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Lecture 2 –RADIATION

2.1 EARTH-SUN GEOMETRY

- The Earth has an elliptical orbit around the sun
- The average Earth-Sun distance is **93,000,000** mi (**150,000,000** km)
- ***Aphelion*** – the farthest Earth-Sun distance occurs in July, and is about **94,000,000** mi (**152,000,000** km)
- ***Perihelion*** – the closest Earth-Sun distance occurs in January, and is about **91,000,000** mi (**147,000,000** km)
- Astronomical seasons and climatological seasons

▪ *Astronomical seasons* are :-

- ***Winter*** – Winter Solstice to Spring Equinox (Dec **21** – Mar **21**)
- ***Spring*** – Spring Equinox to Summer Solstice (Mar **21-** Jun **21**)
- ***Summer*** – Summer Solstice to Fall Equinox (Jun **21** – Sep **21**)
- ***Autumn*** – Fall Equinox to Winter Solstice (Sep **21** – Dec **21**)

▪ *Climatological seasons* :-

- ***Winter*** – December, January, February
- ***Spring*** – March, April, May
- ***Summer*** – June, July, August
- ***Autumn*** – September, October, November

2.2 ENERGY, HEAT, AND TEMPERATURE

- *Energy* is defined as *the ability to do work*
- Types of energy
  - *Kinetic energy* – energy of motion
  - *Potential energy* – stored energy
- *Thermal Energy* is defined as *the total kinetic energy of all the atoms and molecules that make up a substance*
- *Temperature* is *a measure of the average of kinetic energy of all the atoms or molecules of the substance*
- Adding heat to a substance raises its temperature
- Subtracting heat will lower its temperature
- Methods of energy transfer
  - Conduction
  - Convection
    - Meteorologists refer to horizontal convection as *advection*
  - Radiation

