Interactions Between Electromagnetic Wave and Targets

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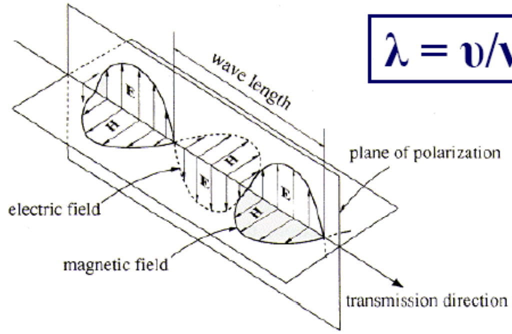
http://pirun.ku.ac.th/~fengwks/rs/

Electromagnetic radiation

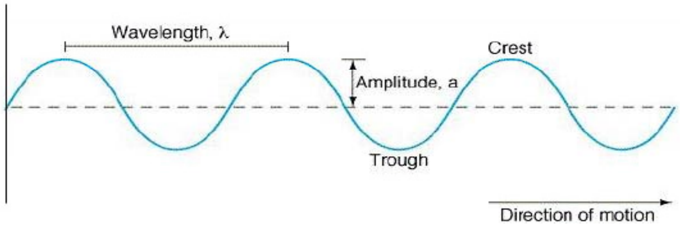
wavelength λ , **frequency v** and the **velocity υ** have the following relation.



$$\lambda = \upsilon / v$$

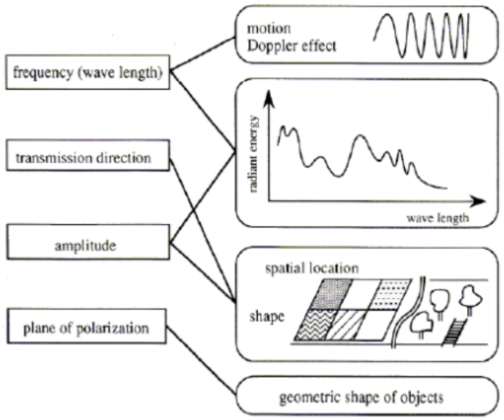
Note: Electro-magnetic radiation has the characteristics of both wave motion and particle motion.

The three properties of electromagnetic energy

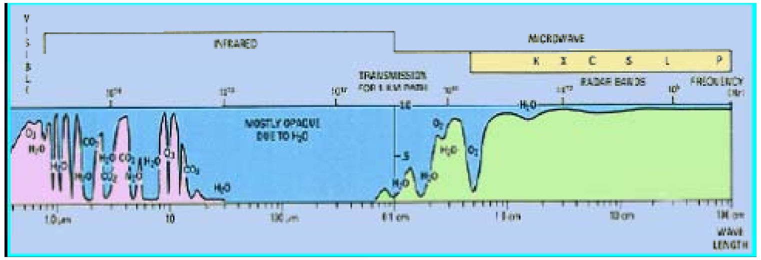


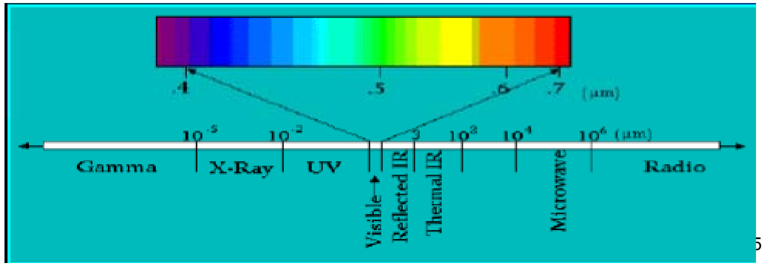
Wavelength (λ) is the distance from one wave crest to the next.
Amplitude is equivalent to the height of each peak, often measured as energy levels.
Frequency (v) is measured as the number of crests passing a fixed point in a given period.

