Subject	Geology
Paper No and Title	**Remote Sensing and GIS**
Module No and Title	Basic Physics of Remote Sensing
Module Tag	RS & GIS II

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1. Introduction

The term 'remote sensing', was given by Ms. Evelyn Pruitt of U.S. Naval Research Office sometime in the 1950s. It can be defined as means acquiring information about a phenomenon, object or surface from a particular distance. This field is attributed to the various developments in satellite technology, computers, sensors and spacecraft from 1960 onwards for collecting information about the earth's surface features both natural as well as manmade. At a temperature above absolute zero (i.e. -273.15°C and -459.67°F temperature), all objects radiate electromagnetic energy by virtue of their atomic and molecular vibrations. The total amount of emitted radiation increases with the body's absolute temperature, and its peaks are at progressively shorter wavelengths. The Sun, being a major source of energy for the remote sensing, radiation and illumination, have a sharp power peak around 0.5 µm, and allows to capture reflected Sun's energy using conventional cameras, films or sensor on board satellite. If we see Earth as such, where there are n numbers of a feature. And everything in nature has its own unique distribution of reflected, emitted and absorbed Sun's radiation. These spectral characteristics in remote sensing are being used to distinguish one feature from another in order to obtain reliable information about shape, size, area and other physical and chemical properties. If we know the spectral characteristics of any human or natural feature, we can pick an appropriate sensor/detector to make the desired measurement. The energy emitted by the Sun is mainly divided into 40% visible light, 50% IR, 9% UV and 1% x-ray, radio, etc. The energy which is emitted from the `surface' of the Sun, i.e. the Photosphere is about 5700°K. This energy encounters first the atmosphere than earth and then again, atmosphere before it reaches the sensor on board a sensor. Before discussing the subject matter of electromagnetic radiation (EMR) let us understand some of the basic concepts and principles of energy.

2. Electromagnetic Radiation

EMR is a dynamic form of energy that propagates as wave motion at a velocity of light i.e. c = 3 x 1010 cm/sec. The parameters that characterize a wave motion are wavelength (λ), frequency (ν) and velocity (c) and the relationship between these three are commonly known by the following formula:

$$c = vX$$

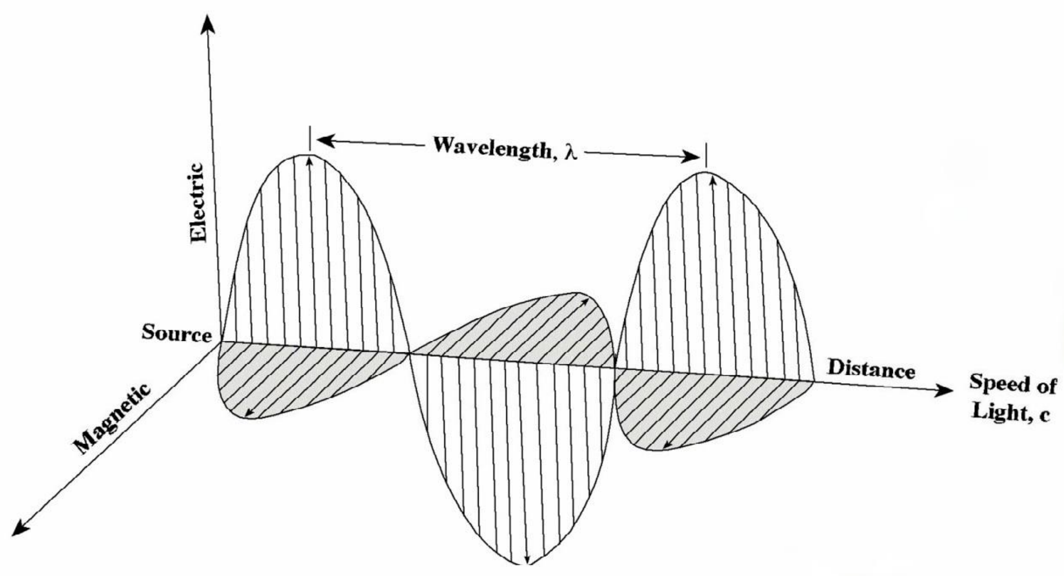

Fig. 1

Electromagnetic energy radiates in accordance with the basic wave theory, and the theory describes the EM energy travels in a harmonic sinusoidal fashion at the velocity of light shown in Fig. 1. Although many characteristics of EM energy are easily described by wave theory another theory known as particle theory, which describes how EM energy interacts with any matter either in the atmosphere or on the surface of the Earth. It suggests that EMR is composed of many discrete units called photons/quanta. The energy of quantum is expressed as follows:

$$Q = hc/X = hcv$$

Where Q is the energy of quantum,
h is the Planck's constant,
λ is the wavelength,
ν is the frequency and c is the velocity