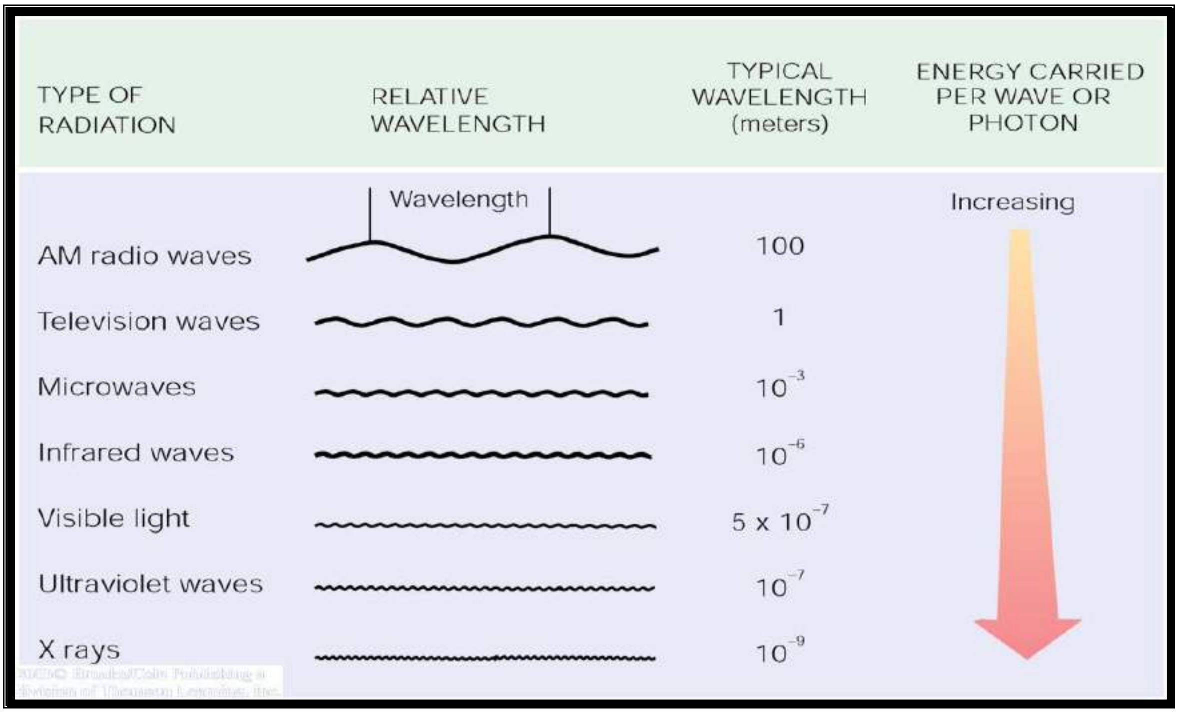
2.3 RADIATION

- Radiation is comprised of electromagnetic waves of differing wavelengths as shown in table (**2.1**)
- Shorter wavelengths (higher frequencies) are more energetic
- Relationship between wave speed (c), wavelength (λ), and frequency (υ)

$$\boxed{c = \lambda . \upsilon}$$

- Radiation moves at a speed of $c = 3.0 \times 10^{8}$ m/s in a vacuum
- Travels slower through matter
- Index of refraction (n) of a medium is speed in a vacuum (c) divided by speed in the medium (v)

$$\boxed{n = \frac{c}{v}}$$



TYPE OF RADIATION	RELATIVE WAVELENGTH	TYPICAL WAVELENGTH (meters)	ENERGY CARRIED PER WAVE OR PHOTON
AM radio waves	Wavelength	100	Increasing
Television waves		1	
Microwaves		10^{-3}	
Infrared waves		10^{-6}	
Visible light		5×10^{-7}	
Ultraviolet waves		10^{-7}	
X rays		10^{-9}	

Table (2.1) : Types of radiation

- Electromagnetic spectrum as shown in figure (**2.1**)
- Visible light comprises only a small part of the spectrum (**0.4** – **0.7** μm)
- Ultra-violet (**UV**) radiation has shorter wavelengths than visible (λ < **0.4** μm)
- Infrared (**IR**) radiation has longer wavelengths than visible (λ > **0.7** μm)
- Short wave radiation λ < **4** μm
- Long wave radiation λ > **4** μm