The four elements of electromagnetic radiation



Electromagnetic Spectrum





Electromagnetic Spectrum II

Table 1.4.1 Classification of electromagnetic radiations

class				wavelength	frequency
ultraviolet				100Å ~ 0.4 μm	750 ~ 3,000 THz
visible				0.4 – 0.7 μm	430 – 750 THz
infrared	near infrared			0.7 ~ 1.3 μm	230 ~ 430 THz
	short wave infrared			1.3 ~ 3 μm	100 ~ 230 THz
	intermediate infrared			3 ~ 8 μm	38 ~ 100 THz
	thermal infrared			8 ~ 14 μm	22 ~ 38 THz
	far infrared			14 μm ~ 1 mm	0.3 ~ 22 THz
radio wave	submillimeter			0.1 ~ 1 mm	3 ~ 3 THz
	micro wave	millimeter	(EHF)	1 ~ 10 mm	30 ~ 300 GHz
		centmeter	(SHF)	1 ~ 10 cm	3 ~ 30 GHz
		decimeter	(UHF)	0.1 ~ 1 m	0.3 ~ 3 GHz
	very short wave		(VHF)	1 ~ 10 m	30 ~ 300 MHz
	short wave		(HF)	10 ~ 100 m	3 ~ 30 MHz
	medium wave		(MF)	0.1 ~ 1 km	0.3 ~ 3 MHz
	long wave		(LF)	1 ~ 10 km	30 ~ 300 KHz
	very long wave		(VLF)	10 ~ 100 km	3 ~ 30 KHz

Definition of Radiometry

In remote sensing, electromagnetic energy reflected or emitted from objects is measured. The measurement is based on either radiometry or photometry, with different technical units and physical units.

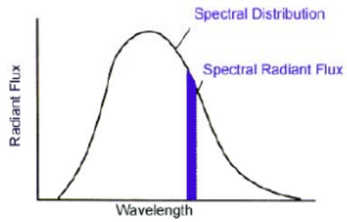
Radiometry is the measurement of a wide range of electromagnetic radiation from x-ray to radio wave.

Photometry is the measurement of electromagnetic radiation detectable by the human eye. It is thus restricted to the wavelength range from about 360 to 830 nanometers.

THUS, the only real difference between radiometry and photometry is that radiometry includes a wide range of the radiation spectrum, while photometry is limited to the visible spectrum as defined by the response of the eye.

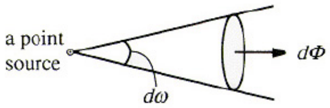
Radiometric Definitions

- **Radiant energy (*Qe*)** is defined as the energy carried by electromagnetic radiation and expressed in the unit of joule (J).

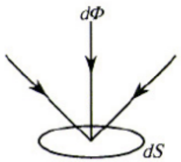


•**Radiant Flux (Φ)** is radiant energy transmitted as a radial direction per unit time and expressed in a unit of watt (W).

Radiometric Definitions



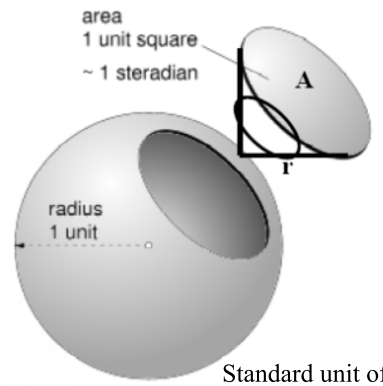
Radiant intensity (*Ie*)
is radiant flux radiated from a point source per unit solid angle in a radiant direction and expressed in the unit of Wsr^{-1}.



Irradiance (Ee)
is radiant flux incident upon a surface per unit area and expressed in the unit Wm^{-2}.

Solid Angle

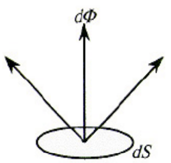
$$\Omega = A / r^2$$



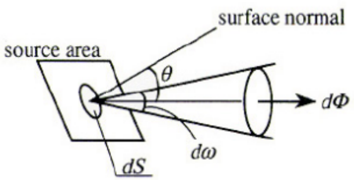
Other than the diagram might suggest, the shape of the area doesn't matter at all. Any shape on the surface of the sphere that holds the same area will define a solid angle of the same size.
Also, the diagram only shows the elements that define a solid angle, not the solid angle itself. The solid angle is the quantitative aspect of the conical slice of space, that has the center of the sphere as its peak, the area on the surface of the sphere as one of its spherical cross sections, and extends to infinity.
The maximum solid angle is ~12.57, corresponding to **the full area of the unit sphere, which is 4*Pi.**

Standard unit of a solid angle is the **Steradian (sr). (Mathematically, the solid angle is unitless, but for practical reasons, the steradian is assigned.)**
http://www.schorsch.com/kbase/glossary/solid_angle.html

Radiometric Definitions



**Radiant emittance (*Me*)
is radiant flux radiated from a surface per unit area, and expressed in a unit Wm^{-2}.**



**Radiance (Le)
is radiant intensity per unit of projected area in a radial direction, and expressed in the unit of $Wm^{-2}sr^{-1}$**

Black Body

Black body is a matter which absorbs all electro-magnetic energy incident upon it and does not reflect nor transmit any energy. It looks black at usual temperature.