Table 1 and Figure 2 shows the major divisions of the electromagnetic spectrum and some of these regions like visible region (4×10^{-5} cm < λ < 7.6×10^{-5} cm), IR region (8×10^{-5} cm < λ < 10^{-1} cm) and micro wave region (10^{-1} cm < λ < 10^{2} cm) are commonly used in the remote sensing.

Table 1: Principal Divisions of the Electromagnetic Spectrum.

S.No.	Division	Wavelength
1	Gamma rays	(10^{-11} cm < λ < 10^{-8} cm)
2	X-rays	(10^{-8} cm < λ < 10^{-6} cm)
3	Ultraviolet light	(10^{-6} cm < λ < 4×10^{-5} cm)
4	Visible light	(4×10^{-5} cm < λ < 7.6×10^{-5} cm)
5	Infra-red light	(8×10^{-5} cm < λ < 10^{-1} cm)
6	Microwaves	(10^{-1} cm < λ < 10^{2} cm)
7	Radiowaves	(10^{2} cm < λ)

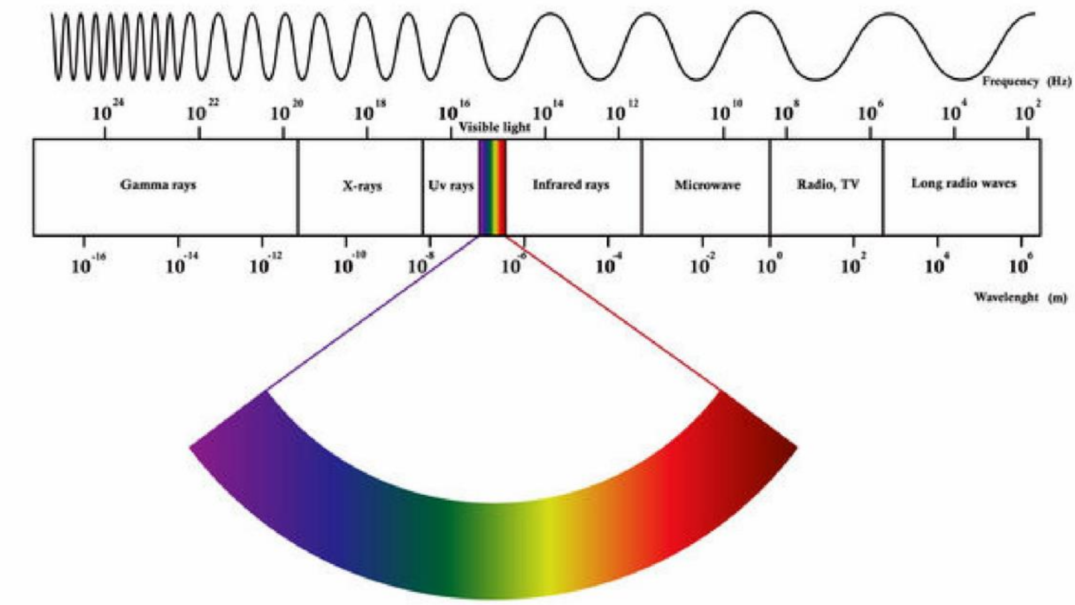

Fig. 2

3. Electromagnetic Radiation Quantities

3.1 ***Radiant Energy:*** Radiant energy is the energy carried by electromagnetic radiation. Radiant energy causes the detector element of the sensor to respond to EMR in some appropriate manner. Unit of Radiant Energy Q is Joule.

