UNIT 2

INTERACTION OF EMR WITH EARTH AND ATMOSPHERE

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2.1 INTRODUCTION

In the previous unit, you studied about history and processes of remote sensing and electromagnetic energy and its properties. You have also studied the models of electromagnetic radiation (EMR). Now you know that EMR is the basis of remote sensing and most of the remote sensing sensors use Sun's energy (radiation) for collecting information about objects on the Earth's surface. Sensors record the radiation coming from the Sun after interacting with the atmosphere and the Earth's surface. Particles and gases in the atmosphere can affect the incoming light or

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radiation. The radiation reaching the remote sensor is modified significantly because of the processes taking place in the atmosphere and the Earth's surface. This unit discusses in detail how these radiations interact in the atmosphere and at the Earth's surface. An account of the important terminologies used in remote sensing is also given.

Expected Learning Outcomes

After studying this unit you should be able to:

- explain the interaction of EMR with atmosphere;
- describe how absorption and scattering together attenuate the electromagnetic radiation through different mechanisms;
- discuss atmospheric windows and their importance; and
- describe how the radiation interacts with the Earth's surface.

2.2 ENERGY-ATMOSPHERE INTERACTION

As you know the word 'atmosphere' refers to the gas layers surrounding the Earth. Constituents of the atmosphere are nitrogen, oxygen, carbon dioxide, ozone, water vapour and other gases. EMR coming from the Sun has to pass through the Earth's atmosphere twice before being detected by the satellite sensor – once on its journey from the Sun to the Earth and the second time after being reflected/emitted by the Earth's surface to the sensor. Particles and gases present in the atmosphere interact with the incoming light and reflected/emitted radiation. Our interest in this interaction is related to the fact that atmospheric components diffuse, refract, reflect, absorb and emit EMR changing the original radiance of the objects observed by a remote sensor. The interaction of EMR with the atmosphere is important to remote sensing for two main reasons:

- information carried by EMR reflected/emitted by the Earth's surface is modified while traversing through the atmosphere, and
- interaction of EMR with the atmosphere can be used to obtain useful information about the atmosphere itself.

The change in incident radiation on its way towards the satellite sensor is governed by several atmospheric effects as shown in Fig. 2.1. These effects are caused by the mechanisms of refraction, reflection, scattering, absorption and transmission.

On hot sunny days, the atmosphere near the Earth's surface is very hot because of the turbulent hot air with different densities and hence different refractive indices. The difference in refractive indices makes the air bubbles act as lenses, slightly deviating the transmitted light. This deviation causes the mirage effect as seen in the following figure.

Fig. 2.2: Mirage seen in the road on a hot sunny day (source: https://www.weatherscapes.com/photo.php?cat=optics&id=w-415-37)

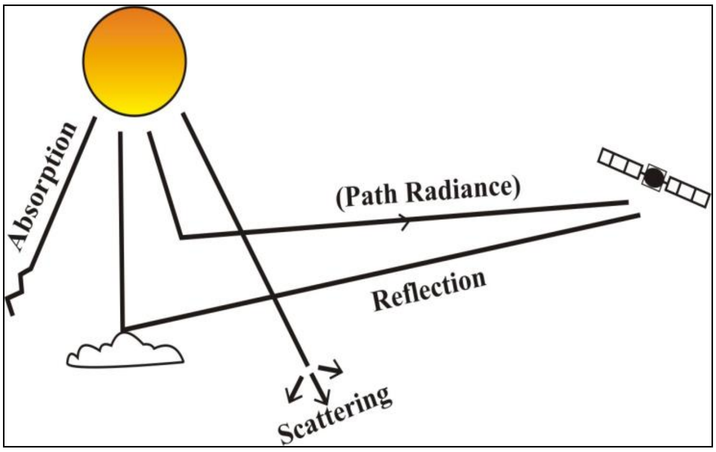
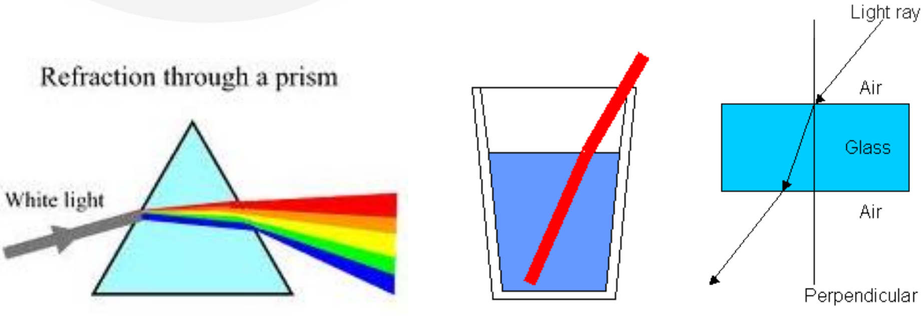


Fig. 2.1: Interaction of EMR in the Atmosphere.

We will now discuss these mechanisms.

2.2.1 Refraction

Atmospheric refraction is the deviation of electromagnetic wave from a straight line as it passes through the atmosphere due to variation in air density, which varies with altitude. Atmospheric refraction near the ground produces mirages (Fig. 2.2) and can change the look of distant objects. Atmospheric refraction causes astronomical objects to appear higher in the sky than they are in reality. It affects the complete spectrum of EMR in varying degrees. For example, in visible light, blue is more affected than red. The amount of atmospheric refraction is a function of temperature, pressure and humidity. The presence of turbulence in the air makes atmospheric refraction inhomogeneous. This is the cause of the twinkling of the stars and deformation of the shape of the Sun at sunset and sunrise (Fig. 2.3). Atmospheric refraction is minimum in the zenith and maximum at the horizon. In day-to-day life, we often experience refraction; e.g., when we insert a spoon in a water-filled bowl, it appears slightly elevated (Fig. 2.4).



