Electromagnetic Radiation

- Oscillating electric and magnetic fields propagate through space
- Virtually all energy exchange between the Earth and the rest of the Universe is by electromagnetic radiation
- Most of what we perceive as temperature is also due to our radiative environment
- May be described as waves or as particles (photons)
- **High energy photons = short waves; lower energy photons = longer waves**

Electromagnetic Radiation

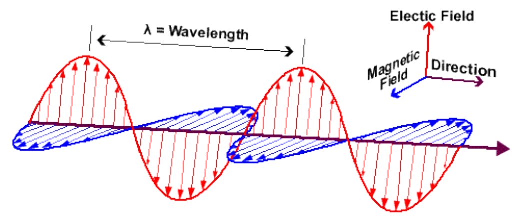
Changing electric fields create changing magnetic fields …

and vice versa!

This makes energy move through space

We can see it, feel it

Plants harvest it directly, and we harvest them!

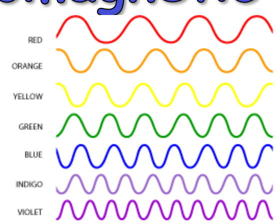


Travels at 3×10^8 m/s
= 186,000 miles / sec !

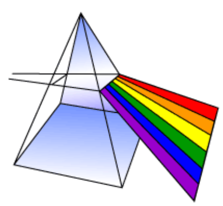
Distance it goes in one cycle is called the wavelength

Electromagnetic Radiation

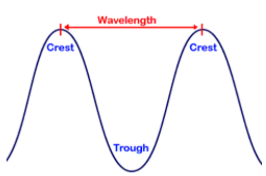
Radiation travels as waves or photons



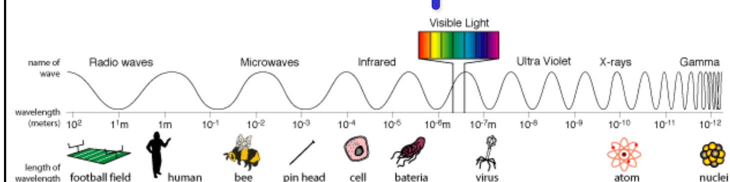
Waves do not require molecules to propagate



Shorter waves carry more energy than longer ones



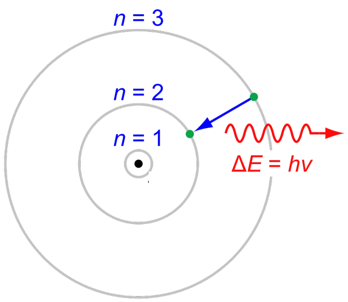
Electromagnetic Radiation Spectrum



Shorter waves carry more energy than longer waves

Electromagnetic waves interact with matter at similar scales (sizes) as the waves

Waves and Photons



Long Waves = small photons

Short Waves = BIG PHOTONS

Is light a wave?
YES!

Is light a particle?
YES!

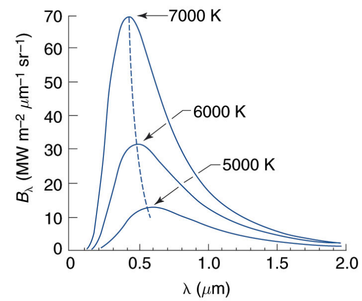
All light travels at the same speed

Think of short waves as BIG HEAVY particles

Think of longer waves as small, lightweight particles

Red is Cool, Blue is Hot

Take the derivative of the Planck function, set to zero, and solve for wavelength of maximum emission