3.2 ***Radiant Flux:*** Radiant flux is defined as the total power of radiation emitted by a source e.g. Sun, lamp, or bulb transmitted through a surface (Fig. 3). It is the time rate of flow of radiant energy. The unit of Radiant flux is joule/second or watt (W) and is denoted by φ (Phi) (Fig. 3).

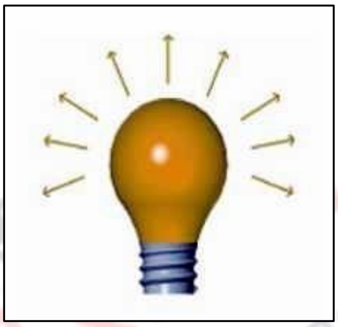

Fig. 3

3.3 ***Irradiance:*** Irradiance is the Radiant flux intercepted by a plane surface per unit area of the surface (Fig. 4). The direction of the flux is not specified. It can arrive at the surface from all directions within a hemisphere over the surface and the unit of Irradiance E is W/m^2 or Wm^{-2} (Watt per square meter) and is denoted by E.

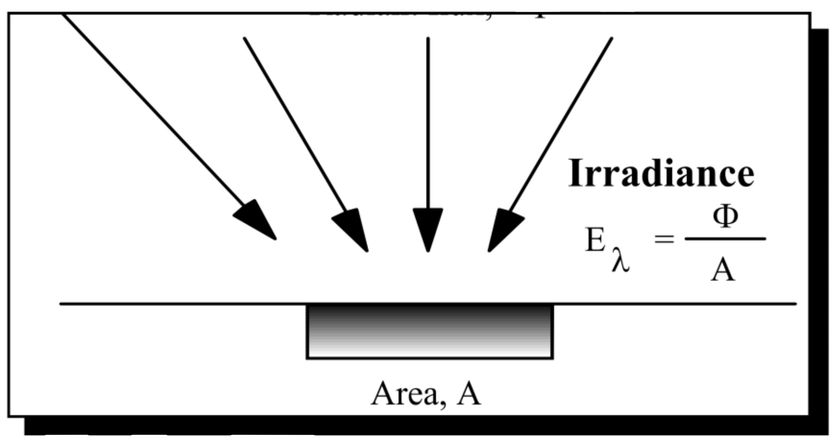

Fig. 4

3.4 ***Exitance (emittance):*** Exitance is the Radiant flux leaving a surface per unit area of the surface. The flux may leave the surface in any or all directions within a hemisphere over the surface and it is denoted by M (Fig. 5).

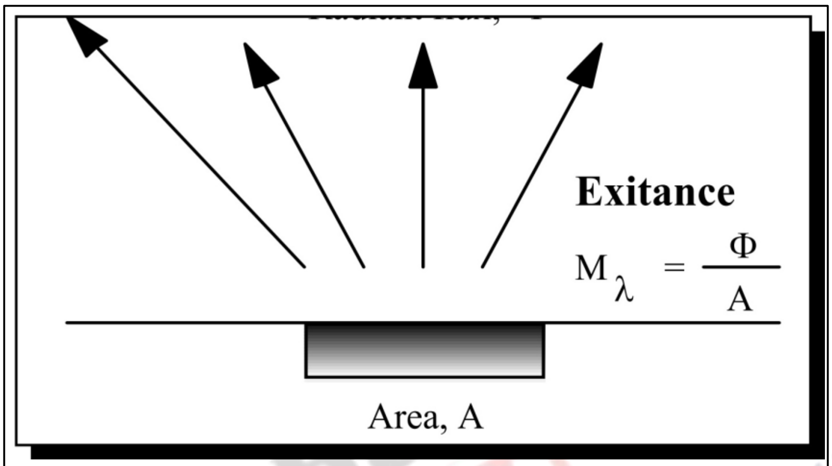

Fig. 5

3.5 ***Solid Angle:*** It is the cone angle subtended by the portion of a spherical surface at the center of the sphere (Fig. 6). It is equal to the area of the spherical surface divided by the square of the radius of the sphere, its unit is steradian (sr), and it is denoted by ω (omega).

