particles, travelling at finite speed.

René Descartes, however, had other ideas — and many of them, as befitted a Renaissance man. In 1637, alongside his *Discours de la méthode* (with its memorable quote, "I think, therefore I am"), he published three essays, on meteorology, geometry and optics. This last, *La dioptrique*, promoted a concept of light as pulses propagating instantaneously through the contact of 'balls' of some medium (aether). Similar ideas are found in Thomas Hobbes' *Tractatus opticus* of 1644 and Robert Hooke's *Micrographia* of 1665. Although Ignace Gaston Pardies is thought to have taken steps, around 1670, in devising a formal wave theory, the manuscript is lost. However, Christiaan Huygens' *Traité de la lumière* of 1690 survives. In it, he treated light as compressible waves in an elastic medium, analogous to sound; by considering the envelope of secondary wavelets, he showed how to construct reflected, refracted and screened waves; he also explained double refraction.

Huygens' beautiful work did not, however, conquer the idea of light as particles or corpuscles. Isaac Beeckman, who was a mentor of Descartes, and Pierre Gassendi led a revival of Greek atomistic theories, which included the interpretation of colour as a mixture of light and shadow. But it was Isaac Newton who became the great champion of the 'corpuscularists'. In his *Opticks* of 1704, he recognized that colour should correspond to the velocity or mass of the light particles, and thus explained why different colours are refracted by different amounts. He rejected wave theory, because light would be able to stray too far into shadow; diffraction he accounted for as the 'inflection' of light particles by matter. Although Descartes' enduring reputation and Leonhard Euler's 1746 milestone work (including a dispersion law) ensured that wave theory maintained a following in France and Germany, Newtonian corpuscular theory was dominant for the rest of the eighteenth century.

A fresh skirmish began in the early 1800s, with what is often considered to be one of the most beautiful demonstrations in physics: Thomas Young's two-slit experiment, with which he introduced the principle of interference for waves of light. But now the corpuscularists were gaining ground in France: polarization, displays of which were delighting Parisian salons, was considered to be due to some kind of asymmetry among light corpuscles. Augustin Fresnel tipped the balance, with a precise wave theory of diffraction. Having revisited Huygens' work and added interference between secondary waves, he was able to explain, in wave terms, how shadows form. Moreover, in 1821, he showed that polarization could be explained if light were a transverse wave, with no longitudinal vibration. Now, wave theory was all; Newton was supplanted.

But one problem remained. Although Maxwell's seminal equations of 1865 (MILESTONE 2) were gradually and successfully adopted in optics, the aether — to support electromagnetic fields, to yield Fresnel's laws of propagation — was missing. The aether, of course, would never be found. As the twentieth century dawned, a new revolution in physics — led by Max Planck (MILESTONE 3) and Albert Einstein (MILESTONE 4) — would again hinge on the nature of light, be it wave or particle. Or both.

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