Topic 23 — Diffraction

We are quite used to the idea that we cannot see round corners, although we can hear round corners. This is, in part at least, a result of the fact that the wavelengths of light and sound differ by many orders of magnitude - visible light having wavelengths of a few hundred nanometers, sound in the audible range from 10 to 20,000 Hz having wavelengths from 30 m to 17mm.

Diffraction is the study of the passage of waves through systems which alter or obscure part of the wavefront, and the extent to which the propagation differs from travel in straight lines.

L23.1 Huygens's principle *AF937*

The easiest approach to this is in terms of Huygens's principle[1], which offers an explanation of the way in which light (or any other wave) propagates as follows:

> Every point on a primary wavefront serves as the source of spherical secondary wavelets, such that the primary wavelet at a later time is the envelope of these secondary wavelets. The wavelets advance with a speed and frequency which are equal to those of the primary wave at every point in space.

We can see how this works out in the simple cases of a plane wave front and a circular wave front in figures L23.1 and L23.2 respectively

illustration using reflection and refraction

Figure L23.3 shows the Huygens construction for a wave being reflected and refracted at an interface. Note how the different wave speeds in the two media give rise to wavefronts expanding at different rates.

L23.2 The Huygens-Fresnel principle

But this cannot be quite the whole truth. In the first place, by only considering the *envelope* of the secondary wavelets, Huygens produces a primary

[1] Christiaan Huygens (1629-95) wrote his *Treatise on Light* in 1678, though it was not published until 1690. His explanations of light in terms of wave motion have a distinctly modern ring to them, although they are couched in terms of vibrations of a medium, the ether, which we would nowadays reject. At the end of his book Huygens gives a mathematical demonstration that Fermat's principle follows from the wavelet construction.

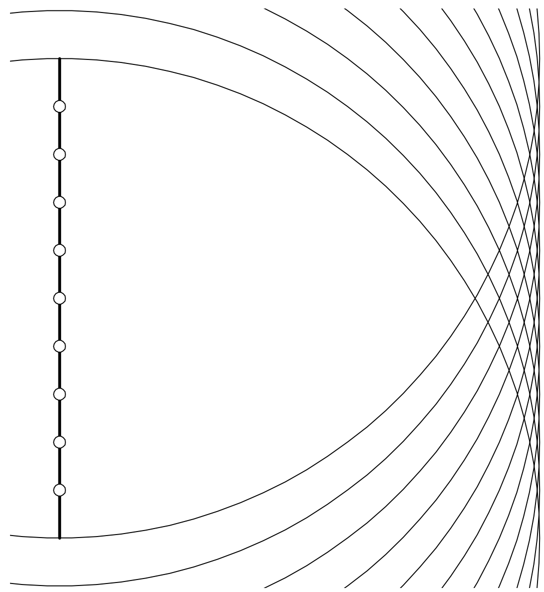

Figure L23.1: Huygens's principle applied to the propagation of a plane wave. The dots on the primary wave front represent the secondary sources, and the circular arcs are the secondary waves. The envelope is another plane wave.

wavefront that does not depend on the wavelength – we would get the same primary front if we shone light or sound past a large obstruction like a telegraph pole, yet the light would cast a clear shadow whereas the sound will be diffracted into the shadow zone. Figure L23.4 shows the corresponding case for waves passing through an aperture. This was fixed by Fresnel's modification[2] of Huygens's principle:

[2]Perhaps Augustin Jean Fresnel (1788-1827) had an even wider vision than Young. His 140-page essay of 1819 showed him to be both an outstanding experimentalist who could locate diffraction fringes to within 0.01 mm and a brilliant mathematician who could explain all his observations using wave theory. He used his mathematics to explain how Huygens's wavelets combine to form a wavelet: for this, of course, he had to consider interference effects more general than those of Young, abandoning the restriction to waves which "...coincide either perfectly or very nearly in Direction."