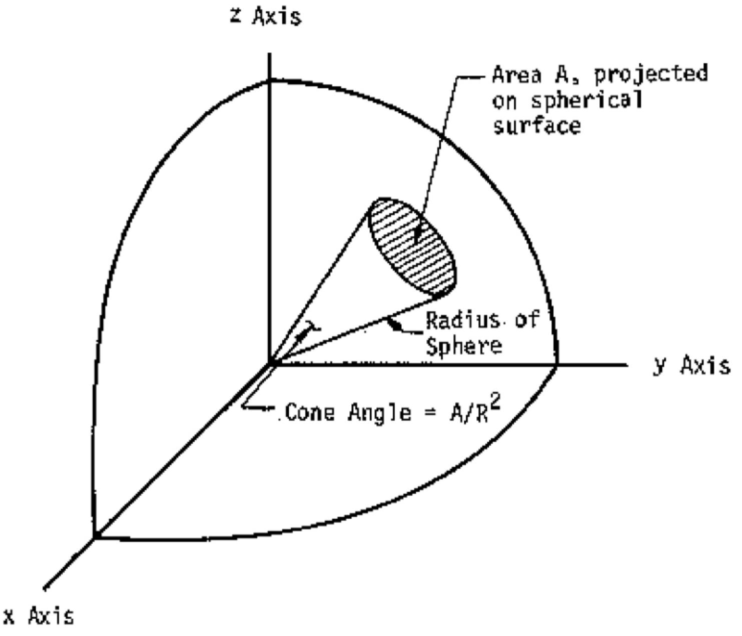

Fig. 6

3.6 ***Radiant Intensity:*** Radiant Intensity (Ie) of a point source in a given direction is the radiant flux per unit solid angle leaving the source in that direction (Fig. 7). Unit of Radiant Intensity is Watts/sr and is denoted by Ie.

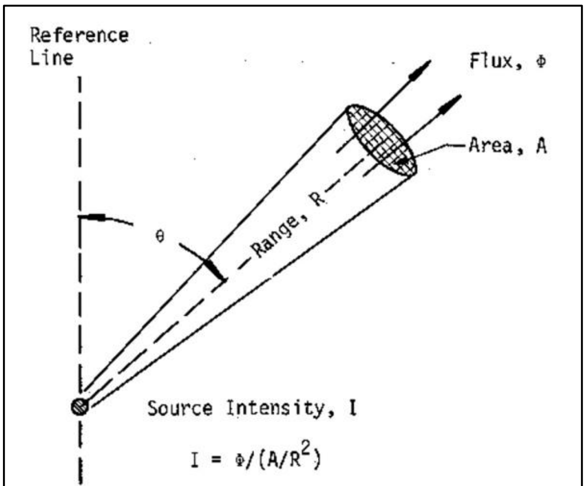

Fig. 7

3.7 ***Radiance:*** Radiance is defined as the radiant flux per unit solid angle leaving an extended source in a given direction per unit-projected area of the source in that direction (Fig. 8). The unit for Radiance is W m^{-2} sr^{-1} and is denoted by L. The concept of radiance is intended to correspond to the concept of brightness. The projected area in a direction that makes an angle θ (Theta) with the normal to the surface of area A is Acosθ. The relationship between radiant intensity and radiance is described as follows:

$$I = L.A.\cos\theta$$

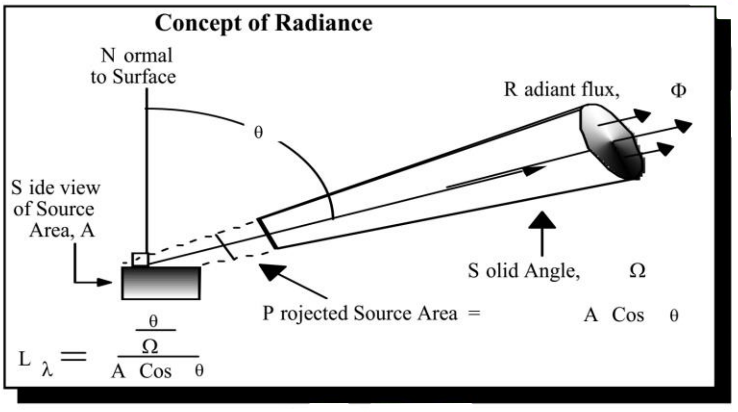

Fig. 8

A comparative picture of radiant energy, radiant flux, and irradiance etc. shown below in (Fig. 9) which can give a better understanding of these important terminologies that is very important for the better understanding of the remote sensing.

