2 Physical Principles

2.1 The Nature of EM Radiation

As discussed in Chap. 1, in remote sensing, the electromagnetic (EM) radiation serves as the communication link between the sensor and the object. Fraser and Curran (1976), Silva (1978) and Suits (1983), provide valuable reviews on the nature of EM radiation and physical principles. The properties of EM radiation can be classified into two main groups: (1) those showing a wave nature and (2) those showing particle characteristics.

Maxwell gave a set of four differential equations, which forms the basis of the electromagnetic wave theory. It considers EM energy as propagating in harmonic sinusoidal wave motion (Fig. 2.1), consisting of inseparable oscillating electric and magnetic fields that are always perpendicular to each other and to the direction of propagation. The wave characteristics of EM radiation are exhibited in space and during interaction with matter on a macroscopic scale. From basic physics, we have

$$C = \nu\lambda \tag{2.1}$$

where c is the speed of light, ν is the frequency and λ is the wavelength. All EM radiation travels with the same speed in a particular medium. The speed varies from one medium to another, the variation being caused due to the change in wavelength of the radiation from medium to medium. The speed of EM radiation in a vacuum is 299,793 km s^{-1} (approx. 3×10^8 m s^{-1}). The frequency (ν), given in hertz (cycles per second), is an inherent property of the radiation that does not change with the medium. The wavelength (λ) is given in µm (10^{-6} m) or nm (10^{-9} m).

The particle or quantum nature of the EM radiation, first logically explained by Max Planck, postulates that the EM radiation is composed of numerous tiny indivisible discrete packets of energy called photons or quanta. The energy of a photon can be written as:

$$E = h\nu = \frac{h \cdot c}{\lambda} \tag{2.2}$$

where E is the energy of a photon (Joules), h is a constant, called Planck's constant (6.62×10^{-34} J s) and ν is the frequency. This means that the photons of shorter wavelength (or higher frequency) radiation carry greater energy than those of larger wavelength (or lower frequency). EM radiation exhibits quantum characteristics when it interacts with matter on an atomic—molecular scale and these characteristics explain strikingly well the phenomena of black-body radiation, selective absorption and photoelectric effect.

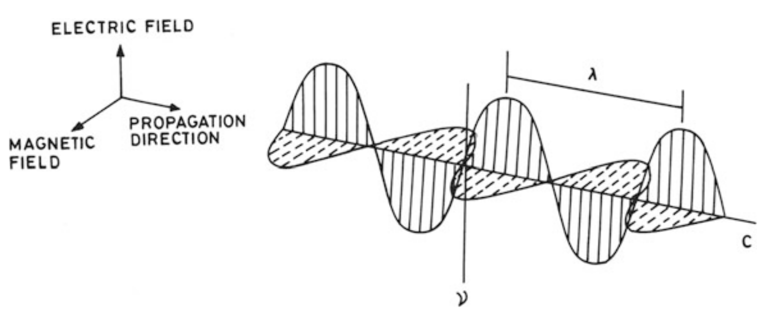

Fig. 2.1 Electromagnetic wave—the electric and magnetic components are perpendicular to each other and to the direction of wave propagation; λ = wavelength, c = velocity of light and ν = frequency

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2.2 Radiation Principles and Sources

2.2.1 Radiation Terminology

Several terms are used while discussing EM radiation. *Radiant energy* is given in joules. *Radiant flux* or power is the radiant energy per second and is given in watts. *Irradiance* implies the amount of radiant energy that is incident on a horizontal surface of unit area per unit time. It is called *spectral irradiance* when considered at a specific wavelength. *Radiance* describes the radiation field as dependent on the angle of view. If we consider the radiation passing through only a small solid angle of view, then the irradiance passing through the small solid angle and incident on the surface is called radiance for the corresponding solid angle.

2.2.2 Blackbody Radiation Principles

Blackbody radiation was studied in depth in the 19th century and is now a well-known physical principle. All matter at temperatures above absolute zero (0 K or −273.1 °C) emits EM radiation continuously. The intensity and spectral composition of the emitted radiation depend upon the composition and temperature of the body. A blackbody is an ideal body and is defined as one that absorbs all radiation incident on it, without any reflection. It has a continuous spectral emission curve, in contrast to natural bodies that emit only at discrete spectral bands, depending upon the composition of the body.

Temperature has a great influence on the intensity of blackbody emitted radiation (Fig. 2.2). Experimentally, it was found initially that the wavelength at which most of the radiation is emitted depends on the temperature of the blackbody. The relationship, called Wien's Displacement Law, is expressed as

$$\lambda_{max} = \frac{A}{T}, \tag{2.3}$$

where λ_{max} is the wavelength (cm) at which peak of the radiation occurs, A is a constant (=0.29 cm K) and T is the temperature (K) of the object. This relationship is found to be valid for shorter wavelengths, and gives the shift in λ_{max} with temperature of the radiating object. Using this law, we can estimate the temperature of objects by measuring the wavelength at which peak radiation occurs. For example, for the Sun, λ_{max} occurs at 0.48 μm, which gives the temperature of the Sun as 6000 K (approx.); similarly for the Earth, the ambient temperature is 300 K and λ_{max} occurs at 9.7 μm (Fig. 2.2).