A black body shows the maximum radiation as compared with other matter. Thus, a black body is
called a perfect radiator.

Black Body Radiation

Black body radiation is defined as thermal radiation of a black body, and can be given by **Plank's law** as a function of temperature T and wavelength.

spectral radiance of black body $B\lambda$ is given as follows.

$$B\lambda = \frac{2hc^2}{\lambda^5} \cdot \frac{1}{exp(hc/k\lambda T) - 1}$$

$B\lambda$	:	black body spectral radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$)		
T	:	absolute temperature of Black body (K)		
λ	:	wavelength (μm)		
c	:	velocity of light	2.998×10^8	($m \cdot s^{-1}$)
h	:	plank's constant	6.626×10^{-34}	($J \cdot s$)
k	:	Boltzmann's constant	1.380×10^{-23}	($J \cdot K^{-1}$)

Black Body Radiation

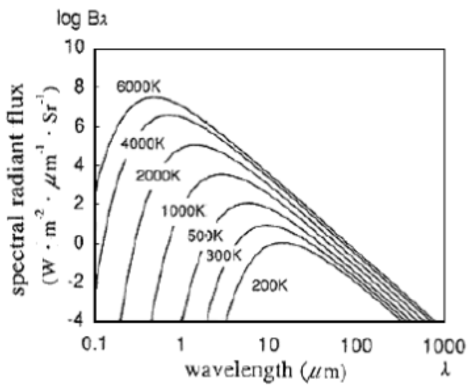


Figure 1.7.1 Plank's law of radiation

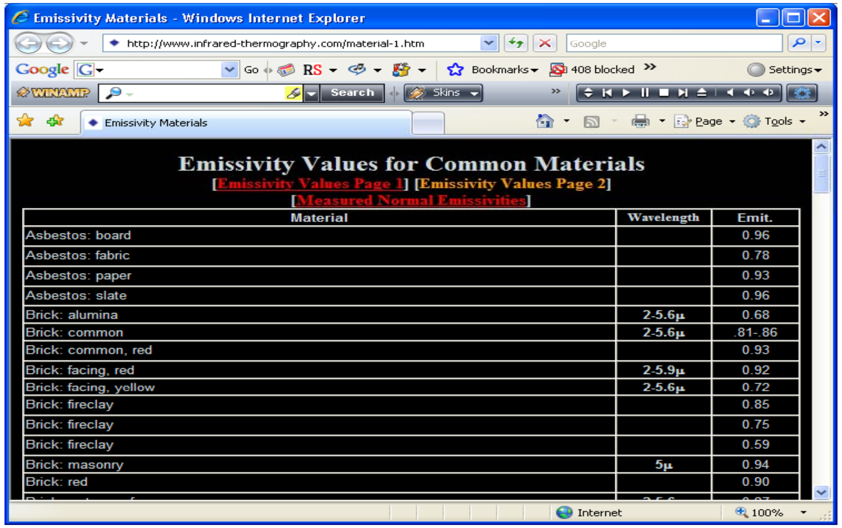
Black body radiation given by Plank's law as a function of temperature T and wavelength.

Black Body Radiation

In remote sensing, a correction for **emissivity** should be made because normal observed objects are not black bodies. Emissivity can be defined by the following formula:

$$\text{Emissivity} = \frac{\text{Radiant energy of an object}}{\text{Radiant energy of a black body with the same temperature as the object}}$$