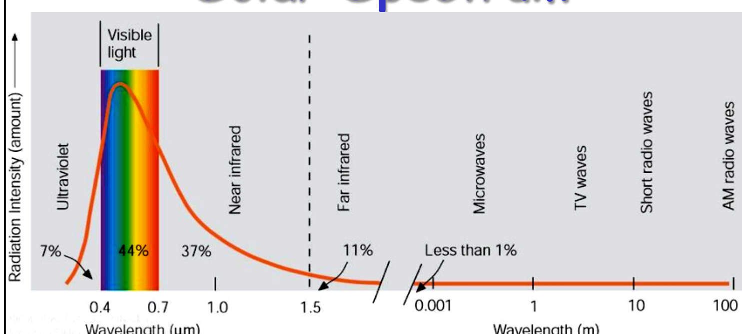


Wien's Displacement Law

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

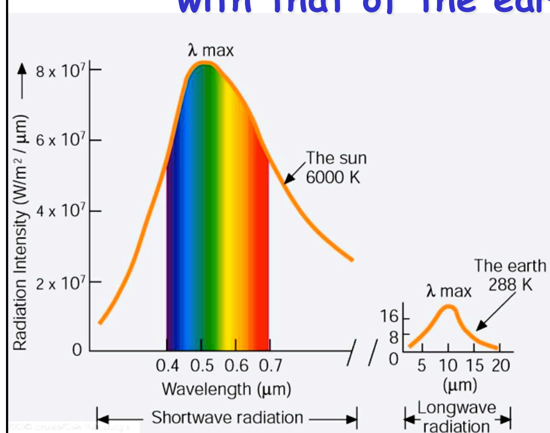
(energy is concentrated at shorter wavelegths for hotter emitters)

Solar Spectrum



Solar radiation has peak intensities in the shorter wavelengths, dominant in the region we know as visible, but extends at low intensity into longwave regions.

Spectrum of the sun compared with that of the earth

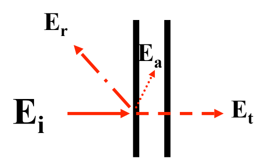


The hot sun radiates at shorter (visible) wavelengths that carry more energy

Energy absorbed by the cooler earth is then re-radiated at longer (thermal infrared) wavelengths

Conservation of Energy

- Radiation incident upon a medium can be:
  - absorbed
  - reflected
  - transmitted
- $E_i = E_a + E_r + E_t$
- **Define**
  - reflectance $r = E_r/E_i$
  - absorptance $a = E_a/E_i$
  - transmittance $t = E_t/E_i$
- Conservation: $r + a + t = 1$



Short Wave (Solar) Radiation

- Absorbed by the atmosphere
- Reflected by clouds, particles and air molecules back to space
- Transmitted to the surface
  - where it is
    - absorbed
    - reflected back upward into the atmosphere
      - some of this may be absorbed by the atmosphere
      - some may be transmitted through the atmosphere back to space

Reflection

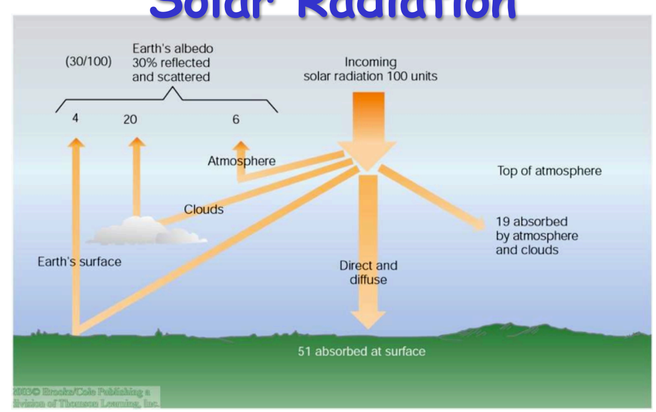
- Albedo: the ratio of reflected radiation to incident radiation
- Surface albedo varies
  - Spatially
  - Temporally

TABLE 2.3 Typical Albedo of Various Surfaces

SURFACE	ALBEDO (PERCENT)
Fresh snow	75 to 95
Clouds (thick)	60 to 90
Clouds (thin)	30 to 50
Venus	78
Ice	30 to 40
Sand	15 to 45
Earth and atmosphere	30
Mars	17
Grassy field	10 to 30
Dry, plowed field	5 to 20
Water	10*
Forest	3 to 10
Moon	7

*Daily average.

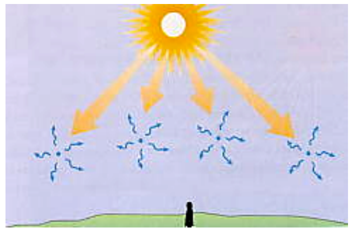
Solar Radiation



Solar radiation is scattered and reflected by the atmosphere, clouds, and earth's surface, creating an average albedo of 30%. Atmospheric gases and clouds absorb another 19 units, leaving 51 units of shortwave absorbed by the earth's surface.

Scattering: Why is the sky blue?