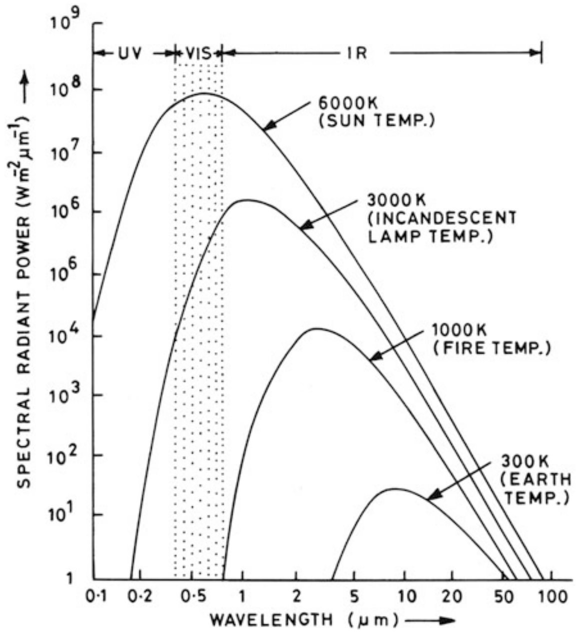

Fig. 2.2 Spectral distribution of energy radiated from blackbodies of various temperatures such as that of the Sun, incandescent lamp, fire and Earth. The spectral radiant power w_λ is the energy emitted ($m^{-2}\ \lambda^{-1}\ s^{-1}$). Total energy radiated, W, is given by the area under the respective curves

Another important relationship is the Stefan−Boltzmann Law that gives the total radiation emitted by a blackbody over the entire EM range:

$$W = \int_0^\infty w_\lambda d\lambda = \sigma T^4 \text{watts m}^{-2}, \tag{2.4}$$

where w_λ is the spectral radiance, i.e. the energy radiated per unit wavelength per second per unit area of the blackbody, T is the temperature (K) of the blackbody and σ is the Stefan −Boltzmann constant. It implies that the total energy emitted is a function of the fourth power of temperature of the blackbody. This relation applies to all wavelengths of the spectrum shorter than microwaves.

Another empirical law is the Rayleigh−Jeans Law, valid for longer wavelengths (such as microwaves), and is written as:

$$w \cong \frac{2\pi ck}{\lambda^4} \cdot T, \tag{2.5}$$

where k is called Boltzmann's constant. This implies that spectral radiance is directly proportional to temperature.

Max Planck, using his quantum theory, developed a radiation law to inter-relate spectral radiance (w_λ in watts) and wavelength (λ in m) of the emitted radiation to the temperature (T in K) of the blackbody:

$$w_\lambda = \frac{2\pi hc^2}{\lambda^5}\left(\frac{1}{\pi\left(e^{\frac{hc}{\lambda KT}}-1\right)}\right) \tag{2.6}$$

where h is Planck's constant (=6.62 × 10^{-34} J s), c is the speed of light in m s^{-1} and k is Boltzmann's constant (1.38 × 10^{-23} J deg^{-1}).

Planck's Law was able to explain all the empirical relations observed earlier. Integrating Planck's radiation equation over the entire EM spectrum, we can derive the Stefan−Boltzmann Law. Wien's Displacement Law is found to be a corollary of Planck's radiation equation when λ is small. The Rayleigh−Jean's Law is also found to be an approximation of Planck's radiation equation when λ is large.

As mentioned earlier, a blackbody is one which absorbs all radiation incident on it, without any reflection. It is observed that the fraction of the radiation absorbed exactly equals the fraction that is emitted by the body. Good absorbers are good emitters of radiation. This was stated by Kirchoff, in what is now called Kirchoff's Law

$$a_\lambda = \varepsilon_\lambda, \tag{2.7}$$

where a_λ is the spectral absorptivity and ε_λ is the spectral emissivity. Both a_λ and ε_λ are dimensionless and less than 1 for natural bodies. A blackbody has

$$a_\lambda = \varepsilon_\lambda = 1, \tag{2.8}$$

A blackbody radiates a continuous spectrum. It is an idealization, and since $a_\lambda = \varepsilon_\lambda = 1$, radiation is emitted at all possible wavelengths (Fig. 2.2). Real materials do not behave as a blackbody. A natural body radiates at only selected wavelengths as permitted by the atomic (shell) configuration. Therefore, the spectrum of a natural body is discontinuous, as typically happens in the case of gases. However, if the solid consists of a variety of densely packed atoms (e.g. as in the case of the Sun and the Earth as whole bodies), the various wavelengths overlap, and the resulting spectrum has *in toto* a near-continuous appearance.

The emitting ability of a real material compared to that of the blackbody is referred to as the material's emissivity (ε). It varies with wavelength and geometric configuration of the surface and has a value ranging between 0 and 1:

$$0 \le \varepsilon_\lambda \le 1, \tag{2.9}$$

A graybody has an emissivity less than 1, but constant at all wavelengths. Natural materials are also not graybodies.

