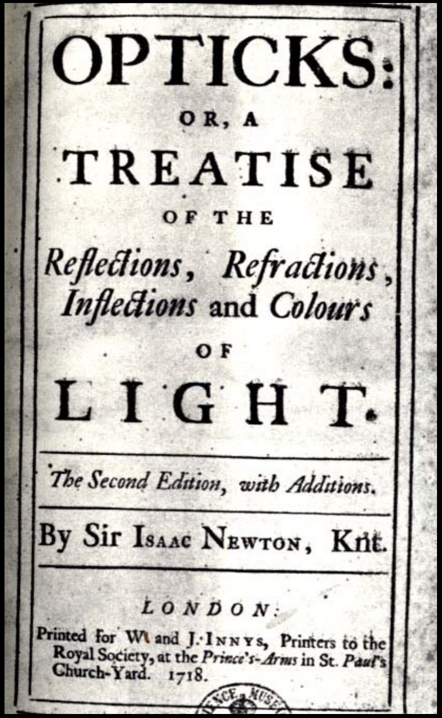
The NATURE of LIGHT: NEWTON vs HUYGHENS (PARTICLE THEORY vs WAVE THEORY)

Newton was interested in light from very early on in his career; the work that first brought him to the attention of the scientific community was his experimental investigation of colour, & his invention of the 'Newtonian' reflecting telescope (work done in 1666-68, and published in 1672). However this work provided no theory of how light worked, and Newton made attempts at this for many years. For various reasons he favoured a particle theory of light – the explanation of light propagation in straight lines, except at interfaces, was then easily understood. Still, the light particles were acted upon by an invisible aether.

Newton did not publish his theory until 1704, after the death of Huyghens; he was by then the best-known scientist in Europe.


OPTICKS: OR, A TREATISE OF THE Reflections, Refractions, Inflections and Colours OF LIGHT.

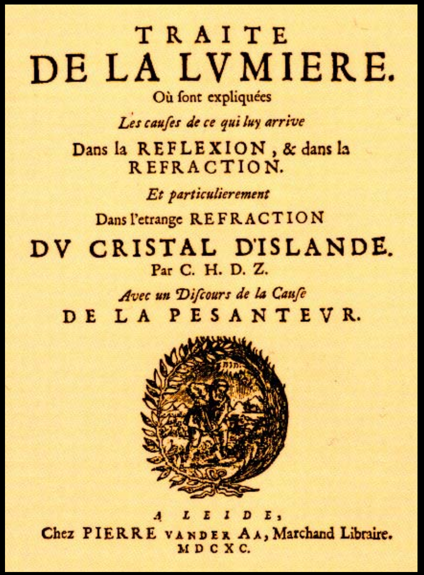
The Second Edition, with Additions.

By Sir Isaac Newton, Knt.

LONDON: Printed for W. and J. Innys, Printers to the Royal Society, at the Prince's-Arms in St. Paul's Church-Yard. 1718.

Isaac Newton, Opticks (1704)

C Huyghens made key contributions to mathematics, astronomy, & physics. However his most important contribution to science by far was his wave theory of light. He argued that the known properties of light, such as refraction, reflection, & propagation in straight lines, could be understood by assuming that light was a wave in some invisible medium, analogous to waves moving in a fluid. Refraction could be understood if the waves traveled more slowly in a dense medium (like waves in shallow water). He gave the first theory of wave propagation, showing, amongst other things how they could be built up from 'elementary wavelets', radiated in circular patterns from multiple sources.


TRAITE DE LA LVMIERE.

