Lecture - 2

భారతీయ సాంకేతిక విజ్ఞాన సంస్థ హైదరాబాద్
भारतीय प्रौद्योगिकी संस्थान हैदराबाद
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Introduction to Remote Sensing

- Remote sensing is the science (and art) of acquiring information about the Earth's surface without being in contact with it (typically from aircrafts and satellites)
- This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information
- Common Generic Examples:

  1) Watching TV, Observing Earth Features, ….
- A Remote Sensing system contains:

  1) Energy Source → To detect the object

  2) Sensor → To sense the object

  3) Platform → To mount the sensor

  4) Interpreter → To read, analyze about the object

Introduction to Remote Sensing

- “The science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation“ (L&K,1994)

Need for Remote Sensing

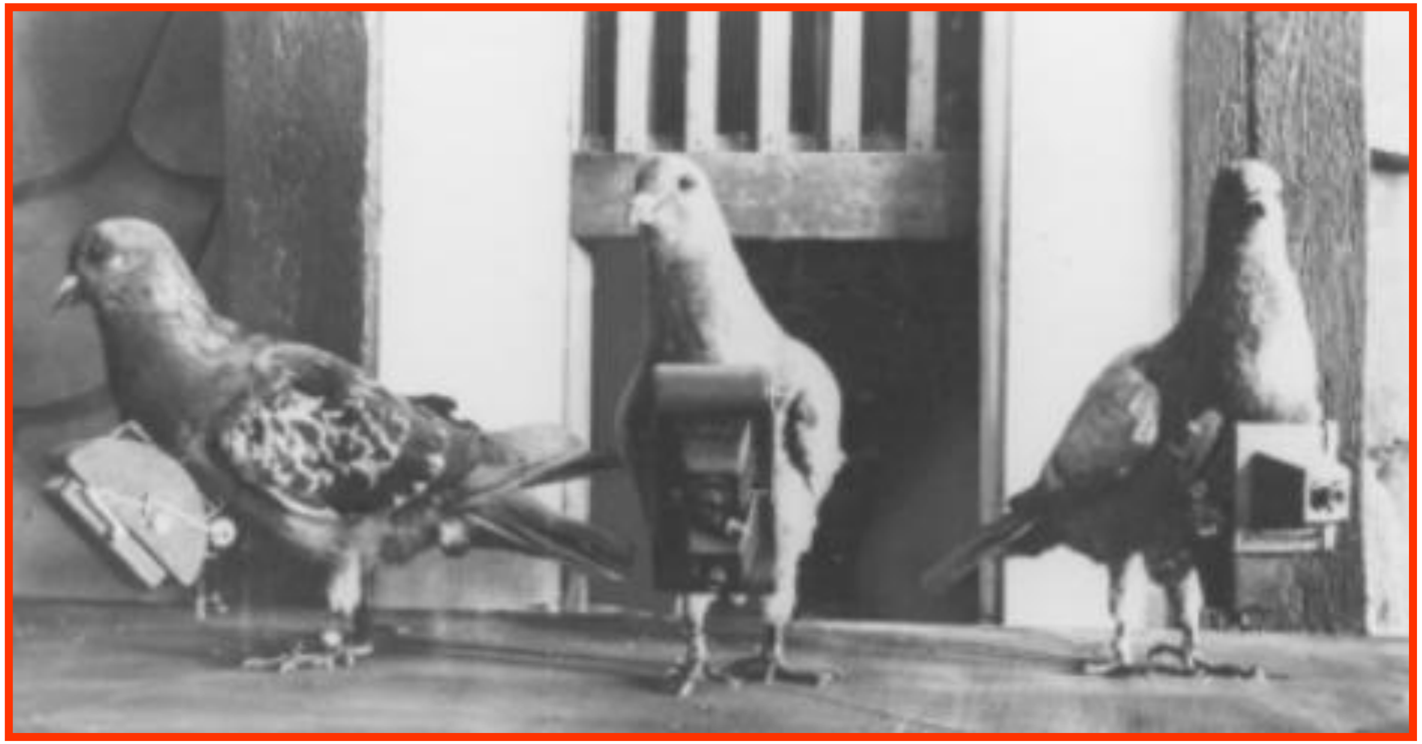
- Systematic data collection
- Information about three dimensions of real objects
- Repeatability
- Global coverage
- The only solution sometimes for the otherwise inaccessible areas
- Multipurpose information

Evolution of Remote Sensing

- “1858 - first aerial photograph from hot air balloon

Evolution of Remote Sensing

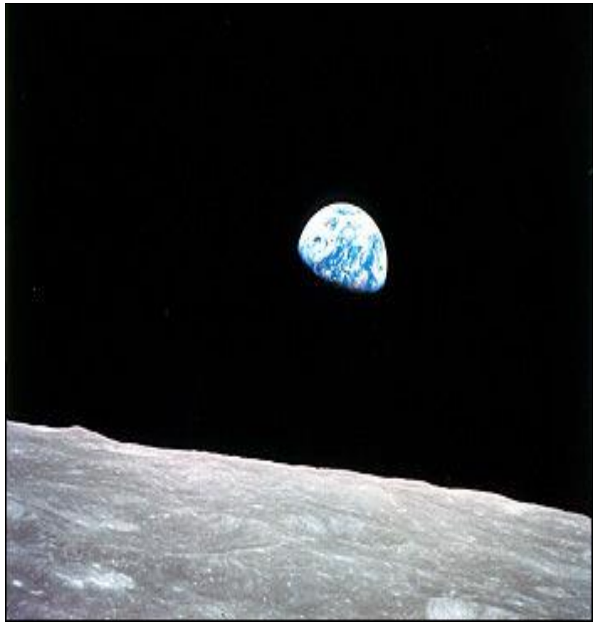
- 1903 - pigeon-mounted camera patented
- 1914-1945 - Plane mounted Cameras



Evolution of Remote Sensing

- Earth's cloudy surface, as seen by the first U.S. manned spaceflight

- The first Earthrise seen from the surface of the moon by the first Apollo Lunar landing mission



