EN671: Solar Energy Conversion Technology

Lecture-3: Physics of propagation of solar radiation from the sun to earth

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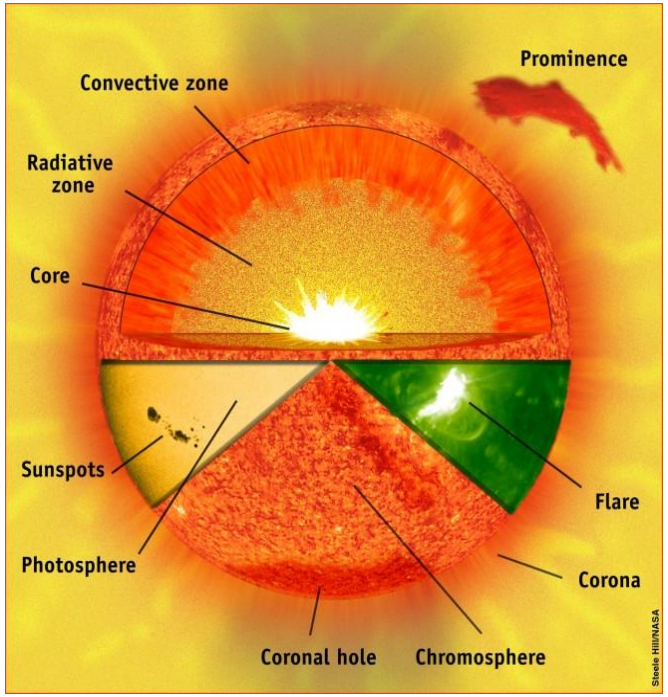
The SUN

- Largest member of the solar system (99.68% of the total mass of the solar system).
- Sphere of intensely hot gaseous matter.
- Sun rotates it own axis about once four weeks.
- Equator takes about 27 days, polar region takes about 30 days for each rotation.
- Density (at its centre): $>10^5$ kg/m^3 (100 times that of water), pressure (at its centre): over 1 billion atmospheres.
- Temperature (at the centre): about 15000000 K (8 x10^6 to 40 x 10^6 K) – ENERGY RELEASE DUE TO CONTINUOUS FUSION REACTION
- Black body temp: 5777 K



$$4\left(H_1^1\right) \rightarrow He_2^4 + 26.7 \text{ Mev}$$

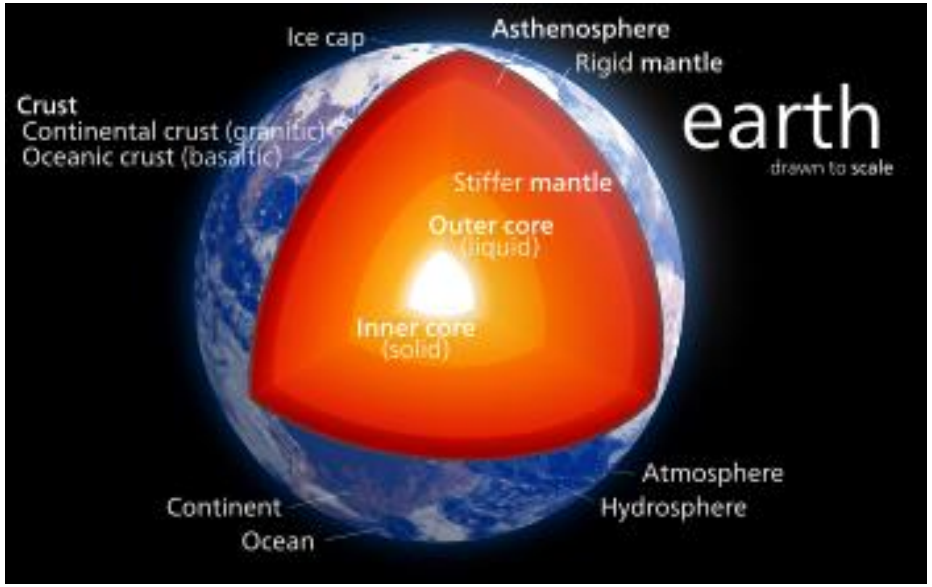
Energy radiation: 3.8 x 10^{26} W

The earth receives: 1.7 x 10^{18} W

Mean distance from the earth: 149600000 km

The Earth

- Came into existence 4.6 billions years ago.
- Earth revolves around the sun in an elliptical shape once per year.
- Earth is inclined at 23.5^{o} and rotates about its own axis.
- Inner core is a solid mass made of iron and nickel.
- Outer core of the Earth's mantle comprises solid rock.
- 70% of earth is covered by water and remaining 30% is land.
- The blackbody temperature of Earth is 288 K (appx.)