(a) **(b)** **(c)**

Fig. 2.4: a) When white light passes through a prism, its components, i.e., VIBGYOR are visible on the other side of the prism illustrating the refraction phenomenon; b) Another example from everyday life is when you insert a spoon or straw in a glass of water, it appears slightly bent at the water surface; and c) Representation of refraction of light at the interface of two media.

If the sun (or moon) is low above the horizon, the optical path of light through the atmosphere is very long, and the atmosphere usually has a layered structure of different temperature gradients and pressure. Refraction of the light by these layers can cause the sun's disk to be deformed, flattened, or distorted (Fig. 2.3).

Fig. 2.3 Deformities seen in Sun's shape when it is on the horizon (source: https://www.weatherscapes.com/photo.php?cat=optics&id=w-396-16)

2.2.2 Scattering

Most of the light that reaches our eyes comes not directly from its sources but indirectly through the process of scattering. You see diffusely scattered solar radiation when you look at clouds or the sky. The land and water surfaces and the objects surrounding us are visible through the light they scatter. An electric lamp does not send us light directly from the luminous filament but usually glows with the light that has been scattered by the glass bulb. Unless you look at a source, such as the Sun, a flame, or an incandescent filament with a clear bulb, you see the light that has been scattered. In the atmosphere, you see many colourful examples of scattering generated by molecules, aerosols, and clouds containing droplets and ice crystals. Blue sky (Fig. 2.5), white clouds, and magnificent rainbows and halos, to name a few, are all optical phenomena due to scattering. Scattering is a physical process associated with the light and its interaction with matter. It occurs at all wavelengths covering the entire electromagnetic spectrum.

Fig. 2.5: Scattering of blue colour from sunlight.

Scattering is a physical process by which a particle in the path of an EM wave continuously abstracts energy from the incident wave and re-radiates that energy in all directions. Therefore, a particle may be thought of as a point source of scattered energy. In the atmosphere, the particles responsible for scattering cover the sizes from gas molecules (~10^{-8}cm) to large raindrops and hail particles (~1 cm). The relative intensity of the scattering pattern depends strongly on the ratio of particle size to the wavelength of the incident wave. If scattering is isotropic, the scattering pattern is symmetric about the direction of the incident wave. A small anisotropic particle tends to scatter light equally into the forward and rear directions. When the particle becomes larger, the scattered energy is increasingly concentrated in the forward directions with greater complexities.

Radiation scattered from a particle is a function of several things such as shape, size and index of refraction of particle, the wavelength of radiation, and surface geometry. For a spherical scatterer, the scattered radiation is a function of only viewing angle, index of refraction, and the size parameter defined as

$$\chi = 2\pi r/\lambda \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,

Anisotropy is the property of being directionally dependent, as opposed to isotropy, which implies identical properties in all directions.

Scattering is different from the reflection in the sense that the direction associated with scattering is unpredictable whereas the direction of reflection is predictable.

Scattering redirects incident EMR and deflects reflected EMR from its path.

Aerosols are airborne particulate matter.

Scattering is a very important consideration in remote sensing investigations because it can severely reduce the information content of remotely sensed data to the point that the imagery loses contrast and then it becomes difficult to differentiate one object from another.

Scattering is a process in which EMR interacts with particles or large gas molecules present in the atmosphere and cause it to be redirected in all direction from its original path by reflection and refraction.

Scattering depends on several factors such as the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere.

χ is the size of the particle,

r is the radius of the sphere, and

λ is the wavelength of the radiation.

Depending on the size parameter, the following two types of scattering take place.

- Selective scattering
- Non-selective scattering

a) Selective Scattering

When the scattering is wavelength-dependent, it is known as selective scattering. Selective scattering is of two types –, Rayleigh scattering and Mie scattering.

- **Rayleigh Scattering**

Rayleigh scattering is named after the English physicist, Lord Rayleigh, who offered its explanation. Rayleigh scattering is caused by very small particles and gas molecules with radii for less than the wavelength of EMR of interest (Fig. 2.6). Primarily, it occurs due to oxygen and nitrogen molecules in the sky; thus it is also known as ***molecular scattering***. Rayleigh scattering can be considered to be elastic scattering since the photon energies of the scattered photons is not changed. Scattering in which the scattered photons have either a higher or lower photon energy is called ***Raman scattering***. Usually, this kind of scattering involves exciting some vibrational modes of the molecules, giving lower scattered photon energy, or scattering off an excited vibrational state of a molecule which adds its vibrational energy to the incident photon.

The intensity of light is inversely proportional to the fourth power of the wavelength of the light.

$$I \propto 1 / \lambda^4 \quad \text{..} \quad (2)$$

where, I and λ are scattering intensity and wavelength of incident radiation, respectively.

Since the extent of scattering is inversely proportional to the 4th power of wavelength, shorter wavelengths such as blue light in the visible spectrum are affected the most. Rayleigh scattering is also responsible for red sunsets. During sunsets, sunlight passes through a longer path of air than at noon. Since the violet and blue wavelengths are scattered more during their longer path through the air than at noon, hence, what we see at sunset is the residue, i.e., the wavelengths of sunlight that are hardly scattered away, especially the oranges and reds.

The sky appears blue because as sunlight passes through the atmosphere, the shorter wavelengths (i.e. blue) of the visible spectrum are scattered more than the other (longer) visible wavelengths. However, during sunrise and sunset, the sky appears red because during the sunrise and sunset the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths light (red) to penetrate the atmosphere.