http://www.infrared-thermography.com/material-1.htm

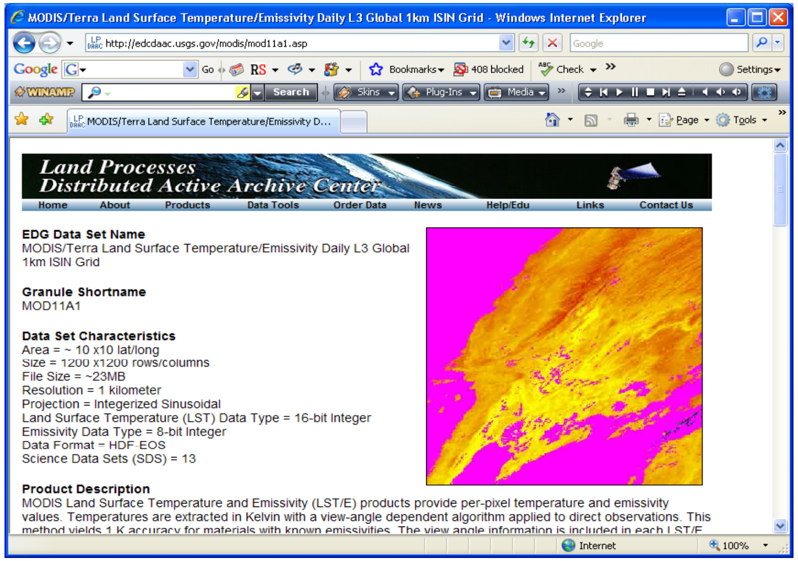

Emissivity Values for Common Materials

[Emissivity Values Page 1] [Emissivity Values Page 2]

[Measured Normal Emissivities]

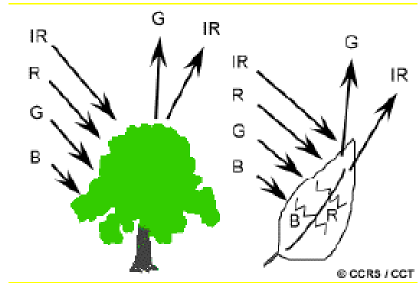
Material	Wavelength	Emit.
Asbestos: board		0.96
Asbestos: fabric		0.78
Asbestos: paper		0.93
Asbestos: slate		0.96
Brick: alumina	2-5.6µ	0.68
Brick: common	2-5.6µ	.81-.86
Brick: common, red		0.93
Brick: facing, red	2-5.9µ	0.92
Brick: facing, yellow	2-5.6µ	0.72
Brick: fireclay		0.85
Brick: fireclay		0.75
Brick: fireclay		0.59
Brick: masonry	5µ	0.94
Brick: red		0.90

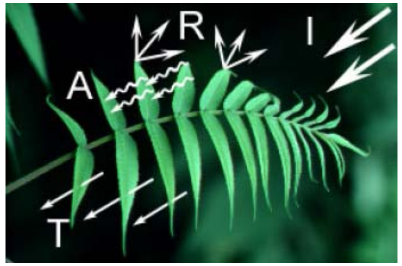
MODIS Products on Temperature and Emissivity



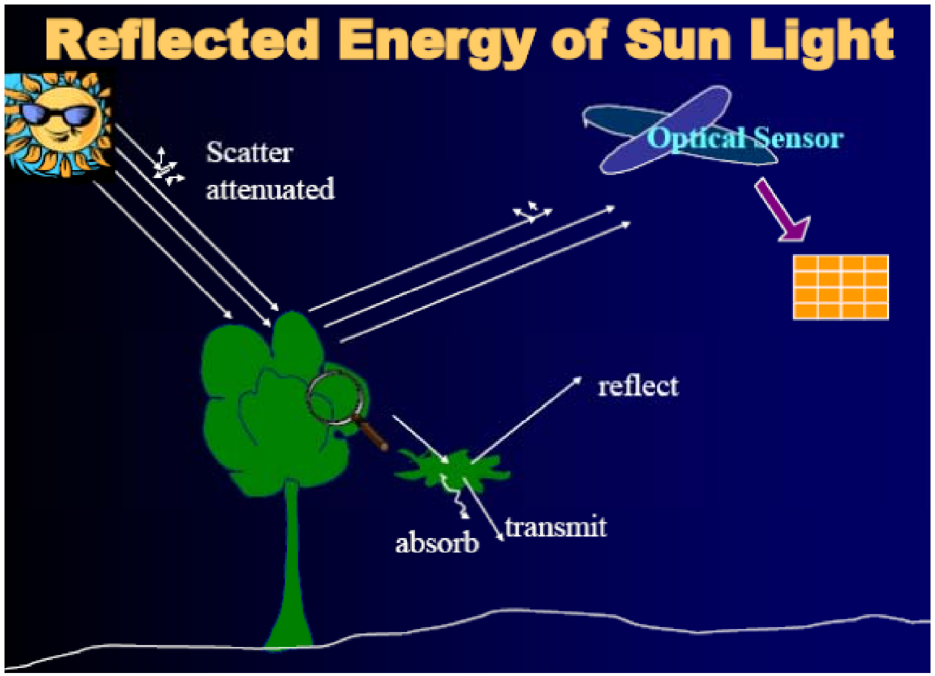
http://edcdaac.usgs.gov/modis/mod11a1.asp

