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(CE- 403)

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6.2 ELECTROMAGNETIC ENERGY

The sun is the most obvious source of electromagnetic radiation (EMR) remote sensing. In fact, all the terrestrial objects having temperatures above 0 K are also sources of electromagnetic radiations, but with different magnitudes and spectral compositions than that of the sun. The physical laws governing EMR are given in Appendix III.

The carrier of information in remote sensing is electromagnetic energy. It is a form of energy which moves with the velocity of light (3×10^8 m/s) in a harmonic pattern consisting of sinusoidal waves as shown in Fig. 6.2. It has two fields—the electrical and the magnetic fields—both being orthogonal to each other. Visible light, for example, is a particular range of electromagnetic radiation. Some of the other familiar forms are radio waves, ultraviolet rays, X-rays and heat. Remote sensing makes use of electromagnetic radiation which is not visible to the human eye; it can supply information during night also. This radiation can be detected only when it interacts with matter whereby a change in the electromagnetic energy takes place, which is detected by remote sensing. The data obtained is used for the determination of the characteristics of the objects.

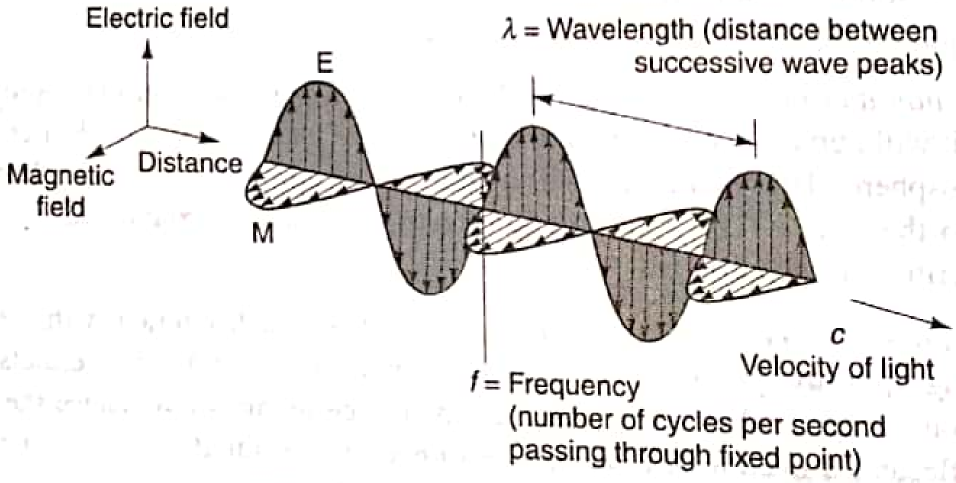


Fig. 6.2 *An electromagnetic wave*

The electromagnetic waves can be described in terms of the basic parameters such as velocity, wavelength, and frequency. Wavelength λ is the distance between any point on one wave to its same position on the next wave, usually expressed in micrometers (μm) or nanometers (nm). Frequency f is the number of cycles completed in one second, usually expressed in megahertz (MHz) or gigahertz (GHz), and c is the speed of the electromagnetic wave. The relation between these parameters is

$$c = \lambda f \tag{6.1}$$

Since c is a constant, frequency f and wavelength λ for any given wave are related inversely, and either term can be used to characterise a wave into a particular form. However, in remote sensing it is customary to categorise the electromagnetic waves by their wavelength location within the electromagnetic spectrum.

The wave theory discussed in Section 6.2 explains how electromagnetic energy propagates in the form of a wave and describes most of the characteristics of the electromagnetic radiations. However, this energy can only be detected when it interacts with matter. This interaction of electromagnetic energy with matter can be described by the particle theory which suggests that electromagnetic energy is composed of photons or quanta and describes as to how the electromagnetic energy interacts with matter. The photons have particle-like properties such as energy and momentum. These photons also move at the speed of light (3×10^8 m/s), exist as reflected or absorbed radiation, and the measurements of their varying energy levels forms the basis of remote sensing.