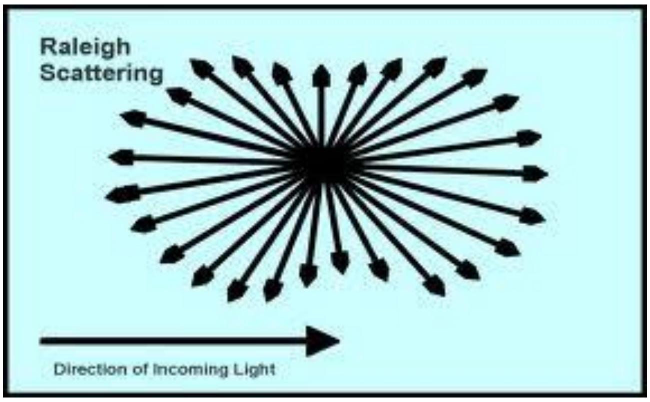


Fig. 2.6: Angular patterns of the scattered intensity for Rayleigh scattering (source: www.islandnet.com/~see/weather/almanac/arc2008/alm08oct.htm)

- **Mie Scattering**

Mie scattering occurs when the particles in the atmosphere are of the same size as the wavelengths being scattered. It is caused by particles with radii between 0.1 and 10µm such as dust, smoke and salt (aerosols). Dust, pollen, smoke and water vapour are common causes of Mie scattering, which tends to affect longer wavelengths. Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant and dominate when cloud conditions are overcast. The amount of scattering is greater than Rayleigh scattering. The violet and blue light are scattered away more with an increasing amount of smoke and dust particles in the atmosphere and only the longer orange and red wavelength light reach our eyes.

b) Non-Selective Scattering

Non-selective scattering is wavelength-independent. It is caused by particles (water droplets and ice fragments in clouds) whose radii exceed 10µm. The scattering is independent of the wavelength; all the wavelengths are scattered equally and not just blue, green or red. Non-selective scattering takes place in the lower portion of the atmosphere where there are particles more than 10 times the wavelength of the incident EMR. The most common example of non-selective scattering is the appearance of clouds as white. As clouds consist of water droplet particles and the wavelengths are scattered in equal amounts, the clouds appear white.

Water droplets and large dust particles can cause this type of scattering and thus cause fog and clouds to appear white to our eyes because blue, green, and red light are all scattered in approximately equal quantities.

Scattering creates an effect of haziness in remote sensing images, which reduces contrast in images. It also creates an ‘adjacency effect’ in which the signal recorded in a pixel partly incorporates the scattered signal from the neighbouring pixels. It is required to introduce an important term here, i.e., ‘path radiance’. The radiation that has been scattered in the Earth’s atmosphere and has reached the sensor without contacting the Earth’s surface is known as ***path***

radiance. It is essential to remove the path radiance from remote sensing images before any image analysis, particularly for multi-date images.

Distortions in remote sensing image due to atmospheric phenomena and the relevant correction processes are discussed in Unit 14 of MGY-102.

2.2.3 Absorption

By the time EMR is recorded by a sensor, it has already passed through the Earth's atmosphere twice (once while travelling from the Sun to the Earth and the second time while travelling from the Earth to the sensor). When light travels through the atmosphere, a gradual reduction in its intensity occurs. The reduction in intensity with distance in a medium (i.e., atmosphere) is called ***attenuation of light*** as shown in Fig. 2.7. This attenuation occurs mainly because of the scattering and absorption of light in the atmosphere. ***Absorption*** is the process by which radiation (radiant energy) is absorbed and converted into other forms of energy such as heat or chemical energy. Absorption is wavelength-dependent. Absorption of light occurs because part of the incident light is transformed into the energy of motions of the atoms in the medium. It can take place in the atmosphere or on the terrain.

Strength of absorption is represented by absorption cross section σ_a in units of cm^2. It is basically division of absorption coefficient and number density (number of molecules per unit volume). It represents a molecule's effective area for absorption of radiation.

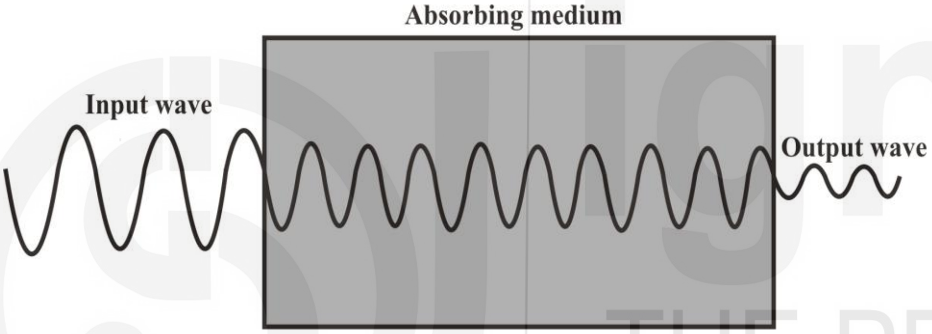


Fig. 2.7: Attenuation of a light wave in an absorbing medium.

To understand it better, let us take an example. Grass appears green because it scatters green light more effectively than red and blue light. Apparently, red and blue light incident on the grass is absorbed. The absorbed energy is converted into some other form, and it is no longer present as red or blue light. In the visible spectrum, absorption of energy is nearly absent in molecular atmospheres. Clouds also absorb very little visible light. Both scattering and absorption remove energy from the beam of light. Thus, the beam of light is attenuated, and we call this ***attenuation extinction***.

There are three main atmospheric constituents, which absorb solar radiation. The three constituents are ozone (O_3), carbon dioxide (CO_2), and water vapour (H_2O). Ozone gas, which plays an important role in the Earth's energy balance, has a maximum concentration in the stratosphere (at the altitude of about 20 to 30 km). Ozone absorbs high energy; it prevents short wavelength portion of the ultraviolet spectrum to transmit through the lower atmosphere.

Carbon dioxide, which occurs mainly in the lower atmosphere, absorbs radiation in the mid and far infrared regions of the electromagnetic spectrum. Maximum absorption occurs in the region from about 13 to 17.5 µm. The abundance of water vapour significantly varies with time and location. However, it is commonly present in the lower atmosphere. Water vapour contributes significantly to the absorption of radiation particularly in several bands in the region between 5.5 and 7 µm.

It is important to note here that all media show some absorption. Media that absorbs all wavelengths more or less equally are said to show general absorption whereas media that absorb some wavelengths more strongly than others are said to show selective absorption.