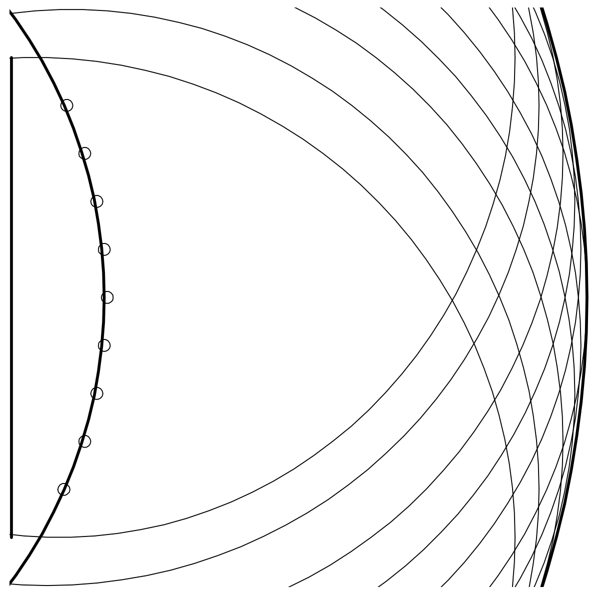

Figure L23.2: Huygens's principle applied to the propagation of a cylindrical wave. The dots on the primary wave front represent the secondary sources, and the circular arcs are the secondary waves. The envelope is another cylindrical wave, with larger radius of curvature.

Every point on the primary wavefront acts as a source of secondary spherical wavelets, with the same frequency and velocity as the primary wave. The amplitude of the field at any point is the superposition of all these wavelets, taking account of their amplitudes and phases

That introduces the possibility of interference, and therefore of patterns which depend on the wavelength.

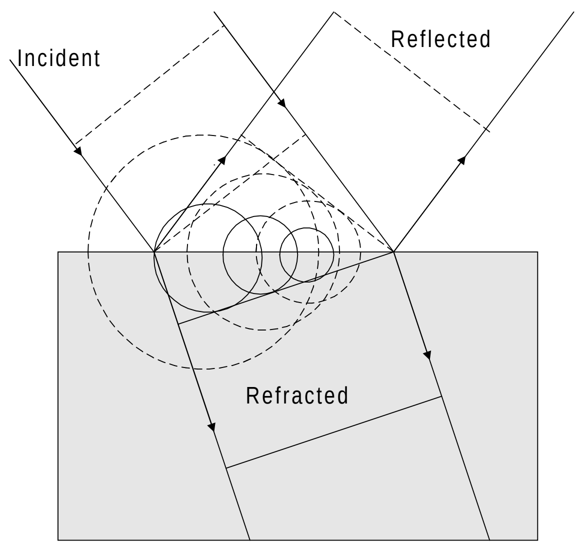

Figure L23.3: Huygens's principle applied to the reflection and refraction of a plane wave at an interface. The circles are drawn with different radii representing the different speeds in the two media and the different times at which the wave arrive at the interface.

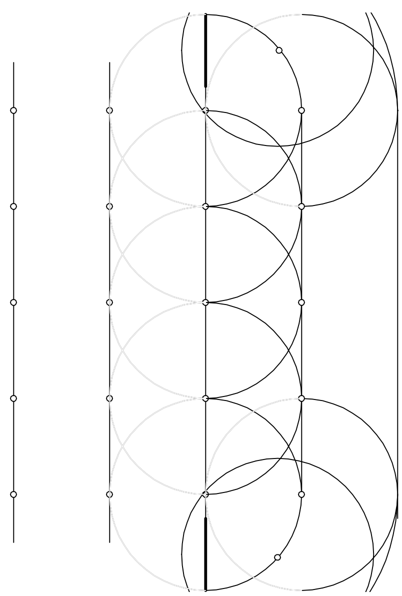

Figure L23.4: Huygens's principle applied to the passage of a plane wave through an aperture. The envelope function shows the wave spreading outwards from the aperture *in a way that is independent of the wavelength.*