To account for non-blackbodiness of the natural materials, the relevant parts of the various equations described above are multiplied by the factor of spectral emissivity, i.e.

$$(w_\lambda)_{object} = (\varepsilon_\lambda)_{object} \cdot (w_\lambda)_{blackbody} \tag{2.10}$$

$$(W)_{object} = \int_0^\infty (\varepsilon_\lambda)_{object} \cdot (w_\lambda)_{blackbody} \cdot d\lambda \tag{2.11}$$

$$(W)_{object} = (\varepsilon_\lambda)_{object} \cdot \sigma \cdot T^4 \tag{2.12}$$

$$(w_\lambda)_{object} = (\varepsilon_\lambda)_{object} \cdot \frac{2\pi hc^2}{\lambda^5}\left(\frac{1}{\pi\left(e^{\frac{hc}{\lambda KT}}-1\right)}\right) \tag{2.13}$$

2.2.3 Electromagnetic Spectrum

The electromagnetic spectrum is the ordering of EM radiation according to wavelength, or in other words, frequency or energy. The EM spectrum is most commonly presented between cosmic rays and radiowaves, the intervening parts being gamma rays, X-rays, ultra-violet, visible, infrared and microwave (Fig. 2.3). The EM spectrum from 0.02 μm to

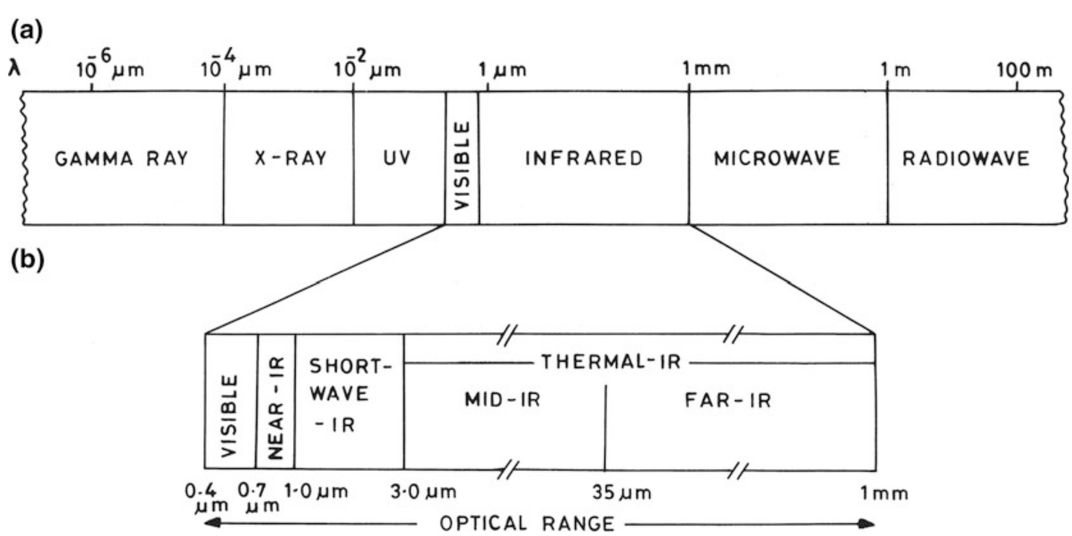

Fig. 2.3 **a** Electromagnetic spectrum between 10^{-8} μm and 10^2 m. **b** Terminology used in the 0.4 μm–1 mm part of the spectrum in this work, involving VIS, NIR, SWIR, MIR and FIR

1 m wavelength can be divided into two main parts, the optical range and the microwave range. The optical range refers to that part of the EM spectrum in which optical phenomena of reflection and refraction can be used to focus the radiation. It extends from X-rays (0.02-μm wavelength) through visible and includes far-infrared (>1 mm wavelength). The microwave range is from 1 mm to 1 m wavelength.

For terrestrial remote sensing purposes, as treated later, the most important spectral regions are 0.4–14 μm (lying in the optical range) and 2 mm–0.8 m (lying in the microwave range). There is a lack of unanimity amount scientists with regard to the nomenclature of some of the parts of the EM spectrum. For example, the wavelength at 1.5 μm is considered as near-IR (Fraser and Curran 1976; Hunt 1980), middle-IR (Silva 1978), and short-wave-IR (Goetz et al. 1983). The nomenclature followed throughout the present work is shown in Fig. 2.3b.

2.2.4 Energy Available for Sensing

Most commonly, in remote sensing, we measure the intensity of naturally available radiation—such sensing is called *passive sensing*, sensors being accordingly called *passive sensors*. The Sun, due to its high temperature (≈6000 K), is the most dominant source of EM energy. The radiation emitted by the Sun is incident on the Earth and is back scattered. Assuming an average value of diffuse reflectance of 10%, the spectral radiance due to solar reflection is as shown in Fig. 2.4a. Additionally, the Earth itself emits radiation due to its thermal state (Fig. 2.4a). All these radiation—the Sun's radiation reflected by the Earth and those emitted by the Earth carry information about ground materials and can be used for terrestrial remote sensing. On the other hand, in some cases, the radiation is artificially generated (*active sensor*!), and the back-scattered signal is used for remote sensing, such as by laser and radar.