The ability of a medium to absorb energy is measured as the absorptance and is expressed as

$$\text{Absorptance} \quad (\alpha) = \frac{\text{Absorbed radiation}}{\text{Incident radiation}}$$

From a remote sensing point of view, absorption in the visible, near Infrared and thermal Infrared regions of EMS is important. A significant amount of absorption in visible and near infrared (NIR) band is basically due to molecular oxygen and ozone, water vapour, carbon dioxide and some other minor gases. Water vapour, carbon dioxide, ozone, methane and chlorofluorocarbons absorb radiation in the thermal infrared band.

As you know, windows are used as a motion for air ventilation and lights. Similarly, there are certain portions of the electromagnetic spectrum where light can travel through the atmosphere with much absorption. The absorption by various constituents in the atmosphere results in limiting portions of the EMR from reaching the Earth. Hence, the Earth’s atmosphere is not completely transparent to EMR. For remote sensing, this limits us to portions of the EMS where radiation is not strongly absorbed. This portion of the atmosphere is called ***Atmospheric Windows***.

The position, extent and effectiveness of the atmospheric window are determined by the absorption spectra of atmospheric gases. The energy outside the atmospheric windows is severely attenuated by the atmosphere and hence cannot be effective for remote sensing. The most important atmospheric windows are the visible window (0.4 – 0.7 µm), the 3.7 µm window, the microwave windows (2 – 4 mm and >6 mm), and the 8.5 –12.5 µm window as shown in Fig. 2.8. The visible window is mainly affected by ozone absorption and by molecular scattering. The 8.5 – 12.5 µm infrared window is punctuated by the 9.6 µm ozone absorption band and is affected by water vapour absorption.

The dark (black) areas in Fig. 2.8 denote regions of the EMS where the atmosphere absorbs most of the radiation and light (grey) areas are the atmospheric windows.

The infrared channels are most often between 1 and 30 µm. The most common infrared band for meteorological satellites is in the 10 – 12.5 µm window, in which the atmosphere is relatively transparent to radiation upwelling from the Earth’s surface. Even in the atmospheric window regions, scattering by the atmospheric constituents produces a spatial redistribution of energy.

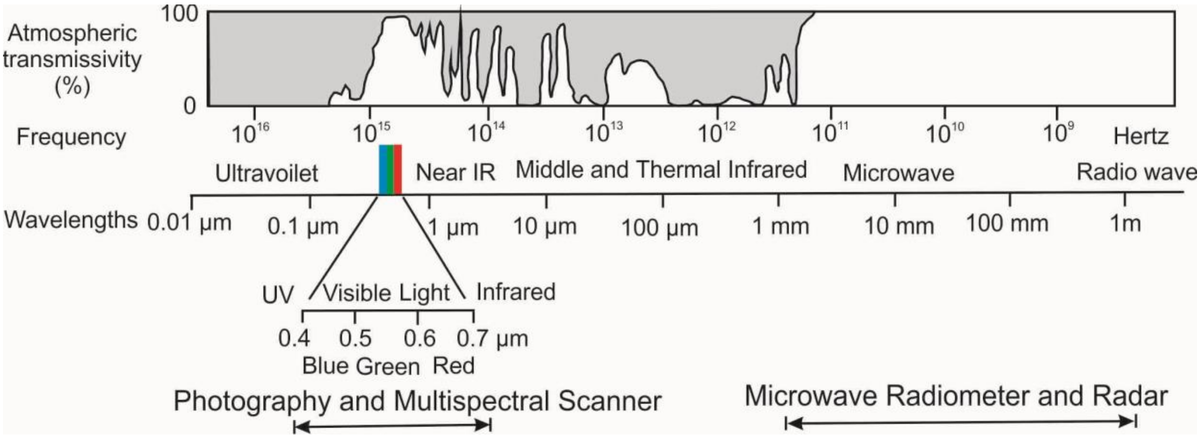


Fig. 2.8: Atmospheric windows in the EM spectrum. Chemical notations (CO_2, O_2, etc.) indicate the gases responsible for blocking the radiation at a particular wavelength. (Source: Redrawn from Bhatta, 2010)

In a broad sense, remote sensing of the Earth's surface is generally confined to certain wavelength regions as given in Table 2.1.

Table 2.1: Atmospheric windows utilised in remote sensing of the Earth's .surface with respect to wavelength region

S. No.	Atmospheric Window (μm)	Region
1	0.3 – 0.4 μm	UV
2	0.4 – 0.7 μm	Visible
3	0.7 – 3.0 μm	Reflected infrared
4	3.0 – 5.0 μm	Thermal infrared
5	8.0 – 11.0 μm	Thermal infrared
6	1.0 mm – 1.0 m	Microwave

SAQ 1

a) Point out the mechanisms that are responsible for the interaction of EMR and atmosphere.

b) What do you mean by scattering?..

2.3 ENERGY-EARTH INTERACTION

Incoming EMR from the sun is subjected to reflection, transmission and absorption by the Earth's surface. The absorbed short wave (visible) radiation by Earth's surface is emitted as a longwave radiation (infrared band). The complete process is shown in Fig. 2.9. This physical process changes the magnitude, direction, wavelength, polarisation and phase of the EMR. These changes are detected by the remote sensor and enable the interpreter to obtain useful information about the object of interest. The remotely sensed data contain both spatial information (size, shape and orientation) and spectral information (tone, colour and spectral signature).

There are three major regions in EMR-Earth interaction that are important in remote sensing. The visible and NIR spectral band from 0.3 μm to 3 μm is known as the ***reflective region***. In this band, the Sun's radiation sensed by the sensor is reflected by the Earth's surface. The band corresponding to the atmospheric window between 8 μm and 14 μm is known as the ***thermal infrared band***. The energy available in this band for remote sensing is due to thermal emission from the Earth's surface. Both reflection and self-emission are important in the intermediate band from 3 μm to 5.5 μm.