Interactions with Surfaces



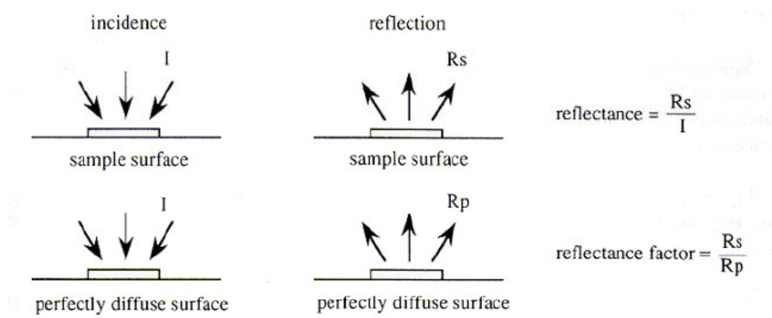


There are three (3) forms of interaction that can take place when energy strikes, or is **incident (I)** upon the surface. These are: **reflection (R)**; **transmission (T)**; and **absorption (A). Interactions**



Reflectance

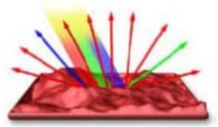
Reflectance is defined as the ratio of incident flux on a sample surface to reflected flux from the surface



The nature of reflection depends on sizes of surface irregularities (roughness or smoothness) in relation to the wavelength of the radiation considered.

Specular reflection

Specular reflection occurs when a smooth surface tends to direct incidentradiation in a single direction.

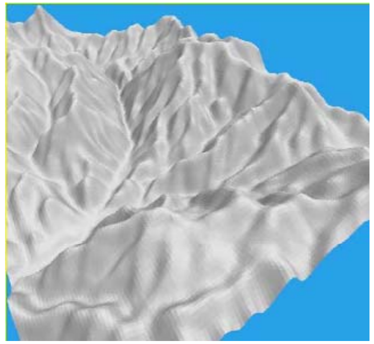


Diffuse reflection

Diffuse reflection occurs when a rough surface tends to scatter energy more or less equally in all directions.

Lambertian Surface

Lambertian Surface is a Uniformly Diffused Surface, reflects a constant radiance regardless of look angle



Perfectly Diffused Surface is Uniformly diffuse surface with a reflectance of 1.

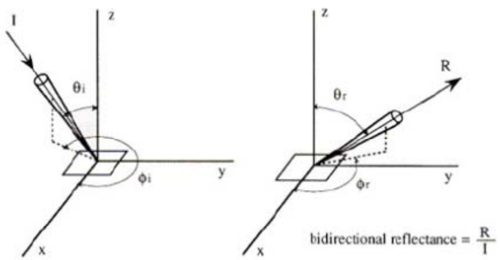
$$I(\theta) = I_n \cdot \cos(\theta)$$

$I(\theta)$ Luminous intensity when incident lights with an angle of theta from the normal to the surface

I_n Luminous intensity when incident lights is the normal to the surface

Directional Reflectance

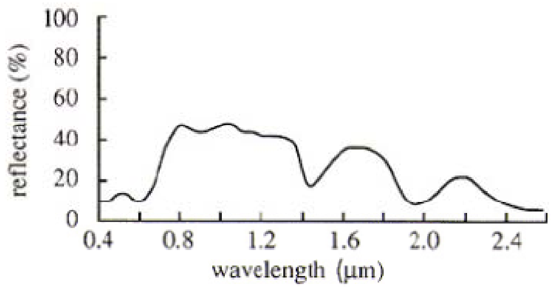
Reflectance with specified incident and reflected direction of electromagnetic direction is called directional reflectance. If incident and reflection are both directional, such reflectance is called bidirectional reflectance.