- Sunlight is *scattered* by air molecules
- Air molecules are much smaller than the light's l
- Shorter wavelengths (green, blue, violet) scattered more efficiently
- Unless we are looking directly at the sun, we are viewing light scattered by the atmosphere, so the color we see is dominated by short visible wavelengths
  - blue dominates over violet because our eyes are more sensitive to blue light



Why are Sunsets Red?

- The sun appears fairly white when it's high in the sky
- Near the horizon, sunlight must penetrate a much greater atmospheric path
  - More scattering
- In a clean atmosphere, scattering by gases removes short visible l's from the line-of-sight
  - Sun appears orange/ yellow because only longer wavelengths make it through
- When particle concentrations are high, the slightly longer yellow l's are also scattered
  - Sun appears red/ orange

Blackbodies and Graybodies

- A blackbody is a hypothetical object that absorbs all of the radiation that strikes it. It also emits radiation at a maximum rate for its given temperature.
  - Does not have to be black!
- A graybody absorbs radiation equally at all wavelengths, but at a certain fraction (absorptivity, emissivity) of the blackbody rate

Total Blackbody Emission

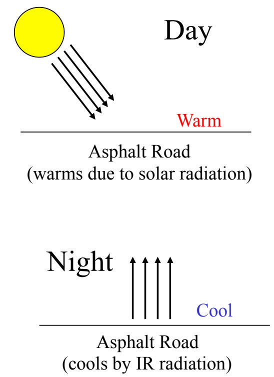
- The total rate of emission of radiant energy from a "blackbody":

$$E^* = sT^4$$

- This is known as the Stefan-Boltzmann Law, and the constant s is the Stefan-Boltzmann constant (5.67×10^{-8} W m^{-2} K^{-4}).
- Stefan-Boltzmann says that total emission depends really strongly on temperature!
- This is strictly true only for a blackbody. For a **gray body**, $E = eE^*$, where **e** is called the emissivity.
- In general, the emissivity depends on wavelength just as the absorptivity does, for the same reasons: $e_l = E_l/E^*_l$

Absorption: Kirchoff's Law

- Objects that are good absorbers are also good emitters
  - Consider an asphalt road
    - During the day the asphalt absorbs solar radiation and warms
    - At night the asphalt emits infrared radiation and cools relative to its surroundings



Absorption of Solar Radiation

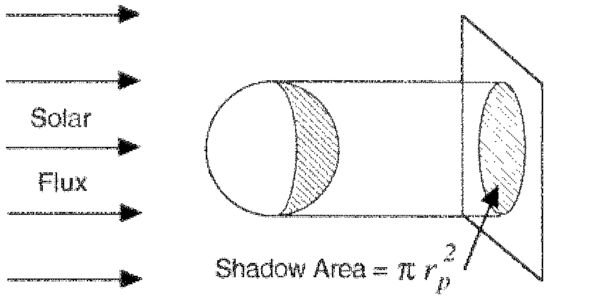
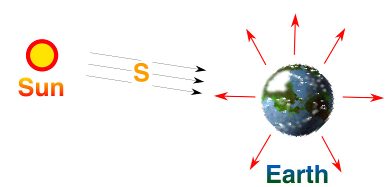


Fig. 2.2 Diagram showing the shadow area of a spherical planet.

Planetary Energy Balance



Energy In = Energy Out

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

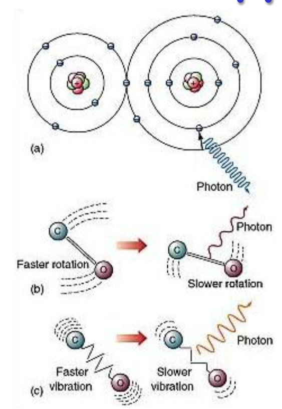
$$T \approx -18^{\circ}\mathrm{C}$$

But the observed T_s is about 15° C

Long Wave (Thermal) Terrestrial Radiation

- The earth's surface emits LW radiation at temperatures warm relative to the *top of the atmosphere*.
  - Some of this radiation escapes directly through the atmosphere to space, thus cooling the planet.
  - Some is absorbed by gases and clouds in the atmosphere.
- Atmospheric gases and clouds emit LW radiation in all directions.
  - The atmosphere's LW emission downward warms the surface.
  - The atmosphere's upward LW emission joins that from the surface escaping to space, thus cooling the planet.