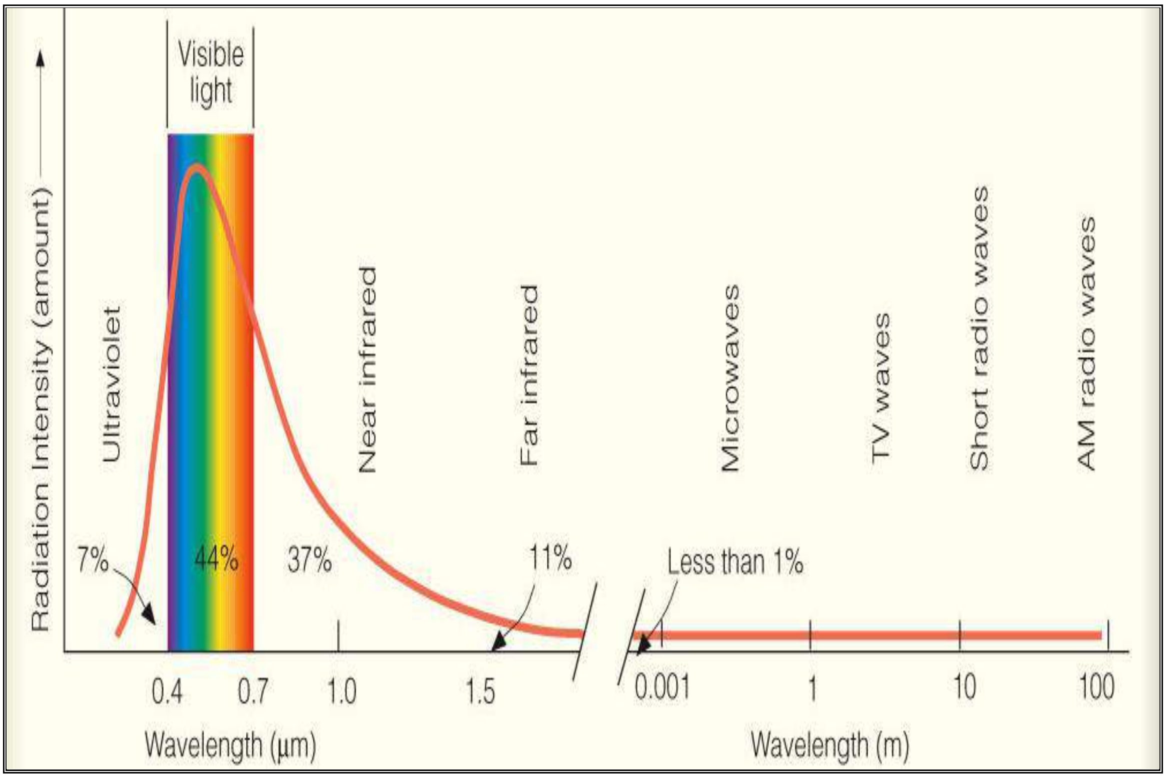


Fig. (2.1) : The sun electromagnetic spectrum

2.4 RADIATION LAWS

- ***Planck's Law***
- It has been determined experimentally that the intensity of radiation emitted by a blackbody
- Blackbody , a hypothetical object that absorbs all of the radiation that strikes it , it also emits radiation at a maximum rate for its given temperature
- The shorter the wavelength the greater the energy

$$E_\lambda = \frac{c_1}{\lambda^5 .(e^{c_2/\lambda T} - 1)}$$

Where :

$\boldsymbol{c_1} = \mathbf{3.74\times10^{-16}}$ W m^2; $\boldsymbol{c_2} = \mathbf{1.44\times10^{-2}}$ m K, $\boldsymbol{E_\lambda}$ has units of W m^{-2} μm^{-1}

- ***Stefan-Boltzmann Law***
- A law of radiation which **states** that the amount of radiant energy emitted from a unit surface area of an object (ideally a blackbody) is proportional to the fourth power of the object's absolute temperature
- Hotter objects radiate more energy per unit area than do cold objects

$$E = \sigma .T^4$$

Where **:**

$\boldsymbol{\sigma} = \mathbf{5.67\times10^{-8}}$ W m^{-2} K^{-4}

E *:* has units of W m^{-2}

- **Wien's Displacement Law**
- A law of radiation which **states** that the wavelength of maximum emitted radiation by an object (ideally a blackbody) is inversely proportional to the object's absolute temperature
- The hotter the object the shorter the wavelength of maximum radiation

$$\lambda_{\max} = \frac{2897\,\mu m.K}{T}$$

λ_{max} : the wavelength of maximum radiation

2.5 SOLAR (SHORTWAVE) RADIATION

- The Sun emits at about **6000 K**, while the earth emits at about **288** K as shown in figure (**2.2**)
- **From Wien's displacement law**
  - The Sun emits its peak radiation at a wavelength of **0.48µm**, which is in the visible part of the spectrum (blue light)
  - The Earth emits its peak radiation at a wavelength of **10µm**, which is in the IR part of the spectrum