Bidirectional Reflectance

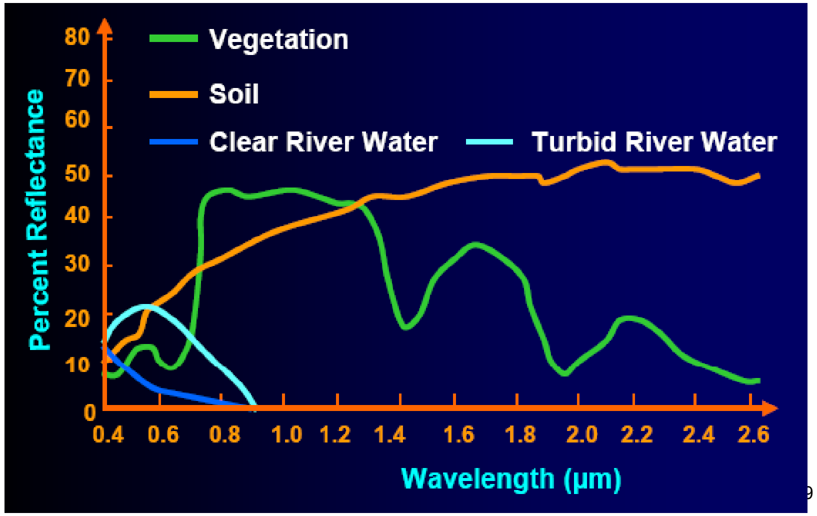
Spectral Reflectance

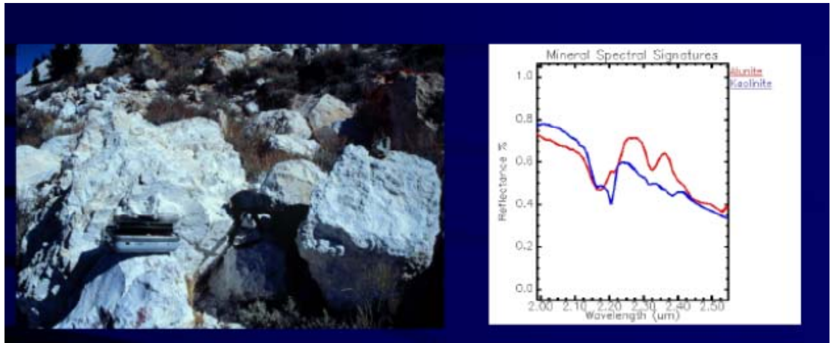
Reflectance with respect to wavelength is called spectral reflectance as shown for a vegetation example



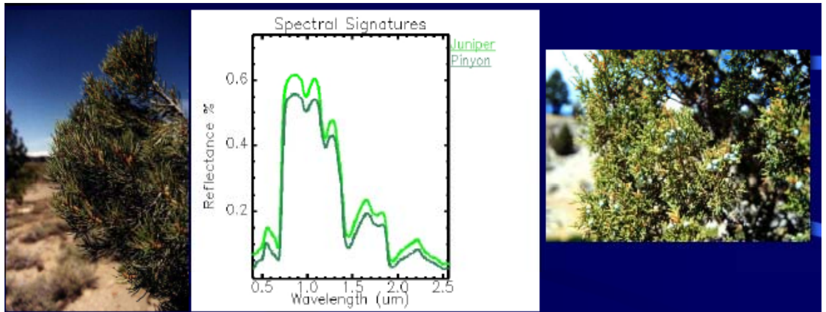
Spectral Reflectance of Vegetation

Spectral Reflectance





- Shown above are the reflected spectral signatures of two important alteration minerals, kaolinite in blue and alunite in red. Wavelength is along the x-axis and is given in microns from 2.0-2.5 um. Reflectance is reported in percent from 0-1.0 on the y-axis. Minerals lend themselves easily to identification due to their highly unique crystal geometries. Such signatures can be measured in the field with a portable field spectroradiometer such as the one sitting atop kaolinite boulders in the photograph. They can also be measured in the imagery itself.