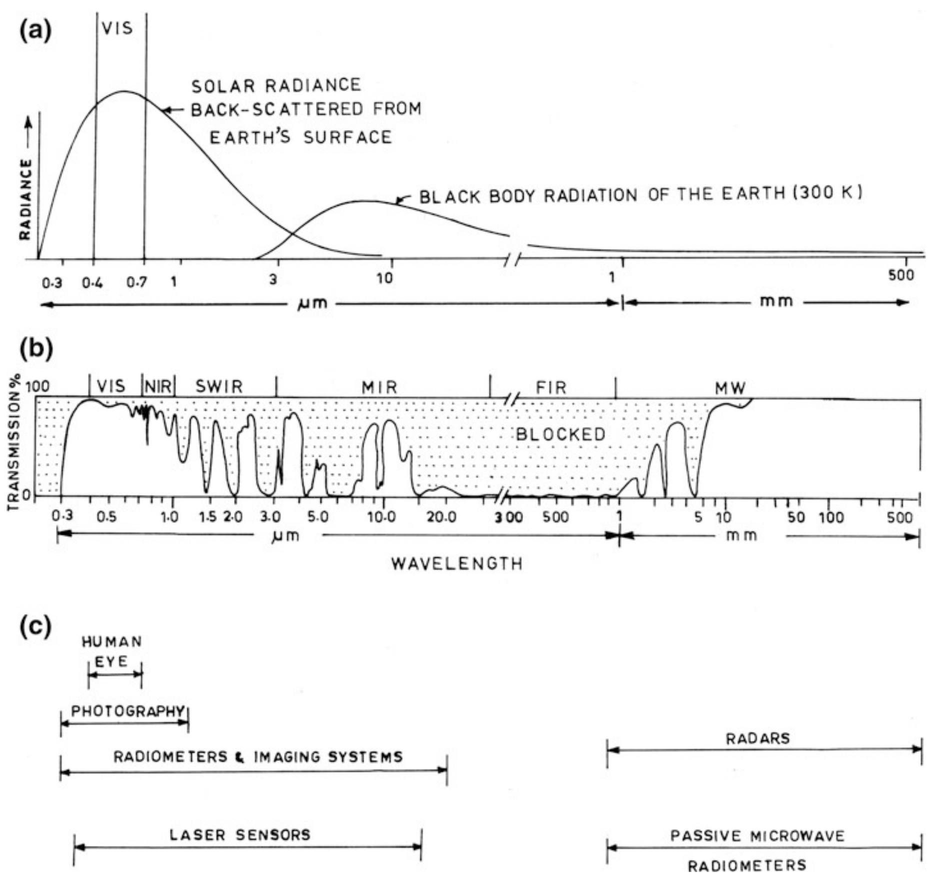

Fig. 2.4 **a** Energy available for remote sensing. The solar radiation curve corresponds to the back-scattered radiation from the Earth's surface, assuming the surface to be Lambertian and having an albedo of 0.1. The Earth's blackbody radiation curve is for 300 K temperature; **b** Transmission of the radiation through the atmosphere; note the presence of numerous atmospheric absorption bands and atmospheric windows. **c** Major sensor types used in different parts of the EM spectrum

2.3 Atmospheric Effects

The radiation reflected and emitted by the Earth passes through the atmosphere. In this process, it interacts with atmospheric constituents such as gases (CO_2, H_2O vapour, O_3 etc.), and suspended materials such as aerosols, dust particles etc. During interaction, it gets partly scattered, absorbed and transmitted. The degree of atmospheric interaction depends on the pathlength and wavelength.

Pathlength means the distance travelled by the radiation through the atmosphere, and depends on the location of the energy source and the altitude of the sensor platform. Sensing in the solar reflection region implies that the radiation travels through the atmosphere twice—in the first instance from the Sun towards the Earth, and then from the Earth towards the sensor, before being sensed. On the other hand, the radiation emitted by the Earth traverses the atmosphere only once. Further, pathlength also depends upon the altitude of the platform—whether it is at low aerial altitude, high aerial altitude or space altitude.

Attenuation of the radiation due to atmosphere interaction also depends on the wavelength. Some of the wavelengths are transmitted with higher efficiency, whereas others are more susceptible to atmospheric scattering and absorption. The *transmissivity* of the atmosphere at a particular wavelength is a measure of the fraction of the radiance that emanates from the ground (due to solar reflection or self-emission) and passes through the atmosphere without interacting with it. It varies from 0 to 1. The transmissivity is inversely related to another attribute called the *optical thickness* of the atmosphere, which describes the efficiency of the atmosphere in blocking the ground EM radiation by absorption or scattering.

Thus the atmosphere acts as scatterer and absorber of the radiation emanating from the ground. In addition, the atmosphere also acts as a source of EM radiation due to its thermal state. Therefore, the atmosphere–radiation interactions can be grouped into three physical processes: scattering, absorption and emission.

A remote sensor collects the total radiation reaching the sensor—that emanating from the ground as well as that due to the atmospheric effects. The part of the signal emanating from the atmosphere is called *path radiance*, and that coming from the ground is called *ground radiance*. The path radiance tends to mask the ground signal and acts as a background noise.

2.3.1 Atmospheric Scattering

Atmospheric scattering is the result of diffuse multiple reflections of EM radiation by gas molecules and suspended particles in the atmosphere. These interactions do not bring any change in the wavelength of the radiation and are considered as elastic scattering. Several models have been proposed to explain the scattering phenomena.

There are two basic types of scattering: (a) nonselective scattering and (b) selective scattering. *Nonselective scattering* occurs when all wavelengths are equally scattered. It is caused by dust, cloud and fog, such that the scatterer particles are much larger than the wavelengths involved. As all visible wavelengths are equally scattered, clouds and fog appear white.