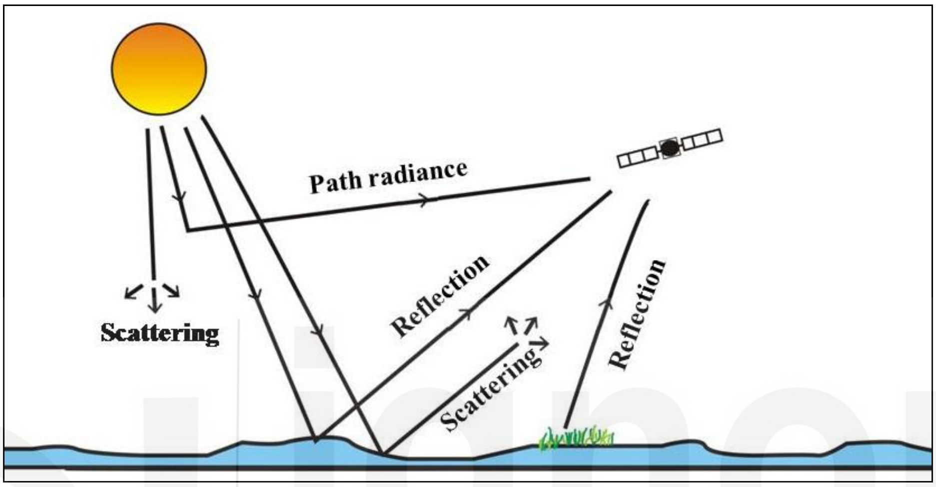


Fig. 2.9: Interaction of EMR with Earth's surface.

In the microwave region (1-30 cm) of the spectrum, the sensor is normally a radar, which is an active sensor, as it provides its own source of EMR. The EMR produced by the radar is transmitted to the Earth's surface and the EMR reflected (back-scattered/radar return) from the surface is recorded and analysed. The microwave region can also be monitored with passive sensors, called ***microwave radiometers***, which record the radiation emitted by the Earth's surface and its atmosphere in the microwave region. We will now discuss two phenomena, i.e., reflection and transmission.

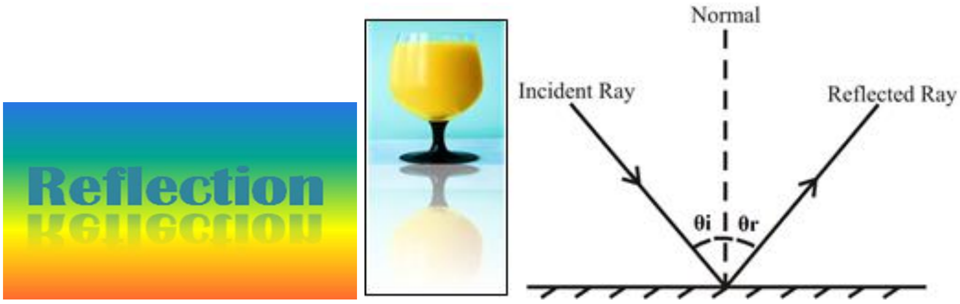
2.3.1 Reflection

When light travelling in a medium (i.e., atmosphere) encounters a surface leading to a second medium (Earth's surface), part of the incident light is returned to the first medium from which it came. This phenomenon is called ***reflection***. In other words, reflection is the phenomenon in which the incident radiation is returned back to the same medium due to the discontinuity of electromagnetic characteristics at the interface of two media. Reflection occurs when a ray of light is re-directed as it strikes a surface as shown in Fig. 2.10. Understanding reflection is important since about a third of the energy from the sun is reflected.

Let us recall the laws of reflection here. As you know, the first law of reflection states that if the reflecting surface is very smooth, the reflection of light that occurs is called specular or regular reflection. The laws of reflection are as given below:

- the incident ray (***θi)***, the reflected ray and the normal to the reflection surface at the point of the incidence lie in the same plane as shown in Fig. 2.10(c). This plane is called the ***plane of incidence.***

- the angle of reflection (***θ****r*) (the angle which the reflected ray makes to the same normal) is equal to the angle of incidence (the angle which the incident ray makes with the normal) as shown in Fig. 2.10(c).



(a) (b) (c)

Fig. 2.10: An illustration of reflection of light. You can see inverted images of the (a) letters and (b) the glass object on the floor. You can see the inverted images of the objects on the shiny floor because of the reflection of light (c) (θi is the angle of the incident ray and θr is the angle of the reflected ray).

The ability of a medium to reflect energy is measured as the reflectance and it is defined as a ratio between reflected radiation and incident radiation [*ρ(λ*)]:

$$\text{Reflectance } \rho(\lambda) = \frac{\text{Reflectance radiation}}{\text{Incident radiation}}$$

Reflectance [*ρ(λ)*] is the ratio of reflected energy to incident energy and hence is a measure of how much radiation is reflected off a surface. Its value ranges from 0 to 1. Value of 0 means that 0% of incident radiation is reflected off the surface and the value of 1indicates that 100% of the incident radiation is reflected.

Spectral reflectance [*ρ(λ)*] is the ratio of reflected energy to incident energy as a function of wavelength. Various materials of the Earth's surface have different spectral reflectance characteristics. Spectral reflectance is responsible for the colour or tone in a photographic image of an object. Trees appear green because they reflect more of the green wavelength. The values of the spectral reflectance of objects averaged over different, well-defined wavelength intervals comprise the spectral signature of the objects or features by which they can be distinguished. To obtain the necessary ground truth for the interpretation of multispectral imagery, the spectral characteristics of various natural objects have been extensively measured and recorded.

The spectral reflectance is dependent on wavelength. It has different values at different wavelengths for a given terrain feature. The reflectance characteristics of the Earth's surface features are expressed by spectral reflectance, which is given by:

$$\rho(\lambda) = [\ E_R(\lambda) / E_I(\lambda)\ ] \times 100 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

where,

$\rho(\lambda)$ is spectral reflectance (reflectivity) at a particular wavelength,

$E_R(\lambda)$ is the energy of wavelength, reflected from the object, and

$E_I(\lambda)$ is the energy of wavelength, incident upon the object.