- **From the Stefan-Boltzman law**

○ The Sun emits **7.35×10^{7}** W m^{-2} of energy per unit area

○ The Earth emits **390** W m^{-2} of energy per unit area

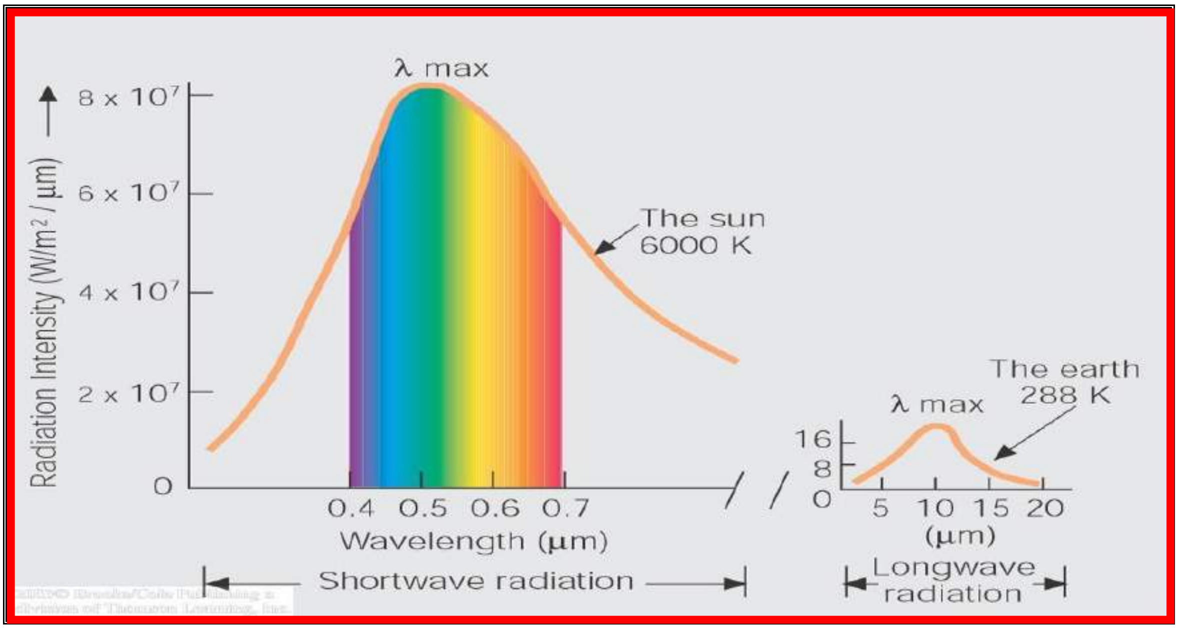


Fig. (2.2) : Short waves and Long waves Radiation

- Incoming solar radiation can be absorbed, reflected, or scattered by the atmosphere or Earth's surface as shown in figure (**2.3**)

○ **Absorption**

▪ **19**% absorbed directly in the atmosphere, primarily by ozone in the **stratosphere**, oxygen and nitrogen in the **thermosphere**, and water vapor and clouds in the **troposphere**

○ **51**% absorbed by land and sea

○ **Reflection**

▪ **30**% reflected back to space by clouds (**20**%) , the atmosphere (**6**%) and the Earth's surface (**4**%)

- *Albedo* is defined as the fraction of radiation reflected by a surface

- The Albedo of the Earth is **0.3**

- **Scattering**

- Produces a bunch of weaker rays that move off in different directions
- Scattering from small molecules is dependent of wavelength, with short wavelengths scattered more than longer wavelengths
- Scattering off of larger particles is not wavelength dependent