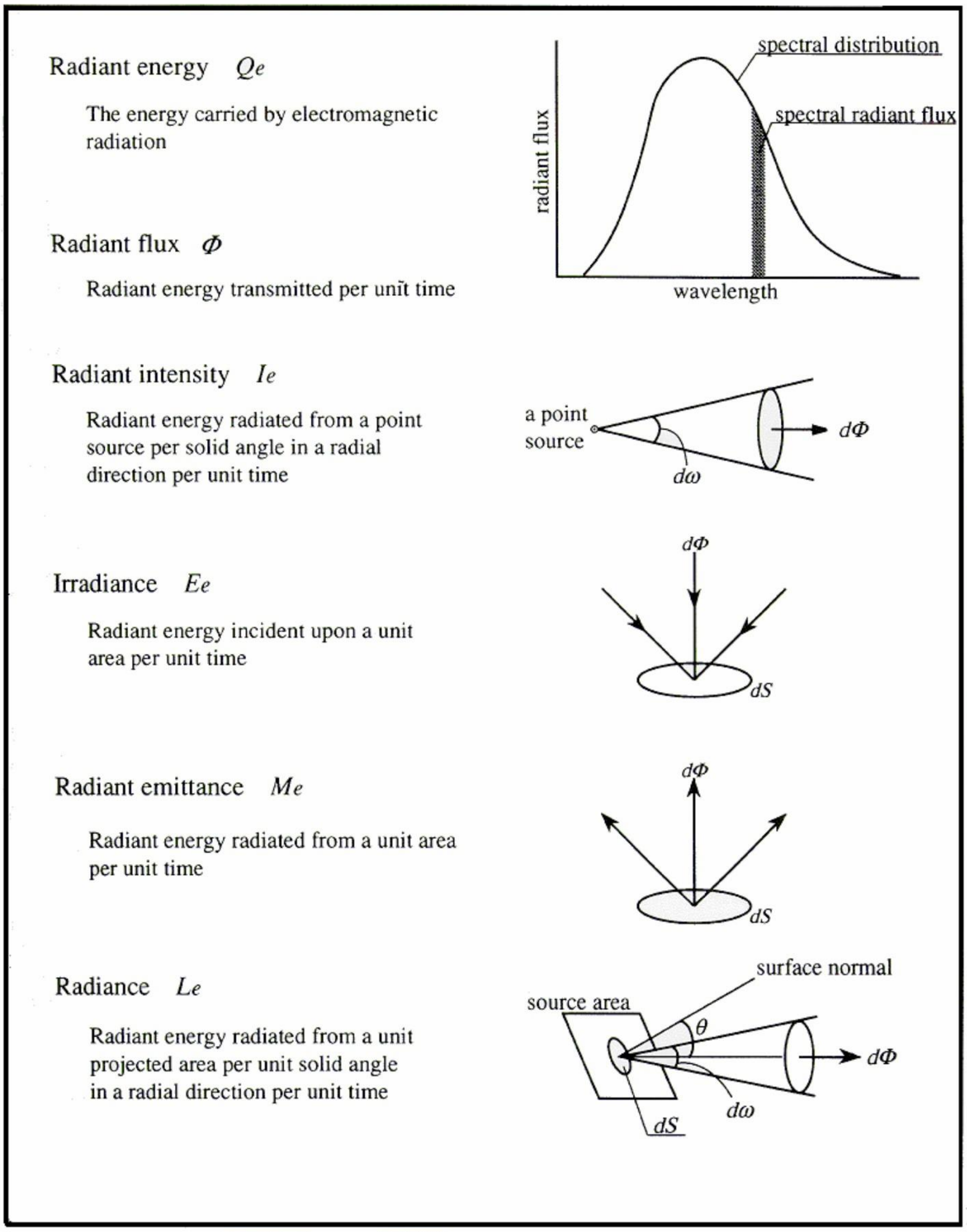

Fig. 9

3.8 ***Lambertian Surface:*** The plane source or surface for which the radiance L does not change as a function of angle of view is called Lambertian, which is known as perfectly diffused surface. For a Lambertian surface the following two characteristics is important

i) The irradiance in the retinal image does not change with viewing angle for a lambertian panel.

ii) For a Lambertian surface, the exitance and radiance are related by

Exitance M = π * radiance L   where π = 3.1415927

3.9 ***Spectral Quantities:*** The electromagnetic spectrum consists of a continuous frequencies or wavelength each of which carry a share of the total radiant flux. The way in which the flux is distributed among the components of different wavelengths is known as the spectral distribution.