The energy of a quanta/photon is given as under:

$$Q = h f \tag{6.2}$$

where

Q = energy of quanta (J)
h = Planck's constant (6.626×10^{-34} Js)
f = frequency

From Eqs. (6.1) and (6.2)

$$Q = \frac{hc}{\lambda} \tag{6.3}$$

Equation (6.3) suggests that the energy of a photon is inversely proportional to its wavelength; the longer the wavelength, the lower is its energy content. This implies that for remote sensing, longer–wavelength emissions (such as microwaves) from terrain features are more difficult to sense than radiations of shorter wavelengths (such as emitted thermal infrared energy).

6.3 ELECTROMAGNETIC SPECTRUM

The range of different types of electromagnetic waves is shown in Fig. 6.3 and described in Table 6.1. To portray all the wavelengths, the horizontal scale is the log. Figure 6.4 shows the expanded spectrum part used in remote sensing.

Table 6.1 *Electromagnetic spectral regions*

Region	*Wavelength*	*Remarks*
Gamma ray	<0.03 nm	Incoming radiation is completely absorbed by the upper atmosphere and is not available for remote sensing.
X-ray	0.03 – 3.0 nm	Completely absorbed by atmosphere. Not employed in remote sensing.
Ultraviolet	0.03 – 0.4 μm	Incoming wavelengths less than 0.3 μm are completely absorbed by ozone in the upper atmosphere.
Photographic UV band	0.3 – 0.4 μm	Transmitted through atmosphere. Detectable with film and photodetectors, but atmospheric scattering is severe.
Visible	0.4 – 0.7 μm	Imaged with film and photodetectors. Includes reflected energy peak of earth at 0.5 μm.
Infrared	0.7 – 1.0 μm	Interaction with matter varies with wavelength. Atmospheric transmission windows are separated by absorption bands.
Reflected IR band	0.7 – 3.0 μm	Reflected solar radiation that contains no information about the thermal properties of materials. The band from 0.7 to 0.9 μm is detectable with film and is called the *photographic IR band*.
Thermal IR band	3 – 5 μm 8 – 14 μm	Principal atmospheric windows in the thermal region. Images at these wavelengths are acquired by optical-mechanical scanners and special vidicon systems but not by film.
Microwave	0.1 – 30 cm	Longer wavelengths can penetrate clouds, fog, and rain. Images may be acquired in the active or passive mode.
Radar	0.1 – 30 cm	Active form of microwave remote sensing. Radar images are acquired at various wavelength bands.
Radio	>30 cm	Longest wavelength portion of electromagnetic spectrum. Some classified radars with very long wavelength operate in this region.

There is no clear-cut dividing line between one nominal spectral region and the next. However for convenience, names (such as ultraviolet and microwave) are assigned to regions of the electromagnetic spectrum. Since Gamma-rays and X-rays are completely absorbed by the atmosphere, these cannot be registered with remote sensing techniques.