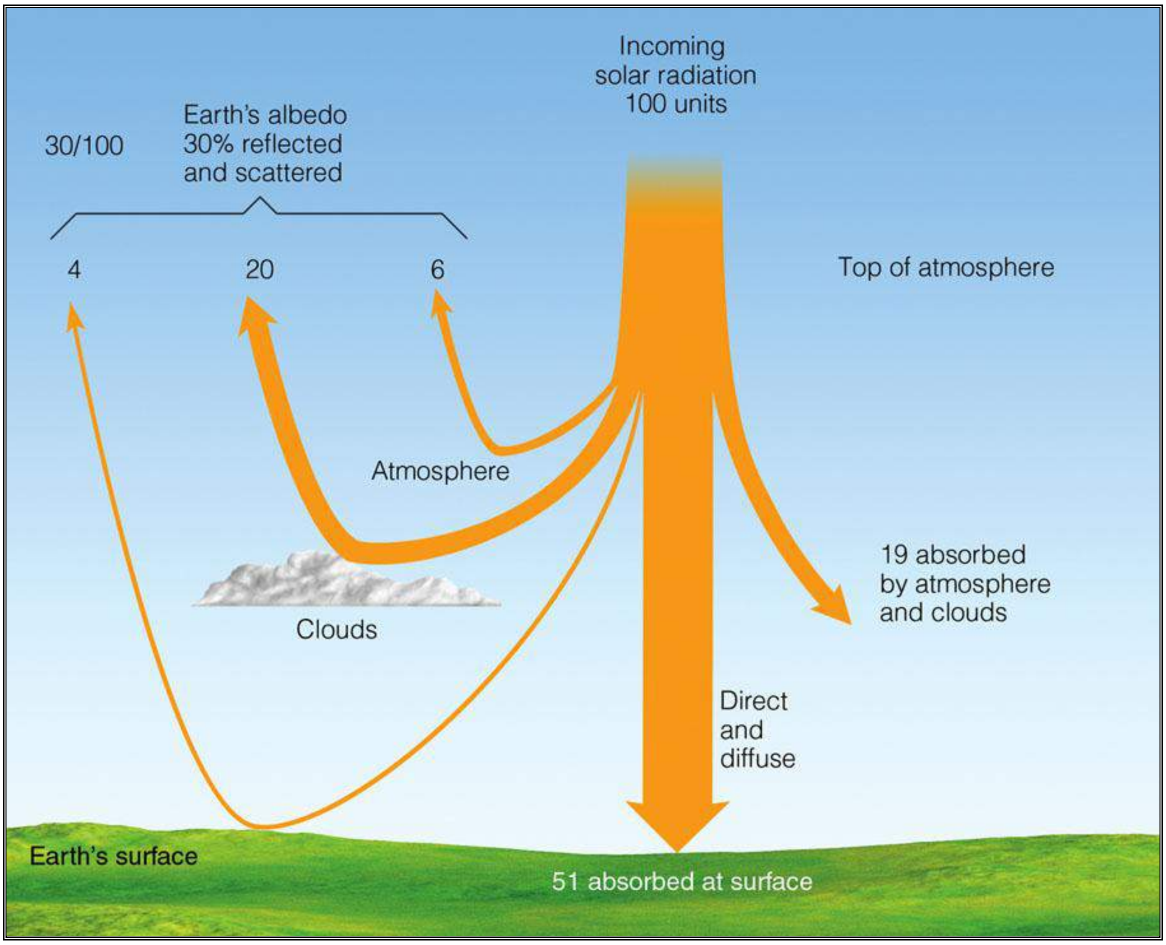


Fig. (2.3) : Fate of incoming Solar Radiation (Solae energy budget)

2.6 TERRESTRIAL (LONGWAVE) RADIATION

- Earth's surface emits radiation at a temperature of **288** K
- Maximum emission is in the near infrared
- Almost all emission is between **5** and **25** μm
- The atmosphere absorbs and reradiates much of the emitted **IR** radiation called "**greenhouse effect**."
- The "**greenhouse**" gases:-
  - H_2O
  - CO_2
  - N_2O
  - CH_4
  - O_3
- **Clouds** have a dual role in the radiation balance of the earth
  - Reflect incoming solar radiation, keeping daytime temperatures lower
  - Absorb outgoing terrestrial radiation, keeping nighttime temperatures higher
- Latitudinal heat balance
  - Tropics have net surplus of heat
  - Polar Regions have net deficit of heat
  - Heat must be transported from tropics to poles

