Electromagnetic radiation

Lec. 2

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Outlines

- Radiation Laws
- Conservation energy
- EMR interaction in the earth surface
- EMR interaction in the Atmosphere

RADIATION LAWS

- **Planck Law:** Energy and Frequency
- **Kirchhoff Law:** Energy, Wavelength, and Temperature
- **Stefan-Boltzmann Law:** Emitted radiation and temperature
- **Wien Displacement Law:** Wavelength and temperature

PLANCK LAW

Planck discovered that electromagnetic energy is absorbed and emitted in discrete units now called **quanta** or **photons**.

The size of each unit is directly proportional to the frequency of the energy's radiation.

$$Q = h\upsilon$$

Where,

Q = Energy of a photon (joules)

h = Planck's constant (joules * s)

υ = frequency (hertz)

1 hertz=cycle/second

$Q = h\boxed{\nu}$

where

Q = radiant energy of quanta (joules)

h = Planck's constant (6.626×10^{-34} joules.sec)

ν = frequency of EMR (sec^{-1})

Remember: $c = \nu\lambda$ or: $\nu = \boxed{c/\lambda}$

$Q = h\, c/\lambda$

As h & c are constants, energy is inversely proportional to wavelength

Electromagnetic energy radiates in accordance with the basic wave theory. This theory describes the EM energy as travelling in a harmonic sinusoidal fashion at the velocity of light. Although many characteristics of EM energy are easily described by wave theory, another theory known as particle theory offers insight into how electromagnetic energy interacts with matter. It suggests that EMR is composed of many discrete units called photons/quanta. The energy of photon is

$$Q = hc / \lambda = h \nu$$

Where

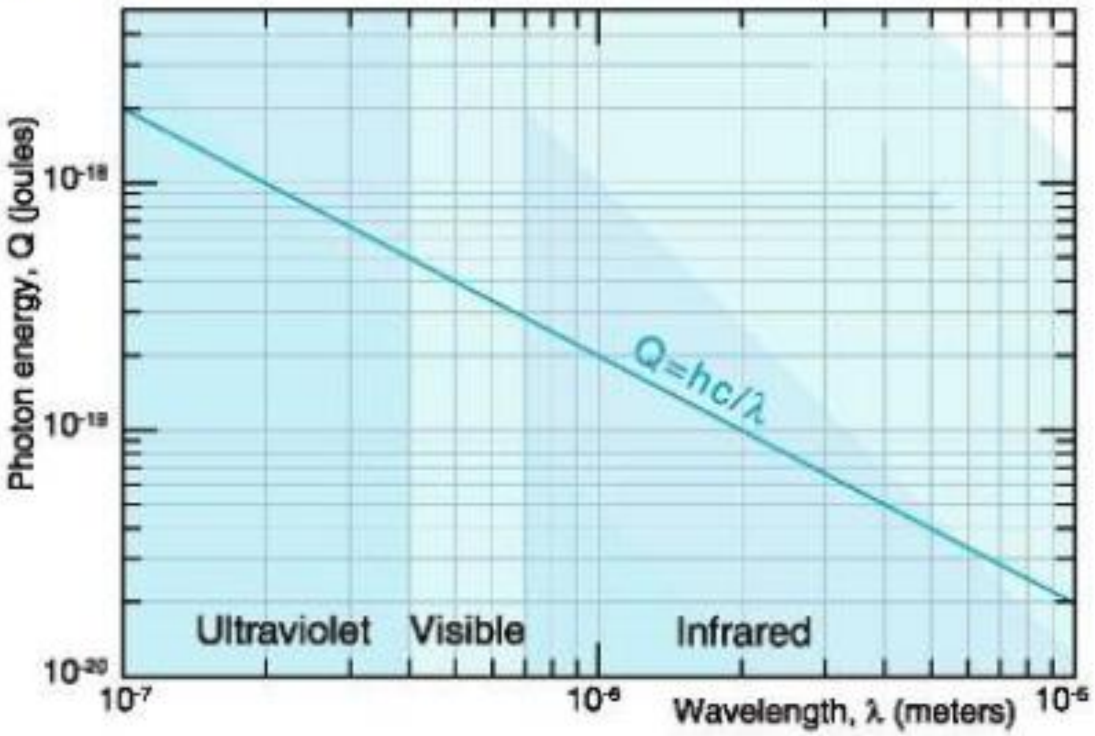
Q is the energy of quantum,

h = Planck's constant

Particle theory and wave theory propose that electromagnetic radiation is composed of discrete units called photons or quanta. From this relationship, it is seen that quantum energy is inversely proportional to wavelength; the longer the wave, the smaller its energy. This is of particular importance in remote sensing, as naturally emitted radiation with long wavelengths, such as microwaves from natural terrestrial phenomena, is more difficult to detect than phenomena that emit radiation with shorter wavelengths. This means that low-energy long-wave radiation emitted or reflected from terrestrial phenomena requires sensing systems to conduct large and repeated scans at different times so that these systems can detect this low energy.