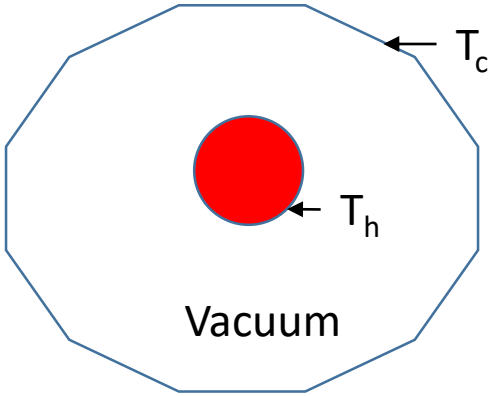


Half of the earth is lit by

Sunlight at a time

Reflects 1/3rd of sunlight – earth's Albedo

Radiation Heat Exchange



Thermal Radiation:

$$T_{body} > T_{Absolute\ zero}$$

The bulk of thermal energy emitted by a body lies in wavelengths between 0.1 to 100 micron

Ex. Transfer of energy from the sun to the earth (no intervening medium is required)

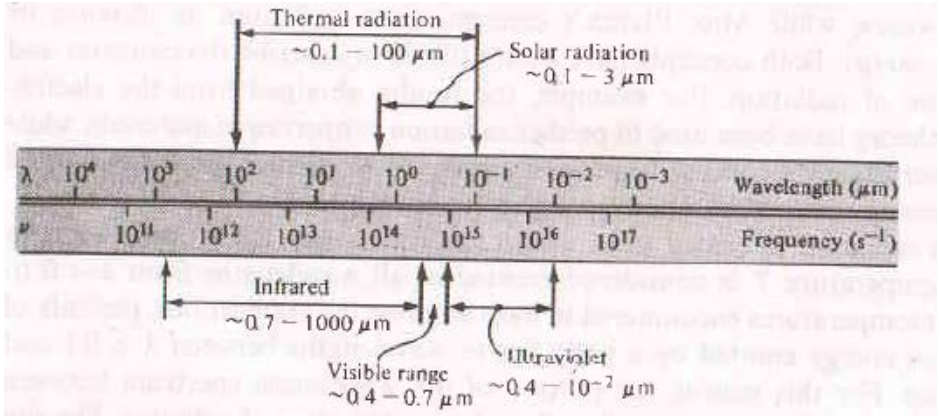
Radiation

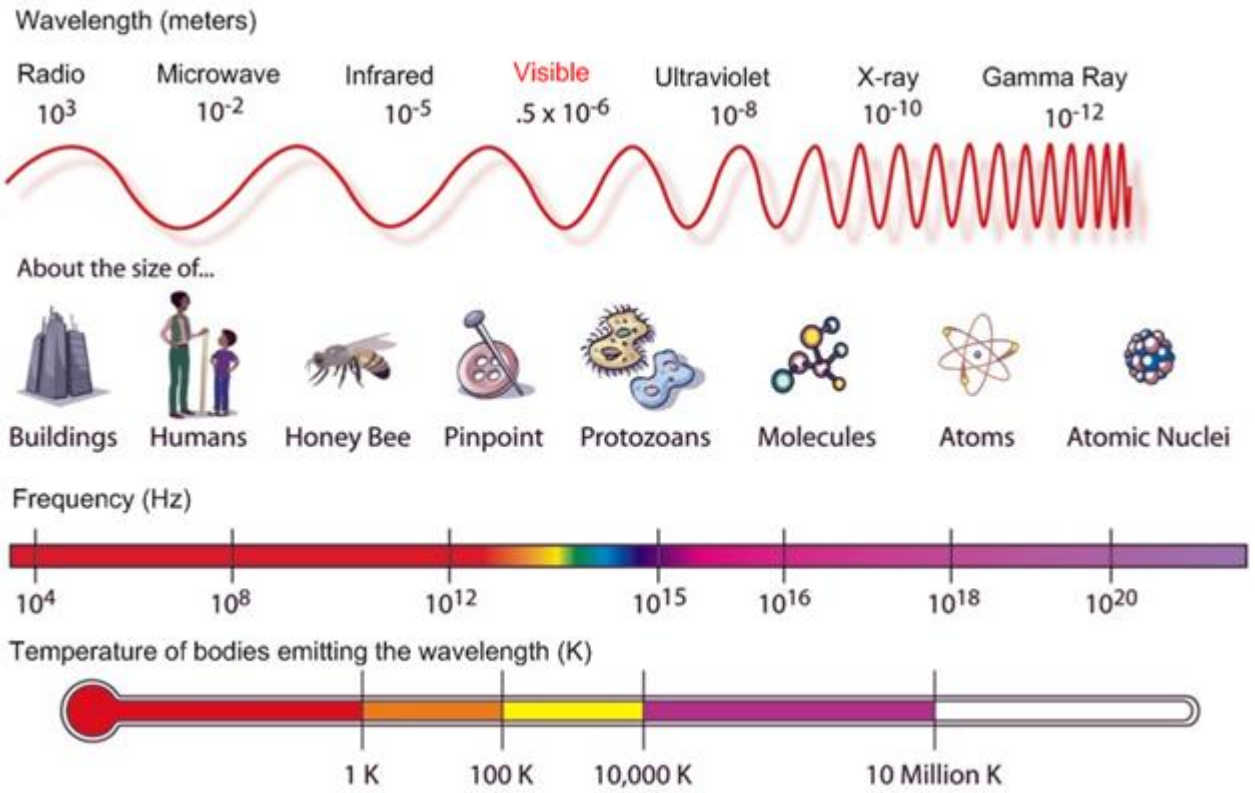
- Maxwell's electromagnetic theory (radiation is treated as Electromagnetic wave)