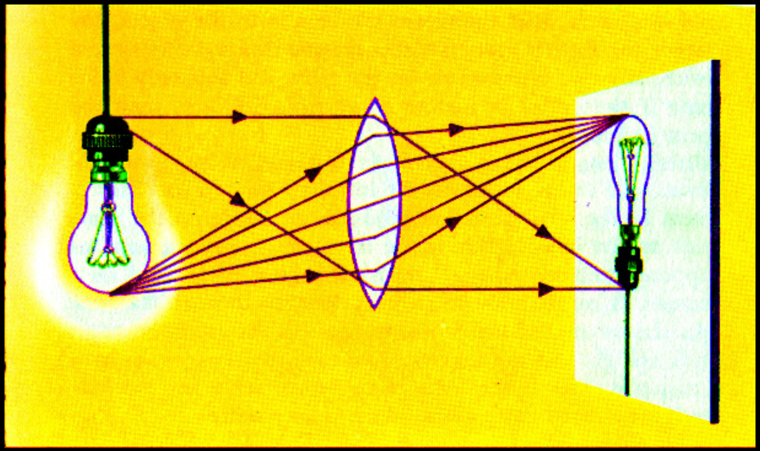
Où sont expliquées Les causes de ce qui luy arrive Dans la REFLEXION, & dans la REFRACTION. Et particulierement Dans l'etrange REFRACTION DV CRISTAL D'ISLANDE. Par C. H. D. Z.

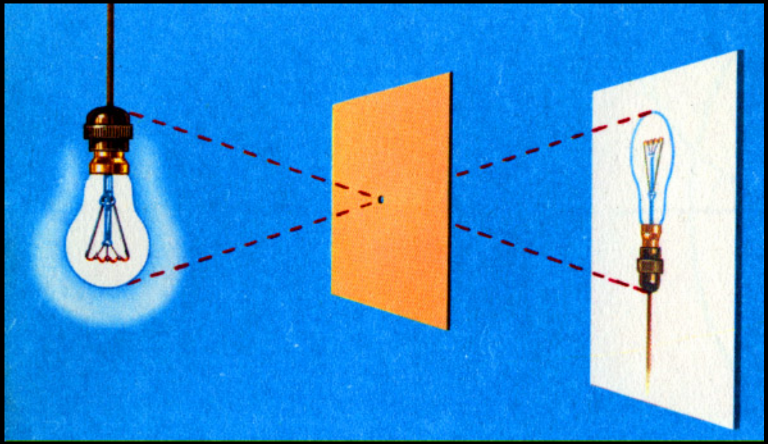
Avec un Discours de la Cause DE LA PESANTEVR.

A LEIDE, Chez PIERRE VANDER AA, Marchand Libraire. MDCXC.

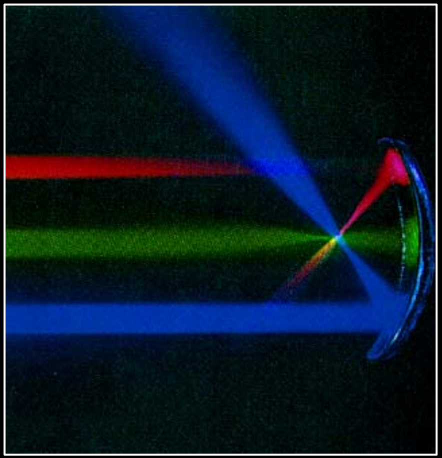
Christiaan Huyghens 'Traite de la Lumiere' (1690)

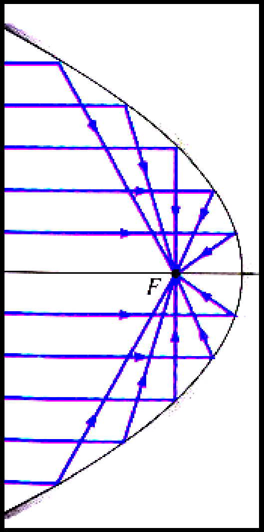
The CORPUSCULAR THEORY of LIGHT (Newton)