Energy, Wavelength & Frequency

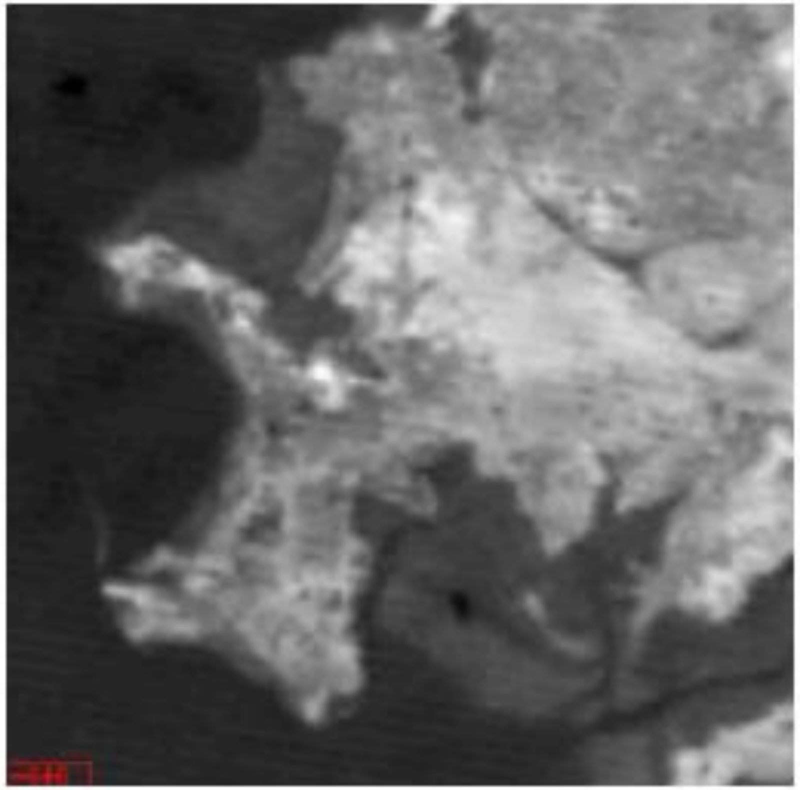
- Wavelength (inverse) and frequency (direct) relationships with EMR energy levels



(Diagram source: The Light Measurement handbook http://www.intl-light.com/handbook/)

Energy & Wavelength

MIR



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EMR Units

- Airborne and satellite imaging systems record the amount of EMR being reflected or emitted from a target
- Amount of EMR reaching a sensor is in one of the following units:

TERM	UNIT	DESCRIPTION
radiant energy (Q)	joule	energy per quanta
radiant flux (ϕ)	watt (joule.second^{-1})	energy per unit time
<u>Radiant flux density</u>		
irradiance (E,Q)	watt.m^{-2}	incident flux per unit area over all angles
radiance (L)	watt.m^{-2}.sr^{-1}	incident flux per unit area at specific solid/3-D angle
spectral radiance (L)	watt.m^{-2}.sr^{-1}.μm^{-1}	incident flux per unit area at specific angle over a set range of wavelengths

KIRCHHOFF LAW

This law states that the ratio of emitted radiation to absorbed radiation flux is the same for all blackbodies at the same temperature.

It forms the basis for the definition of **emissivity (ε)**:

$$\varepsilon = \frac{M}{M_b}$$

Where,

M = the emittance of a given object

M_b = the emittance of a blackbody at the same temperature

The emissivity of a true blackbody is 1, and that of a perfect reflector (a whitebody) would be 0. In nature, all objects have emissivities that fall between these extremes (graybodies).

- **Kirchhoff's law also states that objects that contain good absorb a certain amount of radiation energy well are also good at radiating**
- **Therefore, objects that behave as black bodies radiate more radiation energy than other objects because they absorb all the radiation waves falling on them, and then radiate them back in their maximum quantities according to their temperature and the length of the radiation waves.**