Amongst *selective scattering,* the most common is *Raleigh scattering*, also called molecular scattering, which occurs due to interaction of the radiation with mainly gas molecules and tiny particles (much smaller than the wavelength involved). Raleigh scattering is inversely proportional to the fourth power of the wavelength. This implies that shorter wavelengths are scattered more than longer wavelengths. This type of scattering is most severe in the ultraviolet and blue end of the spectrum and is negligible at wavelengths beyond 1 μm. This is responsible for the blue colour of the sky. If there were no atmosphere, the sky would appear just as a dark space.

In the context of remote sensing, Raleigh scattering is the most important type of scattering and causes high path radiance at the blue-end of the spectrum. It leads to haze on images and photographs, which results in reduced contrast and unsharp pictures. The effect of this type of scattering can be reduced by using appropriate filters to eliminate shorter wavelength radiation.

Another type of scattering is the large-particle scattering, also called *Mie scattering*, which occurs when the particles are spherical. It is caused by coarse sus-pended particles of a size larger than the wavelength involved. The main scatterers of this type are suspended dust particles and water vapour molecules, which are more important in lower altitudes of the atmosphere, close to the Earth's surface. Mie scattering influences the entire spectral region from near-UV up to and including the near-IR, and has a greater effect on the larger wavelengths than Raleigh scattering. Mie scattering depends on various factors such as the ratio of the size of scatterer particle to the wavelength incident, the refractive index of the object and the angle of incidence.

As it is influenced by water vapour, the Mie effect is more manifest in overcast atmospheric conditions.

2.3.2 Atmospheric Absorption

The atmospheric gases selectively absorb EM radiation. The atoms and molecules of the gases possess certain specific energy states (rotational, vibrational and electronic energy levels; see Chap. 3). Photon energies of some of the EM radiation may be just sufficient to cause permissible energy

Table 2.1 Major atmospheric windows (clearer windows shown in boldface)

Name	Wavelength range	Region
Ultraviolet—visible	**0.30–0.75 μm**	Optical
Near-IR	**0.77–0.91 μm**	Optical
Short-wave-IR	1.00–1.12 μm	Optical
	1.19–1.34 μm	
	1.55–1.75 μm	
	2.05–2.4 μm	
Mid-IR (Thermal-IR)	3.50–4.16 μm	Optical
	4.50–5.0 μm	
	8.00–9.2 μm	
	10.20–12.4 μm	
	(**8–14 μm** for aerial sensing)	
	17.00–22.0 μm	
Microwave	2.06–2.22 mm	Microwave
	7.50–11.5 mm	
	20.0+ mm	

level changes in the gas molecule leading to selective absorption of EM radiation (Fig. 2.4b). The most important atmospheric constituents in this regard are H_2O vapour (absorption at 0.69, 0.72, 0.76 μm), CO_2 (absorption at 1.6, 2.005, 2.055 μm) and O_3 (absorption at 0.35, 9.6 μm). The spectral regions of least absorption are called *atmospheric windows*, as they can be used for looking at ground surface phenomena from aerial or space platforms across the atmosphere. Important atmospheric windows available for space-borne sensing are listed in Table 2.1. The visible part of the spectrum is marked by the presence of an excellent atmospheric window. Prominent windows occur throughout the EM spectrum at intervals. In the thermal-IR region, two important windows occur at 8.0–9.2 and 10.2–12.4 μm that are separated by an absorption band due to ozone, present in the upper atmosphere. For sensing from aerial platforms, the thermal channel can be used as 8–14 μm. The atmosphere is essentially opaque in the region of 22 μm to 1 mm wavelength. Microwaves of wavelength greater than 20 mm are propagated through the atmosphere with least attenuation.

2.3.3 Atmospheric Emission

The atmosphere also emits EM radiation due to its thermal state. Owing to its gaseous nature, only discrete bands of radiation (not forming a continuous spectrum) are emitted by the atmosphere. The atmospheric emission would tend to increase the path radiance, which would act as a background noise, superimposed over the ground signal. However, as spectral emissivity equals spectral absorptivity, the atmospheric windows are marked by low atmospheric emission. Therefore, for terrestrial sensing, the effect of self-emission by the atmosphere can be significantly reduced by restricting remote sensing observations to good atmospheric windows.

2.4 Energy Interaction Mechanisms on the Ground

The EM-energy incident on the earth-surface may be reflected, absorbed and or transmitted (Fig. 2.5). Following the Law of Conservation of Energy, the energy balance can be written as:

$$Ei_\lambda \equiv Er_\lambda + Ea_\lambda + Et_\lambda, \tag{2.14}$$

where Ei_λ is the spectral incident energy, Er_λ, Ea_λ and Et_λ are the energy components reflected, absorbed and transmitted respectively. The components Er_λ, Ea_λ and Et_λ differ

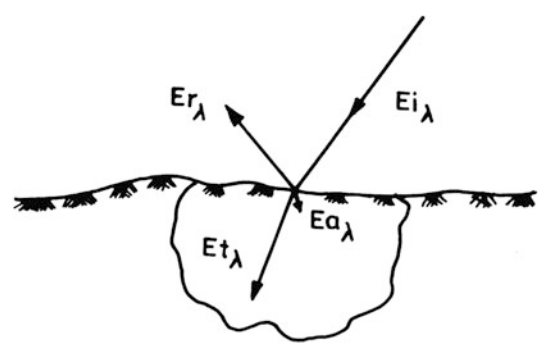

Fig. 2.5 Energy interaction mechanism on ground; Ei_λ is the incident EM energy; Er_λ, Ea_λ and Et_λ are the energy components reflected, absorbed and transmitted respectively

for different objects at different wavelengths. These inherent differences build up the avenues for discrimination of objects by remote sensing measurements.