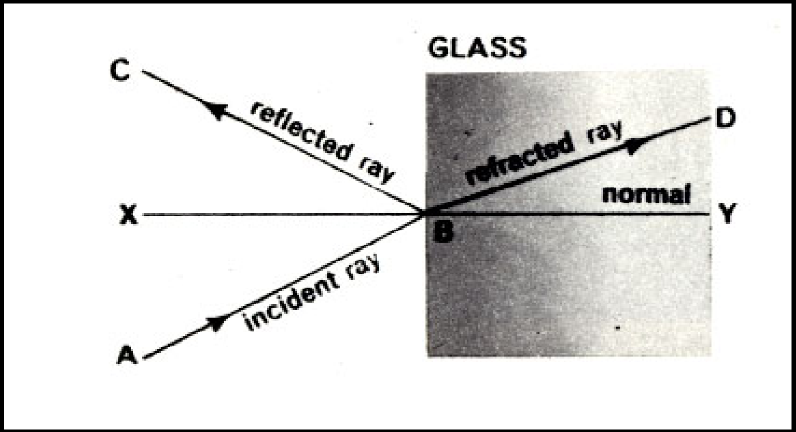
In common with most thinkers in his day, Newton thought that light was a motion of particles (light corpuscles) in straight lines. This made a lot of sense- it seemed to be in accord with Newton's 2nd law (refraction being explained by forces acting on boundaries between different different media), and explained image formation by lenses or pinholes. In the same way one could understand reflected light beams, mirrors, etc. The dependence of refraction on colour was explained by assuming the force acting at interfaces depends on colour.





In the top figure we see the formation of an image by a lens- the paths of different light rays from a given point of the light bulb all focus to the same point on the screen if (i) the lens has the right shape, and (ii) the screen is at the right distance. The pinhole (below) forms an image at any distance.

PROBLEMS with the PARTICLE THEORY of LIGHT

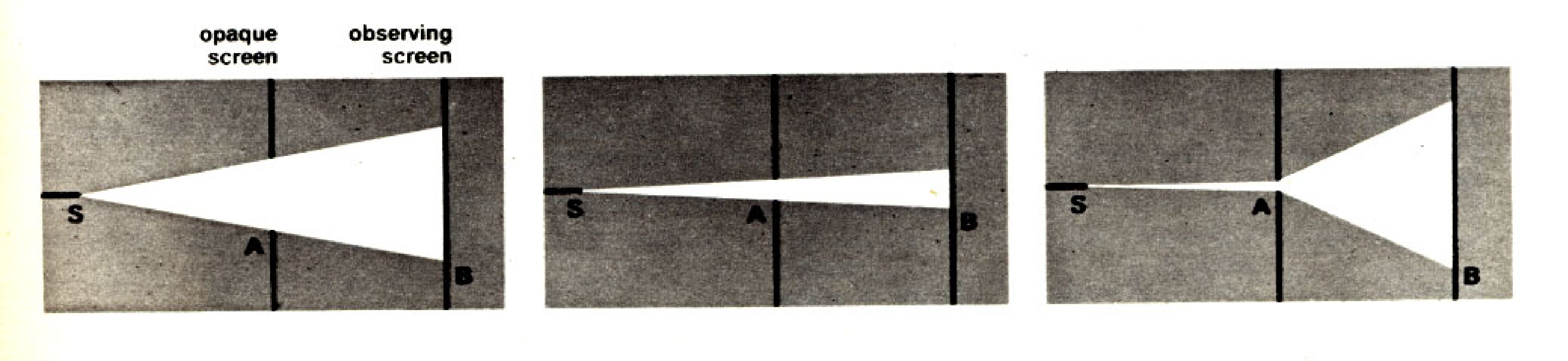


In spite of the virtues of the particle theory of light, careful thinkers like Huyghens realised that there were weaknesses that could not be dismissed. For example

(i) at an interface, one never has refraction OR reflection- both happen, with the relative intensities of the 2 components depending on the angle of incidence.

(ii) if one makes a pinhole very small, the image of the light going through begins to *widen*, instead of narrowing (see below).