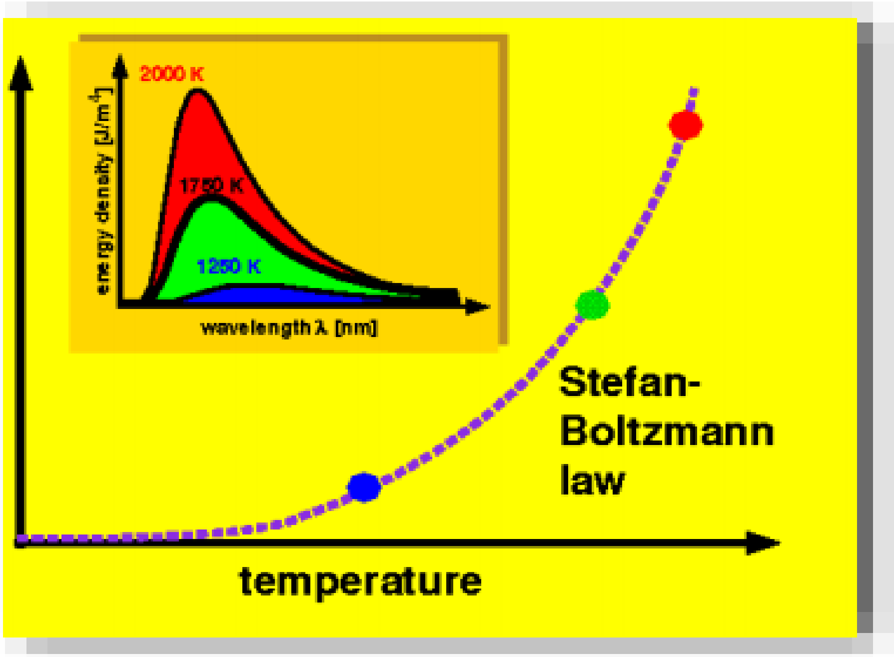
STEFAN-BOLTZMANN LAW

Defines the relationship between the total emitted radiation (W) and temperature (T).

It states that total radiation emitted from a blackbody is proportional to the fourth power of its absolute temperature.

$$W = \sigma T^4$$

where σ is the Stefan-Boltzmann constant, 5.6697×10^{-8} W m^{-2} K^{-4}.



It states that hot blackbodies emit more energy per unit area than do cool blackbodies.

WIEN DISPLACEMENT LAW

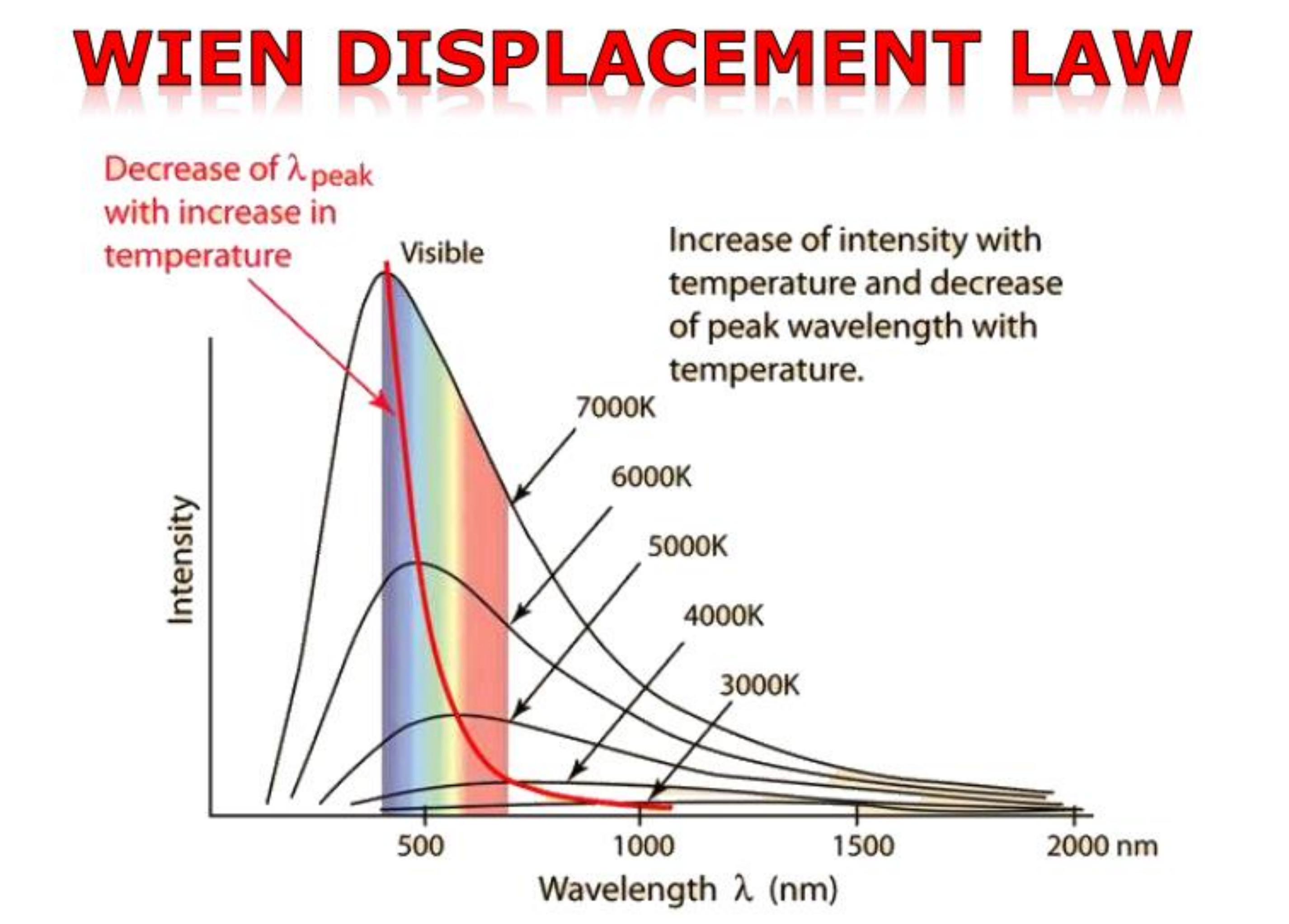
This law specifies the relationship between the wavelength of radiation emitted and the temperature of a blackbody.

$$\lambda = \frac{k}{T}$$

where k is a constant equaling 2898 μm K, and T is the absolute temperature in kelvin.