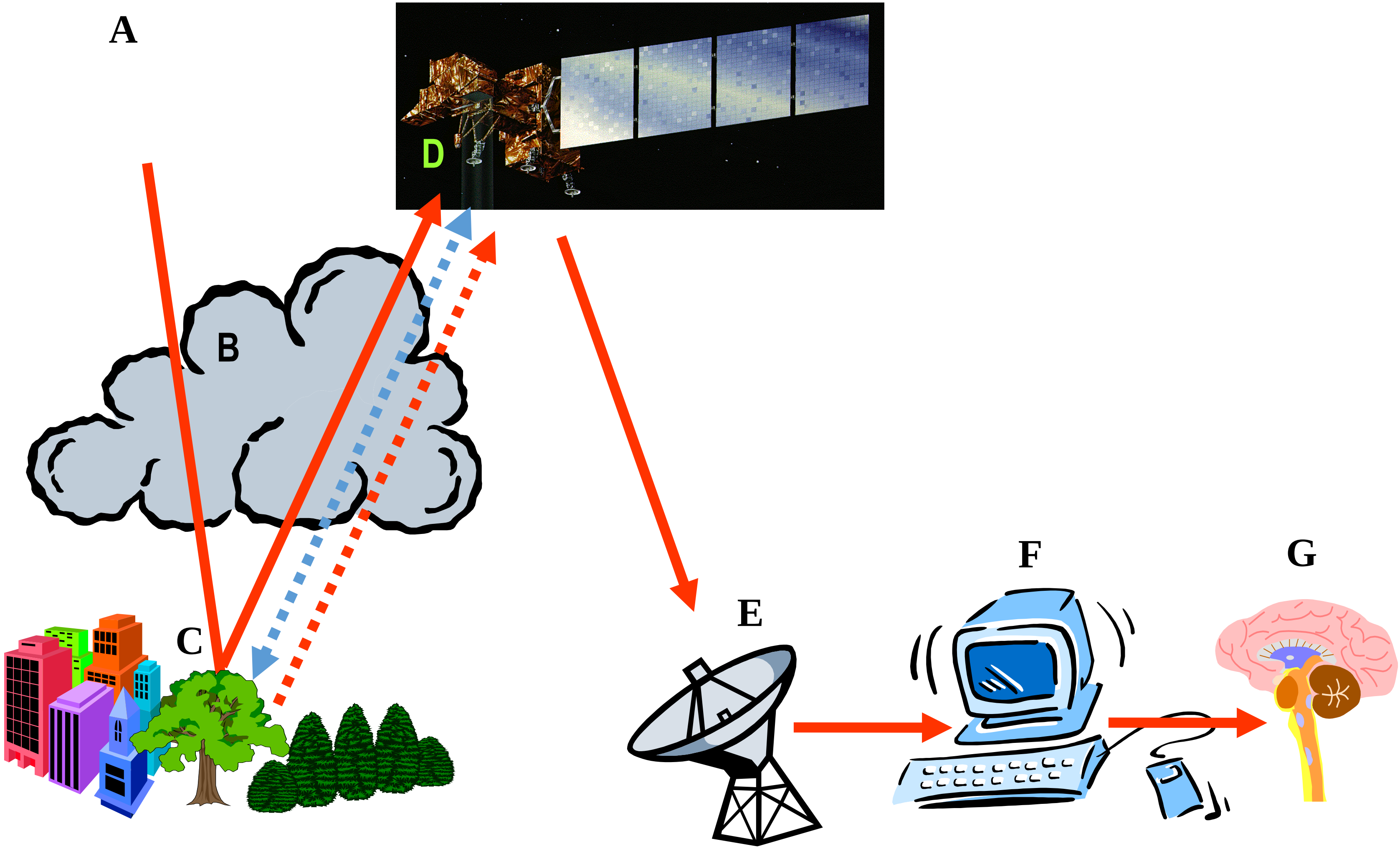
Evolution of Remote Sensing

- 1972 : Launch of Landsat I
- 1970-1980 : Rapid advances in Digital Image Processing
- 1980s : Development of Hyperspectral sensors

Steps in Remote Sensing System

- Origin of energy source (electro-magnetic radiation)
- Transmission of energy from source to surface of earth (object of interest)
- Transmission of reflected energy from the object to the sensor
- Detection of energy by the sensor, conversion into photographic image (or, electrical output)
- Recording and transmission of sensor output
- Pre-processing of data (and, data products)
- Collection of ground truth observations
- Data analysis and interpretation
- Integration of images and data for decision making

Steps in Remote Sensing System



Requirements for Remote Sensing System

1. Energy Source or Illumination -- Illuminates or provides electromagnetic energy to the target of interest
2. Radiation and the Atmosphere – For energy to travel from sensor to the target (and, back)
3. Interaction with the Target – To get back reflected energy
4. Recording of Energy by the Sensor -- To collect and record the electromagnetic radiation
5. Transmission, Reception, and Processing – To transmit the recorded energy in electronic form, to a receiving and processing station
6. Interpretation and Analysis -- To extract information about the target
7. Application – To assist in solving a particular problem

Electro Magnetic Radiation

- There are 2 theories:

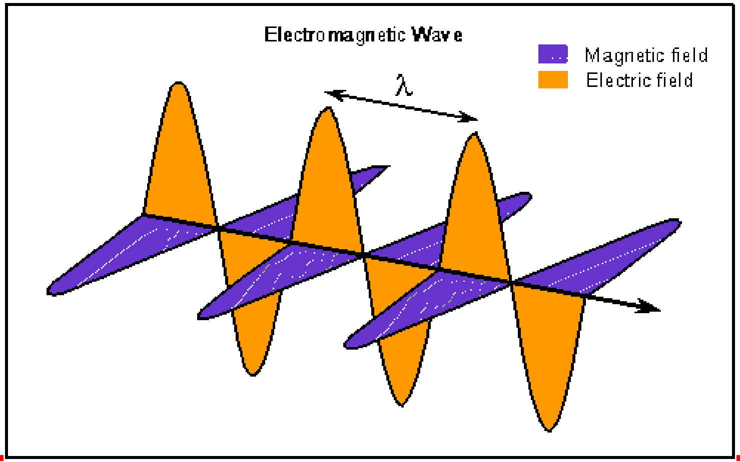
1. **Wave theory:** considers electromagnetic energy as a harmonic, sinusoidal wave
2. **Particle theory:** considers electromagnetic radiation as consisting of many discreet units – **photons**

1. Electro Magnetic Energy

- Electro magnetic (EM) energy is the main source for remote sensing observations (usually gets from Sun)

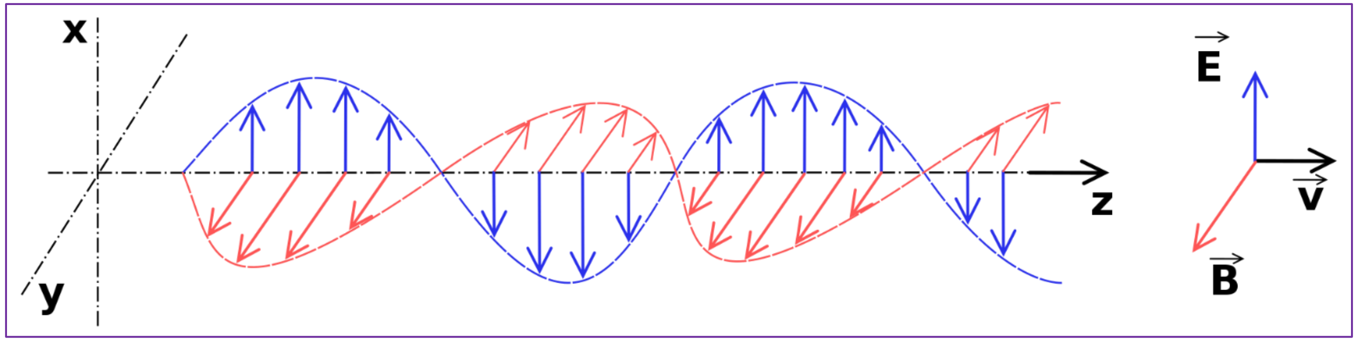
- Electro magnetic waves are the carriers of energy through space in the form of periodic disturbances of electric and magnetic fields

- EM radiation consists of an electrical field (E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field.



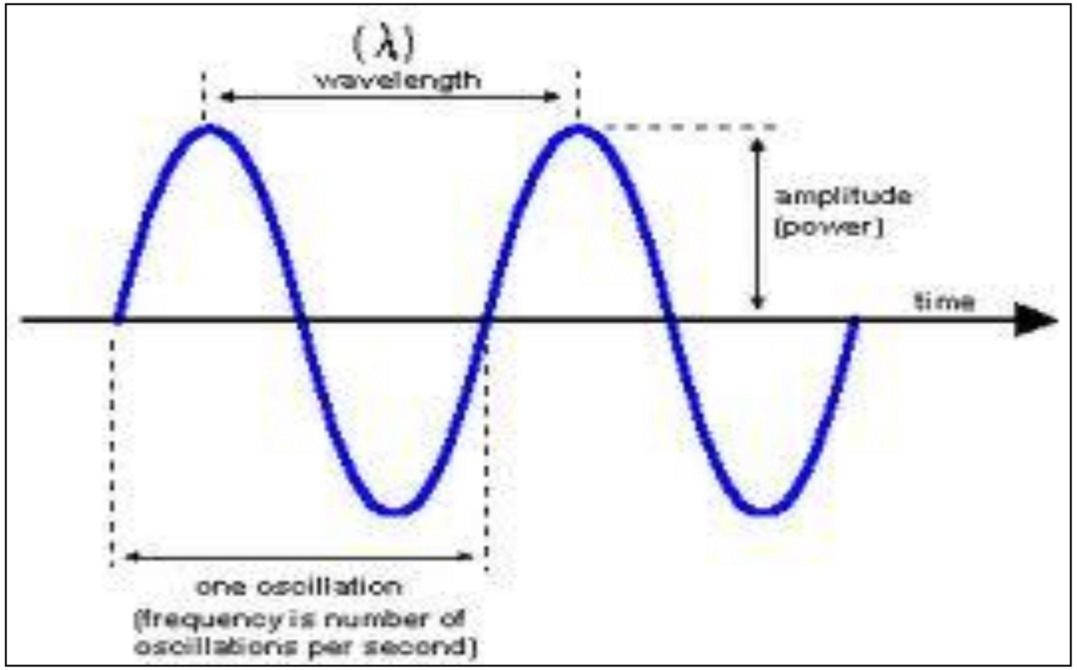
1. Electro Magnetic Energy

- Electromagnetic radiation consists of electromagnetic waves, which are synchronized oscillations of electric and magnetic fields that propagate at the speed of light ($c = 3 \times 10^8$ m/s)
- EM radiation includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays
- Electro magnetic waves are self propagating
- The directions of electric and magnetic fields of EM wave are at right angles to each other, and at right angles to the direction of flow
- Both these fields travel at the speed of light (c) in vacuum