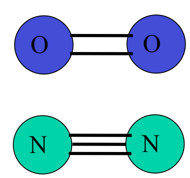
Atoms, Molecules, and Photons



- Atmospheric gases are made of molecules
- Molecules are groups of atoms that share electrons (bonds)
- Photons can interact with molecules
- Transitions between one state and another involve specific amounts of energy

Dancing Molecules and Heat Rays!

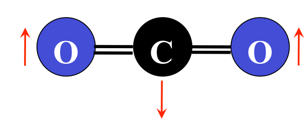
- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which two atoms of the same element share electrons
- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well

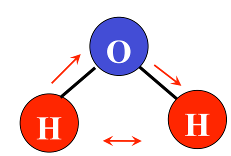


Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules and Heat Rays!

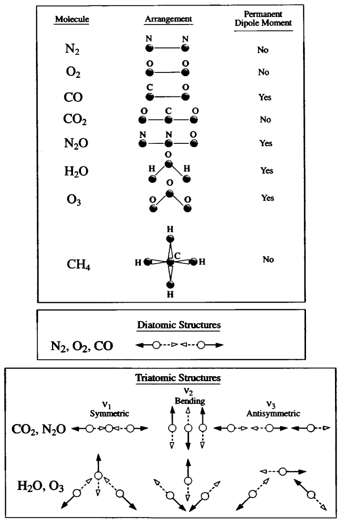
- Carbon dioxide (CO_2) and water vapor (H_2O) are different!
- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation





Molecules that have many ways to wiggle are called "Greenhouse" molecules

Molecular Absorbers/ Emitters



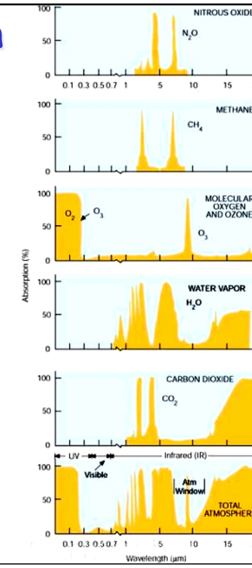
- Molecules of gas in the atmosphere interact with photons of electromagnetic radiation
- Different kinds of molecular transitions can absorb/emit very different wavelengths of radiation
- Some molecules are able to interact much more with photons than others
- Molecules with more freedom to jiggle and bend in different ways absorb more types of photons
- Water vapor (H_2O) and CO_2 are pretty good at this, and abundant enough to make a big difference!
- These are the "greenhouse gases!"

Atmospheric Absorption

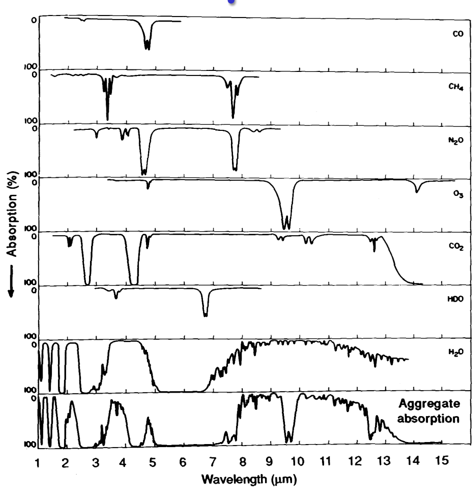
Solar radiation passes rather freely through Earth's atmosphere

Earth's re-emitted longwave energy either fits through a narrow "window" or is absorbed by greenhouse gases and re-radiated toward earth

Major LW absorbers:
- Water vapor
- CO_2
- O_3
- Clouds

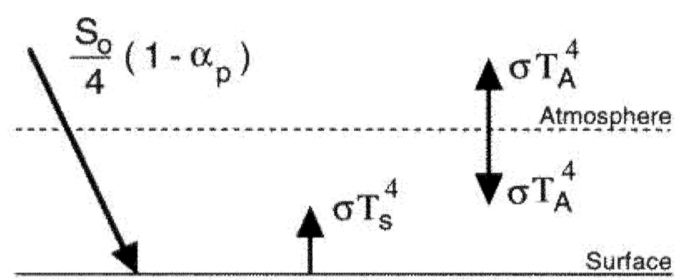


Atmospheric Absorption



- Triatomic modelcules have the most absorption bands
- Complete absorption from 5-8 m(H_2O) and > 14 m(CO_2)
- Little absorption between about 8 m and 11 m ("window")

Planetary Energy Balance



Atmosphere of hypothetical planet is transparent in SW, but behaves as a blackbody in LW