Therefore, as the Sun approximates a 6000 K blackbody, its dominant wavelength (λ_{max}) is:

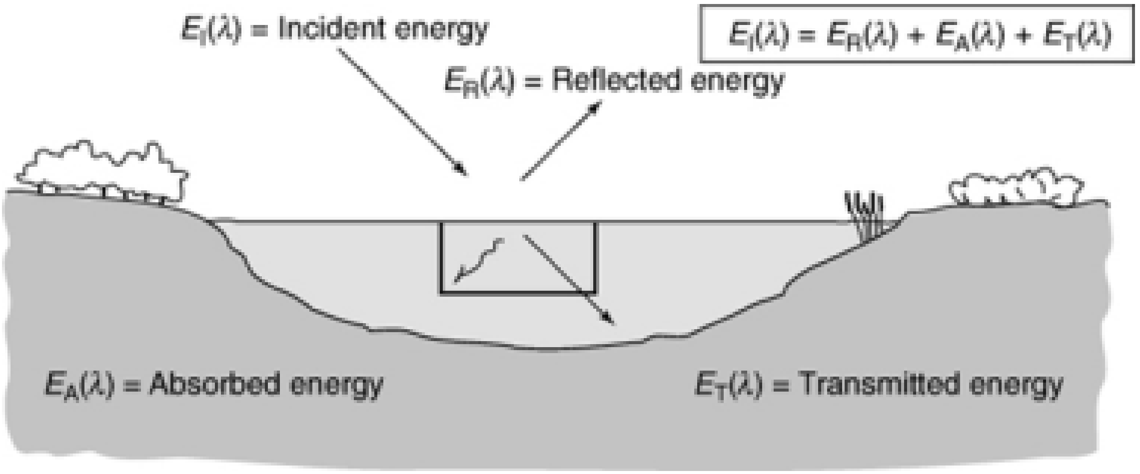
$$\frac{2898\ \mu m\ K}{6000\ K} = 0.483\ \mu m$$



A BLACK BODY HAS A SPECIFIC WAVELENGTH OF RADIATION AT WHICH IT EMITS ITS MAXIMUM RADIATION ENERGY, AND THE LENGTH OF THIS WAVE IS INVERSELY PROPORTIONAL TO THE TEMPERATURE OF THE BODY. THE HIGHER THE TEMPERATURE OF THE BODY, THE MORE THE WAVELENGTH AT WHICH IT EMITS ITS MAXIMUM ENERGY SHIFTS TOWARDS SHORTER WAVELENGTHS.

Conservation of Energy

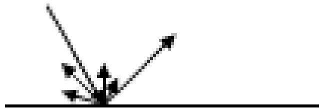
- Need to understand this to interpret image data sets and measure processes responsible for absorption, reflection and transmission of EMR
- Controls on elements of image formation
- For any wavelength of EMR and incident amount of EMR (E) interacting with a surface:



E = Reflected + Transmitted + Absorbed

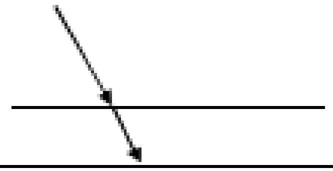
EMR Interactions

- Reflection
  - Re-direction of light striking non-transparent surface
  - Strength of reflection – type of surface
  - Diffuse – smooth
  - Specular (Lambertian) – rough