The plot between $\rho(\lambda)$ and λ is called a ***spectral reflectance curve***. This varies with the variation in the chemical composition, physical conditions and EM properties of the object, which results in a range of values. The spectral response patterns are averaged to get a generalised form, which is called the spectral response pattern for the object concerned. Spectral signature is a term used for a unique spectral response pattern, which is characteristic of a terrain feature. Fig. 2.11 shows a set of typical reflectance curves for three basic types of Earth surface features, viz., the healthy vegetation, the dry bare soil (grey-brown and loamy) and clear lake water.

Johann Heinrich Lambert (1728-1777) was a Swiss mathematician, physicist, and astronomer. He conducted many experiments designed to describe the behaviour of light. Lambert was the first to introduce hyperbolic functions into trigonometry. He was also the first mathematician to address the general properties of map projections. He also developed a theory of the generation of the universe that was similar to the nebular hypothesis.

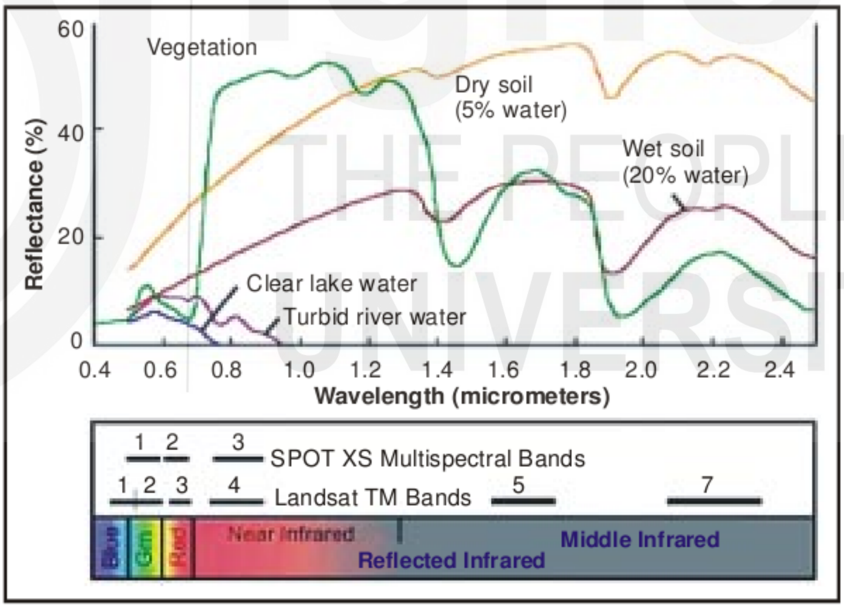


Fig. 2.11: Typical spectral reflectance curves for vegetation, soil and water.
(Source: Liliesand and Kiefer, 1993)

The spectral characteristics of these three main Earth surface features are discussed below.

The nature of reflection depends on the sizes of surface irregularities (i.e., roughness or smoothness) with respect to the wavelength of the radiation considered. If the surface is smooth in comparison to wavelength, then specular reflection occurs (Fig. 2.12a). In specular reflection, almost all the incident radiation is redirected in a single direction. For such reflection, the angle of incidence is equal to the angle of reflection. Specular reflection can occur with surfaces such as smooth metal and calm water bodies. If the surface is rough relative to the wavelength, then energy is scattered more or less equally in all directions as shown in Fig. 2.12 d. This property of light is known as ***diffuse reflection***. So, whichever angle we observe from, a perfectly diffuse reflector would have equal brightness in all the directions. It is largely by the diffuse reflection that we see non-luminous objects around us. Uniform grass surface is a good example of diffuse reflectors. Perfectly diffuse reflectors are also called ***Lambertian surface*** since the concept of the perfectly diffuse reflecting surface is derived from the work of J.H. Lambert. He observed that the perceived brightness of a perfectly diffuse surface does not change with the angle of view. This behaviour of light is known as ***Lambert's cosine law***.

It is important to note here that the two laws of reflection are obeyed in specular reflection. They do not hold in case of irregular or diffuse reflection. Much of the reflection of solar radiation takes place from the top of clouds and other materials in the atmosphere and hence a significant amount of this energy is reradiated back to space.

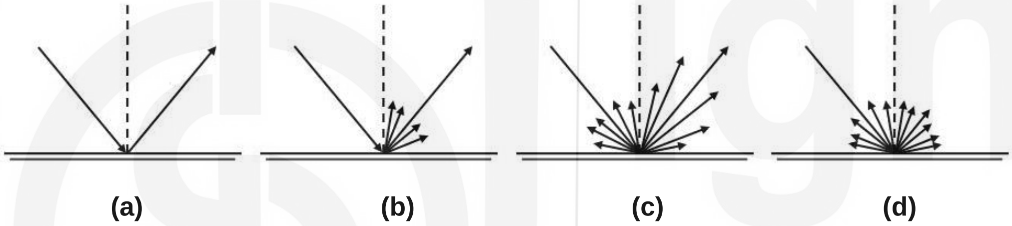


Fig. 2.12: Different types of scattering surfaces (a) perfect specular reflector; (b) near-perfect specular reflector; (c) near perfect diffuse reflector; and (d) perfect diffuse reflector (Lambertian surface).

In optics, the refractive index of a substance is a measure of the speed of light in that medium and is expressed as a ratio of the speed of light in a vacuum relative to the medium i.e. n = speed of light in a vacuum/speed of light in the medium.

To have true reflection, a real discontinuity in the index of reflection is required. The spatial scale of discontinuity, compared to the wavelength of the radiation, must also be significant for a perfect reflection to take place. The energy reflects off at an interface, at the same angle at which it initially strikes the surface, as seen in Fig. 2.12. Of all the interactions in the reflective region, surface reflections are the most useful and revealing in remote sensing applications. The reflection intensity depends on the surface refractive index, absorption coefficient and the angles of incidence.

As you have now understood, reflection exhibits certain fundamental characteristics (as stated in laws of reflection) that are important in remote sensing.