3.10 ***Hemispherical reflectance, transmittance and absorptance:*** When radiant energy from the Sun reaches/incident on a particular surface either natural or manmade, there things happens i) it is returned back by reflection, or ii) transmitted through the medium, or iii) it is absorbed by the surface and get transformed into some other form of energy within the surface depending upon the physical and chemical properties of the surface/object. These three phenomena can be understood/calculated as follows:

i. The hemispherical reflectance ρ (roh) is defined by the ratio of reflected exitance of the plane to the irradiance on the plane it can be expresses as follows:

ρ (roh) = reflected (M) / irradiance (E)

ii. The hemispherical transmittance τ (tou) is defined as the ratio of transmitted exitance, leaving the opposite side of plane, to the irradiance on that plane and it is expresses as follows:

τ (tou) = transmitted (M) / irradiance (E)

iii. The hemispherical absorptance α (alpha) which denotes the fraction of incident energy which is absorbed by the surface is given in the following formula:

$$\alpha \text{ (alpha)} = 1 - \tau \text{ (tou)} - \rho \text{ (roh)}$$

For a perfect blackbody, reflectance and transmittance are zero (0) and absorptance is unity (1). Whereas for perfectly white bodies, absorptance and transmittance are zero (0) and reflectance is unity (1). However, in reality there is neither perfect black nor white body. It means that the real bodies are usually known as gray bodies and have these coefficients in between 0 and 1.

4. Thermal Emission of Radiation

All objects at all temperatures emit electromagnetic radiation at all wavelengths. The thermal emission of radiation is due to the conversion of heat energy, which is the kinetic energy of the random motion of the particles of the matter, into electromagnetic energy. Thermal emission of radiation depends upon two parameters i.e. absolute Temperature (T) and Emissivity (ε). The total thermal radiation from a body increases with fourth power of T. The absolute temperature is given by T = 273+ temperature in degrees centigrade in units of degrees Kelvin (°K). The emissivity factor (ε) is the characteristics of the material, a measure of its capability to emit radiation due to thermal energy conversion. The emissivity of a body depends upon its absorptive ability. It is a fact that good absorbers are good radiators e.g. metals and rocks, whereas poor absorbers are poor radiators e.g. water bodies. For an ideal thermal emitter, called a blackbody, ε will be 1.

5. Radiation Principles

Before discussing various radiation principles lets us, understand radiation in the context of remote sensing. Basically, it is energy that comes from a source (Sun) as mentioned above and it travels through some material or through space. There are mainly three types of radiation i.e. light, heat and sound.

5.1 *Planck's Law:*

Planck’s law of a black body radiation predicts the spectral intensities of EMR at all wavelengths from a black body at a given temperature T. The spectral exitance (M) for a blackbody can be calculated by Planck's Law as follows:

M = C1 -5 [exp. (C2/ T) - 1]-1

Where: C1 and C2 are constant, is the wavelength

T is the absolute temperature

We all know that the spectral exitance of a blackbody is not the same at all wavelengths and the spectral exitance is low both at very short and very long wavelengths. It reaches the maximum value (fig. 10) for some wavelengths in between, depending on the temperature of the blackbody. The radiation curves as seen in the fig. 8 corresponding to black bodies at different temperatures do not cross each other. It is known that a blackbody at higher temperature emits more radiation than a blackbody at lower temperature at all the wavelengths.