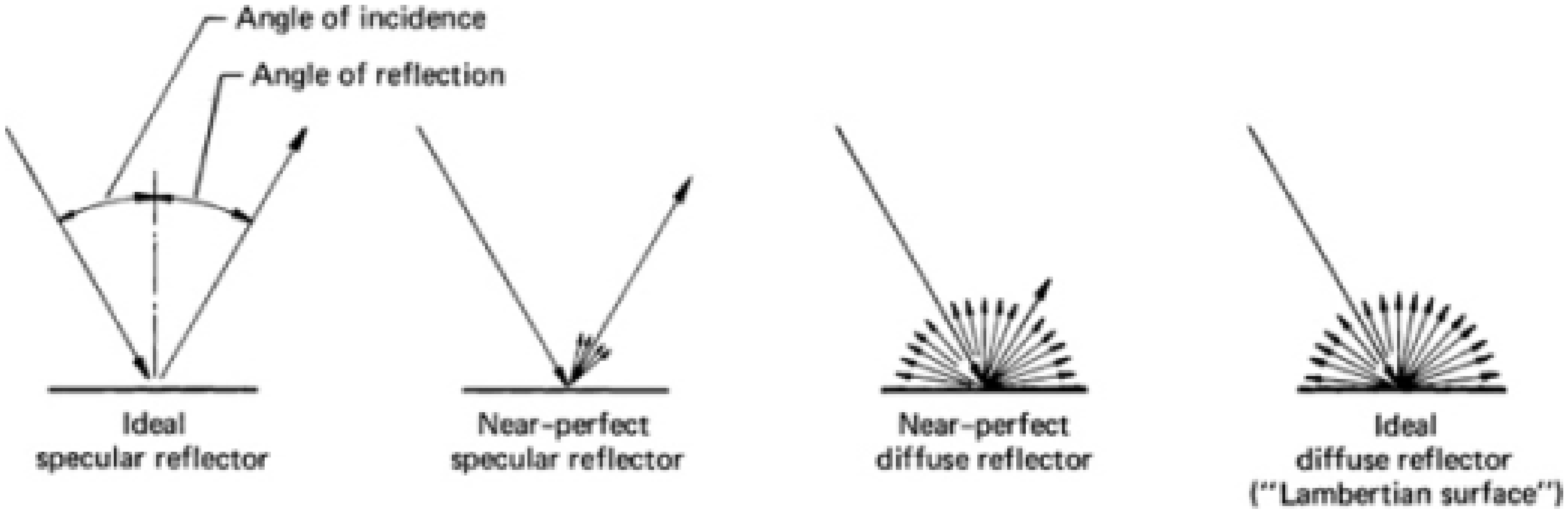
- Absorption
  - Energy of the photon is taken up by the feature and converted to other forms of energy (eg used for photosynthesis

- Transmission
  - Light passing through material without much attenuation
  - Water most affected by transmission of light
  - Plant leaves



