

Reflection and refraction

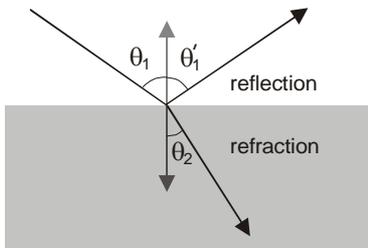
When light hits a surface, one or more of three things may happen. The light may be *reflected* back from the surface, transmitted through the material (in which case it will deviate from its initial direction, a process known as *refraction*) or *absorbed* by the material if it is not transparent at the wavelength of the incident light.

1. Reflection and refraction

Reflection and refraction are governed by two very simple laws. We consider a light wave travelling through medium 1 and striking medium 2. We define the angle of incidence θ as the angle between the incident ray and the normal to the surface (a vector pointing out perpendicular to the surface).

For reflection, the reflected ray lies in the plane of incidence, and $\theta_1' = \theta_1$

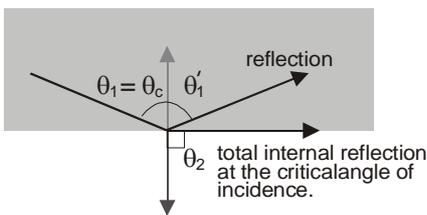
For refraction, the refracted ray lies in the plane of incidence, and $n_1 \sin \theta_1 = n_2 \sin \theta_2$ (this expression is called Snell's law).



In the above equations, n_i is a dimensionless constant known as the *index of refraction* or *refractive index* of medium i . In addition to determining the angle of refraction, n also determines the speed of the light wave in the medium, $v = c/n$. Just as θ_1 is the angle between the incident ray and the surface normal *outside* the medium, θ_2 is the angle between the transmitted ray and the surface normal *inside* the medium (i.e. pointing out from the other side of the surface to the original surface normal)

2. Total internal reflection

A consequence of Snell's law is a phenomenon known as *total internal reflection*. If the ratio of refractive indices n_2/n_1 is less than unity, there will be some 'critical' angle of incidence above which the angle of refraction is always greater than 90 degrees. Remembering that the angle of refraction is measured from the surface normal, when this is true, none of the incident light is transmitted and all of it is reflected. For obvious reasons this is known as total internal reflection.



Mathematically, we can find the critical angle θ_c by setting θ_2 equal to 90 degrees in Snell's law and rearranging. When $\theta_2 = 90^\circ$, $\sin \theta_2 = 1$, and we have

$$\theta_c = \sin^{-1}(n_2/n_1)$$

Note that there is no critical angle when $n_2 > n_1$ since $\sin \theta$ cannot be greater than 1. This means, for example, that total internal reflection can occur when light travelling through water or glass strikes air, but not the other way around.

Total internal reflection is different from ordinary reflection in that it really is 'total'; there are no losses and the totally internally reflected light has the same intensity as the incident light. Ordinary reflection from even a mirrored surface involves a loss of a few percent of the intensity, usually due to absorption by the material from which the mirror is made. Fibreoptic cables rely on the principle of

total internal reflection at the glass/air interface to transmit light over long distances with almost zero losses.

3. Polarisation by reflection

Unpolarised light can be partially or totally polarised by reflection from a surface (this is one reason why Polaroid sunglasses often vastly reduce the glare from sunlight reflecting off water and other shiny surfaces). Each wavetrain in a beam can be written as a linear combination of a parallel component (lying in the plane of incidence defined by the propagation direction of the light and the surface normal) and a perpendicular component (lying perpendicular to the plane of incidence and parallel to the surface). It is found experimentally that there is a particular angle of incidence (known as the Brewster angle) for which the reflection for the parallel component is zero. This means that when unpolarised light is incident at the Brewster angle, the reflected beam is completely polarised parallel to the surface (perpendicular to the plane of incidence). Since the parallel component is not reflected, it must be completely transmitted. This is the opposite of total internal reflection; instead of having lossless reflection, we have lossless transmission for light of the appropriate polarisation.

We can find the Brewster angle for a given interface by using the fact that experimentally it is found that at the Brewster angle of incidence, the reflected and refracted beams are at right angles to each other. This means that $\theta_B + \theta_r = 90^\circ$, where θ_B is the Brewster angle (equal to the angle of reflection) and θ_r is the angle of refraction. Combining this with Snell's law, $n_1 \sin \theta_B = n_2 \sin \theta_r$, gives

$$n_1 \sin \theta_B = n_2 \sin(90^\circ - \theta_B) = n_2 \cos \theta_B \quad \Rightarrow \quad \theta_B = \tan^{-1}(n_2/n_1)$$

This expression is known as Brewster's law, and was determined empirically by Sir David Brewster in 1812.