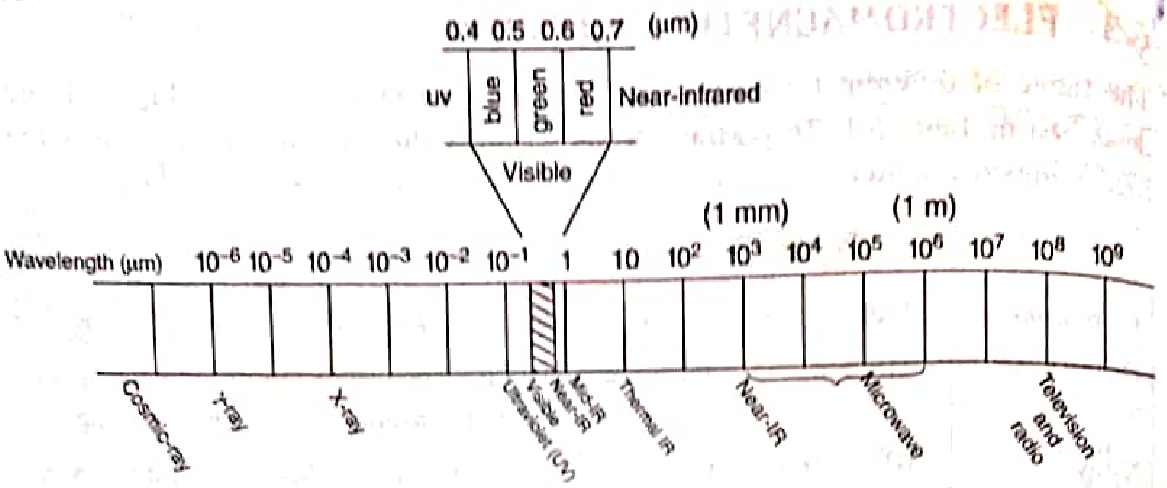


Fig. 6.3 *The electromagnetic spectrum*

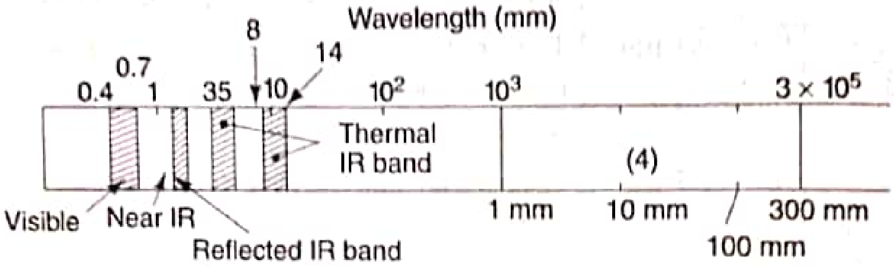


Fig. 6.4 *Expanded spectrum part used in remote sensing*

The various suitable regions of electromagnetic radiations are the visible region—wavelength ranging from 0.4 to 0.7 μm (of which 0.4–0.5 μm represents the blue, 0.5–0.6 μm the green, and 0.6–0.7 μm the red region), particularly suitable for photogrammetry; the reflected infrared region—ranging from 0.7 to 3 μm (of which 0.7–1.5 μm represents the near infrared, and 1.5–3 μm the shortwave infrared), which is invisible; the thermal infrared region—ranging from 3 to 14 μm (of which 3–8 μm represents the midwave infrared, and 8–14 μm the longwave infrared), which is invisible, and can be detected by crystal detectors, and such systems work day and night; the microwave region—wavelength ranging from 1 to 300 mm and which is used in radar.

The remote-sensing systems operate in one or more of the visible, reflected-infrared, thermal-infrared, and microwave portions of the electromagnetic spectrum described above. However, the existing gases and water vapours in the atmosphere, which absorb electromagnetic energy in specific wavelength bands, influence the selection of the spectrum for use in the remote-sensing system.

One of the most important aspect is the selection of those portions of the spectrum which have a high transmission of electromagnetic radiations, called *atmospheric windows*, and their corresponding wavelengths are very suitable for remote sensing since these produce good images. In simple words, the wavelengths which are able to pass through the atmosphere without loss are called the atmospheric windows. Most remote-sensing instruments acquire data from the discrete segments of an atmospheric window by making measurements with the detectors tuned to specific wavelengths.

Table 6.2 gives the wavelength regions along with the principal applications in remote sensing. Energy reflected from the earth during day time may be recorded as a function of wavelength. The maximum amount of energy is reflected at 0.5 μm, called the *reflected energy peak*. The earth also radiates energy, both during day and night time, with the maximum energy radiated at 9.7 μm, called the *radiant energy peak*.

Table 6.2 *Wave length regions and their applications in remote sensing*

Region	*Wavelength (μm)*	*Principal Applications*
1. Blue	0.45–0.52	Coastal morphology and sedimentation study, soil and vegetation differentiation, conifers and deciduous vegetation discrimination
2. Green	0.52–0.60	Vigor assessment of vegetation, rock and soil discrimination, turbidity and bathymetry studies
3. Red	0.63–0.69	Plant-species differentiation
4. Near infrared	0.70–1.50	Vegetation, biomass, delineation of water feartures, landforms/geomorphic studies
5. Reflected infrared	1.55–1.75	Vegetation, moisture content, soil moisture content, snow and cloud differentiation
	2.08–2.35	Differentiation of geological materials and soil
6. Thermal IR	3.0–5.0	For hot targets, i.e., fires and volcanoes
	10.4–12.5	Thermal sensing, vegetation discrimination, vegetation stress analysis, volcanic studies
7. Microwave/ Radar (0.1–30.0 cm)	2–6 cm	Suitable for sensing crop canopies and tree leaves Useful for determining ice types
	15–30 cm	Affords greater depth penetration measured in terms of metres; can penetrate 1–2 m into a dry material to reveal underlying bedrock structure. Useful for mapping total extent of ice and for sensing tree-trunks

16.4.5. Basic Radiation Laws

1. *Stefan-Boltzmann law*

All bodies above temperature of 0 K emit EM radiation and the energy radiated by an object at a particular temperature is given by

$$M = \sigma T^4 \qquad \text{...(16.3)}$$

where M = total *spectral existance* of a black body, W/m^2

σ = Stefan-Boltzmann constant = 5.6697×10^{-11} W/m^2/K^4

T = absolute temperature.