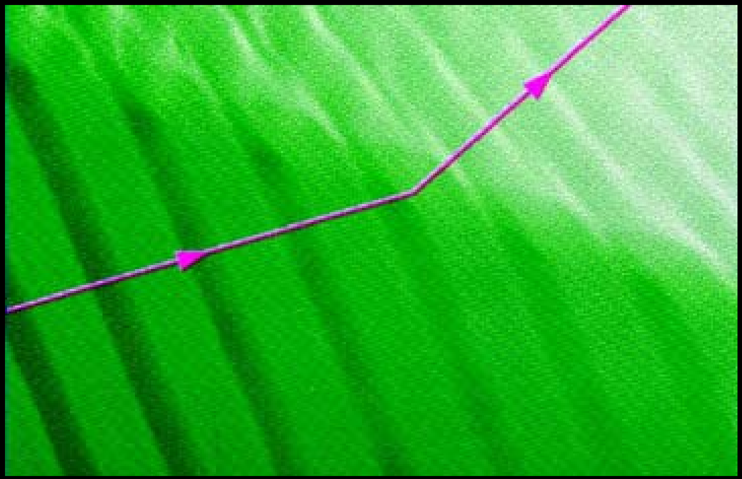
The problem of simultaneous reflection and refraction is very hard to answer in a corpuscular theory- Newton's attempts were not satisfactory.

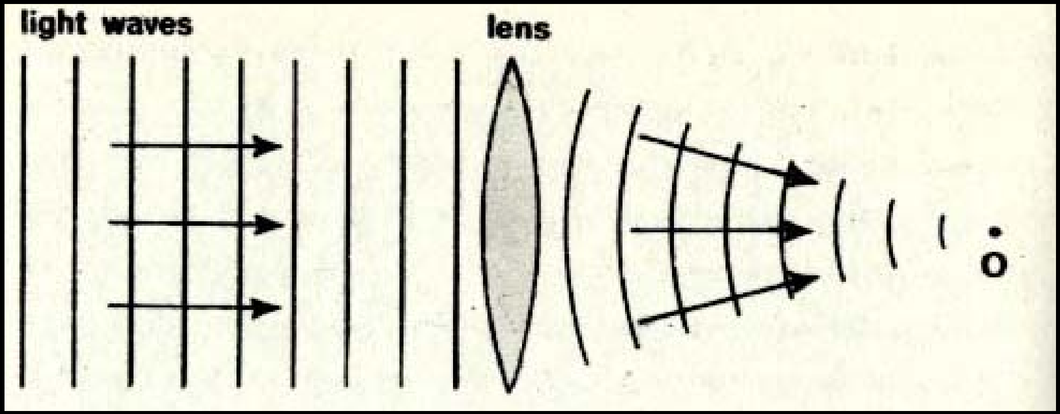


The WAVE THEORY of LIGHT (C Huyghens)

In work very far ahead of its time, C. Huyghens succeeded in explaining almost all of the properties of light propagation known at that time, assuming light was a wave traveling in an unknown medium. His theory, along with detailed analysis of any cases, was published in 1690, very shortly after Newton's 'Principia', as the "Traite de la Lumiere". The details of this are shown in the next 2 slides. By assuming that the waves traveled at different speeds in different media, reflection and refraction were easily explained.