1. Electro Magnetic Energy

- EM waves are emitted by electrically charged particles (molecules / atoms / ions/ …) undergoing acceleration
- EM waves carry energy, momentum, and angular momentum away from their source particle
- Wave forms of EM waves were derived by James Maxwell
- EM waves are characterized by
  - Frequency;
  - Wavelength;
  - Intensity;
  - Direction of travel;
  - Amplitude



1. Electro Magnetic Energy

- The energy of a photon is given by :
- $E = h\nu$
- $\quad = hc/\lambda$
- where c, ν and λ are the velocity, frequency and wavelength respectively and h is Plank's constant

$$h = 6.6260\ldots \times 10^{-34} \text{ Joules-sec}$$

Wave-Particle Dual Theory

- In 1924, Louis-Victor de Broglie formulated the de Broglie hypothesis, claiming that *all* matter, not just light, has a wave-like nature; and related wavelength (denoted as λ), and momentum (denoted as *p*):

$$\lambda = h/p$$

h is Plank's constant

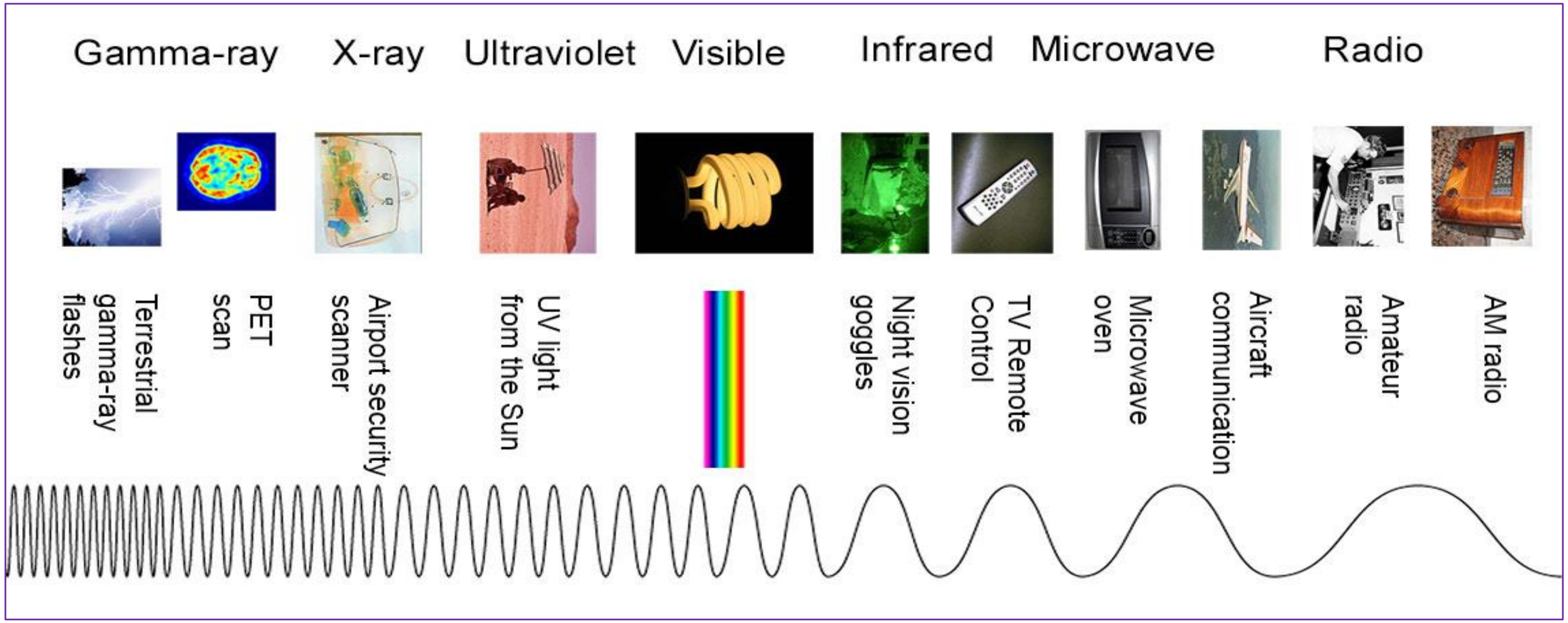
1. Electro Magnetic Energy - Terminology

- EM radiation → Wave form of energy produced by moving charged particles *[has both electric and magnetic field components]*
- Wavelength (λ) → Distance between two successive crests (or, troughs) of EM wave *[expressed in meters, or part of m]*
- Frequency (ν) → Number of wave crests (or, troughs) passing a fixed point in one second *[expressed in Hertz or multiples of Hz]*
- Amplitude (A) → height of crest (or, trough) from mid point

❖ Energy transported by wave is directly proportional to square of amplitude

- Intensity → The rate at which the energy is transferred per unit area *[expressed in W/m^2]*