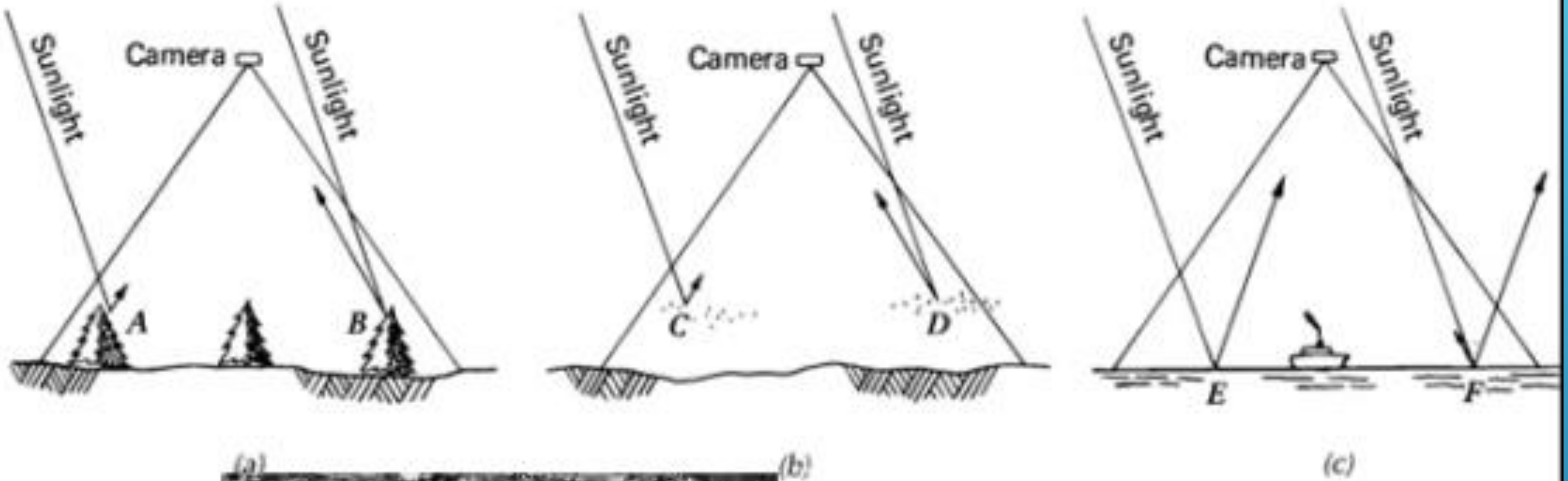
Reflectance

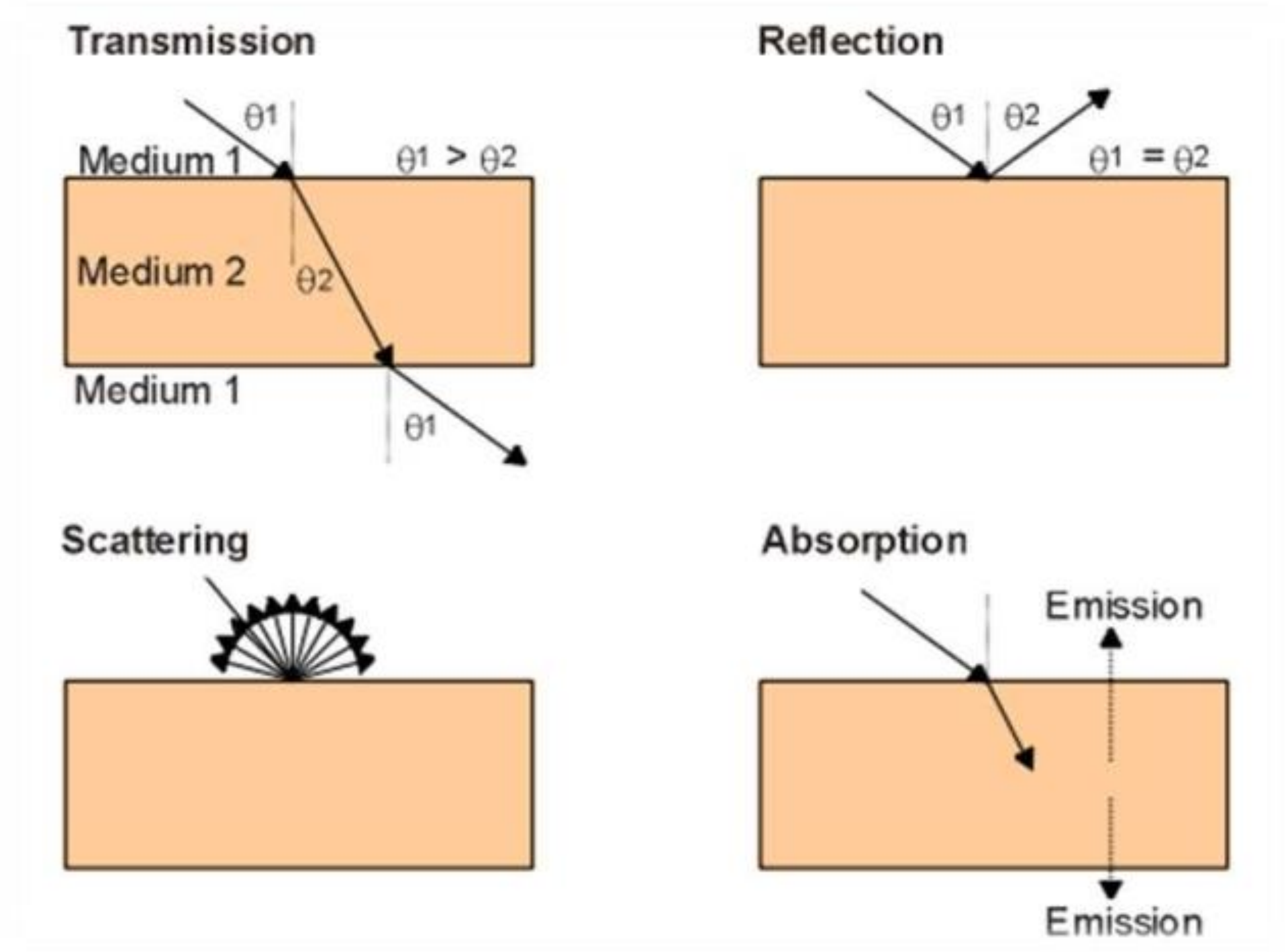
- **Diffuse reflectance** - uniform in all directions (Contains information on the characteristics of a target, by the nature of its interactions with EMR)
- **Specular reflectance** - mirror like / directional with no information on the characteristics of a target
- Accounts for amount of incoming radiation