2.3.2 Transmission

When electromagnetic radiation is incident on Earth's surface, part of the energy gets scattered from the surface (which is known as ***surface scattering***) and a part of the energy gets transmitted into the medium. In homogeneous materials, the radiation is simply transmitted but in inhomogeneous materials, the transmitted radiation gets further scattered (which is known as ***volume***

scattering). The signal received by sensors is a combination of both processes, i.e., surface and volume scattering.

Transmission of radiation occurs when radiation passes through a substance without significant attenuation (Fig. 2.13). The ability of a medium to transmit energy is measured as the **transmittance** and it is defined as the ratio between transmitted radiation and incident radiation (τ):

$$\text{Transmittance } (\tau) = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}$$


(a) (b)

Fig. 2.13: An illustration of transmission of light: a) The transparent glass allows light to pass through it hence you can see the juice inside; and b) Translucent frosted glass scatters the light that passes through it hence you are not able to see the object inside.

Water is a good example of a transmitter on Earth surface, which is capable of transmitting significant amounts of radiation. However, there are many other materials that act as transmitters. It is important to note here that the transmittance of materials varies with wavelength. For example, plant leaves are generally opaque to visible radiation but they transmit a significant amount of radiation in the infrared part of the EMS.

The transmittance of films and filters used in aerial cameras are also important in remote sensing. The transmission also occurs in the atmosphere. Atmospheric transmittance may be characterised either by transmission coefficient or transmittance (τ), which is equal to the fraction of radiation that passes through the atmosphere when rays fall vertically or by the turbidity factor, which indicates the extent to which the transmittance of an actual atmosphere under given conditions differs from the transmittance of an ideal (ideally clean and dry) atmosphere. Fig. 2.14 shows the transmittance of different gases.

Atmospheric transmittance is dependent on the air mass penetrated by rays, as well as on the amount of water vapour and dust in the air. It varies for radiations of different wavelengths; the smaller the atmospheric absorption and scattering, the greater the atmospheric transmittance.

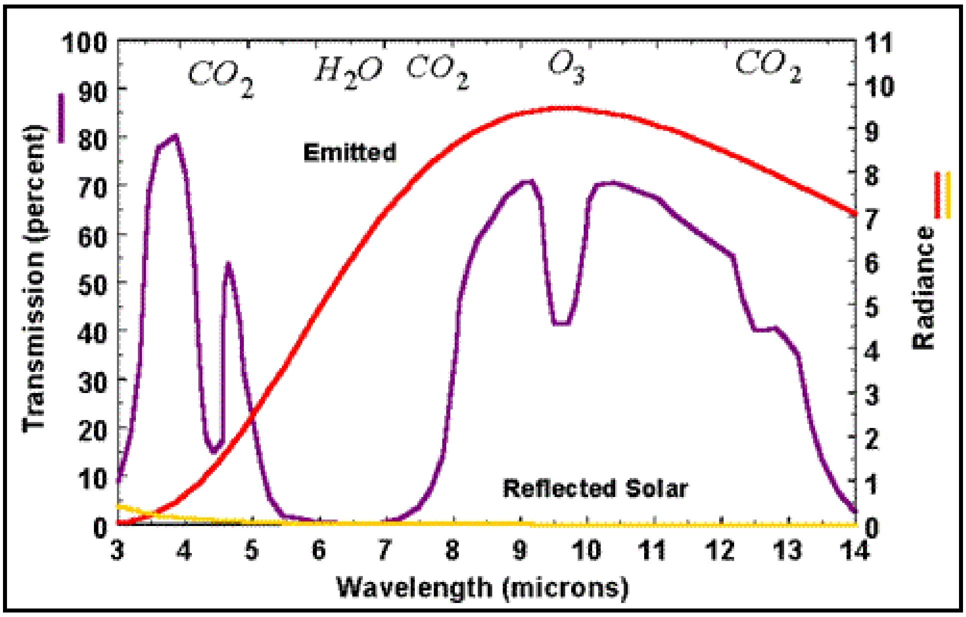


Fig. 2.14: Illustration showing the amount of energy absorbed and transmitted for different gases. (Source: www.everythingweather.com/atmospheric-radiation/transmission.shtml)

The atmospheric transmittance of the rays of a celestial body decreases as the body approaches the horizon because the length of the path of the rays in the air increases, which is expressed by the optical air mass.

Atmospheric transmittance varies at different points on the Earth's surface. The most transmissive air is in Polar regions because it contains the least amount of dust and moisture. Changing humidity and the dust content in the air at a given point throughout the year determine the annual atmospheric transmittance at that point. The atmosphere is most transmissive in winter and least transmissive in summer. A significant decrease in atmospheric transmittance is observed as a result of increasing air pollution, especially when the dust content increases.

SAQ 2

a) What is the range of the thermal infrared band?

b) Spectral reflectance is the ratio of ______________________.

2.4 IMPORTANT TERMINOLOGIES

It is essential for us to get introduced to some important radiometric terminologies which are often used in remote sensing.

2.4.1 Radiant Energy

It is the quantity of energy carried by the EMR. It is a measure of the capacity of radiation to perform work (heat, movement, etc.). Radiant energy refers to the quantity of energy propagating into or through a surface of a given area in a given period of time. It is represented as Q and its unit is Joules (J). When radiant energy is considered at a particular wavelength, it is called ***spectral radiant energy*** and is represented as Q_λ.

2.4.2 Radiant Flux

It is the rate of flow of radiant energy onto or through a surface. To understand it better, it may be compared to the rate of flow of water past a position along a pipe. It is represented by Φ and is measured in Joules per second (J s^{-1}) or watts (W).

When the radiant flux is considered at a wavelength, it is called ***spectral radiant flux*** and is represented as Φ_λ. It is measured in Joules per second per micron (J s^{-1} m^{-1}) or watts per micron (W m^{-1}).

2.4.3 Radiant Intensity

We can further refine our measurement of radiant flux by including a direction. Radiant flux leaving a source per unit solid angle in a given direction is called radiant intensity. It is represented by I and its unit is watts per steradian (W sr^{-1}).