A black body is a hypothetical ideal radiator that totally absorbs and remits all energy incident upon it. The distribution of spectral existance for a black body at 5900 K closely approximates the sun's spectral exitance curve (Mather, 1987), while the earth can be considered to act like a black body with a temperature of 290 K.

2. *Wien's displacement law*

The wavelength at which a black body radiates its maximum energy is inversely proportional to temperature and is given by

$$\lambda_m = \frac{A}{T} \qquad \text{...(16.4)}$$

λ_m = wavelength of maximum spectral exitance

A = Wien's constant = 2.898×10^{-3} mK

T = temperature of the body.

As the temperature of the black body increases, the dominant wavelength of the emitted radiation shifts towards shorter wavelength.

3. *Planck's law*

The total energy radiated in all directions by unit area in unit time in a spectral band for a is given by

$$M_\lambda = \frac{C_1}{\lambda^5 . e^{(C_2/\lambda T)-1}} \qquad \text{...(16.5)}$$

where M_λ = Spectral exitance per unit wavelength

C_1 = First radiation constant = 3.742×10^{-16} W/m^2

C_2 = Second radiation constant = 1.4388×10^{-2} mK

It enables to assess the proportion of total radiant exitance within selected wavelength.

6.5 EFFECT OF ATMOSPHERE ON ELECTROMAGNETIC RADIATION

The electromagnetic radiations detected by remote sensors covers some distance, or path length, of the atmosphere. Since the atmospheric path length involved varies, the net effect of the atmosphere on radiation varies too. Some of the other factors, for example, the atmospheric conditions present, the wavelengths involved and the magnitude of the energy signal sensed, also contribute to the net effect of the atmosphere on radiation. The atmospheric effects are principally caused through the mechanism of atmospheric scattering and absorption.

6.5.1 Scattering

Atmospheric scattering is the unpredictable diffusion of radiation caused by the molecules of the gases, dust and smoke in the atmosphere. Scattering is basically classified as *selective* and *non-selective*, depending upon the size of particles with which the electromagnetic radiation interacts.

1. *Non-selective scatter:* The non-selective scatter occurs when the diameter of particles with which electromagnetic radiation interacts, is several times (about 10 times) the wavelength. Water droplets, pollen grains, ice and snow crystals, for example, cause non-selective scatter.

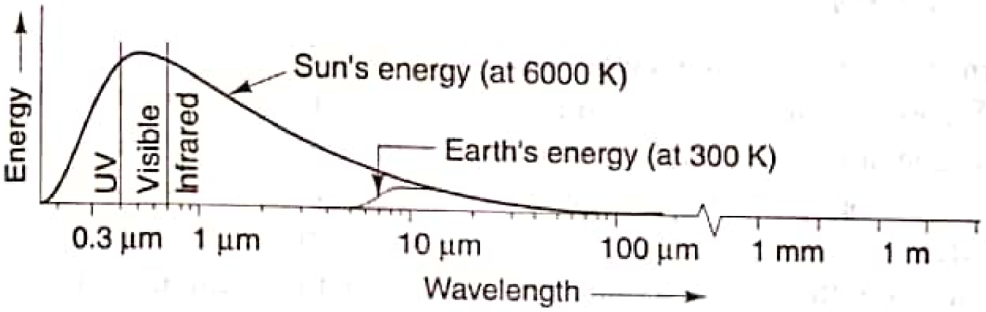
2. *Selective scatter:* The selective scatter is classified as Rayleigh scatter and Mie scatter.

