2.2: Light Incident Normally at a Boundary

The result described by Equation (3) for the transmitted and reflected amplitudes is an inevitable consequence of the continuity of displacement and gradient of a wave at a boundary, and is not particularly restricted to waves in a rope. It should be equally applicable to electromagnetic waves moving from one medium to another at normal incidence, and indeed it is verified by measurement. Thus, as with the ropes, the amplitudes of the incident, transmitted and reflected waves are in the ratio

$$1 : \frac{2c_2}{c_2+c_1} : \frac{c_2-c_1}{c_2+c_1}. \tag{2.2.1}$$

One hopes that energy is conserved, so let's see. The energy stored per unit volume in an electric field in an isotropic medium is $\frac{1}{2}\epsilon E^2$. The rate of transmission of energy per unit area (i.e. the flux density) is this times the speed of propagation. But $\epsilon = \frac{1}{\mu_0 c^2}$.

(We suppose in the present context that both media are nonmagnetic, so both have permeability μ_0.) Thus we see that the rate of propagation of energy per unit area is proportional to the square of the amplitude and inversely proportional to the speed.

Thus the incident, transmitted and reflected powers are in the ratio

$$1 : \frac{4c_1c_2}{(c_1+c_2)^2} : \frac{(c_1-c_2)^2}{(c_1+c_2)^2}. \tag{2.2.2}$$

As with the two ropes, the sum of the transmitted and reflected flux densities is equal to the incident flux density, and, once again, all's well with the world.

It may at first glance be surprising that the rate of transmission of energy is *inversely* proportional to the speed. In the case of the ropes, the "slow" rope has a larger mass per unit length. In the case of the electromagnetic field, the "slow" medium has a larger permittivity, so the electric field is having to work the harder.

The speed of light in a medium is inversely proportional to the refractive index, so the amplitude ratios can be expressed as

$$1 : \frac{2n_1}{n_1+n_2} : \frac{n_1-n_2}{n_1+n_2}. \tag{2.2.3}$$

We see that there is a phase change on reflection from an optically denser medium.

The flux density ratios can be written as

$$1 : \frac{4n_1n_2}{(n_2+n_1)^2} : \frac{(n_2-n_1)^2}{(n_2+n_1)^2}. \tag{2.2.4}$$

If light is going from air $(n_1 = 1)$ to glass $(n_2 = 1.5)$, the transmitted amplitude will be 80 percent of the incident amplitude, and the reflected amplitude will be 20 percent of the incident amplitude. The transmitted flux density will be 96 percent of the incident flux density, and the reflected flux density will be 4 percent of the incident flux density.

If $n_2 = n_1$ there will be no reflection at the boundary; in effect there is no boundary. The larva of the midge *Chaoborus*, known as the Phantom Midge, is an aquatic creature whose body has a refractive index equal to the refractive index of water. The picture below shows a photograph of one of them in the water:

Larva of the Phantom Midge, Chaoborus sp. (If you don't believe me, look it up on the Web.)

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