- Max Planck's concept (treats radiation as Photon or quanta of energy)

- Both the concepts utilized to describe the emission and propagation of radiation.
- Result obtained from Electromagnetic theory used to predict radiation properties of the materials.
- Results from Planck's concept have been employed to predict the magnitude of radiation energy emitted by a body at a given temperature.

Spectrum of electromagnetic radiation

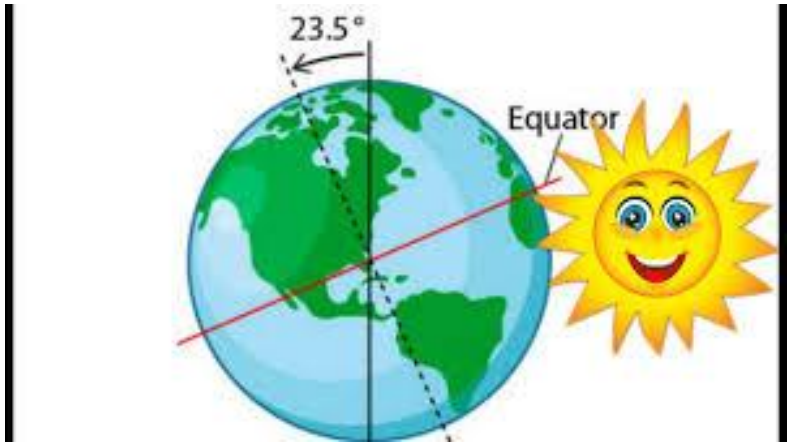
When the radiation is treated as electromagnetic wave, the radiation from a body at temperature T is considered at all wavelengths.