(a) Rayleigh scatter In the upper layers of the atmosphere, scatter is mainly due to interaction of gas molecules with the radiation. Consequently, a haze results on the remotely sensed imagery. This is known as *Rayleigh scatter.* The effect of Rayleigh scatter is inversely proportional to the fourth power of the wavelength. So, the short wavelengths are scattered more by the scattering mechanism than the longer ones. A blue sky is a manifestation of Rayleigh scatter; with no scatter, the sky would appear black.

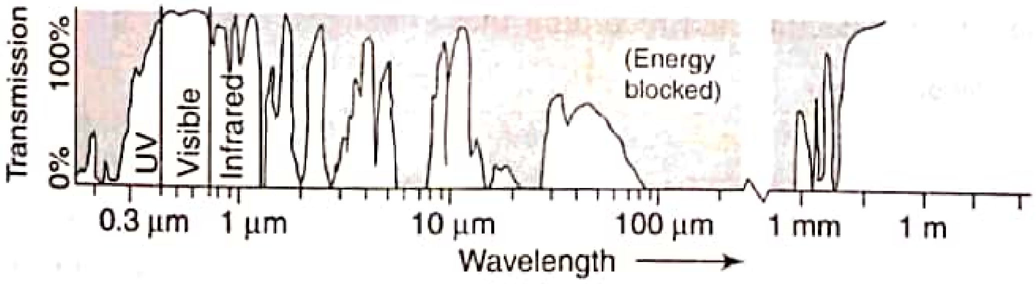
(b) Mie scatter In the lower layers of the atmosphere, the scatter is mainly because dust, water vapour and smoke particles interact with the radiation. This is known as *Mie scatter.* This type of scatter tends to influence the longer wavelengths. Although Rayleigh scatter dominates under most atmospheric conditions, Mie scatter is significant in overcast conditions.

6.5.2 Absorption

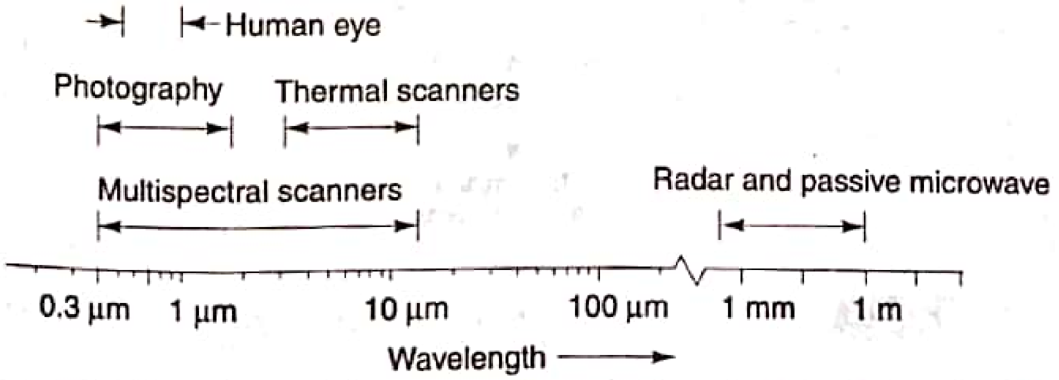
A part of electromagnetic radiation is absorbed by the molecules of ozone, carbon dioxide and water vapours. The absorption of radiation occurs in specific wavelength intervals called *absorption band* and governs the regions of the spectrum to be used in remote sensing. Wavelengths shorter than 0.3 µm are completely absorbed by the ozone layer in the upper atmosphere (Fig. 6.5), which allows life on earth; a prolonged exposure to the intense energy of these wavelengths destroys living tissue. The aerosol-sized particles of liquid water in clouds absorb and scatter electromagnetic radiation at wavelengths less than about 0.3 µm. Only radiations of microwave and longer wavelengths are capable of penetrating clouds without being scattered, reflected, or absorbed.