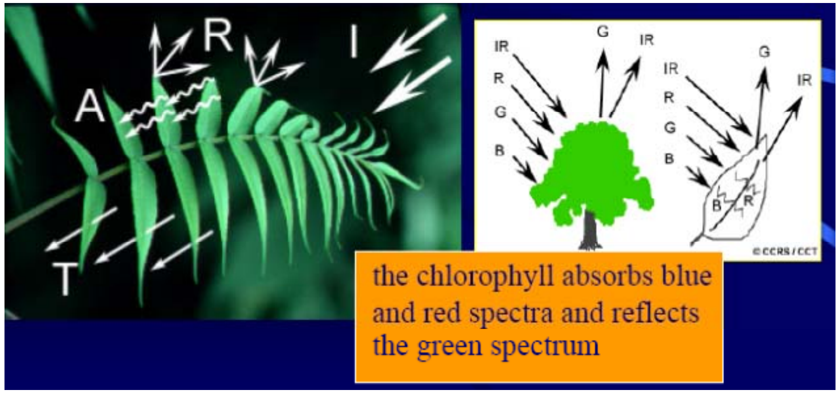
- However, spectral signatures may be similar due to their similar chemical constituents. The chlorophyll-induced greeness of vegetation is an excellent example of this problem. Green vegetation species can look very similar to each other as illustrated by the Pinyon pine and Juniper reflectance signatures shown below. Wavelength is again reported in microns from .45-2.5 um and reflectance is given as a percentage along the y-axis.

Spectral characteristics

Why does an object have a peculiar characteristic of reflection, transmission, or absorption?

Interactions between Matter and Electro-magnetic Radiation

Why a leaf looks green ??



Simplification by hydrogen atom and absorption of electro-magnetic radiation

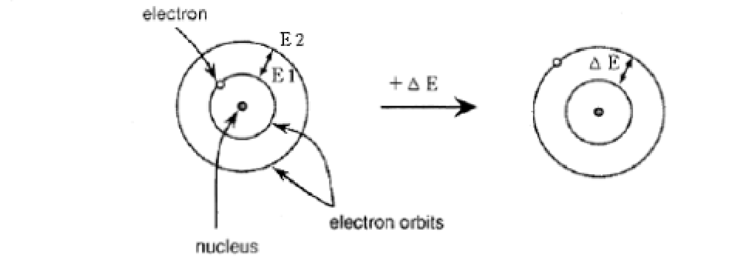


Figure 1.3.1 Change in energy level of the electron of a H atom according to absorption of electromagnetic radiation wavelength λ H

Electro-magnetic energy

$E = hc / \lambda$

where h : Plank's constant

c : velocity of light

λ : wavelength

Therefore, matter will emit or absorb electro-magnetic radiation at a particular wavelength with respect to the inner state.

The types of inner state are classified into several classes, such as ionization, excitation,molecular vibration, molecular rotation etc.

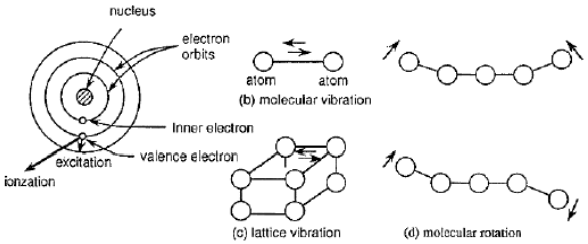


Figure 1.3.2 Schematics of characteristic states associated with electromagnetic radiation

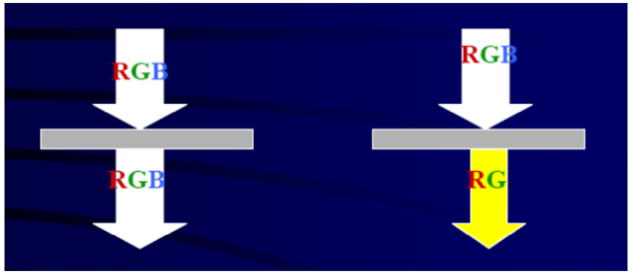
Transmission

Transmission of radiation occurs when radiation passes through a substance without significant attenuation.

From a given thickness, or depth, of a substance, the ability of a medium to transmit energy is measured as the transmittance (*t*)