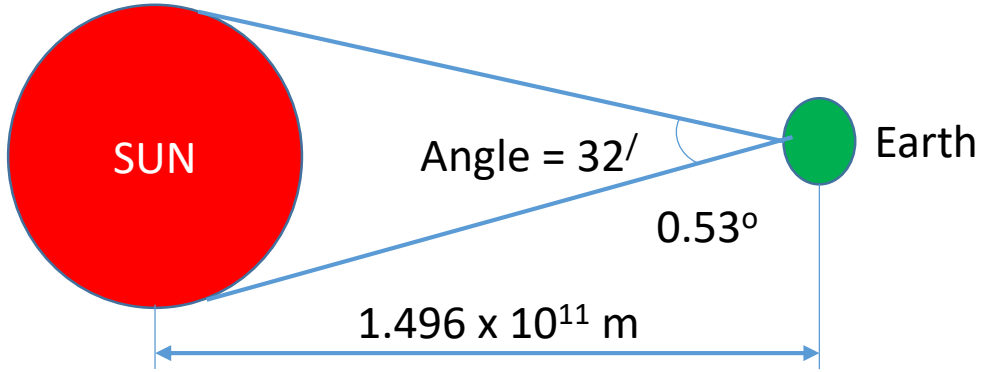




	Wavelength	Frequency	Examples of use
Gamma rays	<0.01 nm		
X-rays	0.01–10 nm		Radiography
Ultraviolet	10–400 nm		Suntanning, water purification
Visible	400–800 nm		Daytime vision, photosynthesis
Near infrared	800 nm–10 μm		Nocturnal vision
Thermal infrared	10 μm–1 mm		Heating, cooking
Microwaves	1 mm–10 cm		Microwave ovens
Radar waves	10 cm–1 m	3 GHz–300 MHz	Mobile telephone, speed detectors
Radio waves	>1 m	<300 MHz	Radio, TV, telecommunications

Sun-earth relationship





$D_{Sun} = 1.39 \times 10^9$ m

$D_{Earth} = 1.27 \times 10^7$ m

One astronomical unit

Eccentricity of earth's orbit – the distance between the sun and the earth varies by ± 1.7%

Solar Constant

98.3 % when closest to the sun and 101.7 % when earth sun distance is maximum

The actual solar radiation flux varies by +3.3%, maximum on Dec 21 and minimum on June 21.

- Sun-Earth distance is not fixed due to elliptical orbit of the Earth's motion around the Sun
- Solar intensity in the extraterrestrial region has been measured by NASA with the help of satellite
- For the nth day of the year the solar intensity on a plane perpendicular to the direction of solar radiation is calculated by

$$I_{ext} = I_{sc}\left[1.0 + 0.033\cos\left(360\,n/365\right)\right]$$

I_{sc} Solar constant defined as the radiant solar flux received in the extraterrestrial region on a plane of unit area kept perpendicular to the solar radiation at the mean Sun-Earth distance. The value of solar constant is 1367 W/m^2

For June 22, 2015, $n = 173$ $I_{ext} = 1322.49$ W/m^2

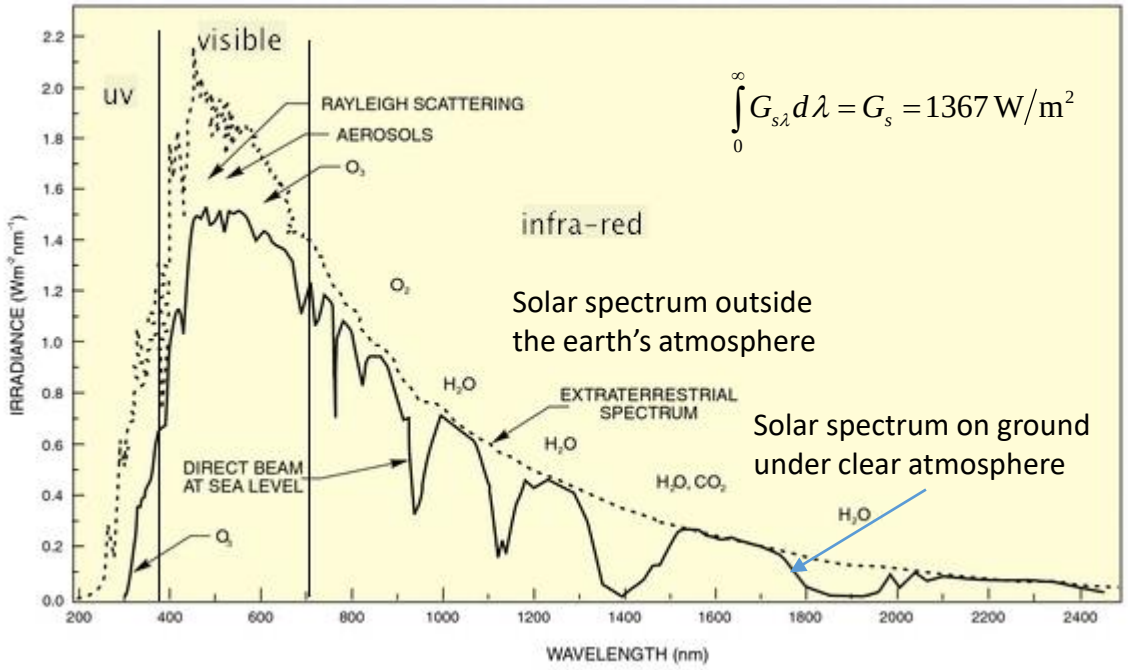
For December 21, 2015, $n = 173$ $I_{ext} = 1411.43$ W/m^2