1. Electro Magnetic Spectrum

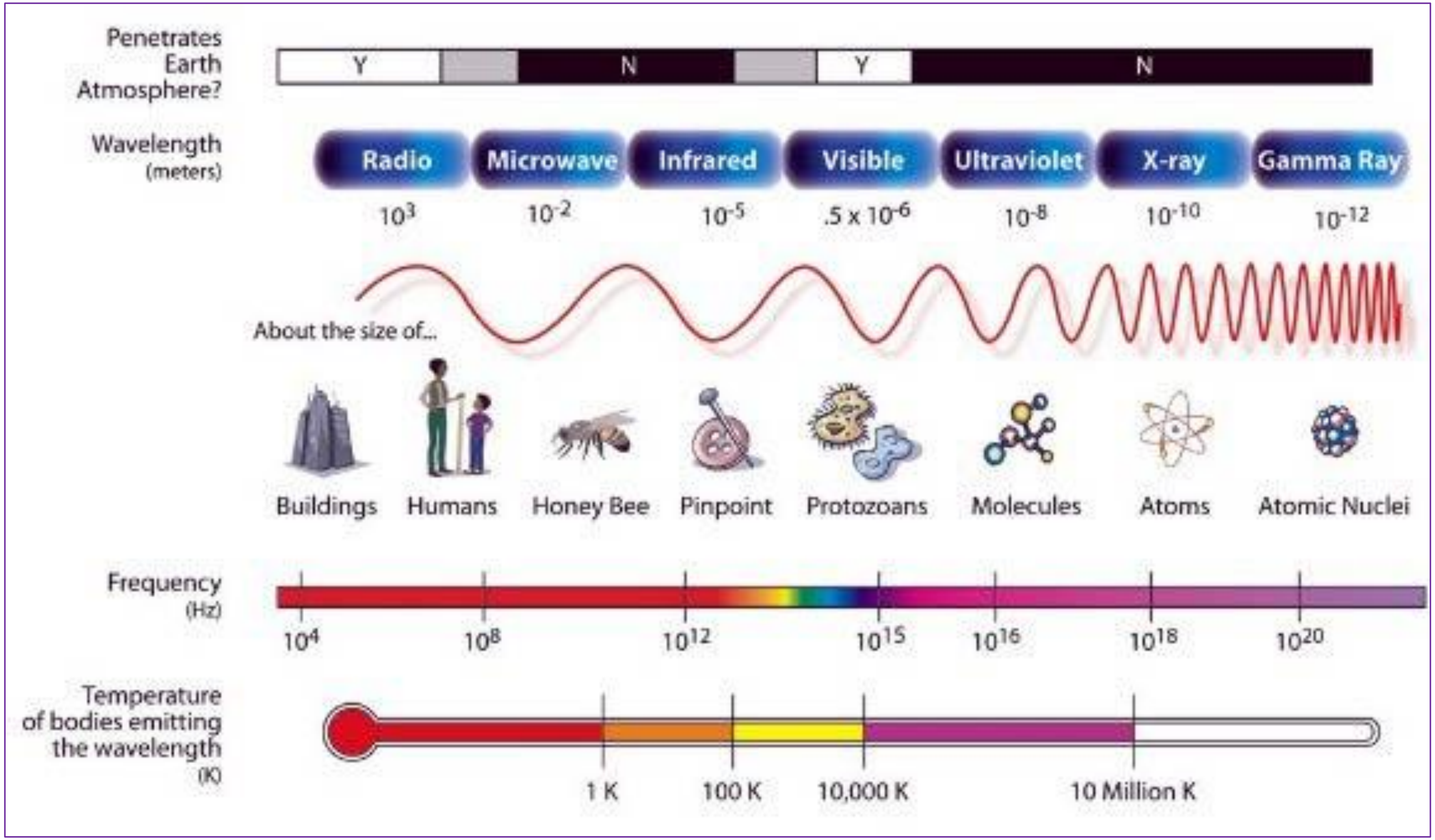


Wavelength

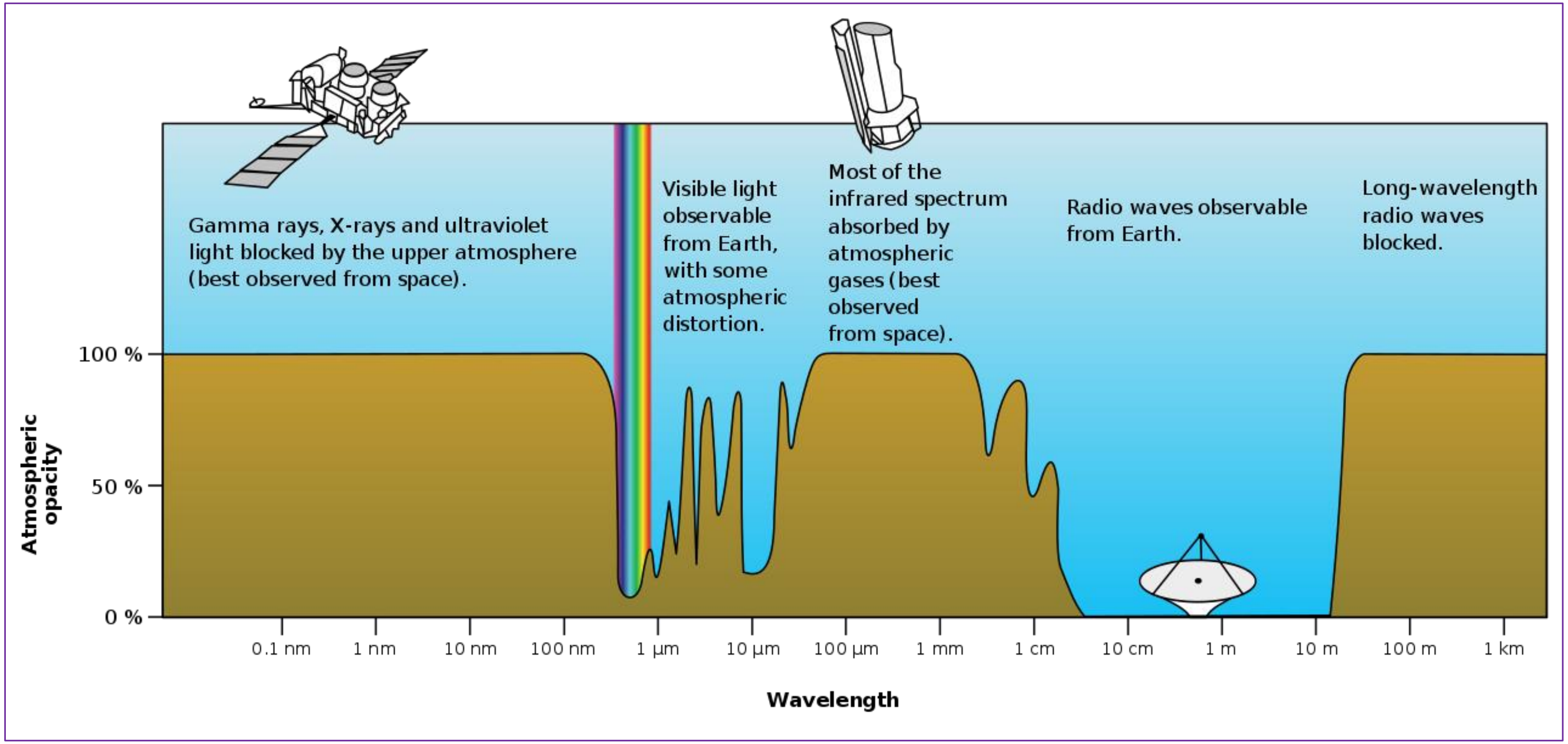
Energy / Frequency

- The electromagnetic (EM) spectrum is the range of all types of EM radiation
- Electromagnetic radiation can be expressed in terms of energy, wavelength, or frequency