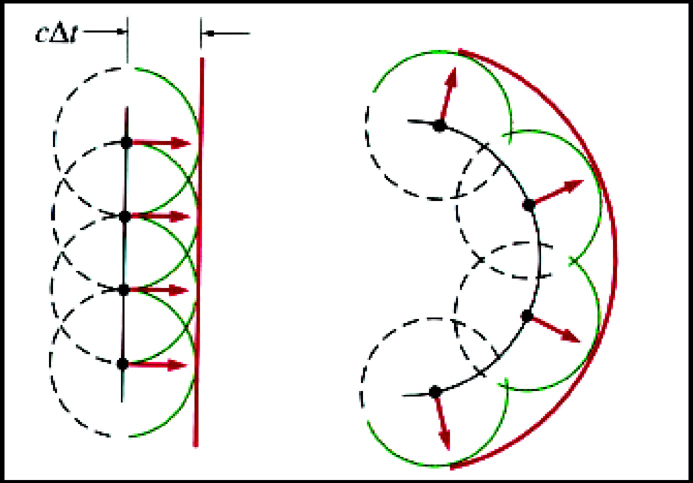
The way in which waves propagate across interfaces is easily seen by looking at surface waves on water (the speed depends on the water depth). Once this is understood, one can work out a theory of how waves propagate through, eg., lenses (the waves traveling more slowly in the glass) – the direction of propagation of a ray is perpendicular to the wave fronts. In a lens light passing via the centre is held up, and the light around the edges catches up to it, so they focus together.



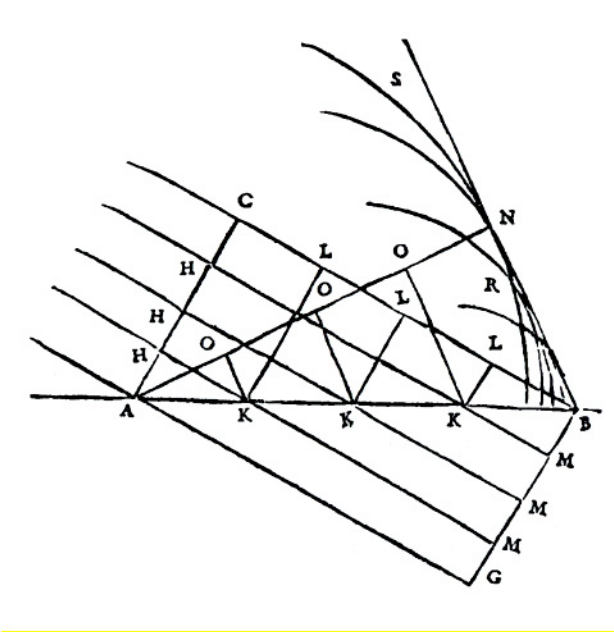


The WAVE THEORY of LIGHT
Wavelets, Reflection, & Refraction

The famous Hughens construction is shown at right. We imagine that at each point of a wave-front, another wavefront is emitted in all directions at equal velocity (unless it arrives in another medium where the velocity is different). In this way, by imagining the 're-emission' of wavefronts after successive short intervals of time, one can build up the dynamics of the wavefronts

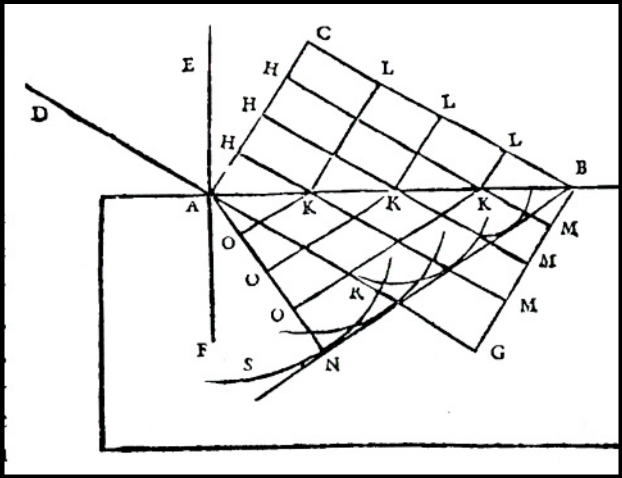


Reflection is easily understood as the radiation of the wave back into the medium – it is fairly obvious by symmetry that a wave incident at some angle on an interface must have lead to a wave moving out at the same angle to the interface.

