6.10.3 Reflections from Curved Reflectors

Ray tracing is the traditional solution for producing reflections. See Section 6.13.2 for details. A reflection ray starts from the viewed location and picks up and adds in the color in the reflection direction. Ofek and Rappoport [593] present a technique for sharp, true reflections from convex and concave reflectors that can be considerably faster. Their observation is that in a convex reflector (e.g., a sphere), the reflected object is distorted by the surface, but otherwise unchanged. That is, each reflected vertex is reflected by only one point on the reflector (unlike what can happen with a concave reflector). The curved reflector can be treated like a window into a mirror world, in a similar manner to the planar reflector. The full description of this method is fairly involved, and the interested reader should see the original paper [593].

6.11 Refractions

There are a few physical effects that come into play in simulating refraction. One has already been described, the Fresnel term. For transparent objects, this term is essentially a blend factor of reflection and refraction. That is, if the Fresnel term is, say, 0.7, then reflected light is attenuated to 70% and refracted light coming through the surface to 30%. Plate XXXV (following page 562) shows this effect; objects underwater are visible when looking directly into the water, but looking at a grazing angle mostly hides what is beneath the waves.

Another important factor is Snell's Law, which states the relationship between the incoming and outgoing vectors when moving from one medium (such as air) to another (such as water):

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \tag{6.25}$$

where n_i is the index of refraction of each medium and θ_i the angle compared to the surface normal. See Figure 6.33. Water has an index of refraction of 1.33, glass typically around 1.5, and air essentially 1.0. When travelling from a higher index of refraction to a lower one (e.g., looking out from under water to the sky), total internal reflection will start to occur at some critical angle. At this angle, all light is reflected and none refracted through the surface.

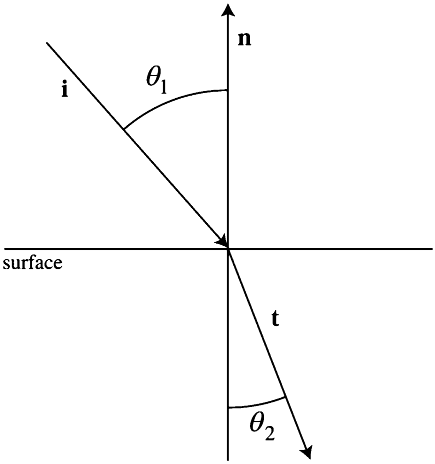

Figure 6.33. Snell's Law. Light travelling from one medium to another refracts depending on each medium's index of refraction. The angle of incidence for the incoming ray is greater than or equal to the angle of refraction when travelling from a lower to higher index of refraction.

Defining $\mathbf{i}$ as the incoming vector and $\mathbf{n}$ as the surface normal, both normalized, an efficient method of computing the refraction vector from Bec [53] is:

$$\mathbf{t} = r\mathbf{i} + (w - k)\mathbf{n} \tag{6.26}$$

where $\mathbf{t}$ is the resulting normalized refraction vector, $r = n_1/n_2$ is the relative index of refraction, and:

$$\begin{aligned} w &= -(\mathbf{i} \cdot \mathbf{n})r, \\ k &= \sqrt{1 + (w - r)(w + r)}. \end{aligned} \tag{6.27}$$

This evaluation can be expensive. Oliveira [597] notes that because the contribution of refraction drops off near the horizon, an approximation for small incoming angles is:

$$\mathbf{t} = -c\mathbf{n} + \mathbf{i} \tag{6.28}$$

where c is somewhere around 1.0 for simulating water. Note that the resulting vector $\mathbf{t}$ needs to be normalized when using this formula.

The techniques for simulating refraction are somewhat comparable to those of reflection. However, for refraction through a planar surface, it is