1. Electro Magnetic Spectrum



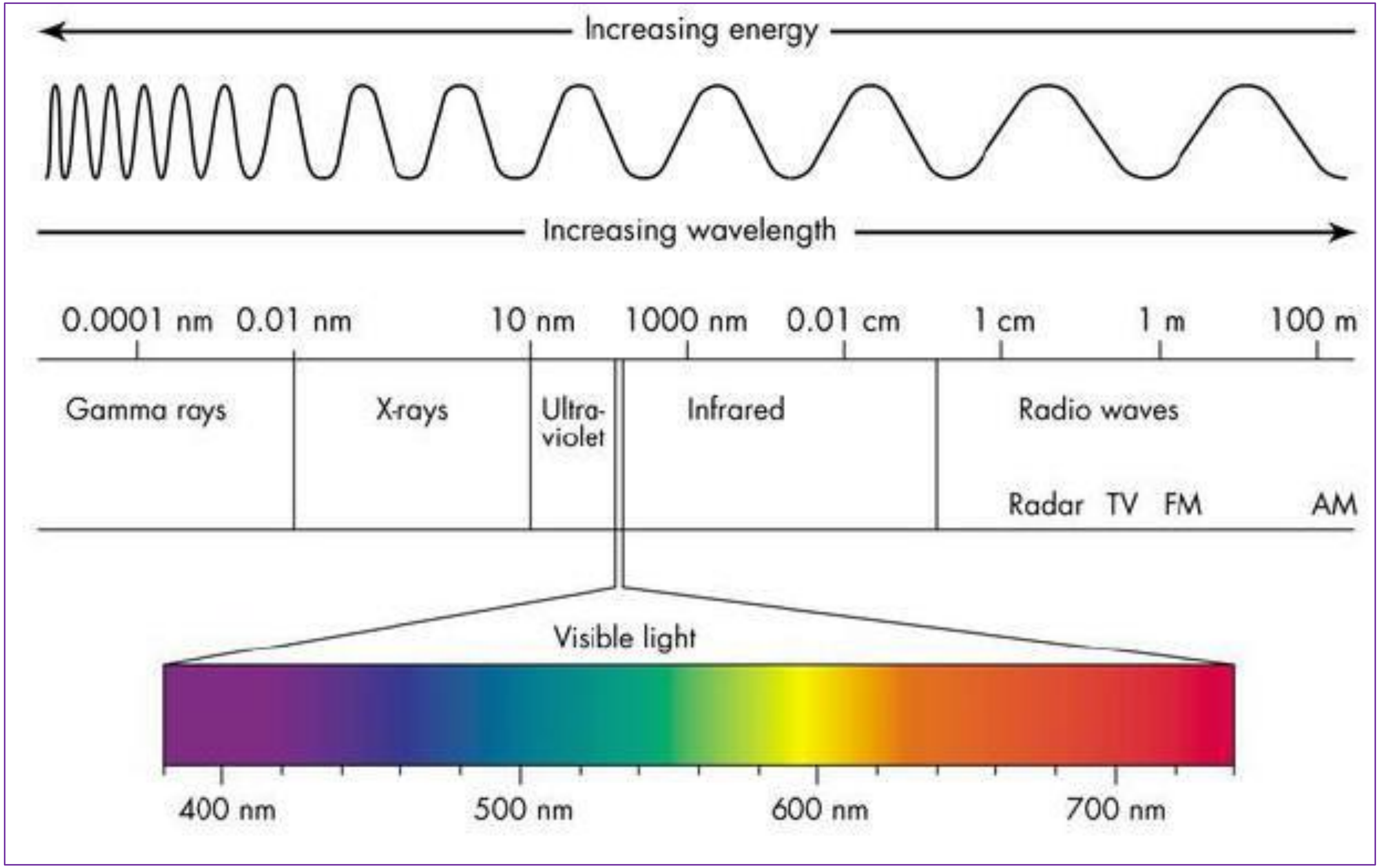
1. Electro Magnetic Spectrum



1. Electro Magnetic Spectrum

Region Name	Wavelength	Comments
Gamma Ray	< 0.03 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
X-ray	0.03 to 30 nanometers	Entirely absorbed by the Earth's atmosphere and not available for remote sensing.
Ultraviolet	0.03 to 0.4 micrometers	Wavelengths from 0.03 to 0.3 micrometers absorbed by **ozone** in the Earth's atmosphere.
Photographic Ultraviolet	0.3 to 0.4 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Visible	0.4 to 0.7 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Infrared	0.7 to 100 micrometers	Available for remote sensing the Earth. Can be imaged with photographic film.
Reflected Infrared	0.7 to 3.0 micrometers	Available for remote sensing the Earth. Near Infrared 0.7 to 0.9 micrometers. Can be imaged with photographic film.
Thermal Infrared	3.0 to 14 micrometers	Available for remote sensing the Earth. This wavelength cannot be captured with photographic film. Instead, mechanical sensors are used to image this wavelength band.
Microwave or Radar	0.1 to 100 centimeters	Longer wavelengths of this band can pass through clouds, fog, and rain. Images using this band can be made with sensors that **actively** emit microwaves.
Radio	> 100 centimeters	Not normally used for remote sensing the Earth.

1. Electro Magnetic Spectrum



1. Electro Magnetic Spectrum

Optical Infrared (OIR) Region

Visible	0.4 – 0.7 μm
Near infrared (NIR)	0.7 – 1.5 μm
Shortwave infrared (SWIR)	1.5 – 3 μm
Mid-wave infrared (MWIR)	3 – 8 μm

Microwaves

P band	0.3 – 1 GHz (30 – 100 cm)
L band	1 – 2 GHz (15 – 30 cm)
S band	2 – 4 GHz (7.5 – 15 cm)
C band	4 – 8 GHz (3.8 – 7.5 cm)
X band	8 – 12.5 GHz (2.4 – 3.8 cm)
Ku band	12.5 – 18 GHz (1.7 – 2.4 cm)
K band	18 – 26.5 GHz (1.1 – 1.7 cm)
Ka band	26.5 – 40 GHz (0.75 – 1.1 cm)

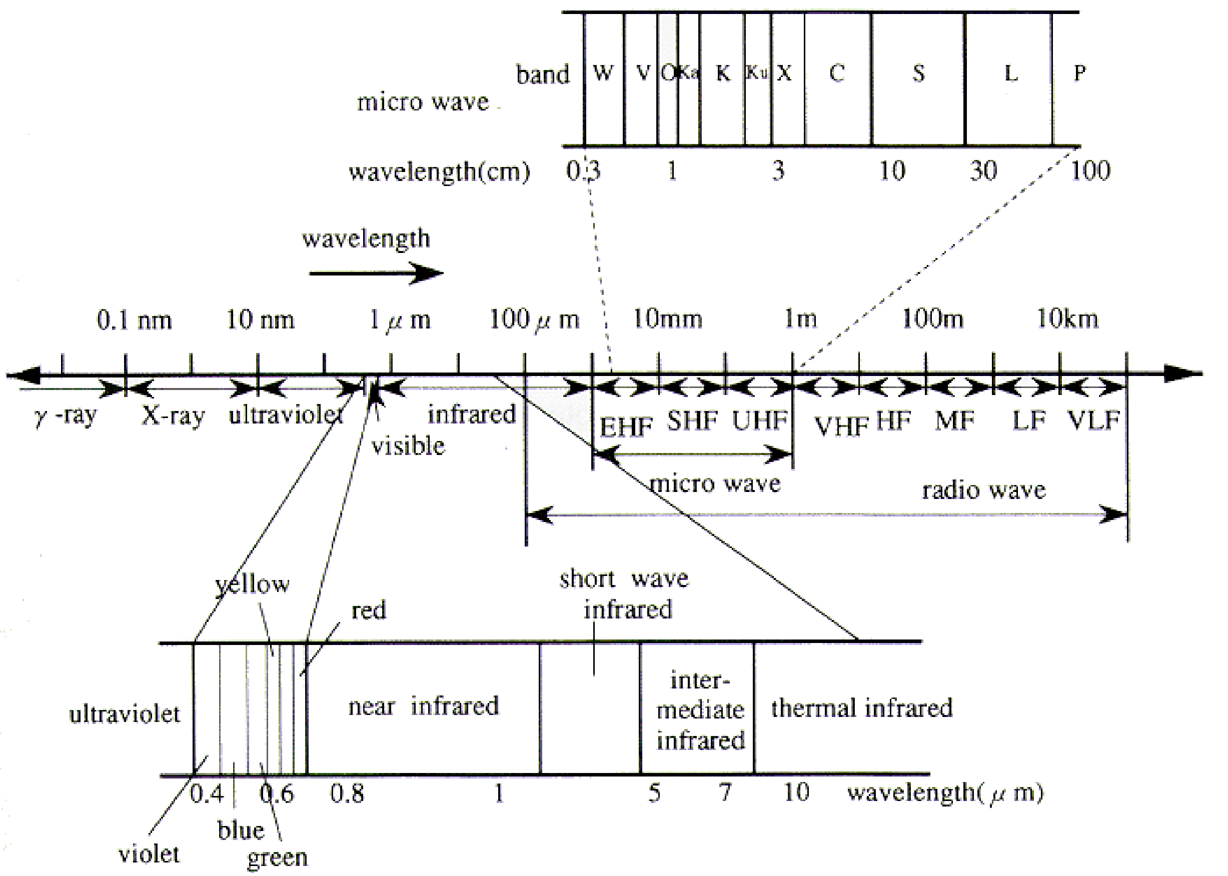


Figure 1.4.1 The bands used in remote sensing

1. Velocity of EM Radiation

- Velocity of EM wave depends on the properties of medium travelling *[Maxwell's Theorem]*
- Velocity of EM wave is given by:

$$c_m = \frac{1}{\sqrt{\epsilon\mu}}$$

c_m → Velocity of EM wave in m/s

ε → Electric permittivity of the medium in Farad/m

μ → Magnetic permeability of the medium in Henry/m

- For flow of EM wave through Vacuum:

$\varepsilon = \varepsilon_0 = 8.85 \times 10^{-12}$ Farad/m

$\mu = \mu_0 = 4\pi\, 10^{-7}$ Henry/m

Hence: $\mathbf{c_m = c_0 = 3 \times 10^8}$ **m/s**

- For any other medium;

$\varepsilon = \varepsilon_r\, \varepsilon_0$ ε_r = Relative permittivity of the medium