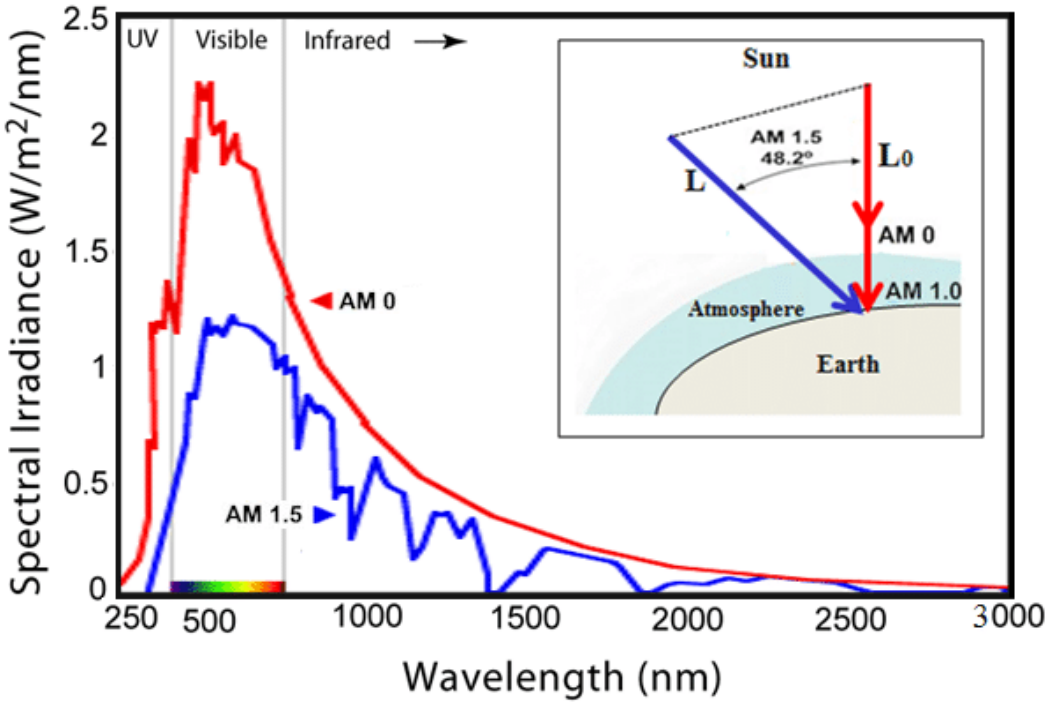
For Leap year ?

Propagation of solar radiation from the sun to earth through atmosphere

Spectral solar irradiation, extraterrestrial and terrestrial

Appx. 99% of the atmosphere is contained within a distance of about 30 km from the earth's surface