2.4.1 Reflection Mechanism

The reflection mechanism has relevance to techniques in the solar reflection region and active microwave sensing, where sensors record intensity of EM radiation reflected from the ground. In the reflectance domain, the reflected energy can be written as:

$$\mathrm{Er}_{\lambda} = \mathrm{Ei}_{\lambda} - (\mathrm{Ea}_{\lambda} + \mathrm{Et}_{\lambda}), \tag{2.15}$$

Therefore, the amount of reflected energy depends upon the incident energy, and mechanisms of reflection, absorption and transmission. The reflectance is defined as the proportion of the incident energy, which is reflected:

$$\mathrm{R}_{\lambda} = \frac{\mathrm{Er}_{\lambda}}{\mathrm{Ei}_{\lambda}}, \tag{2.16}$$

When considered over a broader wavelength range, it is also called as *albedo*. Further, the interactions between EM radiation and ground objects may result in reflection, polarization and diffraction of the wave, which are governed by mainly composite physical factors like shape, size, surface features and environment. These phenomena occur at boundaries, and are best explained by the wave nature of light.

If the surface of the object is an ideal mirror-like plane, specular reflection occurs following the Snell's Law (Fig. 2.6a). The angle of reflection equals the angle of incidence and the incident ray the normal and the reflected ray are in the same plane. Rough surfaces reflect in multitudes of directions, and such reflection is said to be scattering or non-specular reflection. It is basically an elastic or coherent type of phenomenon in which no change in the wavelength of the radiation occurs. The uneven surfaces can be considered as being composed of numerous small non-parallel plane surfaces and fine edges and irregularities, the dimensions of which are of the order of the wavelength of the incident radiation. This results in multitudes of reflections in numerous directions and diffraction at fine edges and small irregularities, leading to a sum total of the scattered radiation from the surface (Fig. 2.7). An extreme ideal case is the Lambertian surface in which the radiation is reflected equally in all directions, irrespective of the angle of incidence (Fig. 2.6b). Most natural bodies are in-between the two extremes of specular reflection and Lambertian reflection, and show a semi-diffuse reflection pattern. The radiation is scattered in various directions, but is maximum in a direction, which corresponds to the Snell's Law (Fig. 2.6c).

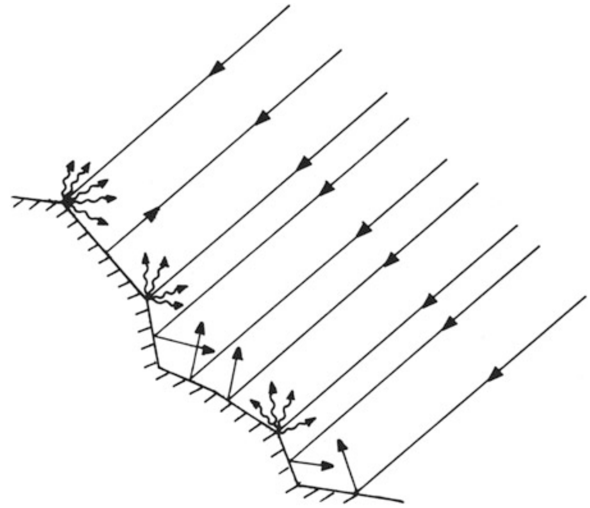

Fig. 2.7 Mechanism of scattering in multiple directions from natural uneven surfaces

Further, whether a particular surface behaves as a specular or a rough surface depends on the dimension of the wavelength involved and the local relief. For example, a level bed composed of coarse sand (grain size, e.g. 1 mm) would behave as a rough surface for VNIR wavelengths and as a smooth surface for microwaves.

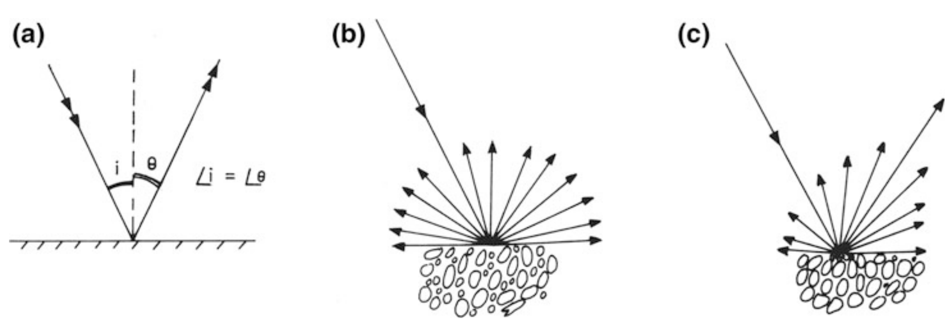

Fig. 2.6 Reflection mechanisms. **a** specular reflection from a plane surface; **b** Lambertian reflection from a rough surface (diffuse reflection); **c** semi-diffused reflection (natural bodies)