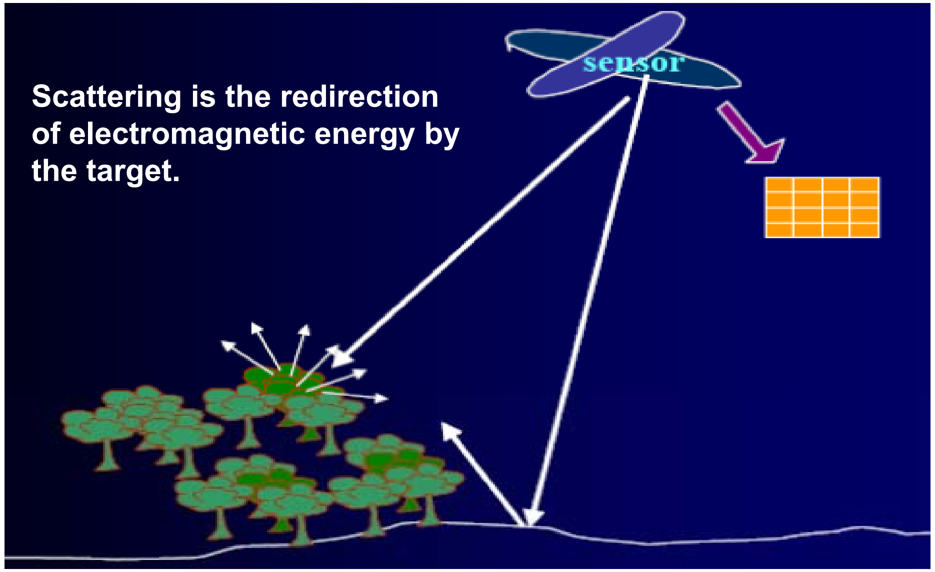
$$t = \frac{\text{Transmitted radiation}}{\text{Incident radiation}}$$

Transmission

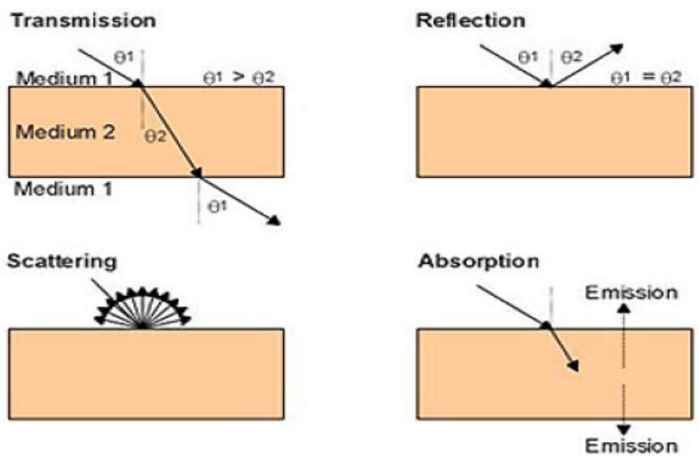


Incident radiation passes through an object without significant attenuation (left), or may be selectively transmitted (right). The object on the right would act as a yellow ("minus blue") filter, as it would transmit all visible radiation except for blue light.

Scattering



Interactions with Surfaces (Summary)



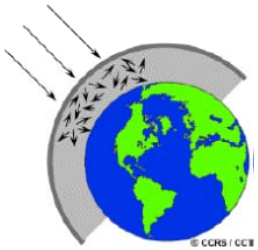
Interactions with the Atmosphere

Space shuttle view of the atmosphere

Particles and gases in the atmosphere can affect the incoming light and radiation. These effects are caused by the mechanisms of **scattering** and **absorption**.

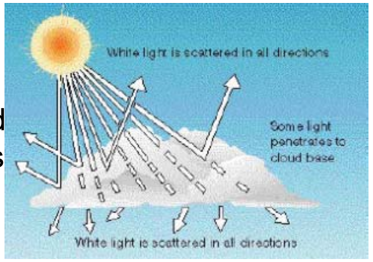
Interactions with the Atmosphere

Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path. How much scattering takes place depends on several factors including the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere.



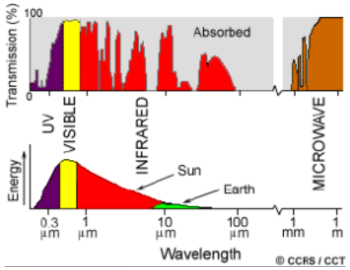
Interactions with the Atmosphere

Mie scattering occurs when the particles are just about the same size as the wavelength of the radiation. Dust, pollen, smoke and water vapour are common causes of Mie scattering which tends to affect longer wavelengths than those affected by Rayleigh scattering.



Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.

Interactions with the Atmosphere



Atmospheric windows are areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors.

By comparing the characteristics of the two most common energy/radiation sources (the sun and the earth) with the atmospheric windows available to us, we can define those wavelengths that we can use **most effectively** for remote sensing.