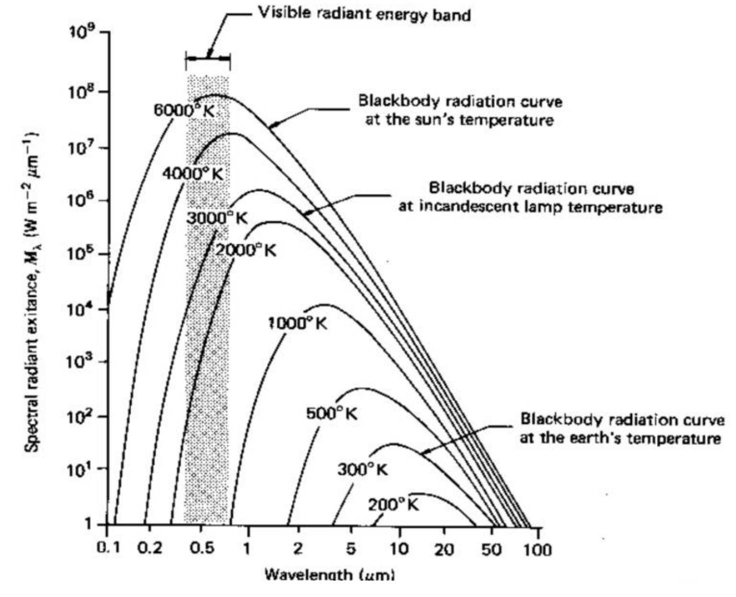

Fig. 10

A relationship between the radiant power peak and the temperatures of a body can be explained by the Wien's Displacement Law.

5.2 *Wien's Displacement Law:*

Wien's Displacement law states that the wavelength carrying the maximum energy is inversely proportional to the absolute temperature of a black body. The shift of that peak is a direct consequence of the Planck radiation law, which describes the spectral brightness of black body radiation as a function of wavelength at any given temperature. The wavelength for which the spectral exitance has its maximum is given as follows:

$$\lambda_m \text{ (in microns)} = 2{,}898/T$$

For a blackbody at T = 300°K, the peak in spectral emission occurs at λ_m = 10 µm. When the temperature of the object is raised, the peak emission shifts toward the shorter wavelength side. At T = 6,000°K, about the temperature of the sun, the peak emission occurs in the visible region of the spectrum (λ_m = 0.5 µm).

5.3 *The Stephen-Boltzman Law:*

The total radiation emitted by a blackbody in the entire electromagnetic spectrum is obtained by integrating the area under Planck's distribution curve is directly proportional to the 4th power of the absolute temperature.

$$M \text{ (blackbody)} = \sigma T^4$$

Where $\sigma = 5.67 \times 10^{-8}$ W/m^2 (°K)^4

5.4 *Spectral Emissivity:*

There are three basic radiation laws as discussed earlier hold good for blackbody radiation only and all other substances are characterized by their spectral emissivity (ε), which can be defined as the ratio of spectral exitance of the material to the spectral exitance of a blackbody at the same temperature is expressed as follows:

$$\varepsilon(\lambda) = M \text{ (material, °K)} / M_\lambda \text{ (blackbody °K)}$$

If we know the spectral emissivity of a body, its spectral exitance, total exitance and the wavelength of peak emission can be easily determined.

5.5 *Kirchoff's Law:*

In order to understand emissivity we need to know the Kirchoff's law. The law states that the spectral emissivity of a material is equal to its spectral absorptivity, i.e. $\varepsilon(\lambda) = \alpha(\lambda)$. It means that if a body is capable of emitting certain radiation, it will absorb that radiation when exposed to it. The value of emissivity (ε) varies between 0 to 1 depending upon the dielectric constant of the material, its temperature, wavelength and surface roughness etc. For clear water emissivity (ε) is between 0.98 – 0.99, healthy green vegetation is 0.96-0.99 wet soil is 0.95-0.98 and dry vegetation 0.88-0.94.

The emissivity characteristics of material can be summarized as follows:

i. Blackbody: $\varepsilon = 1$ at all wavelengths
ii. Grey body : $0 < \varepsilon < 1$ (does not depend upon wavelength)
iii. Imperfect blackbody (perfect reflector): $\varepsilon = 0$
iv. All other bodies: $\varepsilon = \varepsilon(\lambda)$ is a function of wavelength.