$\mu = \mu_r\, \mu_0$ μ_r = Relative permeability of the medium

1. Frequency of EM Radiation

- Velocity of EM wave through a medium is given by:

$$c = \nu \cdot \lambda$$

$c \rightarrow$ Velocity of EM wave in m/s

$\nu \rightarrow$ Frequency of EM wave in Hz

$\lambda \rightarrow$ Wavelength of EM wave in m

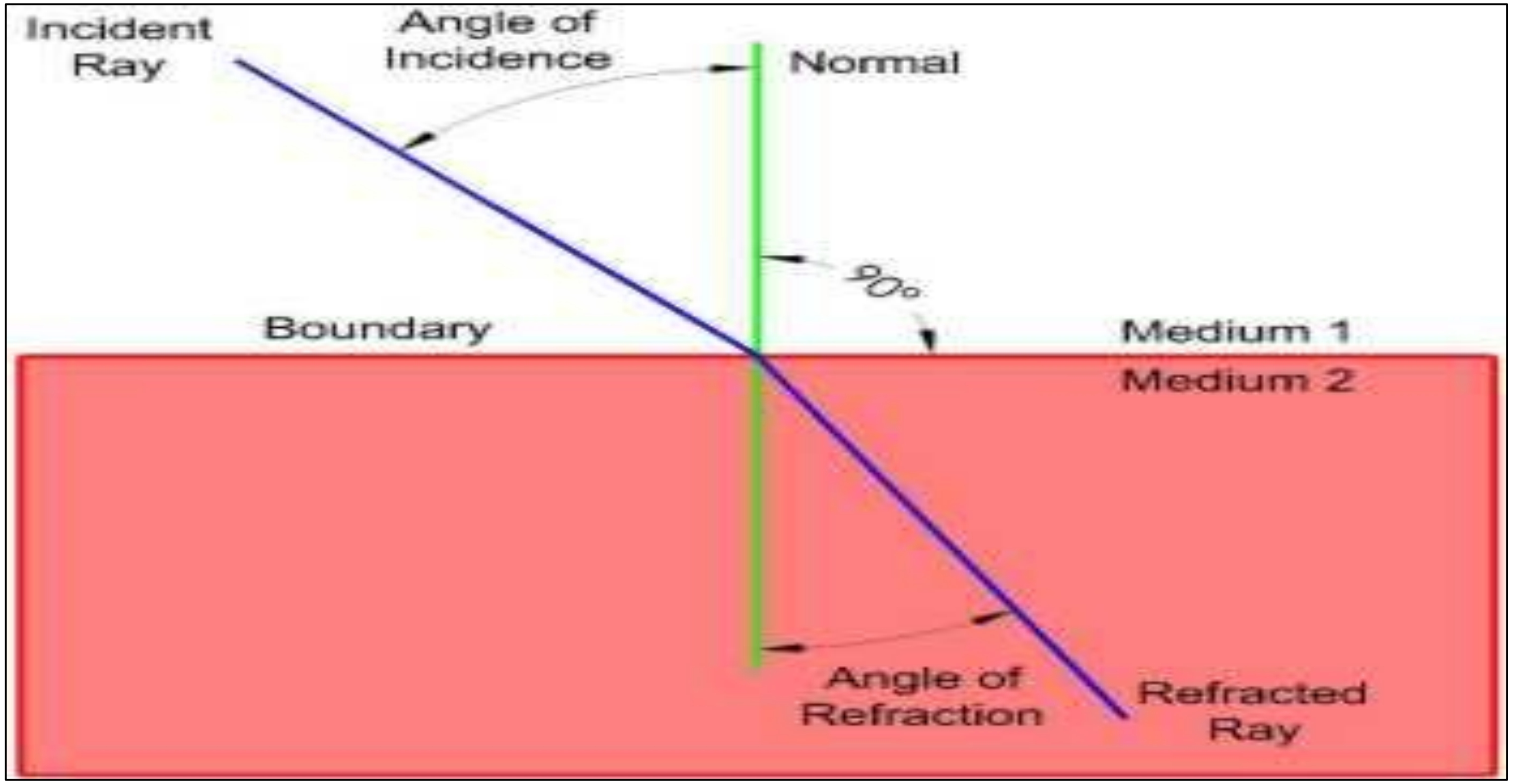
- Time Period of EM Wave (T) is given by:
- Amount of time required to complete one full cycle

$$T = \frac{1}{\nu}$$

Propagation of EM Waves

- When EM waves propagates from one medium to other:

1) A part of the wave is reflected back to the incident medium
2) Waves propagated to the second medium are refracted (transmitted) waves



Properties Of EM Waves

1. REFLECTION

-- Change in direction of the EM wave at an interface between two different media, so that wave returns to the medium from which it is originated

Law of Reflection: $\propto_{incedent} = \propto_{reflection}$

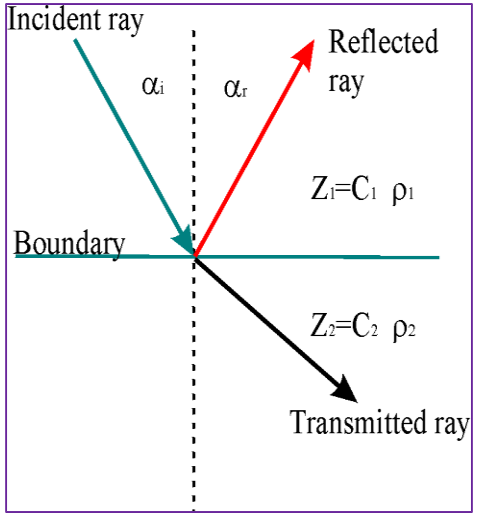
2. REFRACTION

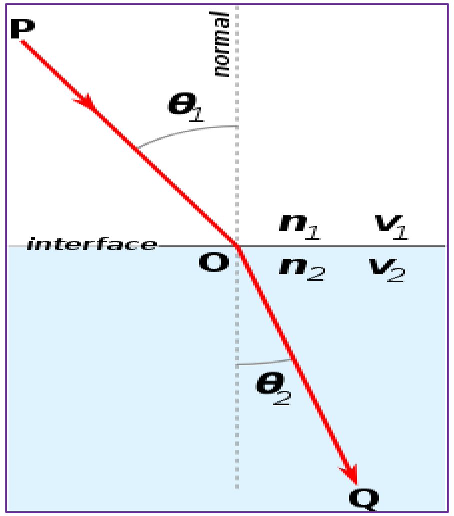
-- Change in direction of the EM wave due to change in medium, so that the wave passes through the medium

-- Also called, Transmission

As per Snell's law:

$$\frac{Sin\theta_1}{Sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$





v → Velocity of EM wave in medium

n → Refractive index of the medium

= the ratio of the velocity of light in a vacuum to its velocity in a specified medium

Properties Of EM Waves

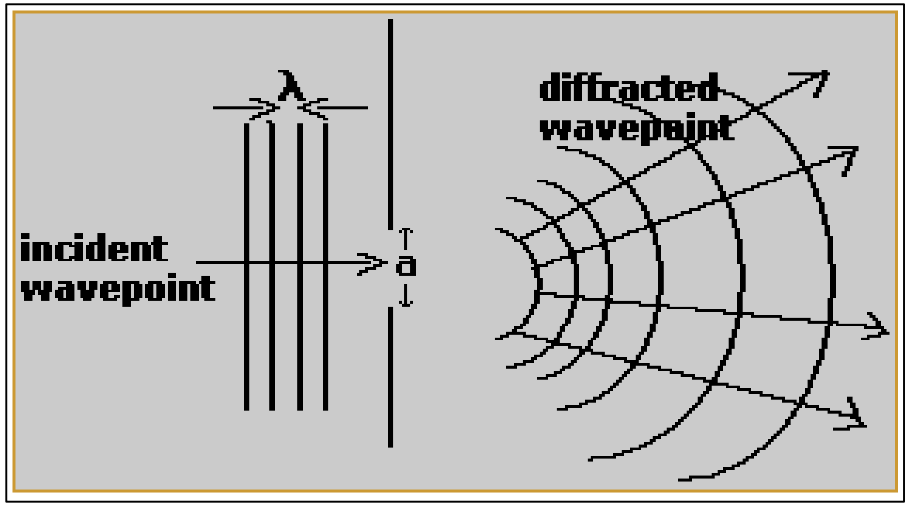
3. DIFFRACTION

-- Bending of the EM waves around an object (edge, slit, hole, …)

-- The amount of bending depends on the relative size of the wavelength of light to the size of the opening

-- Diffraction of EM wave depends on $\frac{\lambda}{d}$

(λ → Wavelength; d → aperture width / diameter)



Properties Of EM Waves

4. ATTENUATION

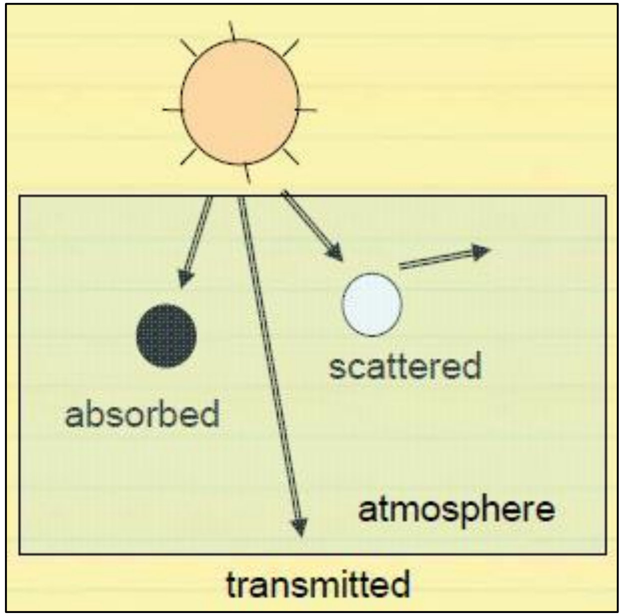
When EMR Passes through a medium, a gradual loss in the intensity (energy) can take place due to:

5. ABSORPTION

-- Energy of the EM wave is taken up by the matter, and transfers to other form *(heat energy)*

6. SCATTERING

-- Energy is radiated to other directions and there by decreasing the amount of radiation in the original direction



Properties Of EM Waves

7. POLARISATION

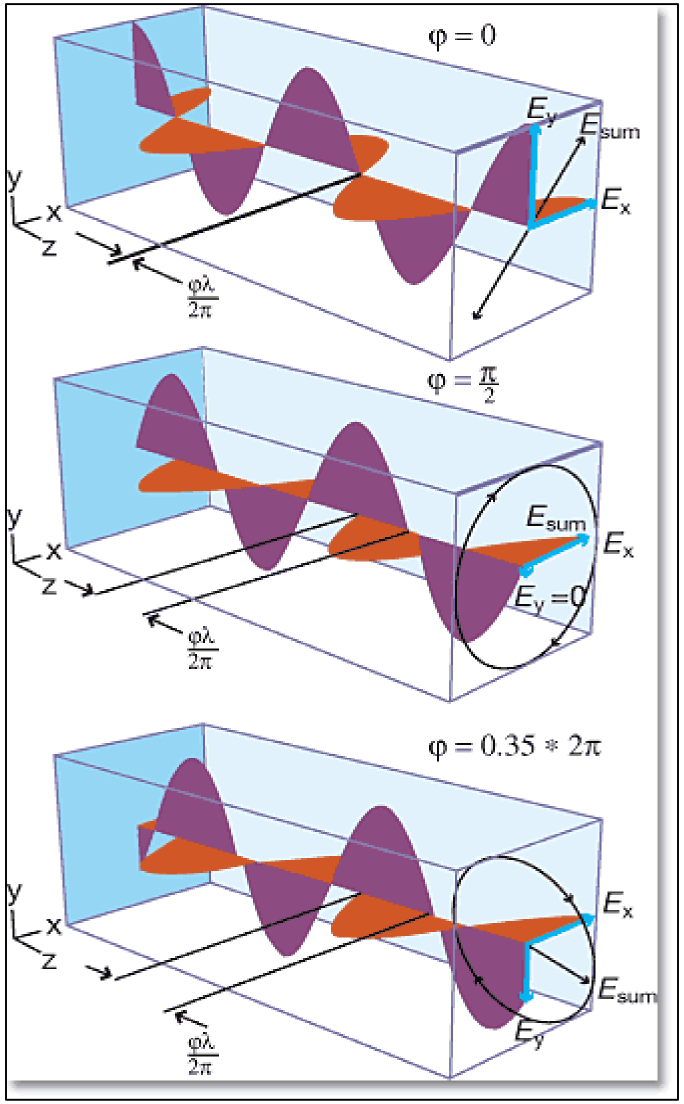
-- Property applying to transverse waves that specifies the geometrical orientation of the oscillations

-- EM wave is made of electric and magnetic fields, which are mutually orthogonal and transverse to direction of propagation

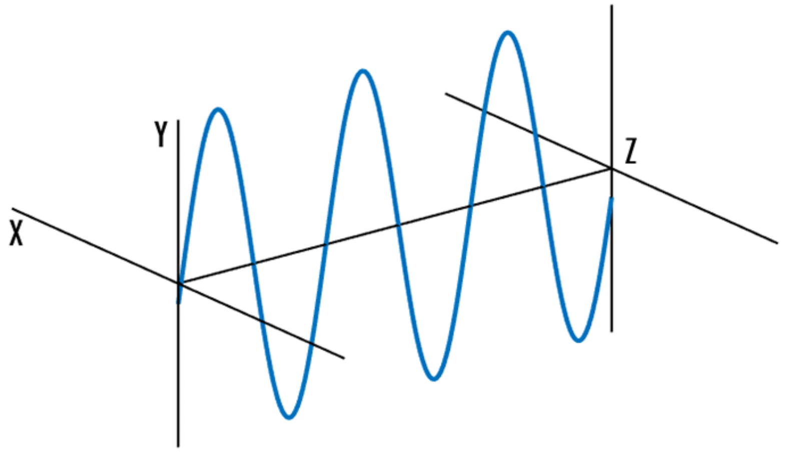
-- Polarisation defines the orientation of the two fields (mainly, electric field)

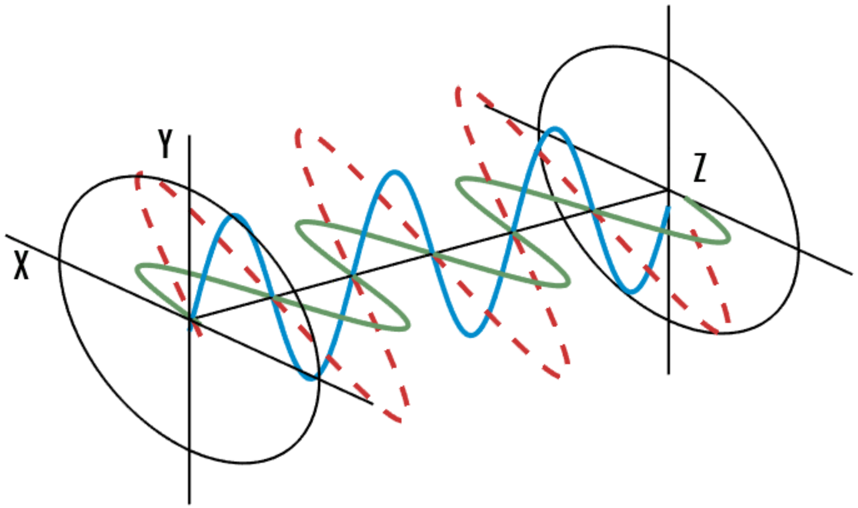
-- If the electric field orients in a single direction, it results in linear polarization

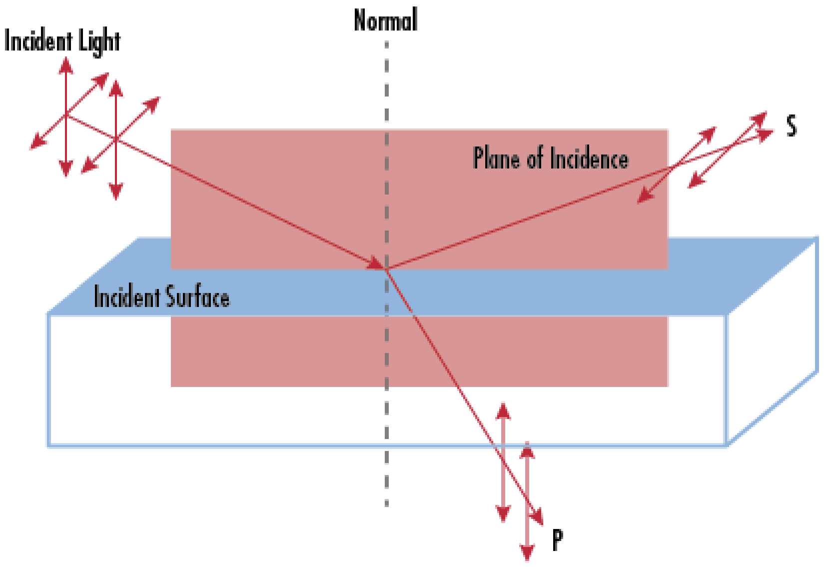
-- If the electric field rotates as the wave travels, it results in circular / elliptical polarization