Reflectance and Geometry

- Reflected EMR depends on angles of incident light and camera position

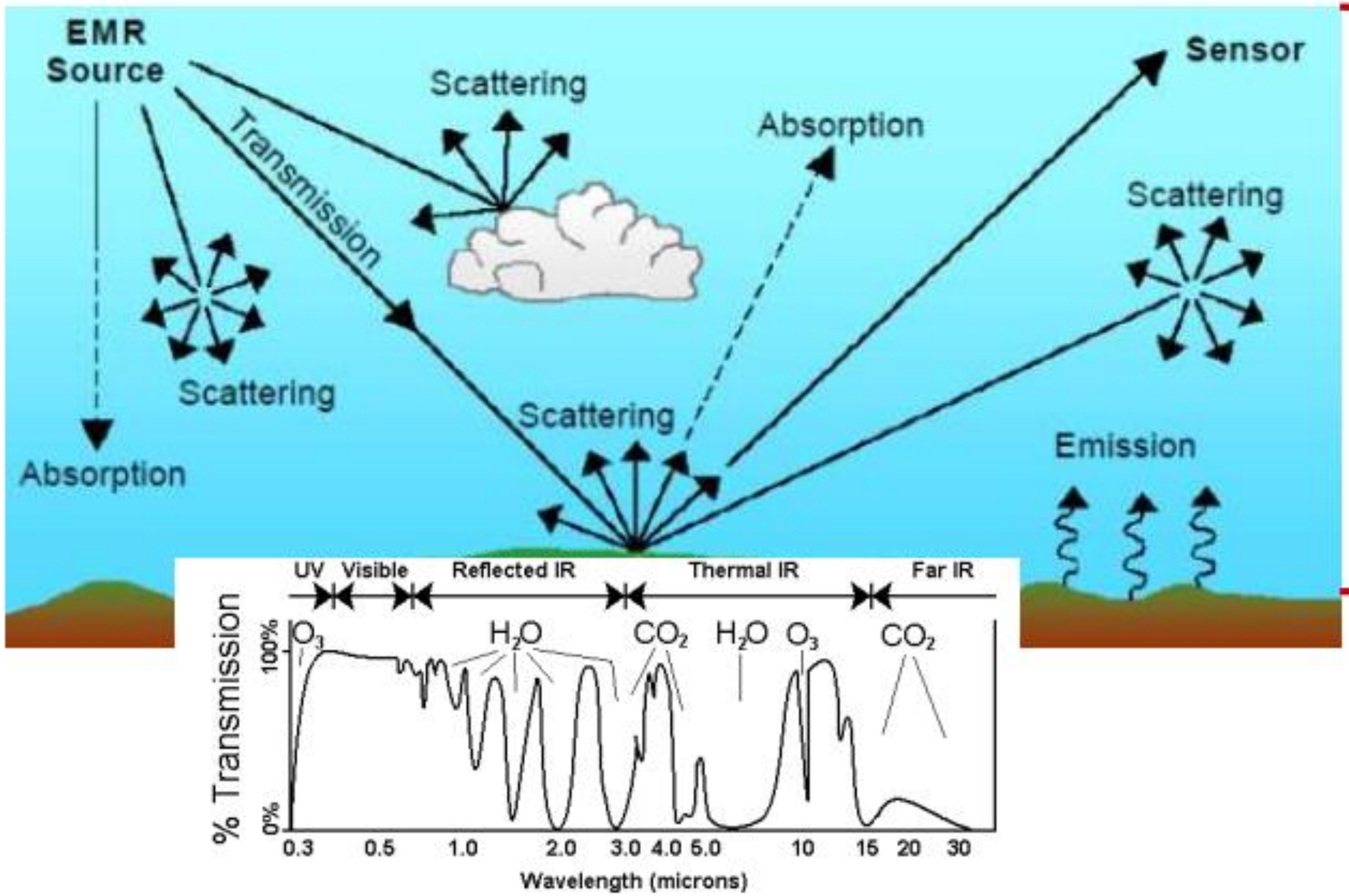



Transmission
θ1
Medium 1
θ1 > θ2
Medium 2
θ2
Medium 1
θ1
Reflection
θ1
θ2
θ1 = θ2
Scattering
Absorption
Emission
Emission

EMR Interactions in the Atmosphere

- How does the atmosphere alter the "quality" of satellite/ airborne images and aerial photographs?
- Identification of EMR interactions affecting an airborne or satellite image
- The effect of the atmosphere on the transmission of EMR to and from the earth's surface by scattering and absorption processes is a function of
  - Path length
  - EMR wavelength
  - Atmospheric conditions