We need to understand the relationship between reflectance (ρ), absorptivity (α) and transmittance (τ) as given below because the philosophy of remote sensing depends upon these three key issues of an object.

$$\rho(\lambda) + \alpha(\lambda) + \tau(\lambda) = 1.$$

It can now be written as

$$\rho(\lambda) + \varepsilon(\lambda) + \tau(\lambda) = 1.$$

For opaque substances, $\tau(\lambda) = 0$; hence, emissivity and reflectance are related by

$$\varepsilon(\lambda) = 1 - \rho(\lambda)$$

6. Summary

Before understanding the subject matter of 'remote sensing', we need to understand the science involved in it and that can only be understood by going through the fundamental concepts and principle of physics and optics. Sun, being a major source of energy for the remote sensing, radiation and illumination, have a sharp power peak around 0.5 µm, and allows to capture reflected Suns energy using conventional cameras, films or sensor on board satellite. The energy emitted by the Sun is mainly divided into 40% visible light, 50% IR, 9% UV and 1% x-ray, radio, etc. In remote sensing one core, part is that of electromagnetic radiation (EMR) and in this context, we need to understand the basic concepts and principles of energy i.e. Radiant Energy, Radiant Flux, Irradiance, Exitance, Radiance and Radiant Intensity etc. The thermal emission of radiation is due to the conversion of heat energy, which is the kinetic energy of the random motion of the particles of the matter, into electromagnetic energy. Thermal emission of radiation depends upon two parameters i.e. absolute Temperature (T) and Emissivity (ε). The emissivity factor (ε) is the characteristics of the material, a measure of its capability to emit radiation due to thermal energy conversion. The emissivity of a body depends upon its absorptive ability. It is a fact that good absorbers are good radiators e.g. metals and rocks, whereas poor absorbers are poor radiators e.g. water bodies.

Frequently Asked Questions-

Q1. What do you understand by remote sensing?

The term 'remote sensing', coined by Ms. Evelyn Pruitt a woman U.S. Naval Research Officer in 1950s. It can be defined as means acquiring information about a phenomenon, object or surface without being in contact with it or from a distance. This field is attributed to the various developments in satellite technology, computers, sensors and spacecraft from 1960 onwards for collecting information about the earth's surface features both natural as well as manmade.

Q2. What is Electromagnetic Radiation (EMR)?

EMR is a dynamic form of energy that propagates as wave motion at a velocity of light i.e. c = 3 x 1010 cm/sec. The parameters that characterize a wave motion are wavelength (λ), frequency (ν) and velocity (c) and the relationship between these three are commonly expressed as $c = \nu\lambda$.

Q3. How can you define Lambertian Surface?

The plane source or surface for which the radiance L does not change as a function of angle of view is called Lambertian, which is known as perfectly diffused surface. Where the irradiance in the retinal image does not change with viewing angle for a lambertian panel.

Q4. Differentiate between Irradiance and Exitance?

Irradiance is the Radiant flux intercepted by a plane surface per unit area of the surface where as exitance is the Radiant flux leaving a surface per unit area of the surface. Both are opposite to each other.

Q5. What happened when the Sun's energy reaches at the surface of the Earth?

When radiant energy from the Sun reaches/incident on a particular surface either natural or manmade, i) some portion of it is returned back by reflection, ii) some part of it is transmitted through the medium, and iii) and some of energy gets absorbed by the surface and get transformed into some other form of energy within the surface depending upon the physical and chemical properties of the surface/ object.

Multiple Choice Questions-

1. Approximately how much energy emitted by the Sun is in the visible region.

(a) 40%
(b) 50%
(c) 20%
(d) 30%

2. In the Electromagnetic Spectrum which one of the following region is represented by Infrared light

(a) 8×10^{-5} cm < λ < 10^{-1} cm
(b) 10^{-11} cm < λ < 10^{-8} cm
(c) 10^{-6} cm < λ < 10^{-4} cm
(d) 10^{-1} cm < λ < 10^{2} cm

3. Radiant flux intercepted by a plane surface per unit area of the surface

(a) Radiance
(b) Exitance
(c) Radiant Energy
(d) Irradiance

4. A perfect blackbody, reflectance and transmittance is

(a) 1
(b) 0
(c) 2
(d) <1

5. The emissivity of clear water ranges between

(a) 0.98-0.99
(b) 0.88-0.90
(c) 0.65-0.85
(d) 9.0-1.0

Suggested Readings:

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