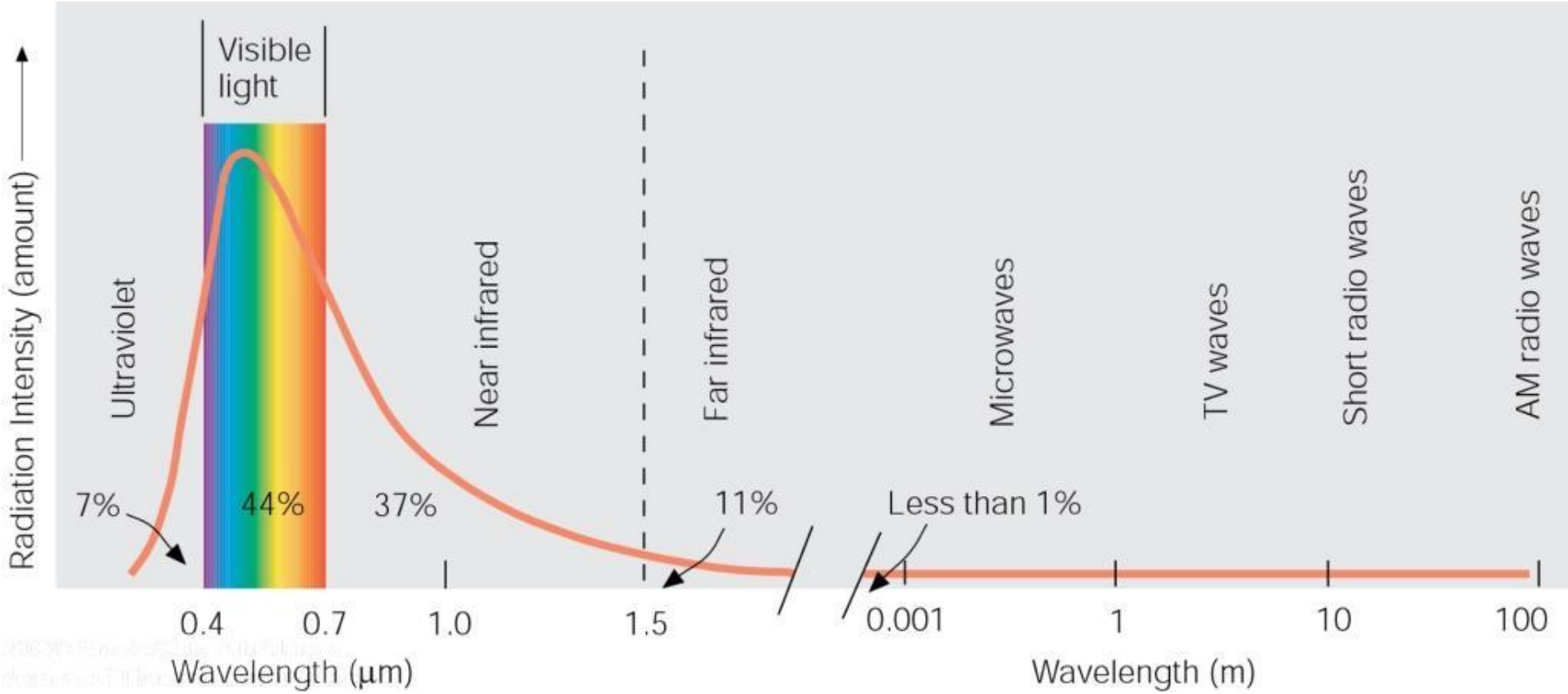




- ✓ The ozone is concentrated in a layer 10 to 30 km from the earth's surface *(strongly absorbs UV in 0.2 to 0.29 µm and relatively strongly in 0.29 to 0.34 µm).*
- ✓ Oxygen absorption occurs in a very narrow line centered at 0.76 µm
- ✓ Water : 0.7 to 2.2 µm, CO_2 absorbs >2.2 µm