Properties Of EM Waves







Properties Of EM Waves

- **FRESNEL'S RELATIONS**

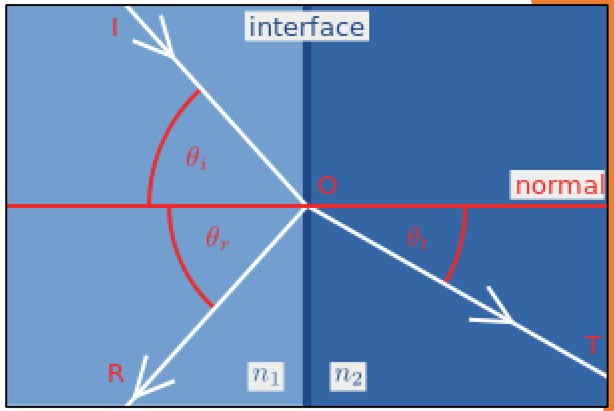
-- The reflectance and transmittance (refraction) of an incident wave depends on

a) Wavelength

b) Angular distortion

c) Polarisation

-- When light moves from a medium of a given refractive index, n_1, into a second medium with refractive index, n_2 both reflection and refraction of the light may occur



-- The Fresnel equations describe what fraction of the light is reflected and what fraction is refracted

-- P-polarized light has an electric field polarized parallel to the plane of incidence, while s-polarized light is perpendicular to this plane

Properties Of EM Waves

- Reflection Coefficient (R) for S- and P- polarized lights are given by:

$$R_s = \left| \frac{n_1 \cos\theta_i - n_2 \cos\theta_t}{n_1 \cos\theta_i + n_2 \cos\theta_t} \right|^2 = \left| \frac{n_1 \cos\theta_i - n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i\right)^2}}{n_1 \cos\theta_i + n_2 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i\right)^2}} \right|^2$$

$$R_p = \left| \frac{n_1 \cos\theta_t - n_2 \cos\theta_i}{n_1 \cos\theta_t + n_2 \cos\theta_i} \right|^2 = \left| \frac{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i\right)^2} - n_2 \cos\theta_i}{n_1 \sqrt{1 - \left(\frac{n_1}{n_2} \sin\theta_i\right)^2} + n_2 \cos\theta_i} \right|^2$$

$$R = \frac{R_s + R_p}{2}$$

- Transmittance Coefficient (T) is given by:

$$T_s = 1 - R_s \qquad T_p = 1 - R_p$$

Thermal Radiation

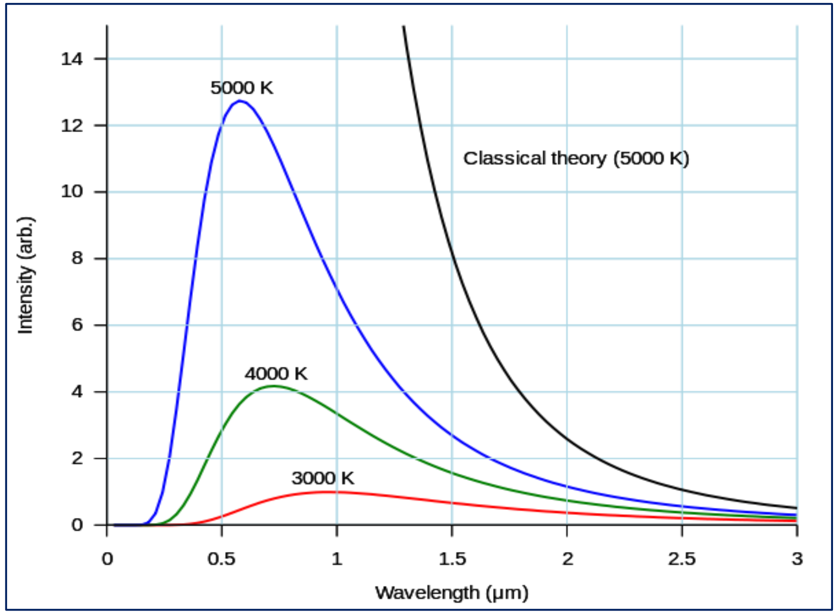
- Any object above Absolute Zero (0 K) emits electromagnetic radiation
- Radiation from an ideal thermal radiator (Black body) is given by Plank's Law:

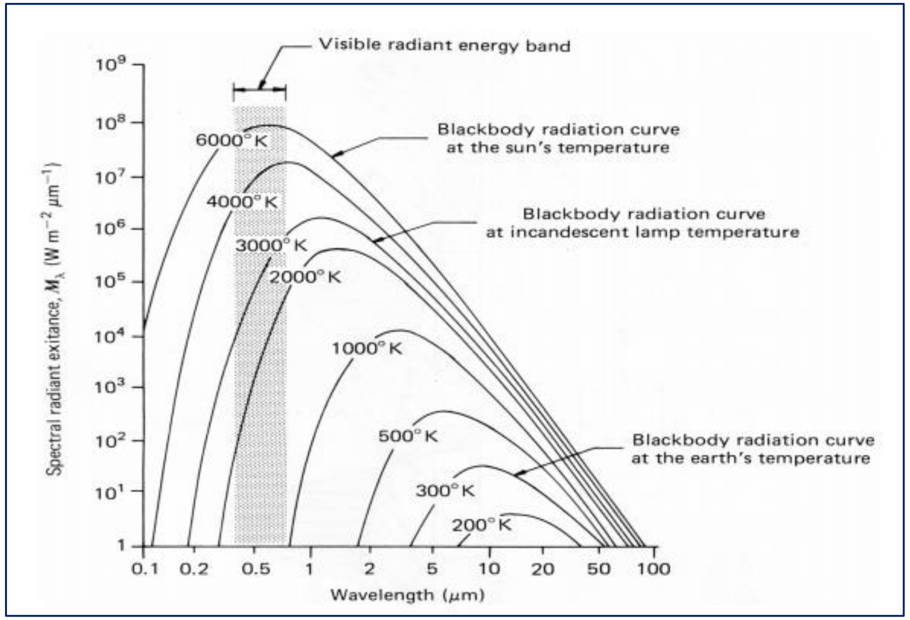
$$B_\nu(T) = \frac{2h\nu^3}{c^2} \frac{1}{e^{\frac{h\nu}{k_B T}} - 1}, \text{ or } B_\lambda(T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda k_B T}} - 1}$$

- $B_v(T)$ → Spectral radiance in $Wm^{-2}\mu m$
- T → absolute Temperature of the body in K
- h → Plank's constant = 6.6256 x 10^{-34} Ws^2
- C → Velocity of light = 3 x 10^8 ms^{-1}
- λ → Wavelength in micro-meters
- k_B → Boltzman's Constant = 1.3805 x 10^{-23} WsK^{-1}

Black Body Radiation

- Spectral exitance (peak) curve is continuous and shows a single maximum for a given temperature
- As temperature increases, maximum shifts towards shorter wavelength
- The exitance is higher for a higher temperature
- Total emission within all wavelengths is obtained by Planks equation from λ = 0 to λ = α





Black Body Radiation

- The total emissions from a black body within all wavelengths is given by Stefan-Boltzman's law

$$M_{Total} = \sigma \cdot T^4$$

$\sigma \rightarrow$ Stefan-Boltzman's Constant = 5.67 x 10^{-8} $Wm^{-2}K^{-4}$

- The maximum wavelength (in micro-meters) for a given temperature (in K) is given by:

$$\lambda_{max} = \frac{2897}{T}$$

EMISSIVITY (e)

- Characterization of emission from a real body interms of black body

$$e = \frac{M_m}{M_b} = \frac{Radiant\ Exitance\ of\ Material\ of\ Interest}{Radiant\ Exitance\ of\ Black\ Body\ at\ same\ Temp.}$$

- Grey body $\rightarrow$ emissivity is constant at all wavelengths

EM Radiation For Remote Sensing

- Sun is the prime source of EM radiation in Visible and Near Infrared regions
- While moving through the atmosphere, Sun's radiation is absorbed and scattered by gasses and particulates
- The incident radiation (spectrum) is modified by: Nitrogen; Oxygen; Helium; Water Vapor; Ozone; …
- Atmospheric Windows are the wavelength regions through which EM radiation passes without much attenuation
- Atmospheric Windows used in RS:

    1) 0.4 – 1.3 μm

    2) 1.5 – 1.8 μm

    3) 2.0 – 2.26 μm

    4) 3.0 – 3.6 μm

    5) 4.2 – 5.0 μm

    6) 7.0 – 15.0 μm

    7) 1.0 – 30.0 cm

Thank you

Questions
???