INTERACTIONS WITH THE ATMOSPHERE



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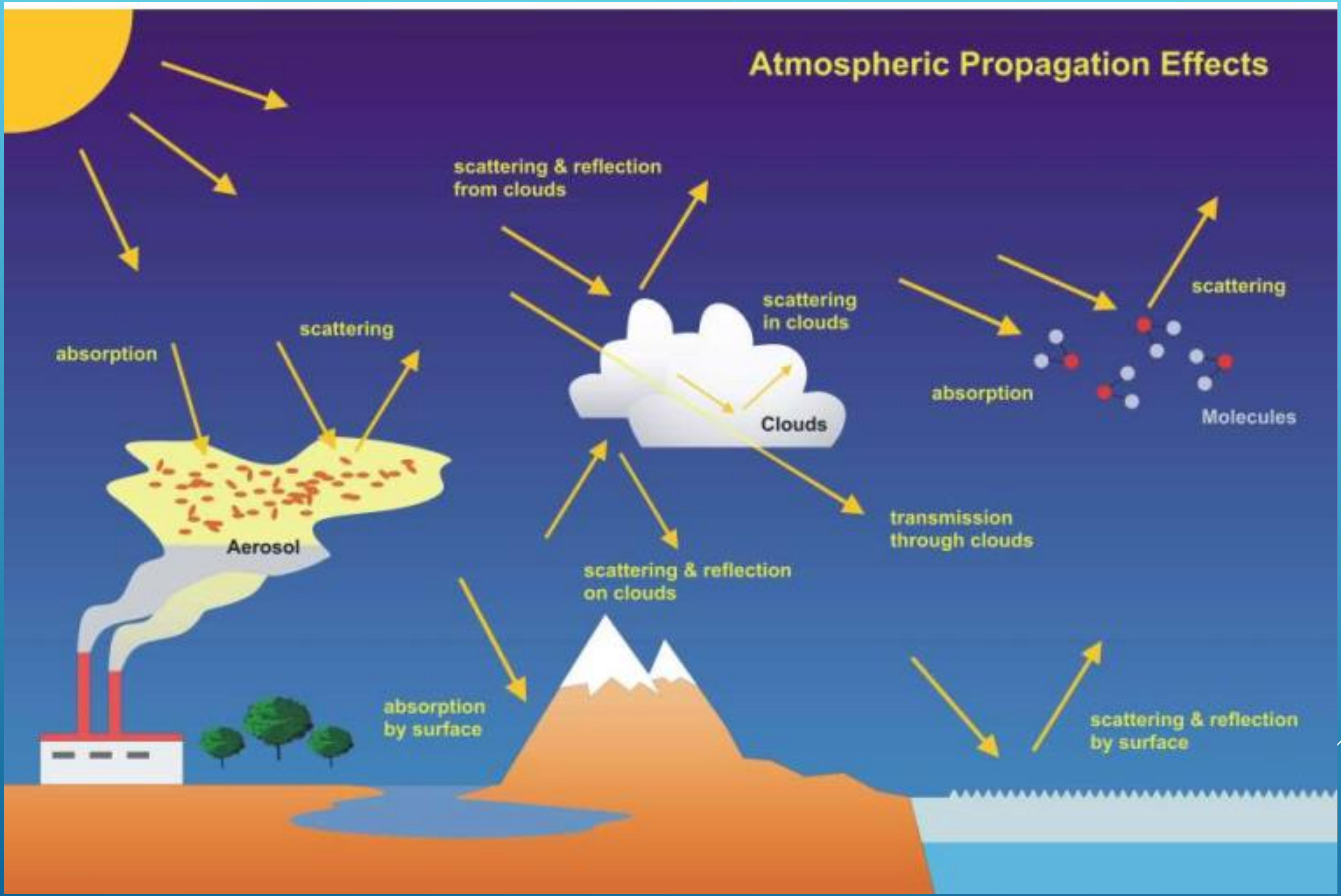
Atmospheric Propagation Effects
scattering & reflection
from clouds
scattering
in clouds
scattering
absorption
scattering
absorption
Molecules
Clouds
Aerosol
transmission
through clouds
scattering & reflection
on clouds
absorption
by surface
scattering & reflection
by surface

Scattering

- Rayleigh
  - particles smaller in diameter than the EMR wavelength
  - inversely proportional to 4th power of wavelength
  - air molecules scatters short wavelengths (blue sky)
- Mie
  - Particles equal in size to wavelength
  - Inversely proportional to 0.6-2nd power of wavelength
  - Water vapour, dust (haze), causes sky to take on reddish appearance
- Non-selective
  - Particles have greater dimensions than wavelength
  - Scatters all wavelengths
  - Water Droplets and ice (fog and clouds), causes white appearance
- All scattering produces "additive path radiance"

ABSORPTIONS

- Is the other main mechanism at work when electromagnetic radiation interacts with the atmosphere. In contrast to scattering, this phenomenon causes molecules in the atmosphere to absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.
- Because these gases absorb electromagnetic energy in very specific regions of the spectrum, they influence where (in the spectrum) we can "look" for remote sensing urposes. Those areas of the spectrum which are not severely influenced by atmospheric absorption and thus, are useful to remote sensors, are called atmospheric windows.

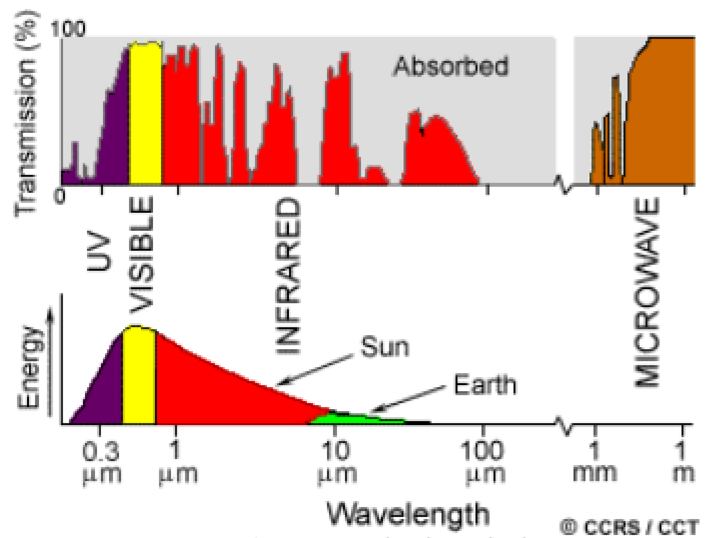

Figure (9): Atmospheric Windows

REFERENCE FROM THIS LECTURE BY

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Bldg Purple 12.3.09

- Thank you