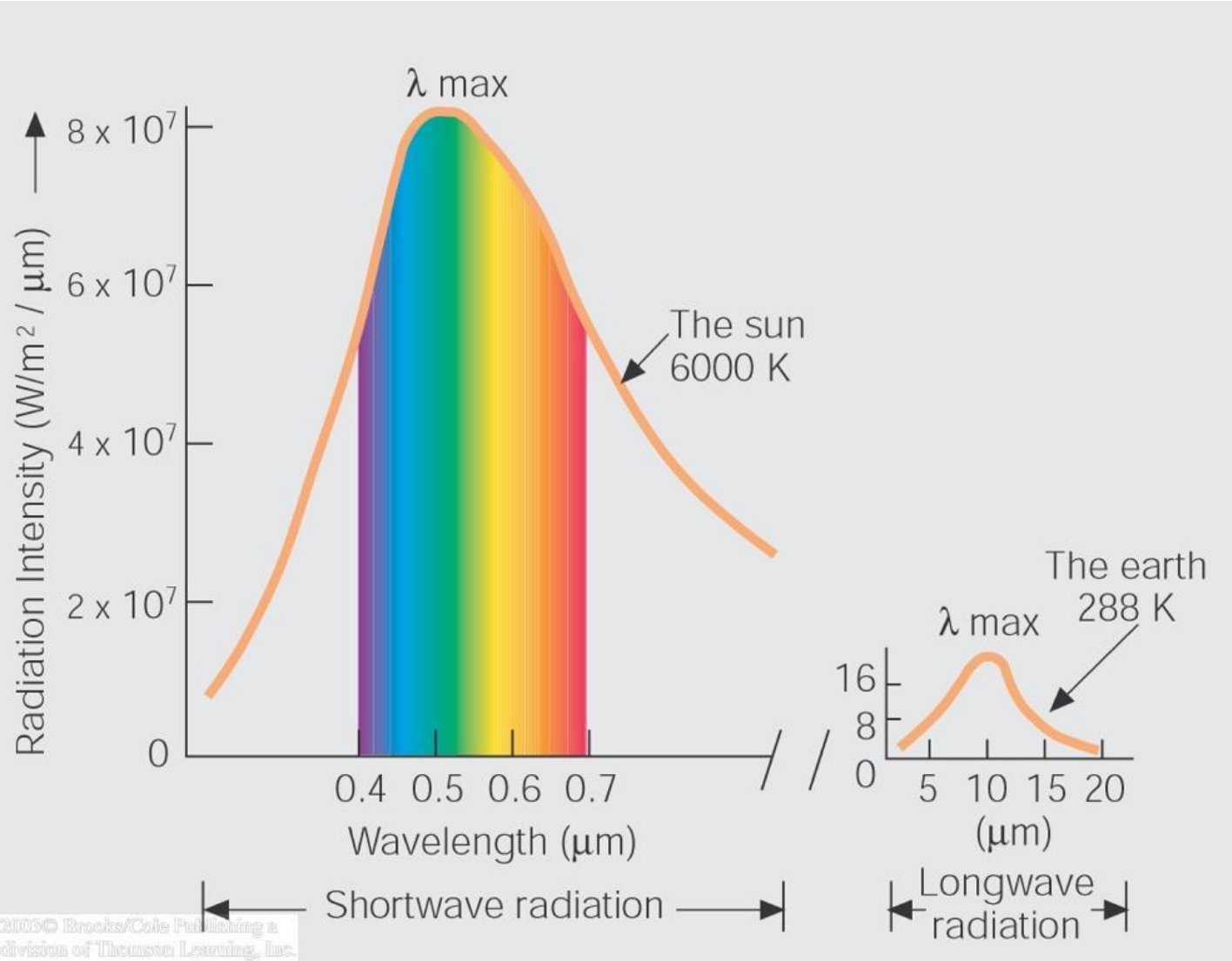
- ❖ Solar radiation reaching the earth's surface is contained in the wavelength between 0.29 and 2.5 µm

Sun's Electromagnetic Spectrum



Solar radiation has peak intensities in the shorter wavelengths, dominant in the region we know as visible, thus shortwave radiation

Longwave & Shortwave Radiation



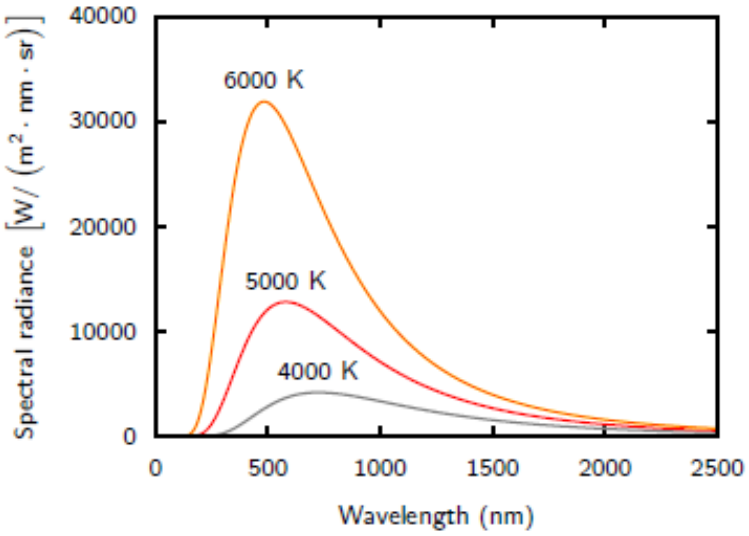
The hot sun radiates at shorter wavelengths that carry more energy, and the fraction absorbed by the cooler earth is then re-radiated at longer wavelengths.

