wavelengths. That is to say, we specify a single average absorptivity that is taken to be representative of the entire band. This is known as the *graybody* approximation.

For example, if the total incident flux of radiation between two widely separated wavelengths is denoted Φ_i, and the reflected flux within the same range of wavelengths is Φ_r, then the effective graybody reflectivity is defined as

$$\boxed{\bar{r} \equiv \frac{\Phi_r}{\Phi_i}\,,} \tag{5.4}$$

and the corresponding graybody absorptivity is $\bar{a} = 1 - \bar{r}$.

A word of caution: $\bar{r}$ and $\bar{a}$ do, in general, depend on the spectral details of the incident radiation, so it usually makes sense to use the graybody approximation only when those details are reasonably constant. For example, the spectrum of solar radiation reaching the surface does not change drastically from one day to the next, so it is reasonable to use the graybody approximation to describe the reflection and absorption of the incident solar flux.

A common application of the graybody approximation is to assign one constant absorptivity a_{sw} to the entire shortwave, or solar, band, and another constant absorptivity a_{lw} to the longwave, or thermal IR, band. For most terrestrial surfaces, a_{lw} is close to unity, whereas a_{sw} can be highly variable, from close to zero in the case of deep snow to close to unity in the case of forests and bodies of water.

The complement of the shortwave absorptivity a_{sw} is of course the shortwave reflectivity $r_{sw} = 1 - a_{sw}$, also commonly known as the shortwave *albedo*. Examples of albedos for common surfaces are given in Table 5.1.

The value of this kind of partitioning between longwave and shortwave absorptivities and reflectivites will become more apparent when we consider simple radiative energy budgets for the surface and atmosphere later on.

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Table 5.1: Shortwave (solar) reflectivity (in percent) of various surfaces.

Fresh, dry snow	70–90
Old, melting snow	35–65
Sand, desert	25–40
Dry vegetation	20–30
Deciduous Forest	15–25
Grass	15–25
Ocean surface (low sun)	10–70
Bare soil	10–25
Coniferous Forest	10–15
Ocean surface (high sun)	<10

5.3 Angular Distribution of Reflected Radiation

Early in this chapter (Section 5.2), I introduced the concept of *reflectivity*, which describes the fraction of incident radiation that is reflected from a surface. Among other things, I pointed out that the reflectivity and absorptivity of an opaque surface must sum to unity; that is, all incident radiation must be either reflected or absorbed:

$$a_\lambda + r_\lambda = 1\ . \tag{5.5}$$

This seems straightforward enough, and you might assume that there's little more to be said. But we have not yet explained *what happens* to the radiation that is reflected from a surface. That is to say, given r_λ, we know how *much* radiation is reflected, but we don't yet know where it goes.

5.3.1 Specular and Lambertian Reflection

In Chapter 4 we discussed reflection from a very smooth boundary between two homogeneous media. In this special case, which is called *specular reflection*, the reflected angle Θ_r (relative to the local normal) is just equal to the incident angle Θ_i. Furthermore, the reflectivity is then given by the Fresnel relationships (4.16) and (4.17).

Surfaces encountered in nature are not so simple. About the only place where you sometimes find true specular reflection on the scales important to us is from the mirror-like surface of a very

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smooth body of water, such as a pond or lake on a completely calm day. Under those conditions, the reflection of the sun and other objects is very sharp and clear.

More commonly however, the surface of open bodies of water are at least somewhat roughened by ripples or waves generated by the wind, so that light from the sun is not reflected in a single direction but rather is scattered in a variety of different directions, depending on the local slope where each light ray from the sun encounters the surface. For a lightly roughened water surface, most of the radiation is scattered in a fairly narrow cone of angles surrounding the specular direction. Thus, the reflection of the sun is still identifiable to the eye (or a radiometer) as a relatively concentrated bright spot, but it appears blurred in comparison to the sun itself. The rougher the surface, the greater the blurring, until the reflected radiation is scattered almost uniformly in all directions, irrespective of the direction of incidence.

Apart from bodies of water, the vast majority of surfaces encountered outdoors, as viewed from a significant altitude, are very rough. A forest or a corn field observed from an airplane tends to look more or less uniformly bright when illuminated by the sun, regardless of which direction you are looking. At least, there is no pronounced "hot spot" in the direction where you would expect the specular reflection of the sun to be.

As a crude approximation, one often assumes the flux of upward reflected radiation is equally distributed over all angles, irrespective of the direction of the source. Reflection obeying this rule is called *Lambertian* . Lambertian reflection is thus the exact opposite of specular reflection, since in the latter case all reflected radiation emerges in a single well-defined direction.

Problem 5.1: Wall paint is sold in several varieties, including *glossy*, *semigloss*, and *flat*. The distinction between these lies in the angular pattern of reflected radiation. Which of these do you think would be best described by the Lambertian model of reflection?

For any kind of reflection, the upward reflected flux F_r is equal