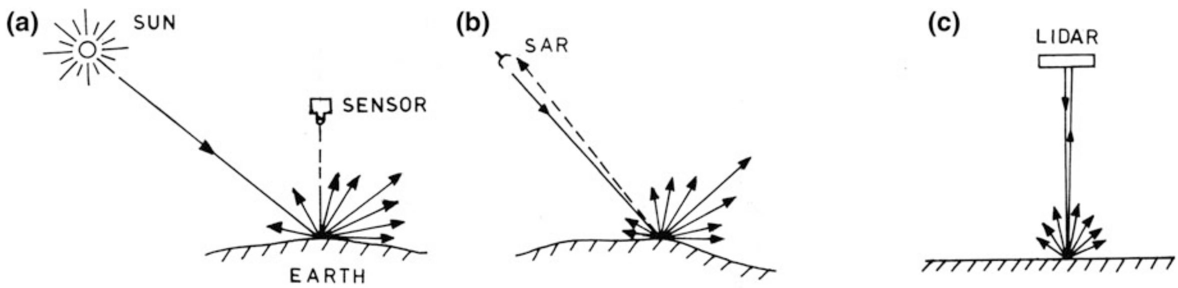

Fig. 2.8 Common geometric configurations in reflection sensing. **a** Solar reflection sensing, **b** SAR sensing, **c** LIDAR sensing

The intensity of reflected EM radiation received at the remote sensor depends, beside other factors, on geometry—both viewing and illuminating. In practice, a number of variations occur: (a) In solar reflection sensing, commonly the Sun is obliquely illuminating the ground, and the remote sensor is viewing the terrain near-vertically from the above (Fig. 2.8a). (b) The radar (SAR) imaging involves illumination and sensing from an oblique direction (Fig. 2.8b). (c) In LIDAR the sensors operate in near-vertical mode and record back-scattered radiation (Fig. 2.8c). It is important that the goniometric aspects are properly taken in-to account while interpreting the remote sensing data.

Some special phenomena may occur in specific circumstances during reflection, the most important of which is polarization. The reflected wave train may become polarized or depolarized in a certain direction depending upon the ground attributes. The potential of utilizing the polarization effects of waves in remote sensing appears to be quite distinct in the microwaves (see Chap. 16).

A remote sensor measures the total intensity of EM radiation received the sensor which depends not only on reflection mechanism but also on factors influencing absorption and transmission processes.

2.4.2 Transmission Mechanism

When a beam of EM energy is incident on a boundary, for example on the Earth's surface, part of the energy gets scattered from the surface (called surface scattering) and part may get transmitted into the medium. If the material is homo-geneous, then this wave is simply transmitted. If, on the other hand, the material is inhomogeneous, the transmitted ray gets further scattered, leading to volume scattering in the medium. In nature, both surface and volume scattering happen, side by side, and both processes contribute to the total signal received at the sensor.

As defined, the depth of penetration is considered as that depth below the surface at which the magnitude of the power of the transmitted wave is equal to 36.8% (1/e) of the power transmitted, at a point just beneath the surface (Ulaby and Goetz 1987).

The transmission mechanism of EM energy is still not fully well understood. It is considered to depend mainly on an electrical property of matter, called the complex dielectric constant (δ). This varies spectrally and is different for different materials. When the dielectric constant is low, the radiation penetrates to a greater depth and the energy travels through a larger volume of the material (therefore there is less surface scattering and greater volume scattering). Conversely, when the object has a higher δ, the energy gets confined to the top surficial layer with little penetration (resulting in dominantly surface scattering). As the complex dielectric constant of materials varies with wavelength, the depth penetration also varies accordingly. For example, water bodies exhibit penetration at visible wavelengths but mainly surface scattering at microwave frequencies, whereas the reverse happens for dry rock/soil (Table 2.2).

It is implicit that the transmission characteristics also influence the amount of energy received at the sensor, for the simple reason that transmission characteristics govern surface vis-à-vis volume scattering, as also the component of the energy which is transmitted and does not reach the remote sensor.

Figure 2.9a, b, c is a set of three images of the same water body illustrating how interaction of the EM radiation may

Table 2.2 Bearing of the spectral complex dielectric constant (δ_λ) of matter on depth penetration (transmission) of EM radiation

Wavelength range	Water/sea body	Dry rock/soil
Visible	Low δ_λ; transmission of radiation and volume scattering	High δ_λ; surface scattering
Microwave	High δ_λ; surface scattering	Low δ_λ; transmission of radiation and volume scattering

differ according to wavelength of the incident radiation resulting in different images. Figure 2.9a, b are images in the blue and near-IR ranges of the EM spectrum respectively, and Fig. 2.9c is a radar image. Figure 2.9d provides explanations for all the three cases. In the blue part of the spectrum, the radiation is partly scattered from the water surface, enters (transmission!) the water body and also exhibits volume scattering due to interaction with suspended particles; therefore, the water body appears in shades of gray. In the near-IR range, the incident radiation is completely absorbed by the water body, and the water body appears very dark on the image. In the case of radar, there is neither absorption nor transmission of radiation into the water body but the radiation is specularly reflected from the water surface with no radar-return at the antenna resulting in nearly black image tones for the water body.