(a) Spectra distribution of emitted energy by energy sources



(b) Atmospheric transmittance

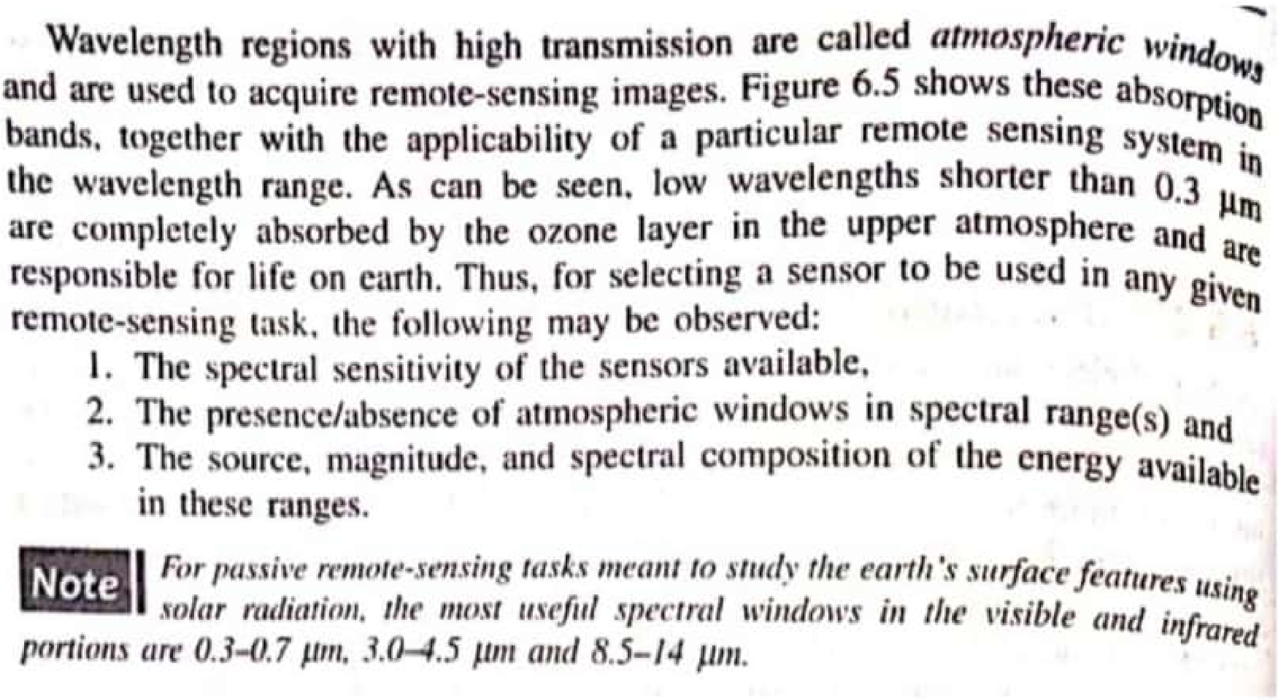


(c) Wavelength regions for common remote sensing systems
(Note that wavelength scale is logarithmic)

Fig. 6.5 *Inter-relationship between energy sources and atmospheric absorption characteristics*

Atmospheric Windows :

Atmospheric windows are the wavelength regions in EM spectrum at which the EM radiations are partially or wholly transmitted through the atmosphere without any distortion or absorption.



Wavelength regions with high transmission are called *atmospheric windows* and are used to acquire remote-sensing images. Figure 6.5 shows these absorption bands, together with the applicability of a particular remote sensing system in the wavelength range. As can be seen, low wavelengths shorter than 0.3 µm are completely absorbed by the ozone layer in the upper atmosphere and are responsible for life on earth. Thus, for selecting a sensor to be used in any given remote-sensing task, the following may be observed:

1. The spectral sensitivity of the sensors available,
2. The presence/absence of atmospheric windows in spectral range(s) and
3. The source, magnitude, and spectral composition of the energy available in these ranges.

Note *For passive remote-sensing tasks meant to study the earth's surface features using solar radiation, the most useful spectral windows in the visible and infrared portions are 0.3–0.7 µm, 3.0–4.5 µm and 8.5–14 µm.*

The sensors on remote sensing satellites must be designed in such a way as to obtain data within these well defined *atmospheric windows.*

16.6 INTERACTION OF EM RADIATION WITH EARTH'S SURFACE

EM energy that strikes or encounters matter (object) is called *incident radiation*. The EM radiation striking the surface may be (*i*) reflected/scattered, (*ii*) absorbed, and/or (*iii*) transmitted. These processes are not mutually exclusive—EM radiations may be partially reflected and partially absorbed. Which processes actually occur depends on the following factors (1) wavelength of radiation (2) angle of incidence, (3) surface roughness, and (4) condition and composition of surface material.