2.4.4 Irradiance and Exitance

Now we can refine the measurement of radian flux by including the size of the area. It is the amount of radiant flux incident (arriving) upon per unit area of a surface. It is represented as E and its unit is watts per meter square (W m^{-2}). When it is considered at a wavelength, it is represented as E_λ and is expressed as

$$E_\lambda = \Phi_\lambda / A \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

The amount of radiant flux emitted (leaving) from a unit area of a surface is called exitance. It is represented as M. When it is considered at a wavelength, it is represented as M_λ and is expressed as

$$M_\lambda = \Phi_\lambda / A \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

2.4.5 Radiance

It is the most precise radiometric measurement in remote sensing. It is the radiant flux per unit solid angle leaving a per unit projected source area in a given direction. In other words, it is the radiant intensity per unit of the projected source area. To better understand the concept of radiance, you can compare it with what you would see if you were in an aeroplane and looking at the ground through a telescope. You would only see the energy that exited the ground and came through the telescope at a specific solid angle (Ω).

Radiance is represented as L and its unit is watts per meter square per steradian (W m^{-2} sr^{-1}). When the radiance is considered in a particular wavelength, it is represented as L_λ.

$$L_\lambda = \frac{(\phi_\lambda / \Omega)}{A \cos\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

2.4.6 Albedo

It is defined as the ratio of the electromagnetic energy reflected or diffused by a surface to the total incident energy. The albedo of objects varies from object to object. Fresh snow has higher albedo (in the range of about 75 to 95%) and dark soil has lower albedo (in the range of about 5 to 10%). Albedo also varies with the Sun's angle and the variations are large with tilted angles of the solar rays from 0º to 30º.

Some of the above discussed and frequently used terminologies are summarised in Table 2.2.

Table 2.2: **Important radiometric terminologies often used in remote sensing.**

Term	Concept	Symbol	Unit
Radiant Energy	The quantity of energy propagating into, off of or through a surface of a given area in a given period of time	Q	J
Radiant Flux	The rate at which photons (quanta) strike a surface, or in other words, rate of flow of radiant energy onto, off of or through a surface	Φ	$J\ s^{-1}$ or W
Radiant Intensity	Radiant flux leaving a source per unit solid angle in a given direction	I	$W\ sr^{-1}$
Irradiance	Radiant flux incident (arriving) upon per unit area of a surface	E	$W\ m^{-2}$
Radiant Exitance	Radiant flux emitted (leaving) from a unit area of a surface	M	$W\ m^{-2}$
Radiance	The radiant flux per unit solid angle leaving a per unit projected source area in a given direction	L	$W\ m^{-2}\ sr^{-1}$
Reflectance	The ratio of reflected energy to incident energy	$\rho(\lambda)$	%
Albedo	The ratio of the electromagnetic energy reflected or diffused by a surface to the total incident energy	A	%

2.5 ACTIVITY

You have read about the interaction of electromagnetic radiation with the atmosphere and the Earth's surface. You are now aware of different types of phenomena taking place in the journey of electromagnetic radiation from the Sun to Earth and back to the satellite sensor. You might be enthusiastic to do some activities to better understand these phenomena.

1. As we know now, the colour of an object is not actually within the object itself. Rather, the colour is in the light that shines upon it and is ultimately

reflected or transmitted to our eyes. So, you can try to see a yellow-coloured object (yellow is a mixture of red and green colour) in red light. You can note down the colour changes observed.

2. You can build your own filter wheel (using different coloured films) through which you can examine a colour image.

3. You can observe the changes in the colour of sun rays from early morning to afternoon and again till evening. The process of scattering will be clearly understood by you.

2.6 SUMMARY

Let us summarise what we have studied in this unit:

- Scattering, reflection and absorption are important phenomena that take place when EMR interacts with the atmosphere and the Earth's surface.
- In the atmosphere, scattering and absorption are the prominent mechanisms for attenuation of the radiation.
- Reflection only deflects the radiation from its actual path of propagation because of variations in the EM properties of the medium.
- In some parts of the EMS, radiation is either not strongly absorbed or remains un-attenuated and are called atmospheric windows.
- Reflection and scattering are dominant over Earth's surface and they depend upon the refractive index, absorption coefficient and the EMR-Earth's surface interaction geometry.

2.7 TERMINAL QUESTIONS

1. How does scattering differ from absorption, although both attenuate the radiation?

2. Define atmospheric windows and state the infrared window which is used for remote sensing.

3. Why does the sky appear blue and Sun on the horizon red?

4. What is spectral reflectance?

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2.10 ANSWERS

SAQ 1

a) Refraction, reflection, scattering, absorption and transmission.

b) Scattering is a physical process by which a particle in the path of an EM wave continuously abstracts energy from the incident wave and re-radiates that energy in all directions.

SAQ 2

a) The band corresponding to the atmospheric window between 8 μm and 14 μm is known as the thermal infrared band.

b) Reflected energy to incident energy.

Terminal Questions

2. Scattering is redistribution of incident energy through the process of reflection and refraction, however in absorption, one form of EMR is transformed to another form through the process of emission.

3. A range of EM wavelengths to which Earth's atmosphere is largely or partially transparent is called atmospheric windows. The infrared window of 10 - 12.5 μm is used for remote sensing in the case of meteorological satellites.

4. Sunlight reaches Earth’s atmosphere and is scattered in all directions by all the gases and particles in the air. Blue light is scattered in all directions by the tiny molecules of air in Earth's atmosphere. Blue is scattered more than other colours because it travels as shorter, smaller waves. This is why we see a blue sky most of the time. As the sun gets lower in the sky, its light passes through a longer distance in the atmosphere to reach you. Even more of the blue light is scattered, allowing the reds and yellows to pass straight through to your eyes. Hence, the Sun at the horizon appears red.

5. Spectral reflectance is the ratio of reflected energy to incident energy as a function of wavelength.