Reflection, Absorption and Transmission

When electromagnetic radiation encounters a layer of material, part of the incident radiant quantity is reflected, transmitted and absorbed. Since energy is conserved,

\[ Q_i = Q_r + Q_t + Q_a \]

Reflectance \( \rho = \frac{Q_r}{Q_i} \); Transmittance \( \tau = \frac{Q_t}{Q_i} \); Absorptance \( \alpha = \frac{Q_a}{Q_i} \).

Hence, we have

\[ \rho + \tau + \alpha = 1 \]

Note that in the above equations, the radiant quantity \( Q \) can be any one of the quantities previously defined (such as irradiance, or radiance).

Specular and Diffused reflection
Surface roughness is a relative quantity, depending on the wavelength of the incident light. According to the Rayleigh criterion, a surface is considered smooth if
\[ h \leq \frac{\lambda}{8\cos\theta_i} \]
where \( h \) is the variation in the surface height, and \( \lambda \) is the wavelength.

**Bidirectional Reflectance**

The bidirectional reflectance of a surface is defined as the ratio of the radiance leaving the surface along a given outgoing direction \((\theta_o, \phi_o)\) to the irradiance of the surface illuminated by a parallel beam along an incidence direction \((\theta_i, \phi_i)\).

If the surface is illuminated by an incident radianc field \(L(\theta, \phi)\), the outgoing radiance field can be calculated by,
\[
L(\theta_o, \phi_o) = \int_0^{\pi/2} \int_0^{\pi} R(\theta_o, \phi_o; \pi - \theta, \phi - \pi) L(\theta, \phi) \cos \theta |\sin \theta| d\theta d\phi
\]
Now, consider again the parallel beam incidence on the surface, the incidence radiance is
\[
L = F \delta (\cos \theta + \cos \theta_i) \delta (\phi - \phi_i) = F \delta (u + u_i) \delta (\phi - \phi_i)
\]
Hence, we get
\[
L(\theta_o, \phi_o) = F \int_0^{\pi/2} \int_0^{\pi} R(\theta_o, \phi_o; \pi - \theta, \phi - \pi) \delta (\cos \theta + \cos \theta_i) \delta (\phi - \phi_i) |\cos \theta| |\sin \theta| d\theta d\phi
\]
\[
= R(\theta_o, \phi_o; \theta_i, \phi_i) F \cos \theta_i
\]
The principle of reciprocity requires that:
\[
R(\theta_2, \phi_2; \theta_1, \phi_1) = R(\theta_1, \phi_1; \theta_2, \phi_2)
\]
Hemispherical Reflectance (Albedo)

The hemispherical reflectance (also known as the albedo) of a surface is defined as the ratio of the exitance leaving a surface to the irradiance incidence onto the surface.

$$\rho = \frac{E_o}{E_i} \text{ [dimensionless]}$$

Lambertian Surface

A Lambertian surface is one where the radiance exiting from the surface is isotropic (constant in all direction), i.e. the bidirectional reflectance is a constant. The exitance is related to the radiance by

$$E_o = \pi L_o$$

Hence, the value of the constant bidirectional reflectance is related to the albedo by

$$R = \rho / \pi$$

If the irradiance of a Lambertian surface is $E_i$, the reflected radiance is

$$L_o = \frac{\rho E_i}{\pi}$$

Variation of reflectance with wavelength: Spectral Signature

For any given material, the amount of incident radiation that is reflected, absorbed, or transmitted varies with wavelength. This important property of matter makes it possible to identify different substances or classes of substances. The different substances can be identified by their spectral signatures (spectral curves).