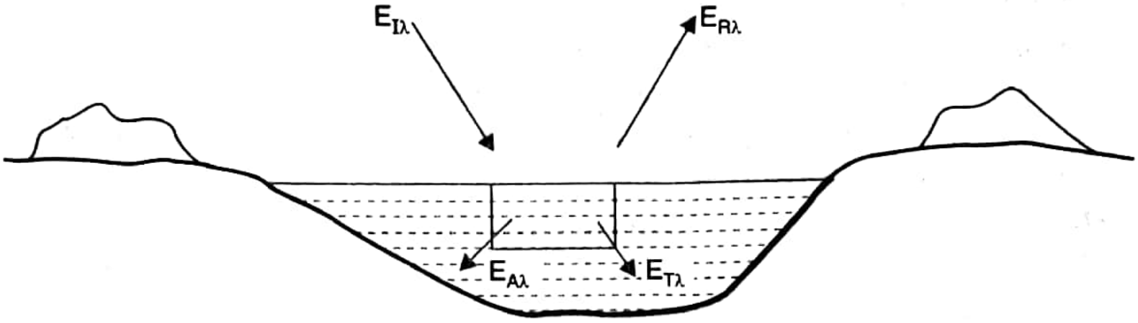


Fig. 16.5 Interaction Mechanism.

Interaction with matter can change the following properties of incident radiation:

(*a*) Intensity (*b*) Direction (*c*) Wavelength (*d*) Polarisation and (*e*) Phase.

The science of remote sensing detects and records there changes.

The energy balance equation for radiation at a given wavelength (λ) can be expressed as follows.

$$E_{I\lambda} = E_{R\lambda} + E_{A\lambda} + E_{T\lambda} \quad \text{...(16.6)}$$

where $E_{I\lambda}$ = Incident energy; $E_{R\lambda}$ = Reflected energy
$E_{A\lambda}$ = Absorbed energy; $E_{T\lambda}$ = Transmitted energy.

The proportion of each fraction ($E_{R\lambda}/E_{A\lambda}/E_{T\lambda}$) will vary for different materials depending upon their composition and condition. Within a given features type, these proportions will vary at different wavelengths, thus helping in discrimination of *different objects*. Reflection, scattering, emission are called surface phenomenon because these are determined by the properties of surface, viz. colour, roughness. Transmission and absorption are called volume phenomena because these are determined by the internal characteristics of the matter, viz. density and condition.

Modification of basic equation: In remote sensing, the amount of reflected energy ($E_{R\lambda}$) is more important than the absorbed and transmitted energies. Hence, it is more convenient to rearrange the terms of Eq. 16.6 as follows

$$E_{R\lambda} = E_{I\lambda} - [E_{A\lambda} + E_{T\lambda}] \quad \text{...(16.7)}$$

Eq. 16.7 is known as the *balance equation*.

Dividing all the terms by $E_{I\lambda}$, we get

The energy-balance equation at a particular wavelength will be as follows:

$$E_I = E_R + E_A + E_T \tag{6.4}$$

where E_I is the incidence energy, E_R is the reflected energy, E_A is the absorbed energy, and E_T is the transmitted energy.

The proportions of energy reflected, absorbed and transmitted will vary for different earth features. These differences enable us to distinguish different features on an image. It should be noted that two features may be indistinguishable in one spectral range and may appear different in another wavelength band. It is so because even within a given feature type, the proportions of reflected, absorbed, and transmitted energy will vary at different wavelengths. Equation (6.4) may be rearranged as

$$E_R = E_I - (E_A + E_T)$$

or

$$\frac{E_R}{E_I} = 1 - \left(\frac{E_A}{E_I} + \frac{E_T}{E_I}\right) \tag{6.5}$$

or

$$\rho = 1 - (\alpha + \gamma)$$

where ρ is the reflectance, α is the absorbance and γ is the transmittance.

Since almost all the earth surfaces are quite opaque, the transmittance (γ) can be neglected. Also, according to Kirchhoff's law, the absorbance (α) is taken as emissivity (ξ). Equation (6.5) reduces to

$$\rho = 1 - \xi \tag{6.6}$$

Equation (6.6) is the fundamental equation for the conceptual design of remote-sensing technology.