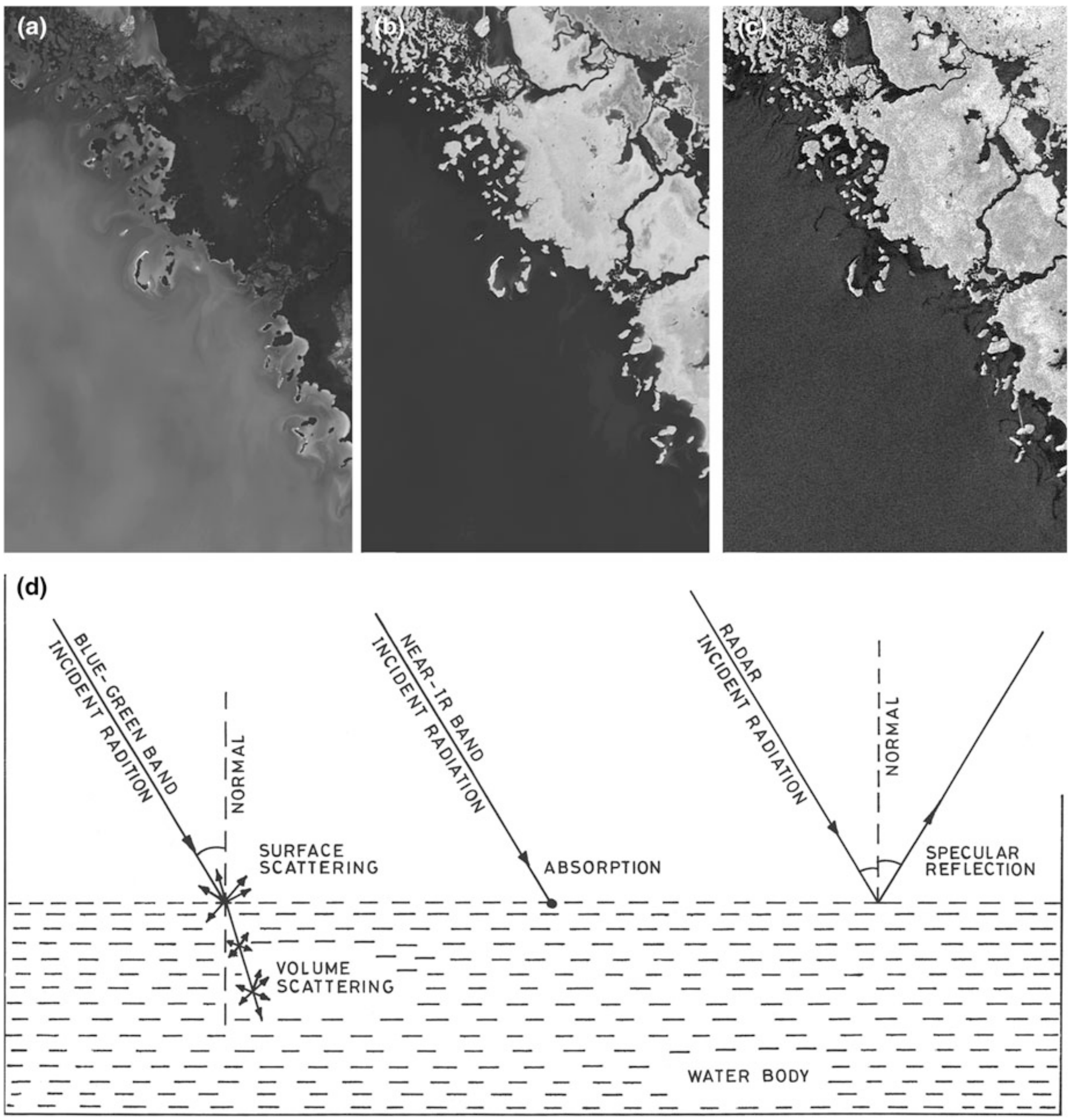

Fig. 2.9 Interaction mechanism of the EM radiation of different wavelengths resulting in different images. Figure 2.9**a–c** is a set of three images of the same water body in three wavelength ranges: **a** = blue-green band, **b** = near-IR band and **c** = SAR; Fig. 2.9**d** schematically explains the corresponding interaction mechanisms. For details see text. (ALOS—AVNIR and PALSAR images of west coast of Florida, USA) (**a–c** courtesy: A. Prakash)

2.4.3 Absorption Mechanism

Interaction of incident energy with matter on the atomic–molecular scale leads to selective absorption of the EM radiation. An atomic–molecular system is characterized by a set of inherent energy states (i.e. rotational, vibrational and electronic). A different amount of energy is required for transition from one energy level to another for each of these states. An object absorbs radiation of a particular wavelength if the corresponding photon energy is just sufficient to cause a set of permissible transitions in the atomic–molecular energy levels of the object. The wavelengths absorbed are related to many factors, such as dominant cations and anions present, solid solutions, impurities, trace elements, crystal lattice etc. (for further details see Chap. 3).

2.4.4 Earth's Emission

The Earth, owing to its ambient temperature, is a source of blackbody radiation, which constitutes the predominant energy available for terrestrial sensing at wavelengths >3.5 µm (Fig. 2.4a). The emitted radiation depends upon temperature and emissivity of the materials. These aspects are presented in greater detail in Chap. 12.

In the above paragraphs, we have discussed the sources of radiation, atmospheric effects and the mechanism of ground interactions. The sensors used in the various spectral regions are shown in Fig. 2.4c. They include the human eye, radiometer, scanner, radar, lidar and microwave passive sensors.

Further discussion is divided into two main parts: optical range (Chaps. 3–14) and microwave range (Chaps. 15–17) (see Table 1.2).

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