Mechanism of absorption and scattering

- Absorption: Occurs primarily due to Ozone and water vapour present in the earth's atmosphere and lesser extent to the other gases and particulate matter (leads to atmospheric emission – thermal radiation at that temperature)
- Scattering: Occurs due to all gaseous molecules as well as particulate matter present in the earth's atmosphere

Black body radiation

- For a given temperature and wavelength , no other body at the same temperature can emit more radiation than a black body.
- Spectral black body emissive power
- Stefan Boltzman constant



Blackbody spectrum at 3 different temperatures

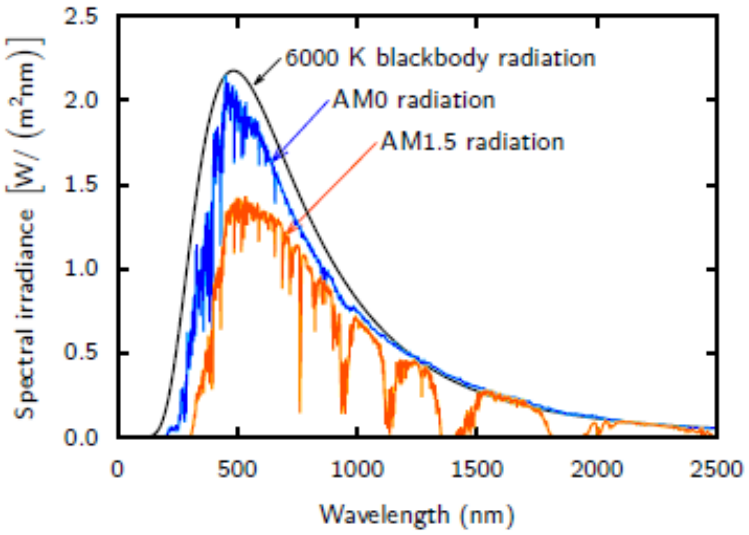
Black body radiation

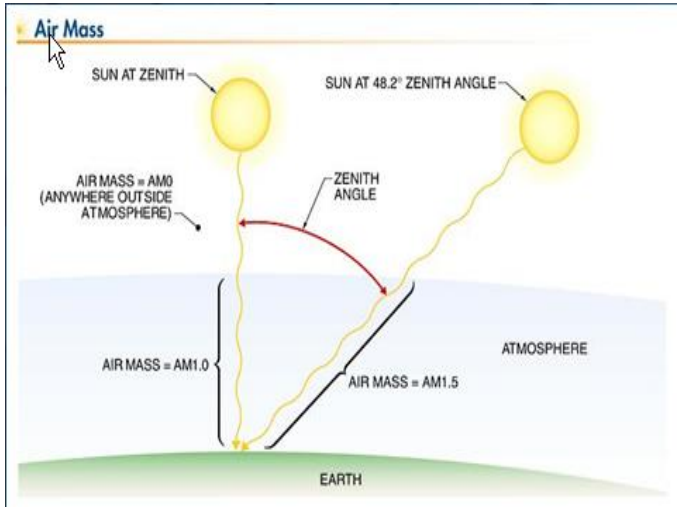
Q1: Determine the temperature of the Sun for the following data:

$I_{sc} = 1367$ W/m^2, radius of Sun (R_s)= 0.619 x 10^9 m, mean Sun-Earth distance (L_{se}) = 1.5 x 10^{11}m, and $\sigma = 5.67 \times 10^{-8}$ W/m^{2}K^4

Air Mass (AM)

- The most important parameter that determines the solar irradiance under clear sky conditions is the distance that the sunlight has to travel through the atmosphere.
- This distance is the shortest when the Sun is at the zenith, i.e. directly overhead.
- The ratio of an actual path length of the sunlight to this minimal distance is known as the optical air mass. When the Sun is at its zenith the optical air mass is unity and the spectrum is called the air mass 1 (AM1) spectrum.





Summary

- We have learned the how solar radiation is propagated from the surface of the Sun to the earth's surface.
- Atmospheric absorption and scattering.
- Sun-earth relationship.
- Different types of radiation .
- Air mass (AM0, AM1, AM2, AM1.5 – Wp -1000 W/m^2)

Thank you