Notes

i. For $\xi = 0$; $\rho = 1$: the total incident energy is reflected by the target and recorded by the sensor and the objects appear white (for example, snow).

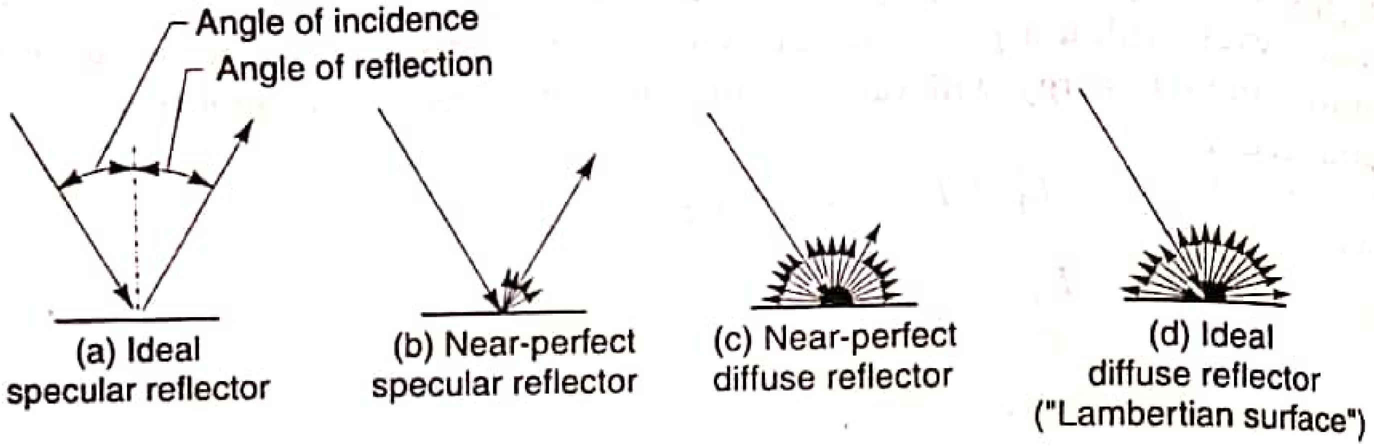
ii. For; $\xi = 1$; $\rho = 0$: the total incident energy is absorbed by the target and they appear black (for example, smoke).

Since most of the remote-sensing systems operate in the wavelength regions in which reflected energy predominates, the reflectance properties are of prime importance. The reflected energy is primarily a function of the surface roughness. Flat surfaces manifest mirror-like reflections (the angle of reflection is equal to the angle of incidence) and are called *specular reflectors* (Fig. 6.7(a)). Rough surfaces reflect energy uniformly in all directions and are called *diffuse* or *Lambertian reflectors* (Fig. 6.7(d)). Most earth features are neither perfectly specular nor Lambertian reflectors, and the characteristics of most earth features lie between these two extremes as shown in Fig. 6.7(b, c). The diffuse reflectance property of terrain features is of significant interest since it contains spectral information on the colour of the reflecting surface, whereas specular reflectors do not. That is why in remote sensing, the diffuse reflectance properties of terrain features are measured. To quantify the reflectance characteristics of the earth surface features, the reflected portion and incidence energy is measured. The reflected energy measured as a function of wavelength and called *spectral reflectance*, is expressed mathematically as

$$\rho_\lambda = \frac{E_R(\lambda)}{E_I(\lambda)} \times 100 \tag{6.7}$$

where ρ_λ is the spectral reflectance, $E_R(\lambda)$ is the energy of the wavelength reflected, and $E_I(\lambda)$ is the energy of the wavelength incident.

A graph of the spectral reflectance of an object as a function of the wavelength, called spectral reflectance curve, can be prepared in the laboratory using an instrument spectrometer. The configuration of this curve gives an insight into the spectral characteristics of the target. Several such curves for different targets may be prepared and used for comparing and discriminating various features in the images.



(a) Ideal specular reflector
(b) Near-perfect specular reflector
(c) Near-perfect diffuse reflector
(d) Ideal diffuse reflector ("Lambertian surface")

Fig. 6.7 *Energy reflectance and surface characteristics of earth features*