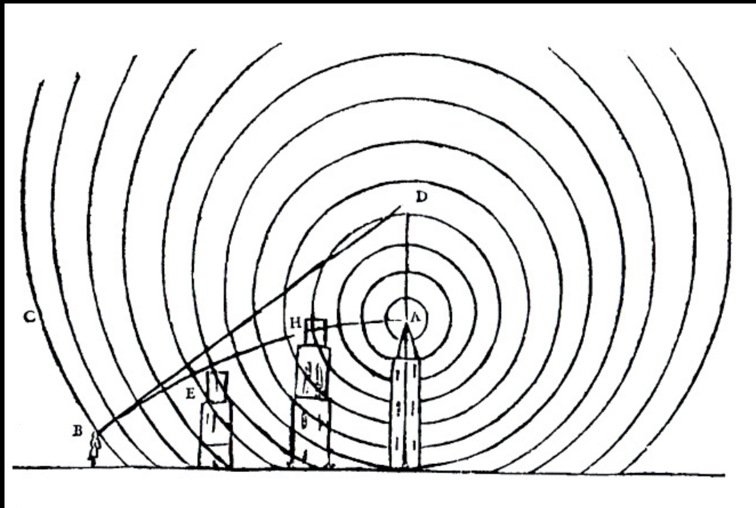


Reflection in the wavelet theory (from the 'Traite de la Lumiere')

Refraction is produced by imagining the same wavelets now radiating INTO the new medium, but at a different velocity. One can actually show how all this works by purely geometric constructions, without elaborate mathematics. Note that simultaneous reflection & refraction is INEVITABLE in this theory.

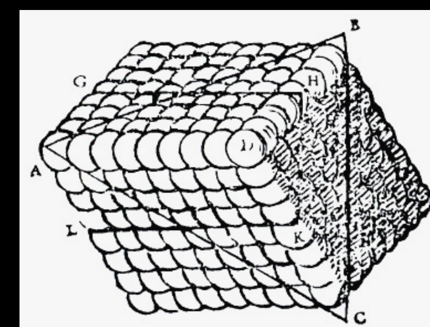


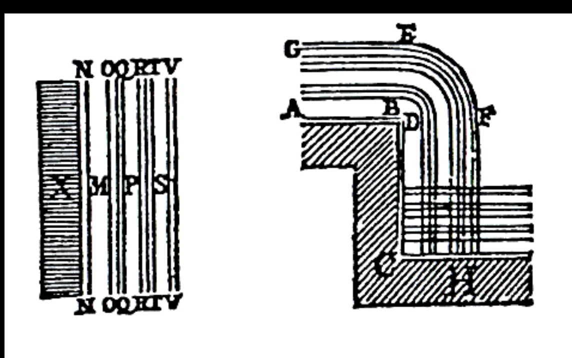
Refraction in the wavelet theory (from the 'Traite de la Lumiere')



Using the wave theory Huyghens could also explain more complex phenomena – eg., the way sound and light can be slowly refracted downwards, because air density decreases with height; or the flickering light from a multiple light source like a candle flame, where the sources themselves changed in intensity with time.

Huyghens also understood that the way to understand wave dynamics in a crystal was to suppose that the crystal was made up of a lattice of particles. He assumed that the medium (the 'aether') via which light was transmitted was made up of tiny spherical particles, through which compression waves could pass. In remarkable work he treated the refraction of light through 'iceland spar' (calcite) which splits a light beam into 2 beams – he was able to partly understand this in terms of wavelets (but not what caused it).





Franges de diffraction au bord de l'ombre d'un obstacle rectiligne

Franges de diffraction au bord de l'ombre d'un obstacle non rectiligne

Huyghens also realised that phenomena like diffraction (see left) had a natural explanation in terms of his waves.

Although neither Newton nor Huyghens realised it, they had uncovered 2 key aspects of one of the most crucial questions in physics – the fundamental nature of light. It would need another 250 years to resolve it.