<u>*2.7 RADIATION BALANCE*</u>

- In order to remain at a constant temperature, an object (earth-atmosphere) must emit the same amount of energy that it receives as shown in figure (**2.4**)
- The amount of solar energy absorbed by the earth and its atmosphere is

$$E_{solar} = \pi R^2 .S.(1-\alpha)...(1)$$

- ***S*** is the radiation flux at the top of the atmosphere, and is called the ***solar constant***, the rate at which solar energy is received on a surface at the outer edge of the atmosphere perpendicular to the sun's rays when the earth is at a mean distance from the sun
- The value of the solar constant is about **1368** W/m^2
- **α** is the albedo

- The amount of energy radiated by the earth and its atmosphere is

$$E_{earth} = 4\pi R^2.\sigma T^4 ...(2)$$

- In order to be in equilibrium, $\boldsymbol{E_{solar}}$ must equal $\boldsymbol{E_{earth}}$, so equating (**1**) and (**2**) we get

$$\pi R^2.S.(1-\alpha) = 4\pi R^2.\sigma T^4 ...(3)$$

which can be solved for ***T*** to get , the radiation temperature of earth

$$T = \sqrt[4]{\frac{S.(1-\alpha)}{4\sigma}} ...(4)$$

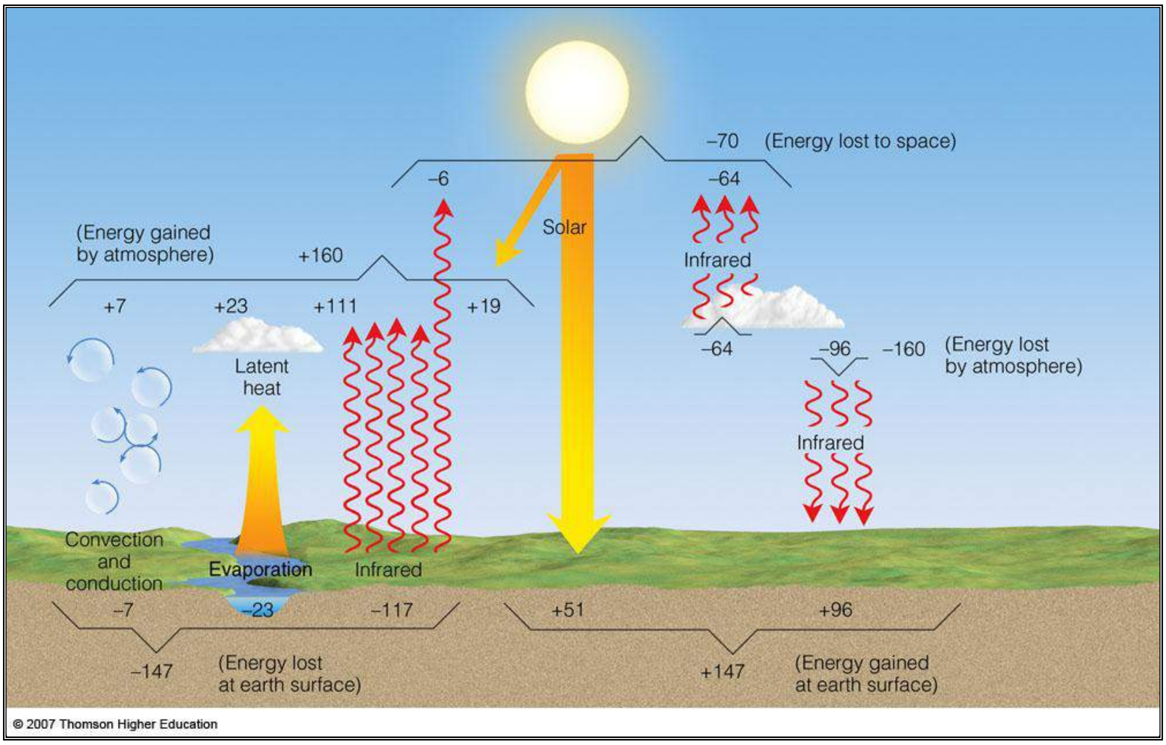


Fig. (2.4) : The earth – atmosphere energy balance